ISOTOPIC AND DENTAL EVIDENCE FOR DIET FROM THE NECROPOLIS OF ISOLA SACRA (1^{ST} – 3^{RD} CENTURIES AD), ITALY

By
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Abstract

This study investigates diet in the human skeletal sample from the necropolis of Isola Sacra, Italy (ca. $1^{st} - 3^{rd}$ centuries AD). Dietary patterns inferred from isotopic and dental health data are examined in relation to documentary and archaeological information on the diets of people in ancient Rome.

The isotopic data indicate that the diet of this coastal population was a mixture of approximately 60% terrestrial and 40% marine resources. Males are enriched in ^{13}C and ^{15}N, suggesting a higher proportion of marine foods in their diet. There is some isotopic variability between age categories, but very little variation between different burial types in the cemetery. Comparison with a rural Roman sample reveals an isotopic distinction between consumers of predominantly terrestrial resources and those consuming a significant proportion of marine resources. Isotopic analysis of infant ribs suggests that weaning began around 3 months and lasted until 2 years of age, and that infants were fed a predominantly grain-based weaning diet.

Caries, antemortem tooth loss (AMTL), tooth wear, abscesses, and calculus were examined, and they indicate a moderately good level of oral health in the Isola Sacra sample, consistent with evidence from other Roman period skeletal samples. Only calculus levels are significantly different between males and females, although males have higher levels of tooth wear and caries and females have higher levels of AMTL. There is no significant association between dental health and burial type. Overall levels

of calculus, caries, and tooth wear in the deciduous teeth are low in this sample, but pathological lesions begin to appear as early as 2.5 years and tooth wear starts as young as 1.5 years. The combined use of isotopic and dental evidence provides insight into the diets and lives of this significant Roman period skeletal sample.

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Chapter 1

Introduction

This thesis is an investigation of diet in a human skeletal sample using evidence from stable isotope analysis of bones and palaeopathological analysis of teeth. The skeletal sample comes from the necropolis of Isola Sacra (1^{st} – 3^{rd} centuries AD), a cemetery associated with one of Imperial Rome's key maritime ports, *Portus Romae*. The sample represents one of the largest Roman period collections in Italy and the Mediterranean region, and is an important source of information about the lives of these Roman people.

One of the objectives of this study is to integrate the skeletal and dental evidence with written and archaeological information on diet in ancient Rome. Textual and archaeological evidence have traditionally been used to reconstruct the diet of the ancient Romans and these sources tell us a great deal about the range of food choices available. The skeletal and dental data are an invaluable addition to the existing information, as they provide an indication of what was actually consumed. The goal is not to describe *the* Roman diet, because information obtained from the Isola Sacra sample can only tell us about the diet of the people at *Portus Romae*. It is, however, important to study these skeletal remains within a historical context in order to gain a fuller understanding of how

diet was interconnected with the lives of this Imperial Roman population. It is also important to remember that all lines of evidence have limitations with respect to what they can tell us about the dietary patterns of past populations.

Stable isotopes have been widely used to investigate dietary patterns in prehistoric human populations since the 1980s (see reviews by Schwarcz and Schoeninger, 1991 and Katzenberg, 1992, 2000). Infant weaning patterns in both prehistoric and historic skeletal samples have also been investigated using stable isotope analysis (reviewed by Katzenberg *et al.*, 1996), but there are very few stable isotope studies on samples from the Graeco-Roman period.

The teeth provide another invaluable source of information about diet because everything eaten passes through the mouth, and it is the interaction between diet, teeth, and the oral environment that affects dental health (Powell, 1985). Patterns of dental health have been studied in samples from the Mediterranean region, beginning with Angel's work on Greek samples in the 1940s (e.g., Angel, 1944). However, the integrated analysis of dental, isotopic, written, and archaeological evidence has not been undertaken in previous studies.

The location of *Portus Romae* on the western coast of Italy, and its role as a maritime trading center suggests that marine foods may have been an important component of this population's diet. This hypothesis is tested using the isotopic data. In addition, historical accounts of Roman diet repeatedly refer to grain as the base of the Roman diet, although some scholars have questioned its true importance (e.g., Frayn,

1975; Evans, 1980). Both the isotopic and dental data will shed some light on the importance of terrestrial and maritime resources in this particular population.

Food choices are not made simply on the basis of availability and appeal. Anthropologists have long recognized that the choices people make about food are intimately connected to cultural values and symbolic meanings of food within societies (Holt, 1991; Gumerman, 1997). This also means that social relations within human societies mediate access to food, and food also acts to define and maintain these social relations (Gumerman, 1997). Fajans (1988:145) argues that "food thereby acts to maintain social control; to enhance prestige; to differentiate nature and society; and to construct aspects of person, gender, generation, status, and health". This study investigates dietary differences within the Isola Sacra sample by examining the data with respect to age, sex, and burial treatment.

Chapter 2

Portus Romae and Evidence of Food Choices Available to the Ancient Romans

2.1 Introduction

The individuals of the Isola Sacra skeletal sample were inhabitants of the Roman Imperial town of *Portus Romae*. In order to interpret the dental and isotopic evidence from the skeletal remains, the historical context of the lives of these people must be understood. It is also necessary to develop a picture of the food choices available in the Mediterranean region during the Imperial period (ca. 27 BC – AD 476) and identify what factors may have affected accessibility to food.

This chapter presents the historical background of the site of *Portus Romae*, and examines and evaluates the archaeological and written evidence for the foods available in the Mediterranean region.

2.2 *Portus Romae* during the Roman Imperial Period

The early Roman Empire was characterized by a period of relative political and economic stability beginning under the rule of Augustus (31 BC – AD 14). There is evidence of increased urbanization, wider distribution of trade goods, and expansion of

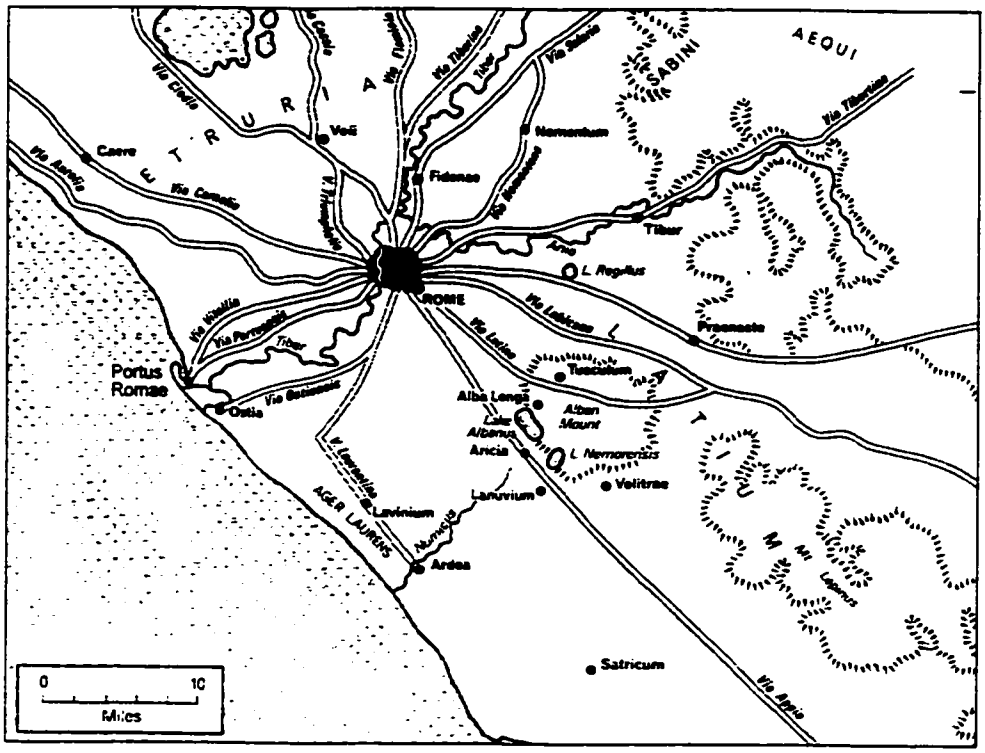
agricultural activities, all of which are considered strong indicators of economic development during the 1st century AD (Alston, 1998). Taxation of imported goods was low and control of trade was left largely in the hands of private traders and entrepreneurs, which further encouraged the exchange of goods throughout the Mediterranean region (Scullard, 1982). The exception was the grain supply needed to feed Rome's citizens and armies, imported from the provinces under the close supervision of Roman officials and soldiers (Alston, 1998).

The site of *Portus Romae* is located approximately 23 km southwest of Rome (Figure 2.1). During the 1st century AD, the original port at Ostia (ca. 3km to the South) was no longer able to accommodate heavy ship traffic due to progressive silting of the waterway. Claudius ordered the construction of a new port, built between AD 42 and AD 64, and Trajan ultimately completed an additional inner harbor in AD 112 (Figure 2.2). This port complex was known as *Portus Ostiensis* or *Portus Augusti* until the 4th century AD (Meiggs, 1960; Calza and Becatti, 1974; Mannucci and Verduchi, 1996). Rome was the ideal 'consumer city' and had imports coming in from provinces throughout the Roman Empire. Figure 2.3 shows the extent of the Roman Empire during the reign of Trajan.

Trajan's port (*Portus*) was an important trading center for the Empire and was directly linked to Rome through a series of docks and quays along the Tiber river. Trade at *Portus* was also supported by a series of smaller ports along the coast interconnected by rivers and roads (Rickman, 1996). Because of its unique commercial role as the trading entry point to the Imperial city of Rome, the inhabitants of *Portus* were primarily

middle-class administrators, traders, and merchants (Mannucci and Verduchi, 1996). The political and economic stability of the Mediterranean region at the beginning of the Roman Imperial period contributed to the wealth of the city of Rome and, as the main port and warehouse to Rome, the lives of the inhabitants at *Portus* were intimately linked with the prosperity and political domination of the Roman Empire.

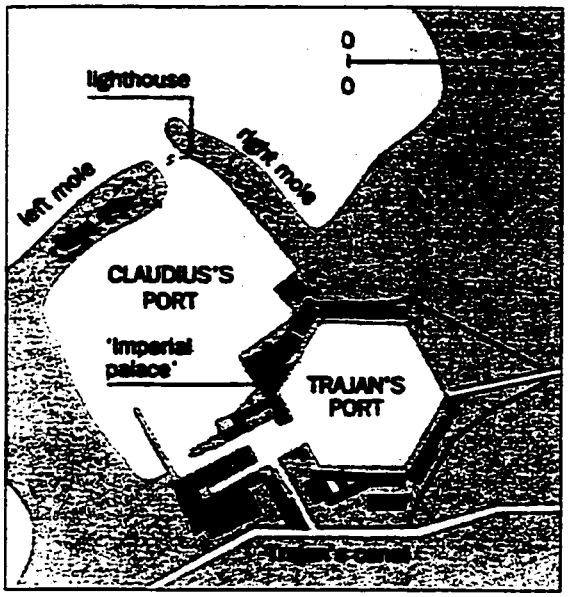
Figure 2.1 – Location of *Portus Romae* and Ostia, SW of Rome (modified from Grant, 1974)



The construction of the new port did not automatically initiate the decline of Ostia; it is suggested that there was increased economic development at Ostia, which changed its character from a market town to an affluent residential city (Calza and

Becatti, 1974; Mannucci and Verduchi, 1996). All main administrative activities continued to occur at Ostia, while *Portus* was considered an extension of the first port with many of its earliest inhabitants coming from Ostia and from Rome (Mannucci and Verduchi, 1996). By the end of the 2nd century AD, *Portus* was handling all commercial traffic coming in to Rome, and it is not until the end of the 3rd century AD that there is evidence of decline at Ostia.

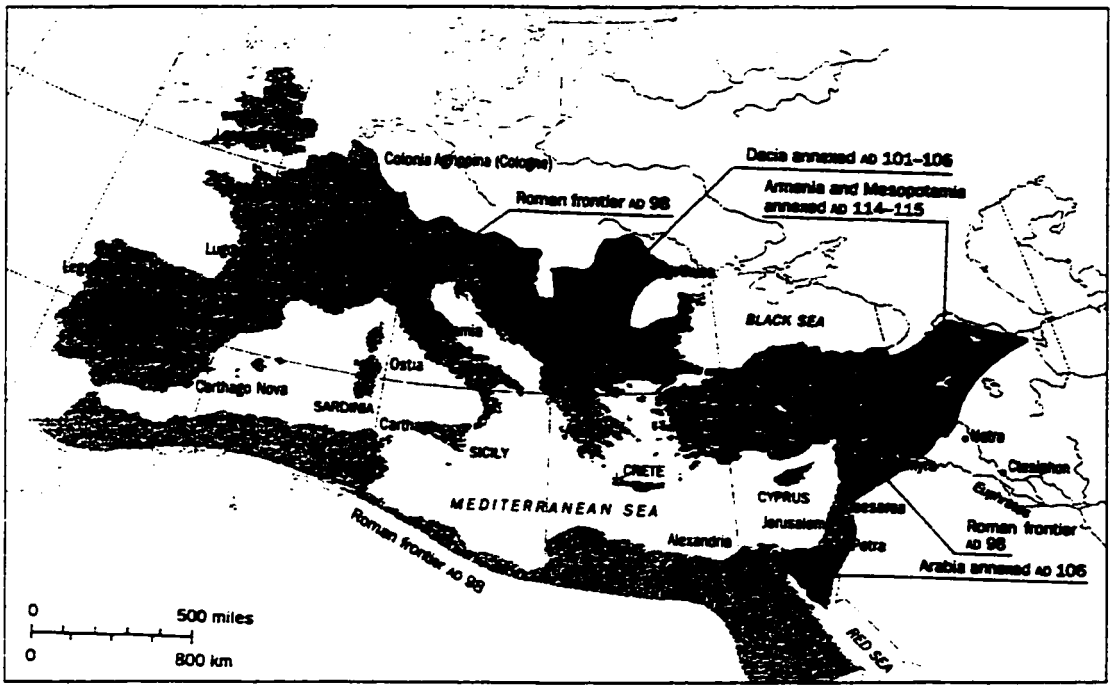
Figure 2.2 – Plan of the ports of Claudius and Trajan (from Scarra, 1995)



The Roman Empire remained relatively stable until the end of the reign of Marcus Aurelius in AD 180. For the next one hundred years, civil war undermined the stability of the Mediterranean region. Under the rule of Emperor Diocletian (AD 284 - 305) a series of political and economic reforms were instituted that stabilized the Empire, but by the beginning of the 4th century AD the Empire had been divided into eastern and western

halves. Emperor Constantine established the capital of the Empire at Byzantium in AD 324, gradually weakening the western provinces, and by the end of the 5th century AD the western Roman Empire had dissolved.

Figure 2.3 – Map showing the extent of the Roman Empire during Trajan's rule (from Scarra, 1995)



In AD 314, Emperor Constantine granted *Portus* the status of an autonomous city, bestowing it with a new name, *Portus Romae*. Commercial activity at *Portus Romae* started to decline by the end of the 4th century AD, but it remained a harbor for the Roman fleet during the Vandal invasion in the 5th century and the Gothic war of the 6th century AD. With the decline of the Roman Empire after the 5th century AD, *Portus Romae* too had collapsed, and by the 9th century *Portus* was completely abandoned.

Archaeological investigations of *Portus* were undertaken between 1864 and 1867, but the only surviving records of the excavation are lists of sculptures. Subsequent visitors to the site found it reburied without any systematic recording of structures (Meiggs, 1960; Mannucci and Verduchi, 1996). In the late 19th century, Ostia was under excavation by the Italian government, but the area around *Portus Romae* was still in the hands of private landowners (Meiggs, 1960). Excavations were undertaken at the beginning of the 20th century and again in the 1930s and 1950s. By the 1940s Trajan's harbor had been restored and is identified as 'Lago di Traiano' on modern maps (near Fiumicino airport). An extensive description of the ruins was published by Lugli in 1935 (Meiggs, 1960). Since the 1980s, archaeological activity at the site of *Portus Romae* has focused on the cleaning and restoration of surviving structures (Mannucci and Verduchi, 1996). The main living quarters of the inhabitants were found to the East and South of the hexagonal basin, but much of the port complex is now buried under the modern Fiumicino Airport, limiting our information about the town itself (Meiggs, 1960). It is fortunate that Ostia is extremely well preserved, thereby offering some indirect information about the organization of Rome's port towns.

There are two cemeteries associated with *Portus Romae*. The first was for the elite, situated along *via Portuensis*, while the second cemetery was for the middle and lower classes of *Portus*, along *via Flavia*, the road that connected *Portus* with Ostia (Pavolini, 1996). There is no mention of skeletal material from the 'elite' cemetery, so it is not known if this cemetery has ever been excavated. The second cemetery, known as Isola Sacra (Sacred Island), is named after the artificial island upon which it is situated.

The main period of use of the Isola Sacra necropolis occurred between AD 100 and 250 (Sperduti, 1995).

2.3 Roman Diet

2.3.1 Textual and Archaeological Sources

Much of the evidence used by modern scholars to reconstruct elements of ancient Roman life is based on surviving ancient literary texts. A number of fragmentary texts by Roman writers provide indirect evidence of the diet and subsistence practices of the Romans, such as Varro's (1st c. BC) *De re rustica,* Cato's (2nd c. BC) *De re agricultura,* and the extensive twelve-volume treatise on agriculture by the agronomist Columella (1st c. AD) (Scullard, 1982; Cornell, 1995). These written sources contain accounts of the types of wild and cultivated plants used by the Romans, techniques of animal husbandry, and food preparation practices. Greek and Roman medical writers are also sources of indirect dietary information, through the provision of lists of foods and herbs prescribed for medical treatment (André, 1981). Descriptions of food and dining practices in works of fiction and depictions in art are sometimes used to infer diet, although they are not considered as reliable as the ancient historians and agronomists (André, 1981).

One of the most complete sources for Roman food and cooking practices is the book, *Apicius de re Coquinaria,* a compilation of recipes attributed to M. Gabius Apicius (1st c. AD) (Vehling, 1977). These recipes provide names of individual food items used by the Romans in their cooking, although quantities are not normally listed. This document has been used to infer the relative popularity of certain food items in the

Roman diet, for example, the ubiquitous use of *garum*[1] (or *liquamen)* in sauces and the comparatively large number of recipes involving pork (e.g., 23 pork recipes versus 4 beef recipes) (Gallo, 1990). One of recognized limitations of this text is that many recipes are exotic dishes created for the elite of Imperial Roman society and, as such, do not accurately reflect the eating habits of the majority of the population (Brothwell, 1988). It is also suggested that a number of existing recipes were modified and new ones were added to later editions of Apicius' cookbook, so that their reliability and authorship are in question (Vehling, 1977). Regardless of these reservations, Apicius' cookbook still provides an indication of some of the food items used in Roman cooking and the methods used to prepare them.

Another less commonly cited source is the *Deipnosophistae* (Philosophers at Dinner) by the Greek author Athenaeus (2nd c. AD). This book was written as a conversation recorded from a dining symposium. Within the text are fragments of recipes that have been used to reconstruct the cuisine of ancient Greece and Rome (e.g., Wilkins and Hill, 1995). Critics note that Athenaeus' information was derived from earlier Greek poets and philosophers and that he largely ignored Roman sources altogether (Garnsey, 1999). The *Deipnosophistae* does, however, provide a description of an elite 'dining' situation, where it can be assumed that the foods described were actually dishes consumed by certain members of Graeco-Roman society.

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[1] *Garum* was a sauce invented by the Greeks in the 4th century BC, and is made primarily from decomposed fish and salt (Brothwell, 1988).

The Edict of Diocletian (AD 301) also provides information on the relative importance of certain food items in the Roman economy. Part of Diocletian's political and economic reforms was legislation that placed maximum prices on supplies and services in an effort to reduce inflation caused by previous economic instability (Grant, 1978). However, interpretations based on this text assume that prices can be equated to consumption levels. In addition, this edict was issued to protect soldiers from being overcharged; so that foods listed may more accurately reflect the common diet of the military rather than the 'average' Roman (Frayn, 1993).

Although the written evidence provides considerable information about food resources, and sometimes actual culinary dishes of the Romans, it has limitations. The texts, like any other form of material evidence from the past, need to be evaluated for their reliability. In many cases only fragments survive to the present, and it is unlikely that any changes to the original texts can be detected. Errors in transcription or translation as well as modifications or omissions also affect the reliability of these documents. Further, it is difficult to assess the impact of the biases held by ancient authors. Some authors were influenced by the Greek philosophy of asceticism, which emphasized a simple vegetarian diet, *or frugalitas* (Corbier, 1989). Much of the literary evidence is also likely biased towards descriptions of the Roman elite and their food preferences; the lifeways of the urban and rural poor were not usually the focus of the ancient authors (White, 1976). The descriptions were usually very focused, and the idea of doing a general survey of consumers and their foods was not a priority. Grant (1995) discusses the reliability of ancient historians in considerable detail.

Some information about rural living can be obtained from the writings of the ancient agronomists, but again the intended readers of these texts were elite members of society. Also, some ancient authors relied heavily on even earlier sources for their information and were often writing about circumstances or details from earlier centuries. Thus, the information that has survived has passed through a succession of unknown filters that may have significantly altered the content of these texts. This kind of bias may have affected descriptions of Roman diet, and must be considered when using this evidence.

Frescos, mosaics, tomb reliefs, and pottery are other potential sources of indirect information on the items available in the ancient Mediterranean. In many cases, only a general idea of the food depicted is possible (e.g., fish versus fowl). Farrar (1998) examined a number of frescos from Pompeii and Rome, and identified many of the plant and animal species depicted therein. It is clear, however, that there is no way to determine whether these images are accurate depictions of plant and animals species or stylized characterizations by the artist.

Plant and animal remains recovered from archaeological contexts can also be used to reconstruct the diet of past human groups, and to investigate spatial and temporal variation in subsistence patterns. The macro- and microanalysis of palaeobotanical remains recovered from settlement sites can be used to infer what plants were important in the economy and diet of the Romans. However, differential preservation of plant remains in the archaeological record limits the quantification of material because small, fragile plant remains do not preserve well, and measures to recover microscopic remains

(e.g., pollen and phytoliths) are often not undertaken (Sobolik, 1994). This can result in an underestimation of the relative importance of poorly preserved remains in the diet of the population under study. In terms of interpretation, the presence of plant remains on a site may not necessarily indicate that they were part of the inhabitants diet, since other factors may have been responsible for their presence, such as rodent activity *(ibid.)*.

The analysis of faunal remains from archaeological middens can be used to infer the relative contribution that certain species made to the economy and diet of human populations. In southern Italy, Carter and coworkers (1985) identified a shift in the composition of faunal assemblages at Pantanello over time, from predominantly cattle remains in the earlier phase of the site to large numbers of sheep and goats during the later period. This is interpreted to indicate a transition from agricultural activities involving the use of cattle as draft animals to an economy based on the herding of sheep and goats *(ibid.)*. The kinds of limitations that exist for faunal remains are similar to those noted for palaeobotanical evidence. The presence of animal remains does not necessarily indicate consumption by humans; they may have played a different role in the economy of a site, as suggested by the analysis of Carter and coworkers (1985). Evidence of cut marks on animal bones and other signs of processing associated with food preparation may clarify the role of certain species. Differential preservation of remains will also have an impact on the interpretation of diet, as smaller animals may not be well preserved and other post-depositional factors may affect preservation (Sobolik, 1994).

In addition to the plant and animal remains recovered from archaeological sites, material remains associated with food production, storage, and consumption can provide further indirect information on diet. The presence of agricultural implements and storage facilities provide evidence of intentional cultivation, and the existence of processing areas for the production of oil, wine, and wool can infer economic activities. The recovery of vessels for large-scale storage and transport (e.g., of wine) from archaeological sites can also be used to infer the importance of certain items in the Roman economy. A relatively unusual source of dietary information has been recovered from the sites of Pompeii and Herculaneum. The eruption of Mount Vesuvius in AD 79 destroyed both these cities, covering them with lava and ash, and preserving elements of daily life rarely recovered by the archaeologist. Carbonized remains of prepared food items have been recovered from kitchens in dwellings at both sites, and areas for commercial food production, such as bakeries, have been uncovered (Gallo, 1990). These sources of evidence can now be examined in an effort to reconstruct the foods that were available in the ancient Mediterranean region and attempt to assess the relative contribution of these foods to the diet of the people at *Portus Romae*.

2.3.2 Cereals

There seems to be little dispute that cereals formed the basis of the ancient Mediterranean diet; however the type of cereals preferred varied between regions and the popularity of certain varieties changed over time. Cereals are widely documented in the

ancient literary sources and extensive descriptions of agricultural activities have survived from antiquity (e.g., Cato's *De Agricultura*).

The importance of cereals in the lives of the Romans is reflected in other realms of society, as in the worship of Ceres, the goddess of grain, and the traditional use of emmer wheat in Roman religious rituals. The elaborate 'Tomb of the Harvester' at Isola Sacra, dated to the 2nd century AD, suggests the importance of grain to the inhabitants of *Portus Romae*. This tomb contains a series of mosaics showing the different scenes of agricultural activity, including tilling soil, sowing seeds, harvesting crops, and threshing grain. Palaeobotanical evidence and literary sources suggest that spelt, emmer wheat, and barley were the predominant types of grains in the Italian diet during the pre-Roman and early Roman periods, consumed in the form of a boiled porridge (*puls*) (Gallo, 1990).

Barley

Barley was widely cultivated and consumed by the ancient Greeks and a great deal of its popularity was due to its ability to flourish in a variety of soil conditions, although the ancient writers reported that barley was not as nourishing as wheat (Braun, 1995). Roman period texts describe barley as an inferior quality of cereal, suitable only for slaves, animals, and the poor, or as an alternate food source when wheat crops failed (White, 1976; Gallo, 1990). Thus, it never attained the same popularity in the diet of the ancient Romans. Barley was reportedly used as a form of punishment in the Roman army if the soldiers did not perform their duties adequately (Braun, 1995). Despite its lack of

popularity among the ancient authors, it was still considered an important component of the diet of the rural peasantry up to the 3rd century AD (Spurr, 1983; Garnsey, 1999).

Wheat

Emmer wheat (*Triticum dicoccum*) was the main cultivated wheat in pre-Roman Italy. It declined in popularity with the introduction of 'naked' (versus husked) wheat, but was still widely grown until the 4th century AD (Spurr, 1986). Like barley, the original popularity of emmer wheat was probably due to its ability to grow in a variety of soil conditions as well as its long storage life. It was a husked grain, so the milling process was more labor intensive.

By the 5th century BC, the 'naked' wheats (e.g., *Triticum vulgare*, *T. durum*, and *T. aestivum*) were the main cultivated cereals in Italy, and it is suggested that this increased cultivation during the Roman period was related to the ease of processing naked wheat for the production of bread (André, 1981). The commercial production of bread began in the first half of the 2nd century BC and Gaius Gracchus regularly distributed wheat to citizens of Rome through the inception of the grain dole in 123 BC (Gallo, 1990; Stambaugh, 1988). The preserved bakeries at Pompeii and Ostia attest to the large-scale commercial production of bread during the Republican and Imperial periods. This increased reliance on wheat for the city of Rome and its armies during the 2nd century BC required that grain be imported from Rome's colonies in Italy, Spain, Gaul, and Africa (Stambaugh, 1988). The vast majority of the grain was supplied from Egypt, collected in the form of taxes and brought to Alexandria for shipment to Rome

(Alston, 1998). Under the rule of Aurelian (AD 270-275) the dole was expanded to included oil, pork, and wine (*ibid.*).

Millet

It is not clear from the written evidence if millet was a regular element in the Roman diet, since conditions for growing this grain were not ideal in all regions of Italy. Millet requires hot, dry summers for optimal growth. Although millet cannot tolerate cold weather, it is resistant to drought, survives better than other grains under conditions of poor fertility, and can be stored for twice the length of time as wheat (Spurr, 1983). These characteristics make it an important alternative food source. There are sporadic references to this grain in the ancient literary sources, usually in reference to its use as animal fodder, but it was often mentioned as an important crop during periods of food shortage or famine (White, 1976; Evans, 1980; Spurr, 1983). Millet, like barley, was considered an inferior grain by the Romans and was consumed by the poorer segments of society under normal conditions of food availability (White, 1976; Spurr, 1983). This suggests status-based differences in the consumption of this grain. Excerpts from the Edict of Diocletian reveal that ground millet and wheat had the same maximum price of 100 denarii (compared to 60 denarii for barley and rye), which suggests that these grains had considerable commercial value in the Roman Empire. Of course, this does not necessarily mean that millet was strictly for human consumption and may instead have been a valuable commodity as animal fodder. Millet was also used as a leaven for bread

when mixed with wine-must and as birdseed for hens and pigeons, so it may have entered the human diet through a variety of routes (Spurr, 1983).

Other Grains

Other grains are occasionally mentioned in the ancient literary sources. Oats and alfalfa were reportedly used as animal fodder, and rye was described as the worst cereal for human consumption and used only during times of famine (André, 1981; Carter *et al.*, 1985). Pliny the Elder (1st c. AD) wrote that sorghum was introduced into Italy in the 1st century AD, although nothing is known of its use (André, 1981).

Milling and Bread Quality

Galen's (ca. 2nd c. AD) survey of bread identified four classes, ranging from 'extra dirty' (coarse) to 'clean' (fine) bread (Garnsey, 1999). Grinding the grain with a hand mill or an animal-driven mill required a series of at least two grindings and siftings to produce the highest quality of flour (*flos* or *pollen*) for bread making (White, 1988). Husked grains (barley and emmer) would first have to be roasted or parched, then hulled to remove the outer shell, and finally milled to produce flour for the production of bread (*ibid.*). Barley and emmer were not commonly used to make bread because the processing required to remove the husk also destroyed the enzymes needed to create a lighter bread, so that bread produced from these cereals was flat and dense (*ibid.*).

Regardless of the number of grindings, it was the sifting of the grain that would produce different qualities of flour. Most people could not afford the finely ground flour, and instead would eat the *secundarius* (secondary) bread made from the coarser products of the milling process; this would have introduced a certain amount of grit, and some Roman sources comment on the presence of 'stones' in bread (*ibid.*).[2] Millstones, like those found in the bakeries at Ostia and Pompeii, were usually made from volcanic rock, which may have also introduced grit into the bread during the grinding process.

2.3.3 Vegetables

Legumes

Legumes commonly consumed by the ancient Romans included the pea, broad bean, chickpea, lentil, lupine and bitter vetch (Brothwell, 1988). Palaeobotanical evidence suggests that the domestication of cereals and legumes occurred concurrently in the Near East, and that legumes were common in Italy from the Bronze Age onwards (Spurr, 1986). They were sometimes referred to as the 'meat of the poor', which suggests that they may have played a more important role in the diets of the urban and rural poor than among other members of society (Corbier, 1989). Although often referred to as animal fodder, lupines were described by Pliny as an important element of the rural diet, in conjunction with a standard mixture of millet and beans (Evans, 1980; Spurr, 1983). Archaeological evidence from central and southern Italy also indicates subsistence

[2]Horace (*Satires* I, 5, 86-91) and Lucretius (*On the Nature of Things*, III, 690ff)

activities characterized by mixed cultivation of cereals and legumes during the pre-Roman and Roman periods (Carter *et al.*, 1985; Barker, 1995). However, the actual proportion of legumes in the diet of the Romans is not clear. Garnsey (1991, 1999) contends that dry legumes were a major source of protein for the entire Mediterranean region and should, in fact, be added to the 'Mediterranean Triad' of cereal, wine, and olives. The cookbook of Apicius also includes several recipes for legumes, but they were probably not a dietary staple of the Roman elite (Garnsey, 1999).

The commercial importance of legumes in the Roman Imperial period is suggested by the discovery of large *dolia* (storage jars) full of beans and chickpeas in a store in Herculaneum (Spurr, 1986). In the Edict of Diocletian, crushed beans, lentils, and split peas were equal in price to the same amount of wheat and ground millet (100 *denarii*) (Jackson, 1966). Further evidence of extensive trade involving legumes occurs in the writings of Pliny, Martial (ca. 1st c. AD) and Virgil (1st c. BC), who describe the shipment of lentils and chickpeas from Alexandria, as well as the recovery of amphorae from Pompeii specifically used for transporting these food items (Spurr, 1986).

Other Vegetables

A wide variety of cultivated and wild vegetables are recorded in the ancient literature, although it is difficult to quantify their role in the diet of the Romans. André (1981) warns that a number of the Roman agronomists (e.g., Cato, Palidius, Pliny, and Columella) relied heavily on Greek sources for information about cultivated vegetables. Without associated palaeobotanical evidence it is difficult to ascertain if descriptions of

foods derived from Greek sources were actually known in Italy. Turnips and cabbages are two of the most widely cited vegetables in the ancient literature, and root crops are commonly mentioned in reference to the diet of rural populations, particularly onions, leeks, radishes, turnips, carrots, parsnips, and beets (André, 1981; Brothwell, 1988; Brothwell and Brothwell, 1998).

Other wild plants in the Roman peasant diet include asparagus, radish, garlic, cucumber, parsnip, and a wide array of herbs[3] (Frayn, 1975). The Edict of Diocletian contains a list of ninety-six items in the fruit and vegetable section, so there was clearly a wide range of products available for consumption, but their availability does not give us any indication of who ate them and in what quantities. Pliny lists seventy garden plants used for cooking in his treatise on 'Natural History' (itemized by Farrar, 1998).

2.3.4 Fruits and Nuts

Columella wrote that apples, pears and figs were important cultivated fruits in the rural Roman diet, although a variety of other fruits, including strawberries, dates, cherries, plums, peaches, and apricots are mentioned in the ancient sources (Evans, 1980; Brothwell, 1988). The military writer Vegetius wrote on the importance of adequate fruit supplies during sieges, and palaeobotanical remains recovered from a 1st century military

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[3]Herbs mentioned by Columella, Pliny, and Cato include; mint, thyme, fennel, sorrel, parsley, capers, butcher's broom, savory, oregano, and poppy, among others. The poet Virgil also provides an extensive list of vegetables and herbs in his work, *Moretum* (including some of those already mentioned); rue, coriander, chives, nasturtium, endive, arugula, sorrel, mallows, chard, elecampane, skirret, and gourds (Evans, 1980).

outpost in Germany (*Novaesium*) include a wide variety of fruits and vegetables, particularly chickpeas, olives, and figs (White, 1988).

Figs have been recovered from Neolithic sites in Greece and were reportedly so popular in Italy that they were both cultivated locally (29 varieties were known to Pliny), and imported from Syria and Africa (Brothwell, 1988; Brothwell and Brothwell, 1998). It is not clear whether the fig, like the grape and olive, was imported from Greece during the period of Greek colonization (ca. 7th - 5th centuries BC), although it appears to have been an integral part of the Roman period diet, particularly as a dried fruit during winter months.

Brothwell (1988) states that all levels of Roman society consumed nuts, including almonds, walnuts, hazelnuts, and chestnuts. Acorns and beechnuts were reportedly used as food for pigs, but humans sometimes ate acorns during periods of food shortage or famine (André, 1981). Pine nuts were included in many of the recipes of Apicius and pistachios were introduced to Italy from Syria in the 1st century AD (*ibid.*). Honey was an additional food item that was widely used by the Romans as a sweetener, both locally made and imported from around the Mediterranean region, but again the level of consumption is not known.

Olives and Vines

Both palaeobotanical and literary evidence indicate that figs, grapes, and olives were the main cultivated fruit crops in Roman Italy, and their symbolic importance in the lives of the ancient Romans is suggested by their intentional planting within the Roman

Forum (Carter *et al.*, 1985; Brothwell, 1988). There is extensive information from agronomists on the planting and cultivation of these fruits, but there is comparatively little information on the amounts consumed.

Although widely identified as two elements of the Mediterranean triad, olives and wine are usually overshadowed by cereals in discussions of diet in the ancient Mediterranean region. One indication that wine and olives were eventually considered basic elements of the Roman diet is their addition to the grain dole in the 3rd century AD (Corbier, 1989).

Varro recommended that the highest quality olives be kept for consumption and the rest of the olives used for the production of oil. There were numerous varieties and qualities of oils produced, depending on the time of year and the number of 'presses'.[4] Cato distributed a half-liter of oil to his male farm laborers each month, supplemented with pickled olives. The problem is that we know very little about actual consumption levels from the fragments of information obtained from ancient literary sources; however Mattingly (1996) suggests that the level of oil production, consumption, and trade were far greater in the ancient Mediterranean than previously suggested. An estimate of olive oil consumption during the Roman period is 20 liters per person per year (Amouretti, 1986, cited in Mattingly, 1988), although it is not clear how these estimates are obtained. Olives are rich in calories, fats, vitamins A and E, and calcium, and although they do not contain much protein, 3.4 oz of oil will provide approximately 900 calories (Mattingly,

[4]André (1981:182) lists the following varieties; *oleum acerbum* (after oil), *oleum aestiuum* (summer oil), *oleum uiride* (green oil), *olei flos* (virgin oil), *oleum cibarium* (ordinary oil), and *oleum sequens* (2nd press oil).

1996). However, the term 'consumption' also refers to the use of olive oil as a fuel, a base for soap, perfume, and cosmetics, and as a medicinal ingredient (Boardman 1976; Mattingly, 1996). Consequently, it is not certain how much olive oil was actually consumed in the Mediterranean diet.

Wine, diluted with water, honey or other additives, was consumed widely in Roman Italy, and various regions of Italy, particularly Campania, were known for their high quality wines (Purcell, 1985). Its original use was likely reserved for ritual purposes, but by the end of the Republican period the populace had developed a 'taste' for wine, and there is a notable expansion of viticulture during the early Imperial period (Purcell, 1985; Dosi and Schnell, 1986). Wine preservation was a problem, so various techniques were developed to extend the life of wine, including the addition of preservatives. Columella advised the addition of wine must (the juice of fermented grapes) for the conservation of wine. Cato is the only source who provides an estimate of the per capita consumption of wine, based on his yearly allowance of ten amphorae per year for each of his farm workers (roughly equivalent to one bottle of wine per day), but this ration was not distributed uniformly throughout the year (Purcell, 1985).

2.3.5 Meat

Meat appears to have played a relatively minor role in the diet of the ancient Romans, although pigs, cows, goats, and sheep were important elements of the Roman economy. Garnsey (1999) suggests that as a consequence of the Italian physical environment, grass and fodder were in short supply due to the brief length of the growing

season. Fertile land was needed for the cultivation of plants and the raising of livestock was not an efficient use of the land. Once again, it is not clear what proportion of the Roman diet was meat, or if it was readily available to all segments of the population. Corbier (1989) suggests that meat was widely available to the wealthier segments of society but was not normally consumed by the lower classes until pork became part of the food dole in the 3rd century AD. Even then, pork was only made widely available to the 'citizens' of Rome.

Both literary and archaeological evidence indicate that pork was the most popular meat consumed by the ancient Romans; it was a standard component of the Mediterranean diet from the Neolithic period onwards (Brothwell, 1988; Gallo, 1990). The Edict of Diocletian indicates that the cost of pork was higher than that of any other meat, and this is considered to be an indication of the relative importance of pork in the Roman diet (Gallo, 1990). The large numbers of pigs required by the city of Rome for the food dole were obtained from rural populations in Campania and Lucania, and faunal remains recovered from the urban sites of Pompeii and Rome reveal that pigs constituted over 50% of the animal remains recovered (Brothwell, 1988; Corbier, 1989). Excavations at Ostia recovered a wide variety of animal remains from successive phases of occupation at this site, the overwhelming majority of which were pigs, corroborating much of the literary evidence on the importance of pork in the Roman economy and diet (Carandini and Panella, 1970).

It is not clear from the literary evidence if the rural populations of Roman Italy consumed pork to the same extent as those in urban areas, although archaeological

excavations have recovered a high number of pig remains from rural sites. A high proportion (40-65%) of pig remains were found at the site of San Giovanni (Campania, 3rd-5th centuries AD) (Barnish, 1987). Faunal remains recovered during Barker's (1995) survey in central Italy indicated that pigs, sheep, goats, and cattle were the animals most commonly found in pre-Roman and Roman settlements, with pig remains predominating. This evidence substantiates suggestions that pigs played an important role in the economy of both rural and urban Italy, but it cannot be assumed that these remains signify a high level of consumption by rural populations. The production of cured pork (*laridum*) for long distance travel to urban markets would have resulted in a large number of pig bones at rural sites (*ibid.*).

Archaeological evidence suggests that sheep and goats made up 1/4 to 1/3 of the meat component of the Roman diet (Brothwell, 1988). However, some written sources state that goat meat was unhealthy because these animals were reportedly prone to fevers and epilepsy, although the milk was considered safe (André, 1981). Beef was probably a relatively minor component of the Roman diet because cattle were used primarily as draft animals, although it was reportedly a major component of the Roman military diet (White, 1988). There are very few recipes for beef or veal in the cookbook of Apicius, but recipes containing pork are much more common.

Frayn (1993) contends that the Roman diet contained a wide variety of birds. The more exotic varieties (e.g., pheasant, peacock) were for the elite; however small birds were widely available in urban and rural markets. Apicius' cookbook included recipes

for more than ten different species of bird, as well as recipes for wild deer, venison, boar, wild fowl, hare, and door mouse (Brothwell, 1988; Gallo, 1990).

2.3.6 Milk, Cheese, and Eggs

Goats and sheep were raised primarily for their wool and milk, much of which was used for the production of cheese (Garnsey, 1999). There are varied opinions about the popularity of milk in the Roman diet, although it is generally agreed that butter was not widely consumed probably because of problems with preservation (André, 1981; Dosi and Schnell, 1992). Milk was consumed fresh or curdled, often flavored with a variety of herbs (Dosi and Schnell, 1992). Cheese was consumed fresh, preserved with salt and herbs, or smoked (Brothwell, 1998; Dosi and Schnell, 1992).

Columella wrote that chickens were found on every farm and used for the production of eggs, but chickens were not as popular as geese for their meat (Dosi and Schnell, 1986). Methods for the preservation of eggs were known during the Roman period and eggs were widely consumed, often at the beginning of a meal (Brothwell, 1998; Dosi and Schnell, 1992). The cookbook of Apicius also contains a recipe for soft-boiled eggs prepared with herbs, honey, vinegar, and *garum* (Dalby and Grainger, 1996).

2.3.7 Fish and Fish Sauces

The Romans consumed a wide variety of marine fish, freshwater fish, and seafood, although this aspect of the Roman diet is not widely discussed by modern scholars, except to list those fish mentioned in the literary sources (e.g., André, 1981;

Brothwell, 1988; Frayn, 1993). Two main sources for the types of fish and seafood that were available for consumption in the Graeco-Roman world are Athenaeus' *Deipnosophistae* and the cookbook of Apicius. Some of the species listed include: squid, octopus, lobster, prawns, sea urchin, scallops, mussels, crayfish, cuttlefish, sturgeon, mackerel, tuna, perch, sardine, tunny, and eel. Fish and shellfish were commonly depicted in Roman art and mosaics, and from the 3rd century BC onward there was a special market in Rome for the sale of fish (Brothwell, 1988). Fish were considered expensive food items by some ancient authors (e.g., Juvenal and Pliny), suggesting that the regular consumption of fish may have been restricted to the elite (Frayn, 1993). In the Edict of Diocletian the price of freshwater fish was half that of saltwater fish, possibly indicating a preference for saltwater fish at that time (*ibid.*). Fish consumption may have been higher along the coastal regions, so that the proportion of fish and seafood in the diets of the people of *Portus Romae* was likely higher than the 'typical' consumption levels for inland populations.

Fish was also consumed salted (*salsamenta*) and as fish sauces (*liquamen, garum, allec*, and *muria*), which were not only used for cooking, but also figured extensively in medicinal recipes (Curtis, 1991).[5] The Greeks are credited for the invention of *garum* in the 4th century BC, described as a liquid extract of decomposed fish and salt mixed with a blend of herbs and other additives (Brothwell, 1988). *Garum* was considered to be the best quality fish sauce and was the one most widely mentioned in ancient recipes (Curtis,

[5] *Liquamen* is the general term used for any kind of fish sauce, whereas *garum* is the filtered liquid derived from the original mixture (Curtis, 1991). *Allec* is the residue left over from this process, and *muria* appears to be another form of liquamen (*ibid.*). *Garum* was used to flavor recipes in the place of salt, although it was believed that it also helped the appetite and digestion (*ibid.*).

1991). It was made by placing a variety of fish and fish entrails between alternate layers of aromatic herbs and salt, and leaving this concoction to mature for around thirty days (André, 1981). There were a variety of recipes for *garum*, some requiring the use of small fish, while other used larger fish cut into pieces (Curtis, 1990). Mackerel was reportedly the most popular fish used in the preparation of *garum*, but tunny (a type of tuna), sprats, smelts, oysters, sea urchins, sea anemones, and shellfish were also used (*ibid.*). Once again, it is not clear whether all members of Roman society consumed *garum*, and how much was used by those who did consume it regularly.

There is archaeological evidence for commercial trade of these fish sauces at the port of Cosa, Italy (c. 100 BC). Archaeological excavations at this site uncovered a vast complex for the processing of salted and dried fish, and for the production of *garum* (McCann, 1988). Curtis (1991) has done an extensive study on the production and commerce of *garum* and *salsamenta* in the Mediterranean region. Much of the physical evidence is based on inscriptions and stamps on amphorae that identify the origin of the container and the product contained within.

2.4 Infant Feeding Practices and Weaning

There are a number of textual and archaeological sources concerning infant feeding practices from the Graeco-Roman period. Most of the surviving written sources on infant feeding, wet nursing, and weaning come from ancient medical texts, such as Soranus' (2nd c. AD) *Gynaecology*, and Galen's *De sanitate tuenda*. The physician Soranus outlined the physical attributes (age, body shape, skin color, and breast size) and

general temperament (sympathetic, congenial, and tidy) of the ideal wet nurse (Joshel, 1986). Other written sources include private letters and wet-nursing contracts from Roman Egypt that provide information on the recommended duration of breast-feeding by wet nurses and the appropriate weaning diet (Lefkowitz and Fant, 1977, 1982). Archaeological evidence includes feeding vessels for infants, as well as images portrayed on paintings and funerary epitaphs.

Soranus criticized upper-class women for being too hasty in giving their infants cereal after only 40 days (Garnsey, 1999). He also recommended that infants be fed only breast milk until 6 months of age and that nursing last between 18 months and 2 years, whereas Galen wrote that infants should be breast-fed until 3 years of age (Fildes, 1986). Wet-nursing contracts from Roman Egypt stipulated that breast-feeding should continue for 6 months, followed by cows' milk up to 18 months of age (*ibid.*). According to these sources, the first weaning foods consisted of cereals and/or bread, softened with milk, sweet wine, or honey wine (Garnsey, 1999).

There is very little evidence from the historical sources about the diets of children after weaning was completed. Sporadic references identify eggs, porridge, and the shoots of figs as foods for young children (Fildes, 1986). Galen recommended that the diet of adolescents reflect the activities they would undertake later in life, so an athlete would have a diet rich in pork, beans, and leavened bread (Fidanza, 1976). Medical writers from the 1st and 2nd centuries AD described an appropriate health regime for young girls, primarily intended to restrict sexual development until an 'appropriate' age for marriage

(Garnsey, 1999). It was said that young females should limit the amount of food consumed, restrict their intake of meat and wine, and engage in work and exercise (*ibid.*).

2.5 Summary

The archaeological and written evidence for the Roman period provides a detailed picture of the food items available in the Mediterranean region, although it is difficult to quantify the contributions of various foods to the diet. The problem is that there is a tendency to speak in terms of *the* Roman diet, because that is how the sources presented the information. This does not provide any indication of the range of possible variation in diets between different members of society or between members of the same household. This is further complicated by the constantly changing economic and social conditions that also had a significant impact on who actually had access to these resources. While the political stability of Italy and the Mediterranean region during the first part of the Imperial period may have ensured a relatively constant supply of goods and food, not all members of Roman society would have equal access to the items flowing into Rome from around the Mediterranean region, as many of the items imported would have been luxury items such as glass, pottery, and spices from Syria, or precious metals, oil and wine from Spain (Scullard, 1982). Even the grain dole was limited to male citizens of Rome; this likely excluded women and children, freedmen, foreigners, and slaves. As Garnsey (1999) points out, access to food is a reflection of the social and

economic distinction between different classes in any society. We might identify the foods that were available, either through local production or trade, but access to these foods was determined by an individual's status in that society.

Food shortages and famine (*limos, fames*) are widely recorded in the ancient literature and were influenced by climatic fluctuations causing crop failures, political instability affecting distribution and transport of supplies, or warfare (*ibid.*). The period of political instability after AD 180 may have also affected accessibility to food, even at *Portus Romae*. The general picture is that the diet of Roman Italy was primarily vegetarian, based largely on the consumption of grains and supplemented by legumes and other vegetables. In addition, the evidence suggests that meat was not a major component of the Roman diet, although archaeological evidence shows that pigs, sheep, goats and cattle were economically important. The literary evidence suggests that there were status-based differences in the diet of the Roman population, with non-elites having limited access to expensive food items such as fish, meat, wine, and oil, and perhaps consuming greater quantities of 'inferior' grains, such as barley or millet. One aspect that is not directly discussed is whether males and females had differential access to certain foods, and the same is true for adults and children.

The commonly reported estimate is that cereals made up approximately 70-75% of the caloric intake of the Roman diet (Foxhall and Forbes, 1982; Garnsey, 1983; Brothwell, 1988; White, 1988). This has generated the hypothesis that the almost exclusively cereal-based diet of the poorer members of Roman society would have resulted in chronic protein-calorie malnutrition (White, 1976; Sippel, 1987). Frayn

(1975) and Evans (1980) have questioned the assumption that the diet of the Romans was mainly cereals, and suggest that there were a variety of wild and cultivated plants available, particularly for rural populations. Furthermore, it is difficult to quantify how much cereal was consumed as a 'staple' in antiquity, although some ancient sources provide quantities of daily rations for soldiers and slaves.[6] More recently, Garnsey (1999) re-examined the question of malnutrition in antiquity, and suggests that malnutrition and disease were probably more common among women and children in the ancient Mediterranean, due to a combination of environmental and socio-cultural factors. The dietary regime of middle-class population from *Portus Romae* would be expected to fall somewhere between that of the urban elite of Imperial Rome and of the rural peasantry in the surrounding countryside.

[6] Polybius (VI.39.13) and Cato (*de Agricultura* 56)

Chapter 3

The Use of Chemical and Dental Evidence to Examine Diet in Past Populations

3.1 Introduction

Isotopic and dental data provide two independent lines of evidence that can be used to study diet in the Isola Sacra skeletal sample. These data complement each other since the teeth and jaws record, to a limited degree, characteristics of the food that enters the mouth, and the bones reflect the isotopic composition of elements incorporated into the body tissues from the diet. The literary and archaeological evidence represent the possible food choices available to the population of *Portus Romae* (i.e., the menu). The dental and skeletal evidence help to identify, in broad terms, the types of food consumed (i.e., the meal).

Part I – Stable Isotopes

3.2 The Use of Stable Isotopes to Study Past Diet

Since the 1980s, chemical analysis of skeletal remains has been increasingly employed in the investigation of prehistoric diets, but this analytical tool has not been widely applied to Classical period populations in the Mediterranean region. There is a

considerable amount of archaeological and written information that already exists concerning the subsistence practices and dietary preferences of the ancient Greeks and Romans, but there are limitations to this evidence. These lines of evidence provide information on the 'menu' (or the food items available and selected for consumption), although *levels* of consumption cannot always be accurately assessed (Bumsted, 1985). Isotopic analyses of human, faunal, and botanical remains provide information about the relative contributions of the foods consumed, or the 'meal' *(ibid.)*. Stable isotope analysis alone cannot pinpoint specific foods consumed, but can give a broad indication of food groups that are distinguishable isotopically (e.g., marine versus terrestrial). The investigation of past diets using stable isotopes requires knowledge of the isotopic values of the dietary components and the tissues analyzed as well as the diet to tissue spacing between food and tissue (Katzenberg, 1992; Ambrose, 1993).

Isotopes are atoms of a particular element that have the same number of protons and electrons, but differ in atomic weight due to the presence of a different number of neutrons. The isotopes of an element will react in a similar manner in chemical reactions, but the slight differences in atomic weight can affect the rate of chemical reactions. Isotopes are either stable or unstable. Carbon-14 (^{14}C) is a widely known unstable, or radioactive, isotope that decays at a constant, known rate, and has been widely used for dating purposes. The stable isotopes of elements do not decay over time under normal conditions, hence the term 'stable'. The stable isotope ratios of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) are most often used in palaeodietary analysis, although strontium isotope ratios ($^{87}Sr/^{86}Sr$) have also been employed. Isotopic values are expressed as a

ratio of the difference between a sample and a specified international standard, measured in parts per thousand (‰, or 'per mil'), and designated by the symbol 'δ' (delta) with respect to the heavier isotope:

Equation 3.1 - $$\delta^{13}C = \left[\frac{^{13}C/^{12}C \text{ sample}}{^{13}C/^{12}C \text{ PDB standard}} - 1 \right] \times 1000 \text{ ‰}$$

Equation 3.2 - $$\delta^{15}N = \left[\frac{^{15}N/^{14}N \text{ sample}}{^{15}N/^{14}N \text{ AIR standard}} - 1 \right] \times 1000 \text{ ‰}$$

The standard for carbon is the Peedee Belemnite marine carbonate fossil (PDB) and the standard for nitrogen is atmospheric N_2 (AIR). When isotopic values are reported, a negative value means that the sample is depleted in the heavier isotope with respect to the standard, and a positive value means that it is enriched (Schoeninger, 1995).

When one isotope of an element is preferentially used over another in a chemical reaction, this leads to differences in isotopic ratios between substrate and product (Schoeninger and Moore, 1992; Schoeninger, 1995). This process is called fractionation. In general, heavier isotopes (i.e., those with the greater number of neutrons) will react more slowly than lighter isotopes. For example, ^{12}C (the lighter isotope of carbon) is preferentially incorporated into plants over ^{13}C during photosynthesis, which means that the $\delta^{13}C$ of CO_2 in the atmosphere is greater than the $\delta^{13}C$ in plants. This kind of fractionation, due to kinetic isotope effects, only occurs if the reaction involved does not go to completion. Since there is a relatively unlimited supply of CO_2 in the atmosphere for use during photosynthesis the reaction will never go to completion (Schwarcz and

Schoeninger, 1991). A second type of fractionation, equilibrium isotope exchange, is a reversible reaction between substrates and products that are in equilibrium; under these conditions the partitioning of isotopes between molecules changes in response to changes in temperature.[1]

Controlled laboratory experiments have demonstrated that isotopic ratios in different skeletal elements of the same animal are the same (DeNiro and Schoeninger, 1983). There appears to be some variability, though, between different tissues in the body (particularly for $\delta^{13}C$ levels). For example, brain, muscle, liver, and fat tissue, have varying $\delta^{13}C$ levels that may be related to their lipid content (DeNiro and Epstein, 1978; Tieszen *et al.*, 1983). Lipids are depleted in ^{13}C, so tissues containing relatively higher amounts of lipids will have more negative $\delta^{13}C$ values. In archaeological contexts, these kinds of tissues are rarely preserved, so bone is the tissue most commonly analyzed.

There is also no apparent correlation between isotopic variation and the age or sex of an individual (DeNiro and Schoeninger, 1983; Lovell *et al.*, 1986). Studies that have found significant correlations between stable isotope values and age or sex have been able to associate these relationships with differences due to diet, such as shifts in $\delta^{15}N$ values associated with weaning (e.g., Katzenberg *et al.*, 1993; Katzenberg and Pfeiffer, 1995).

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[1]For example: $H_2{}^{16}O + \frac{1}{2}\, C^{18}O_2 \rightleftharpoons H_2{}^{18}O + \frac{1}{2}\, C^{16}O_2$. The reactants and the products are the same, and it is only the partitioning of the oxygen isotopes that is changing.

3.3 Bone Collagen and Apatite

By weight, dry bone is approximately 70% inorganic and 30% organic (Katzenberg, 2000). The most frequently used material in the isotopic analysis of past diets is bone collagen, a structural protein that makes up the main organic portion of bone. The remaining organic constituents of bone, including noncollagenous proteins and lipids, surround bundles of collagenous fibers. Estimates for the turnover (i.e., remodeling) rate of bone are variable, but it is generally accepted that it requires between ten to twenty-five years for complete replacement in adults (Stenhouse and Baxter, 1979; Manolagas, 2000). Consequently, isotopic values derived from adult bone collagen are used to study long term dietary patterns, although stable isotope analysis of preserved hair, skin, and nails can be used to study short term variation in diets because of the higher rates of turnover in these tissues (Chisholm, 1989). Turnover rates of bone are higher in subadults, but precise estimates for turnover rates in infants and subadults are not known.

The main inorganic constituent of bone and teeth is hydroxyapatite [$Ca_{10}(PO_4)_6OH_2$]. Carbon is also present as carbonate ions (CO_3^{2-}) within apatite, either substituted for phosphate within the crystalline structure and/or adsorbed onto the surface (Lee-Thorp *et al.*, 1989). Apatite has not been widely used in dietary studies until recently due to the reported diagenetic alteration of the mineral component of bone, related to the extensive substitution of ions between hydroxyapatite and carbonate found in the burial environment (Schoeninger and DeNiro, 1982; Nelson *et al.*, 1986). The implication of this exchange is that $\delta^{13}C$ values may reflect the postmortem environment

and not *in vivo* levels. Lee-Thorp and coworkers (1989) have reviewed the early debate over the use of $\delta^{13}C$ values from apatite and suggest that even if diagenetic alteration of isotopic values has occurred, proper pre-treatment of bone samples can remove the soluble carbonates more prone to diagenetic alteration. The advantage of using bone carbonate is that there may not be much collagen left in extremely old bones. In addtion, carbon from apatite provides different dietary information than that derived from collagen (Katzenberg, 2000). Carbonate in tooth enamel is even more resistant to postmortem exchange, although it only gives us dietary $\delta^{13}C$ values for the early years of an individual (i.e., while the teeth are forming).

3.4 Diagenesis

Diagenesis refers to changes in the physical and chemical composition of bone due to interactions between bone and the burial environment (Katzenberg, 1992; Sandford, 1992). Intrinsic characteristics of bone, such as size, density, and porosity may have an impact on diagenesis, which are compounded by extrinsic variables such as soil pH and microbial activity (Sandford, 1993). Diagenesis is a more serious problem for the inorganic component of bone, since there can be elemental exchange of bone phosphate and carbonate with contaminants from the soil. Postmortem alteration of bone collagen will simply result in insufficient CO_2 or N_2 for stable isotope analysis (Katzenberg, 1992; Schoeninger and Moore, 1992). DeNiro (1985) showed that low collagen yields can produce inaccurate isotopic values, so it is necessary to determine the extent of diagenetic alteration prior to stable isotope analysis.

One way to assess the extent of diagenesis is to examine C:N ratios in the prepared collagen samples. If these range from 2.9 to 3.6, it is assumed that diagenesis has not significantly altered the isotopic values (DeNiro, 1985); however, others have suggested that C:N ratios alone are not adequate indicators of diagenesis, since C:N ratios within the acceptable range have been obtained from noncollagenous material (Schoeninger *et al.*, 1989; Schoeninger and Moore, 1992). Collagen yield from the original bone sample may also be used as an indicator of preservation. Ambrose (1990) found that prehistoric human bones with collagen yields greater than 5% of the original sample weight had relatively high and constant nitrogen and carbon concentrations, but below this level C and N concentrations decreased sharply.

Schwarcz and Schoeninger (1991) recommend that if the organic residue of a sample is less than 5% of the original bone weight then the C:N ratio should not be considered reliable. They argue that only the amino acid composition of the sample can reliably determine the presence of collagenous proteins (*ibid.*). If amino acid analysis cannot be conducted on the samples, the presence of intact collagen pseudomorphs, high yields (>5%), and C:N ratios within the appropriate range should indicate that isotopic values are reliable (Tieszen and Fagre, 1993).

Additional methods may be used to assess diagenesis in archaeological bone, including microscopic examination of histological thin sections and infrared spectroscopy. Stout (1978) has suggested that histological assessment of bone thin sections can be used to qualitatively assess the degree of postmortem alteration to bone. This method has been applied to archaeological bone samples and appears to be a useful

tool when used in combination with other indicators of diagenetic alteration (e.g., Schoeninger *et al.*, 1989; Savorè, 1996).

As mentioned previously, the reported problems with diagenetic alteration of bone apatite has led to the development of techniques to remove diagenetically altered carbonate. Infrared spectroscopy can be used to determine if contaminants remain after pretreatment of the sample. The compounds found in living bone absorb infra-red light to varying extents, depending on the wavelength of the light. A Fourier transform infrared spectrometer (FTIR) can be used to characterize the mineral and protein constituents of bone by measuring the absorption of infrared radiation (Wright and Schwarcz, 1996). Bone hydroxyapatite exhibits clear FTIR peaks arising from vibrations in the molecular groups of phosphate (PO_4) and carbonate (CO_3) (DeNiro and Weiner, 1988; Wright and Schwarcz, 1996). The "crystallinity index" can be calculated by measuring the separation of phosphate peaks between 565 and 605 cm^{-1} (wavelengths). A high crystallinity index in a sample likely indicates post-mortem alteration of the bone, which can be correlated with the conservation of isotopic information in the mineral component of bone (Prowse *et al.*, 1997).

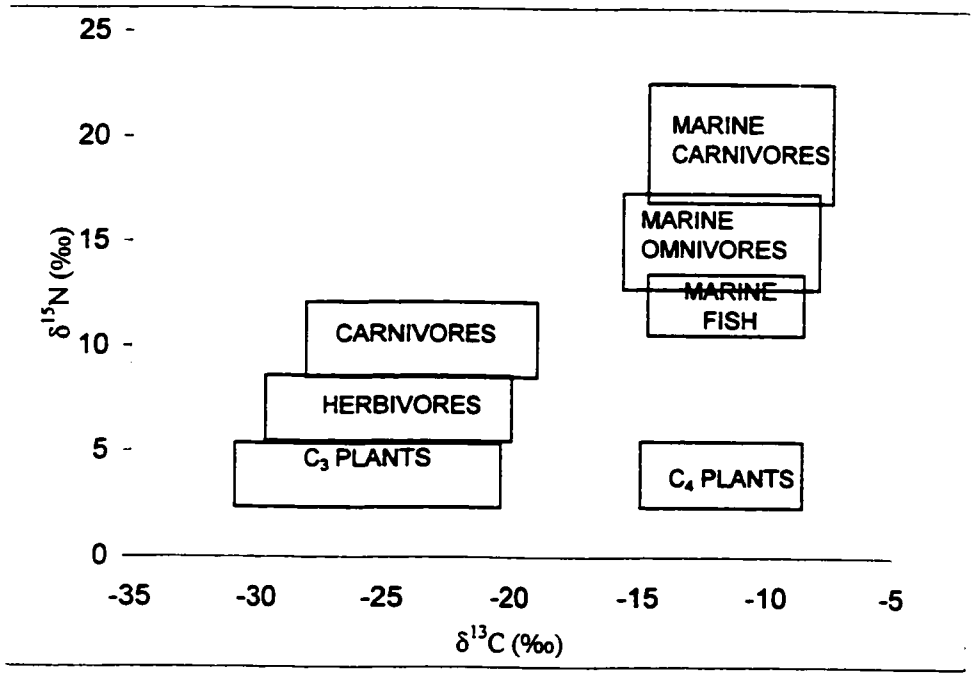
3.5 Carbon

Terrestrial plants are divided into three general categories, C_3, C_4, and CAM, based on the photosynthetic pathway used. Carbon from carbon dioxide (CO_2) in the atmosphere enters the food chain through the process of photosynthesis in terrestrial plants. The distinctive $\delta^{13}C$ values of C_3 and C_4 plants are influenced by the isotopic

composition of atmospheric CO_2 and by the fractionation that occurs during photosynthesis (DeNiro, 1987). Atmospheric CO_2 has a $\delta^{13}C$ value of -7‰, although modern burning of fossil fuels has decreased the $\delta^{13}C$ of atmospheric CO_2 by more than 1‰ so it would have likely been -5 to -6‰ in prehistory (Marino and McElroy, 1991; Schwarcz and Schoeninger, 1991; Schoeninger and Moore, 1992). During photosynthesis, plants that use the C_3 pathway (Calvin cycle) discriminate against ^{13}C in atmospheric CO_2 to a greater extent than do C_4 plants (Hatch-Slack cycle). The consequence is that C_3 plants will have more negative $\delta^{13}C$ values, with an average $\delta^{13}C$ value of -26.5‰, versus -12.5‰ for C_4 plants (Deines, 1980) (Figure 3.1). The characteristic fractionation of carbon in the photosynthetic pathways of C_3 and C_4 plants produces $\delta^{13}C$ ranges that do not overlap. This clear distinction between C_3 and C_4 plants can be useful in palaeodietary analysis.

C_3 plants include trees, shrubs, wheat, barley, rice, root crops, legumes, vegetables, nuts, most fruits, and temperate grasses, while C_4 plants include maize, amaranths, some chenopods, sugar cane, sorghum, tropical grasses, and millet (DeNiro, 1987). Crassulacean acid metabolism (CAM) plants can use either photosynthetic pathway, and have $\delta^{13}C$ values approaching C_3 or C_4 ranges depending on environmental conditions and the pathway used. Plants in this category include cacti, agave, yucca, pineapple, and prickly pear, and have average $\delta^{13}C$ values around -19‰ (Ambrose and DeNiro, 1986). There is no evidence to suggest that CAM plants formed part of the diet of the ancient Romans.

Figure 3.1 – Schematic diagram showing distribution of carbon and nitrogen isotopes in terrestrial and marine food webs



Most marine plants use the C_3 photosynthetic pathway, although there is greater variability in their isotopic values than among terrestrial plants. This is because marine plants obtain their carbon through a variety of sources, including terrestrial carbon washed into the oceans from rivers, dissolved CO_2 from the atmosphere, and dissolved carbonate in sea water (DeNiro, 1987; Keegan, 1989; Schoeninger and Moore, 1992).

There are other environmental factors responsible for variations in isotope levels. Different parts of a plant can have variable $\delta^{13}C$ values (e.g., leaves versus seeds) and carbonized plant remains may have different isotopic values than uncarbonized remains (Ambrose, 1993). DeNiro (1987) suggested that carbonized plants may preserve the true

isotopic signal because the isotopic record is 'burned' into the carbonized remains. The $\delta^{13}C$ values of C_3 plants can also be influenced by the availability of water, light intensity, temperature, CO_2 pressure, and nutrient availability (Tieszen, 1991; Ambrose, 1993). Tieszen (1991) noted that many of these environmental variables have an impact on carbon isotope ratios because of their effect on the activity of enzymes and on a plant's stomatal activity. For example, water stress in arid environments will cause closure of plant stomata in order to minimize water loss, therefore reducing CO_2 intake, and ultimately resulting in more positive $\delta^{13}C$ values (Francey and Farquhar, 1982; Tieszen, 1991). Although C_4 plants are not usually affected by these factors, genetic differences between some C_4 plant species (e.g., certain species of maize) can cause variation in $\delta^{13}C$ values (Ambrose, 1993).

In closed canopy forests the $\delta^{13}C$ values of plants, and their consumers, are depleted because of the recycling of CO_2 through the decomposition of material on the forest floor, known as the 'canopy effect' (van der Merwe and Medina, 1991; Schoeninger, 1995). Thus, the impact of climate and environment on carbon isotope data must be considered in dietary studies of past populations, particularly if there is evidence of changing environmental conditions over time, although these effects appear to be more pronounced in arid environments (Schoeninger, 1995).

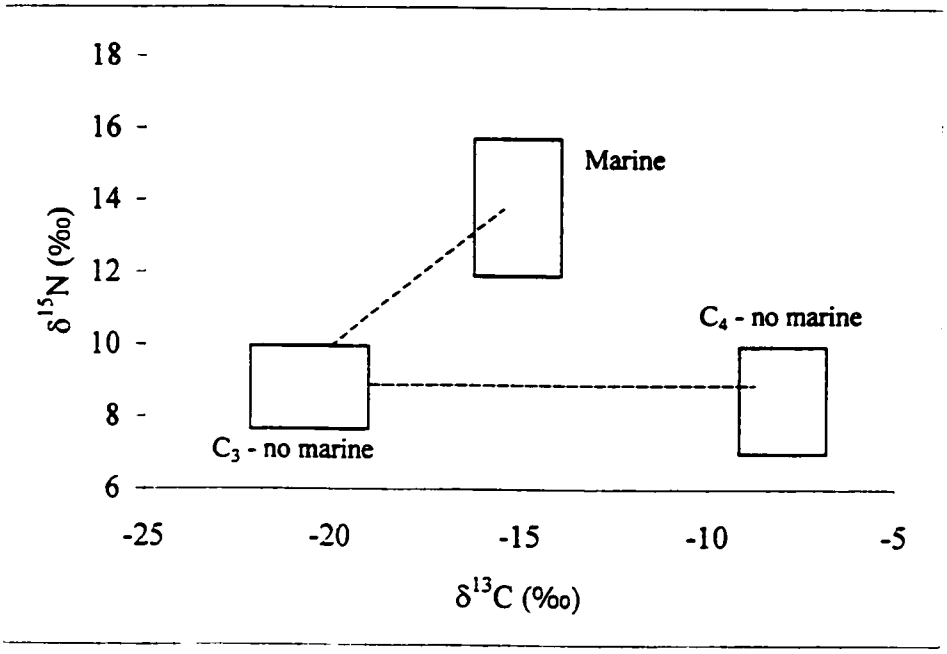
DeNiro and Epstein (1978) were the first to demonstrate that carbon isotopes in animal tissues reflect the isotopic composition of the diet. It was subsequently shown that $\delta^{13}C$ in bone collagen is enriched by approximately 5‰ relative to the diet, and that there is an additional fractionation factor of 1‰ between the bones of herbivores and

carnivores (van der Merwe, 1982; Ambrose and Norr, 1993). Initial studies of archaeological samples from North America showed that carbon isotopes could be used to detect the introduction of maize (a C_4 plant) into the predominantly C_3 diet of indigenous populations (e.g., van der Merwe and Vogel, 1978). Numerous studies of skeletal samples from North America and Mesoamerica have found similar results associated with shifts between C_3- and C_4-based diets (e.g., Schwarcz *et al.*, 1985; White and Schwarcz, 1989; Larsen *et al.*, 1992; Katzenberg *et al.*, 1995; see Larsen, 1999 for a review). These analyses are complicated if the diet of the population contained foods with $\delta^{13}C$ values similar to maize, such as marine resources (Schoeninger and Moore, 1992). Studies of past populations in Europe, Asia, and Africa have focused on the changing consumption patterns of C_4 plants like millet and sorghum (e.g., White, 1993; White and Schwarcz, 1994). Figure 3.2 shows a theoretical model of the expected isotopic values in human bone collagen based on populations consuming a pure C_3 diet, a diet with a significant amount of marine foods, and a pure C_4 diet (after Schoeninger and Moore, 1992).

In environments where C_4 plants are not a major component of the diet, $\delta^{13}C$ values have been used to investigate the proportion of terrestrial and marine foods consumed (e.g., Chisholm *et al.*, 1982; Walker and DeNiro, 1986; Lubell *et al.*, 1994). Organisms in marine environments are enriched in $\delta^{13}C$ relative to C_3 terrestrial food webs, resulting in more positive $\delta^{13}C$ values. This is because the main source of carbon is dissolved carbonate, which has a $\delta^{13}C$ value of 0-2‰ (depending on water depth). This is less negative than the $\delta^{13}C$ of atmospheric CO_2 (-7‰), the main source of carbon for

terrestrial plants and animals. Marine organisms usually have $\delta^{13}C$ values that are 6‰ enriched over terrestrial C_3 plant consumers and approximately 7‰ depleted with respect to C_4 plant consumers (Larsen *et al.*, 1992). Due to regional variability in $\delta^{13}C$ values of marine resources (related to water temperature), it is helpful to know the specific marine foods consumed and their isotopic compositions (Schwarcz and Schoeninger, 1991).

Figure 3.2 – Expected values in human bone collagen for diets composed of C_3, C_4 and marine food sources (modified from Schoeninger and Moore, 1992)



Difficulties in interpretation arise when diets consist of relatively equal contributions of C_3 plants, C_4 plants, and terrestrial animals. These would produce $\delta^{13}C$ values similar to a diet based on marine resources; thus, carbon isotope values alone cannot differentiate marine versus terrestrial diets if C_4 plants are part of that diet

(Schoeninger *et al.*, 1983). Some of these problems can be partially resolved through the analysis of nitrogen isotopes.

3.5.1 Issues Surrounding the Routing of Dietary Carbon to Collagen and Apatite

Carbon in bone can be derived from dietary protein, carbohydrates, or fats. The assumption in early studies was that carbon atoms from all dietary elements are broken down, scrambled, and resynthesized during metabolism, so that $\delta^{13}C$ values of bone collagen should reflect the entire diet (van der Merwe, 1982). The fractionation between diet and $\delta^{13}C$ of bone collagen is +5‰ (van der Merwe and Vogel, 1978). Apatite is more enriched in $\delta^{13}C$ than collagen, with an estimated diet-apatite spacing between 8 and 12‰ (Krueger and Sullivan, 1984). Krueger and Sullivan (1984) hypothesized that carbon atoms are preferentially routed from different components of the diet, such that collagen incorporates the protein component of the diet and apatite incorporates the energy (i.e., carbohydrate and lipid) component of the diet.

It was thought that the difference between the $\delta^{13}C$ values of bone collagen and apatite could be used to determine trophic levels (e.g., herbivore → carnivore), as a function of the changing contribution of proteins, carbohydrates, and lipids to the diet (Krueger and Sullivan, 1984). Both Krueger and Sullivan (1984) and Lee-Thorp *et al.* (1989) found that the difference between $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ is smaller in carnivores than in herbivores, and hypothesized that the size of this difference may be used to indicate the relative contribution of meat to the diet. They assumed that smaller collagen-apatite spacing reflected a higher proportion of meat in the diet (*ibid.*). Krueger and

Sullivan (1984) hypothesized that carbohydrates are the primary energy source for herbivores, and lipids and proteins are the primary energy source for carnivores. Since lipids are isotopically more negative relative to other macronutrients, the incorporation of a larger proportion of lipids into the apatite of carnivores will reduce its overall $\delta^{13}C$ values and, consequently, decrease the difference between collagen and apatite (*ibid.*). Lee-Thorp and coworkers (1989) offered an alternative model, which proposes that the higher proportion of lipids in carnivorous diets reduces plasma biocarbonate and therefore bone carbonate levels, producing a similar reduction in collagen-apatite spacing. As omnivores, humans consume a mixture of plant and animals, which makes the relationship between diet, collagen, and apatite more complex. Krueger and Sullivan (1984) argued that since the level of meat consumption in modern humans appears to be adequate for tissue turnover, carbohydrates would not be needed for protein synthesis, and therefore the $\delta^{13}C$ values in collagen should be derived from the protein component of the diet.

Subsequent laboratory research involving controlled diets of rodents supports the hypothesis that dietary proteins are mainly routed to collagen. Ambrose and Norr (1993) found that $\delta^{13}C$ values of rat collagen reflects estimated $\delta^{13}C$ values of dietary protein (although this depends on the proportion of protein included in the diet), and carbonate in apatite more accurately reflects the isotopic composition of the *entire* diet, not just the carbohydrate and lipid component. Similarly, Tieszen and Fagre (1993) found that bone collagen has a higher correlation with dietary protein than with total dietary composition, accounting for 91% of the variation in isotopic values. They concluded that the $\delta^{13}C$

value of apatite is a better general indicator of total diet than that of collagen (*ibid.*).

More recently, Schwarcz (2000) has suggested that the reason $\delta^{13}C$ of apatite should reflect total diet (and not just the carbohydrate and lipid contributions of the diet) is because there is an almost negligible fractionation between blood biocarbonate and bone carbonate, and the carbon in blood biocarbonate is obtained from all dietary sources. It is apparent that the routing models of certain dietary components to collagen versus apatite may not be appropriate under some conditions of growth or physiological stress, or if there is insufficient protein in the diet (*ibid.*). The currently accepted view is that collagen does represent the protein component of the diet, whereas apatite represents the entire diet (Katzenberg, 2000).

3.6 Nitrogen

Nitrogen exists almost exclusively as N_2 in the atmosphere or dissolved in the world's oceans. The range of observed nitrogen isotope values is related to the manner in which terrestrial and marine plants obtain their nitrogen. This can occur through direct N_2-fixation by plants, or through the uptake of nitrates produced by bacterial composition of organic matter. The $\delta^{15}N$ levels produced by the fractionation of nitrogen are passed up through the food chain and amplified through the 'trophic level effect' (discussed below).

Among terrestrial plants, $\delta^{15}N$ values in legumes and non-legumes are differentiated based on the different methods of nitrogen acquisition. The major source of nitrogen for legumes is atmospheric N_2 that is converted into a usable form through the

process of N_2-fixation by bacteria found in the root nodules of these plants. There is very little fractionation of nitrogen during this process, so that $\delta^{15}N$ values for legumes are similar to the isotopic composition of atmospheric N_2 (0‰). Legumes consumed by humans include peas, peanuts, and beans (DeNiro, 1987). Non-legumes obtain their nitrogen from partially denitrified organic material in the soil, resulting in $\delta^{15}N$ values more positive than atmospheric N_2, with averages around 1-5‰ (Schoeninger and DeNiro, 1984; DeNiro, 1987).

Nitrogen in aquatic environments can be derived from nitrogen fixation of algae and bacteria or, more commonly, through the uptake of nitrogen from dissolved nitrates, producing higher $\delta^{15}N$ values than the surrounding dissolved N_2 (Schwarcz and Schoeninger, 1991; Schoeninger and Moore, 1992). Non-nitrogen-fixing marine plants have $\delta^{15}N$ values approximately 4‰ enriched over terrestrial plants (DeNiro, 1987; Ambrose, 1993). This difference is transferred up the food chain; marine organisms usually have higher $\delta^{15}N$ values than terrestrial organisms with an average $\delta^{15}N$ value of 10‰, but some species can have values as high as 20‰ (e.g., marine carnivores) (DeNiro, 1987; Schwarcz and Schoeninger, 1991). Exceptions are organisms in coral reef systems, because reefs at the base of these food chains are nitrogen-fixers, and therefore their $\delta^{15}N$ values are lower (Schoeninger *et al.*, 1983; Keegan and DeNiro, 1988). Higher $\delta^{15}N$ levels in marine versus terrestrial organisms are due to longer food chains in marine environments, which permit further enrichment of ^{15}N at each successive trophic level (Schoeninger and DeNiro, 1984).

In addition to assessing the relative proportion of legumes and non-legumes in

terrestrial diets nitrogen isotopes have been used primarily to determine the proportion of marine and terrestrial foods in past human diets (e.g., Schoeninger *et al.*, 1983; Schoeninger and DeNiro, 1984; Schwarcz *et al.*, 1985; Walker and DeNiro, 1986). DeNiro and Epstein (1981) demonstrated that $\delta^{15}N$ from animal tissues, like $\delta^{13}C$, reflects the isotopic composition of the diet, but there can be considerable overlap in the $\delta^{15}N$ values of marine and terrestrial plants and animals. It is recommended that carbon and nitrogen isotopes be used together to accurately assess the role of terrestrial and marine food sources in human diets (Schoeninger *et al.*, 1983; Walker and DeNiro, 1986). Isotopic values of two or more specific food sources (with known $\delta^{15}N$ and $\delta^{13}C$ values) can be plotted and compared to skeletal isotopic values in order to examine patterns of distribution relative to the food sources. This is known as the 'linear mixing model' (Schwarcz, 1991). The closer the distribution of the skeletal isotopic values to a particular food source, the greater proportion of that food item in the diet.

In terrestrial ecosystems, $\delta^{15}N$ values may not be comparable between different sites due to the isotopic variability of different soils, which would be reflected in the $\delta^{15}N$ values of these plants (Klepinger, 1984). Further, modern use of chemical fertilizers on plants has reduced their $\delta^{15}N$ values compared to plants from prehistory, so modern and ancient $\delta^{15}N$ values cannot be directly equated (DeNiro, 1987).

Climate can have a pronounced effect on $\delta^{15}N$ values in animals, which can also have implications for the interpretation of diet from stable isotopes. Heaton and coworkers (1986) found that animals in hot, arid environments with low annual rainfall tended to have higher $\delta^{15}N$ values than those found in cooler, wetter regions. One

hypothesis is that this pattern is related to nitrogen metabolism in the body and the retention of water under conditions of water stress (Ambrose and DeNiro, 1986). A study of human skeletal samples found that individuals living in arid environments had higher $\delta^{15}N$ values than those living in more temperate zones (Aufderheide *et al.*, 1988). Recently, a study of pre-Roman and Roman skeletal material from the Dakhleh oasis, Egypt, found a pattern of higher $\delta^{15}N$ values with decreased precipitation (Schwarcz *et al.*, 1999). While the environment of Roman period *Portus Romae* cannot be considered 'arid', the relationship between climate and $\delta^{15}N$ values must be considered, particularly if the data from Isola Sacra are compared with other skeletal samples. Comparability between sites may be limited due to these constraints on $\delta^{15}N$ values.

3.7 Trophic Level Effect

Research on marine and terrestrial organisms has shown a trophic level shift for $\delta^{15}N$ and $\delta^{13}C$ values, such that the tissues of consumers are enriched by approximately 3‰ and 1‰, respectively, relative to the diet consumed (DeNiro and Epstein, 1981; Minagawa and Wada, 1984; Schoeninger and DeNiro, 1984; Schoeninger, 1985). The mechanisms for these fractionations are still not completely understood. It is known that ^{14}N breaks away from bonds with carbon more readily than does ^{15}N and more ^{14}N is excreted by the body in the form of urea $[CO_2(NH_2)_2]$, leaving larger amounts of ^{15}N for incorporation into the body's tissues (Schoeninger and Moore, 1992). Schoeninger (1985) originally proposed that this trophic level effect could be used to determine the relative proportion of meat in the diet, but more recently Schwarcz and Schoeninger

(1991) have suggested that if most of dietary nitrogen comes from meat, then changes in the amount of meat in the diet would not have a significant effect on $\delta^{15}N$ values.

Experiments have also shown that the $\delta^{13}C$ values of most tissues are enriched by approximately 1‰ over diet (DeNiro and Epstein, 1978; Tiezen *et al.*, 1983). This $\delta^{13}C$ trophic level effect has been observed in studies of both marine and terrestrial organisms (e.g., Rau *et al.*, 1983; Schoeninger and DeNiro, 1984; Schoeninger, 1985). The slight differences in $\delta^{13}C$ values between successive trophic levels are often smaller than the overall range of $\delta^{13}C$ in potential food sources, so they are not as useful as differences in $\delta^{15}N$ levels for distinguishing trophic level relationships (Schoeninger, 1985; Ambrose and DeNiro, 1986).

3.8 Infant Feeding and Weaning

Fogel and colleagues (1989) showed that breastfeeding infants are also enriched by 3-4‰ relative to their mothers' $\delta^{15}N$ levels, because the infants are, in effect, consuming the mothers' tissues. This pattern of higher $\delta^{15}N$ values in infants has been observed in archaeological samples and used to investigate the pattern and timing of weaning in past populations (e.g., Katzenberg *et al.*, 1993, 1996; White and Schwarcz, 1994; Katzenberg and Pfeiffer, 1995; Herring *et al.*, 1998; Schurr, 1997, 1998). The pattern is a general increase in $\delta^{15}N$ with increased age, to a peak value roughly one trophic level above adult values. This is followed by a progressive decline in $\delta^{15}N$ attributed to the weaning process, ultimately reaching levels representative of childhood diet. Herring and colleagues (1998) contend that weaning is not a single, one-time event,

but rather is a process characterized by the gradual introduction of solid foods into the infant's diet and a concomitant decrease in breast milk. In a skeletal sample it is assumed that stillborns and neonates should have lower $\delta^{15}N$ values, similar to adults in the same sample, because these individuals died before breastfeeding could have an impact on $\delta^{15}N$ levels in bone collagen (Katzenberg and Pfeiffer, 1995).

A trophic level effect should also be evident in the $\delta^{13}C$ values of infants who are breastfeeding, although this trend has not been studied as widely as $\delta^{15}N$ trophic level differences. Some studies have found higher $\delta^{13}C$ levels in young infants, which have been attributed to this trophic level effect, or to a high carbohydrate weaning diet consisting of C_4 plants (or milk from animals consuming C_4 plants) (Katzenberg, 1993; Katzenberg *et al.*, 1993; Dupras, 1999).

Isotopic studies of weaning patterns contribute to our understanding of the relationship between maternal behavior, infant feeding practices, and morbidity and mortality in past populations (Katzenberg *et al.*, 1996). A significant problem is that infant skeletal remains do not preserve well in the archaeological record so that sample sizes remain extremely small. One of the unknowns in weaning studies is the rate of bone deposition and turnover in growing infants; consequently, it is not possible to determine the lag time between complete cessation of breast-feeding and the associated drop in $\delta^{15}N$ levels (Herring *et al.*, 1998). An additional challenge is the nature of the samples being analyzed. Since the samples come from infants who did not survive, it is not clear if the cause of death was related to breastfeeding, or the lack thereof (e.g., the mother died in childbirth) (*ibid.*). Katzenberg and coworkers (1996) provide a

comprehensive overview of skeletal weaning studies.

3.9 Roman Diet and Stable Isotopes

A number of questions are generated from the archaeological and literary information presented for the diet of the Romans that may be addressed through stable isotope analysis. A predominantly vegetarian diet composed of grains and vegetables, as suggested by historical sources, would produce bone collagen values with the range expected for a diet based on C_3 plants. The literary evidence also suggests that C_4 plants (e.g., millet) and marine resources may have also contributed to the diet of the inhabitants of *Portus Romae*, which would make the interpretation of $\delta^{13}C$ values more complex. It is also assumed that meat played a relatively minor role in the Roman diet. Meat is mainly protein, so even a small amount of meat in the diet will still affect $\delta^{15}N$ levels. The Romans reportedly consumed large quantities of fish sauce (e.g., *garum*) in their diet, although access to fish and seafood may have been restricted to elite members of society. Both $\delta^{13}C$ and $\delta^{15}N$ values are used to examine the relative importance of marine resources to this coastal population.

Although it is suggested that the ancient Romans may not have consumed a significant amount of meat (with the possible exception of pork), their isotopic signatures would still be influenced by the animals they relied on for secondary products such as milk and cheese from goats, cows, and sheep, and eggs from chickens or other birds. It is expected that the high lipid content of these products would reduce $\delta^{13}C$ values (if consumed regularly), because lipids are lighter isotopically. The same should be true for

olive oil, and it is expected that a significant amount of olive oil in the diet would also reduce $\delta^{13}C$ values, particularly in apatite.

Part II – Dental Pathology

3.10 The Use of Teeth to Study Past Diet

Patterns of dental health have often been studied in relation to shifts in subsistence strategies, particularly the transition from hunting and gathering to agriculture (e.g., Cohen and Armelagos, 1984; Patterson, 1987). This research trend continues in more recent studies of past diet and dental health (Kelley *et al.*, 1991; Larsen *et al.*, 1991; Littleton and Frohlich, 1993, and others). This is a review of the categories of dental evidence used to examine diet in this study, as well as a discussion of the general patterns of oral health inferred from such evidence. Comparative studies from the pre-Roman and Roman period are also reviewed, as is the evidence for oral hygiene in ancient Rome.

Tooth enamel is unique in that it is almost entirely inorganic (96% by weight), lacking nerves, blood vessels and cells. Unlike bone that is constantly replaced over the lifetime of an individual, enamel does not remodel. Dentine has a limited capacity to remodel; odontoblasts can produce secondary dentine if primary dentine has worn away. Although enamel does not remodel, the structural integrity of a tooth can be affected by physiological stressors (e.g., dietary deficiency, infectious disease) during development. Evidence of disruption can be seen on tooth crowns as pitted or linear indentations,

known as enamel hypoplasias. There is evidence to suggest that these defects can increase susceptibility to caries (Duray, 1990).

Once teeth have erupted, the surfaces are exposed to the oral environment and to the foods consumed. There are a number of mechanical, chemical, and pathogenic factors that can have an impact on the overall dental health of an individual, many of them directly related to diet (Powell, 1985). A diet composed largely of hard, abrasive foods can rapidly wear away dental enamel and dentine, whereas a diet containing large amounts of soft, sticky foods will produce little wear, but encourage the development of dental caries. The overall dental health of an individual is the result of a complex interaction between diet, tooth morphology, food preparation techniques and conditions in the oral environment (Powell, 1985; Littleton and Frohlich, 1993).

Poor dental health not only affects the teeth and jaws, but can also have consequences for the overall health of an individual. Antemortem tooth loss, abscesses, or inflammation of the gingival tissues may reduce the ability to chew certain foods, effectively restricting the diet (Powell, 1985). This may lead to both malnutrition and undernutrition, with potentially serious consequences for health. An individual under nutritional stress may be less resistant to infectious diseases and the ability to recover from disease may be compromised by nutritional status. In addition, the unchecked development of dental caries may lead to infection of the tooth and the surrounding tissues and bone. If the infection reaches the bloodstream, this can lead to meningitis and osteomyelitis (Ortner and Putschar, 1981). Thus, diet, nutrition, dental pathology, and overall health are interrelated.

3.11 Calculus

Dental calculus is mineralized plaque attached to the surface of the tooth and covered by non-mineralized plaque. The inorganic component of calculus (~80%) consists primarily of calcium and phosphorus, but may also contain carbonate, sodium magnesium and fluoride, while the organic component (~20%) is made of amino acids, peptides, carbohydrates, lipids, glycoproteins and proteins (Hillson, 1996; Lieverse, 1999). Mineralization of plaque occurs through the deposition of calcium phosphate crystals. The respective roles of oral microorganisms, oral fluids, and pH in this mineralization process are still not clearly understood, although the process is enhanced in an alkaline oral environment (Lieverse, 1999).

There are two types of calculus, supragingival and subgingival. Supragingival calculus is found on the crown at, or above, the gingival margin. Subgingival calculus is a thin layer found on the surface of the root in the tooth socket and is normally associated with periodontal disease (Lieverse, 1999; Hillson, 2000). This study is restricted to an examination of supragingival calculus (from this point on referred to as calculus). Calculus is commonly found on the buccal and lingual surfaces of the tooth, near the salivary glands, but has also been found less frequently on the occlusal surfaces, which has been interpreted as an indication of problems with occlusion or mastication (Lukacs, 1989).

The general assumption in studies of dental calculus is that formation is controlled by the pH of the oral environment, in which an alkaline pH encourages the formation of

calculus (Lieverse, 1999). As discussed previously, it is assumed that increased acidity facilitates the development of caries (i.e., demineralization of tooth enamel), because a high carbohydrate diet leads to increased acidity in the mouth from the metabolic activity of cariogenic bacteria. This implies that the prevalence of dental caries and dental calculus may be used to determine the relative contribution of carbohydrates versus proteins to the diet, although it is recognized that this is a simplified explanation (Hillson, 1979).

It is probable that the relationship between diet and the formation of dental calculus is much more complex. While there does tend to be an inverse relationship between caries and calculus, this relationship is not consistent between populations, and it is possible to have both calculus and cavities on the same tooth (Hillson, 2000). Further, laboratory studies on animals have demonstrated that high fat and high carbohydrate diets can also lead to calculus formation, and that there are a number of dietary and non-dietary factors, such as saliva flow and mineral content of water, that may have a significant influence on the formation of calculus (Lieverse, 1999).

Dental calculus has not been as widely studied as other indicators of dental health in archaeological investigations of diet. Lieverse (1999) reviewed studies of dental calculus in archaeological samples with the criticism that their discussions of the relationship between calculus and diet are poorly developed. Studies that have included dental calculus as a measure of oral health have found a great deal of variability in the degree and pattern of calculus formation in their samples (e.g., Evans, 1973; Allison, 1984; Rathbun, 1984; Lukacs, 1989, 1992). Analyses of Mayan and Inca samples from

South America noted an increase in calculus with evidence for increased reliance on carbohydrates in the diet (Evans, 1973; Allison, 1984). In contrast, Rathbun (1984) found that calculus and periodontal disease remained relatively stable in pre-agricultural and agricultural samples from Southwest Asia, implying that factors other than diet may have been responsible for calculus formation. Lukacs (1992) found an increase in all dental lesions, except calculus, with an increased reliance on agriculture in prehistoric Pakistan, but he did not explain why calculus did not conform to the expected pattern. Littleton and Frohlich (1993) also found variable levels of calculus over time in Arabian Gulf samples, and concluded that the differences may be due to variability in diet, food preparation techniques, and levels of oral hygiene.

Non-dietary factors can also influence the development of calculus. Klepinger and coworkers (1977) found that the habit of chewing coca leaves mixed with lime produced high levels of calculus. They proposed that lime facilitated the mineralization of plaque on teeth due to the presence of calcium hydroxide in the lime, which raises the pH in the mouth. Similarly high levels of calculus in Polynesian skeletal samples were correlated with historical evidence for betel nut chewing, although the exact causal relationship between this practice and calculus formation was unclear (Fyfe *et al.*, 1993).

From this review it appears that the formation of calculus cannot be considered an accurate, independent indicator of dietary composition. Its presence is affected by a number of non-dietary factors including food preparation methods, oral hygiene, culturally specific behaviors and individual susceptibility (Lieverse, 1999).

3.12 Dental Caries

Dental caries is a disease process involving the localized, progressive demineralization of dental tissues by organic acids (Larsen, 1999). Left untreated, this may result in the formation of a carious lesion, or cavity. Organic acids are produced through the metabolic activity of bacteria found in dental plaque that colonize tooth surfaces. It is now widely accepted that certain bacteria play a key role in the development of caries (Mandel, 1979; Powell, 1985; Hillson, 1996; Caselitz, 1998). The bacteria most commonly associated with caries are *Streptococcus mutans*, and some species of *Lactobacillus, Staphylococcus* and *Actinomyces* (Mandel, 1979; Caselitz, 1998). As is the case with other infectious diseases, the mere presence of a pathogen does not guarantee that a disease will occur. Larsen (1999) identifies three essential factors for the development of caries; dental plaque, diet, and conditions in the oral environment. A number of other modifying factors may affect the rate of development and distribution of carious lesions.

Dental plaque is an accumulation of microorganisms, food debris, salivary proteins, and polysaccharides formed on surfaces of teeth (Moore and Corbett, 1983). It can form on any tooth surface, but is most commonly found in pits and fissures, at the margins with the gingiva, and in the interproximal spaces (Hillson, 1996; Caselitz, 1998). The bacteria in plaque break down fermentable carbohydrates (e.g., sugar and starch) and proteins found in dairy products, producing metabolic waste and organic acids (Caselitz, 1998; Hillson, 1996). Lactic acid is considered to be the main demineralizing compound in the initial development of carious lesions (Mandel, 1979; Caselitz, 1998). The

formation of acids as a by-product of bacterial metabolism leads to localized demineralization of enamel, and it is the alternating cycles of acidity and alkalinity that eventually lead to the development of carious lesions (Mandel, 1979). Caries is usually a slow, progressive disease characterized by periods of demineralization with alternating periods of inactivity or remineralization, and is thus an age progressive disease (Hillson, 1996). Larsen and coworkers (1991) found coronal crown caries to be more common in individuals under fifteen years of age, while root surface caries were predominant among adults.

Arguably the most important contributing factor to the development of caries is diet, because the type of food consumed affects the metabolic activity of bacteria. It is not simply the food itself, but also the form in which it is consumed and the pattern of consumption. Carbohydrates, particularly simple sugars, are metabolized much more rapidly by bacteria than are fats or proteins, with a resultant increase in the amount of acid produced (Powell, 1985). Studies on laboratory animals and modern human groups have shown that plaque pH will decrease with the ingestion of sugar, indicating that acid is being produced in the mouth, but it will return to neutral levels unless more sugar is introduced (Hillson, 1996). If sugar is repeatedly ingested, the pH will remain low for longer periods of time, encouraging the development of carious lesions.

Starches are considered less cariogenic than sugars because large starch molecules need to be broken down before they can be used by bacteria, although when the pH level is reduced by the consumption of starch it remains low for a longer period of time (Mandel, 1979; Hillson, 1996). Foods containing both sugar and starch are highly

cariogenic due to the marked drop in pH and the extended duration of lowered pH levels (Hillson, 1996). In addition, sugars are more soluble than starch, so that starches may stay on the teeth relatively longer. Bacteria involved in the development of carious lesions do not metabolize proteins and fats; their consumption may actually inhibit bacterial activity by increasing pH levels in the mouth through their initial breakdown (Powell, 1985).

The texture of the food and techniques of food preparation may also affect the cariogenicity of a diet. Sweet, sticky foods are cariogenic because the sugars encourage bacterial activity and the stickiness helps the food adhere to the tooth surfaces, whereas abrasive foods are cariostatic because the grit in the food 'scrubs' the exposed surfaces of the teeth, removing both food and bacteria. A diet composed of coarse, abrasive foods will also erode enamel and remove pits and fissures where bacteria can accumulate. There is generally an inverse relationship between the degree of tooth wear and caries prevalence in populations (Larsen, 1995). Disturbances during tooth development can result in deficiencies in the structure of enamel (hypoplasias) or deficiencies in mineralization (hypocalcifications), which may also contribute to the development of caries. Enamel hypoplasias provide locations for the accumulation of bacteria and hypocalcifications increase porosity and decrease mineral content, reducing a tooth's resistance to the development of caries. Duray (1990) found a strong association between hypocalcifications and caries susceptibility, and a moderate increase in association with hypoplastic pits.

Elements present in the water, soil, or foods can enter the diet and have an impact

on caries prevalence. Elements reported to have cariogenic properties include selenium, magnesium, lead, cadmium, and silicon (Powell, 1985). Fluorine is a cariostatic element because it has a lower solubility than hydroxyapatite (Hillson, 1996). Zinc, copper, and iron may also have cariostatic properties; the presence of these trace mineral elements during enamel calcification may have an impact on the ability of enamel to resist demineralization associated with the caries disease process (Schneider, 1986).

Tooth type also has an impact on caries expression. Premolars and molars tend to have higher caries prevalences than the anterior teeth, mainly due to the complex fissures and pits present on the crowns where plaque can accumulate (Powell, 1985; Hillson, 1996). Saliva can act to inhibit the development of caries in the mouth by inhibiting the activity of acidogenic bacteria. Saliva covers tooth surfaces with a thin layer of fluid (pellicle), flushes away bacteria and food debris, and produces salivary bicarbonate, which acts to buffer the acidic production of plaque bacteria (Mandel, 1979; Hillson, 1996). The interpretation of caries data must take into consideration the multiple factors of food type (e.g., carbohydrate versus protein), presence of bacterial plaque, conditions in the oral environment and individual susceptibility when attempting to investigate diet in archaeological contexts.

Numerous studies have found that changes in subsistence patterns, particularly the shift from hunting & gathering to agriculture, are associated with changes in the prevalence of caries within and between populations (e.g., Turner, 1979; Powell, 1985; Larsen *et al.*, 1991; Larsen, 1995), although there is variability in the expression of caries between groups, because of differences in food choices and food preparation techniques

(Larsen, 1999). Turner's (1979) survey of published data on caries prevalence found that hunting & gathering populations had the lowest frequency of carious lesions (1.7%), slightly higher frequencies among mixed economy populations (4.4%), and the highest rates among agricultural-based populations (8.6%). Moore and Corbett (1983) found that caries rates did not change from the Iron Age to the mediaeval period in Britain, but by the 17th - 19th centuries there was a dramatic increase associated with the increase in sucrose consumption after the 17th century.

Studies of the transition from hunting & gathering to dependence on maize agriculture in North America have found the same increase in caries prevalence with the shift to a carbohydrate-rich diet (e.g., Rose *et al.*, 1984; Larsen *et al.*, 1991; see Larsen, 1999 for a review). There is also a change in the pattern of carious lesions with the transition from a low to high carbohydrate diet. Generally, pre-agricultural societies have fewer lesions and these are located at the cervical margins of teeth, whereas agricultural groups have more lesions, which are located on the root surface or at the cemento-enamel junction (Hillson, 1996). With the introduction of sugar into the diet, fissure and interproximal lesions become more prevalent (*ibid.*).

Investigations of caries prevalence in archaeological samples have shown that there is a general tendency for caries to be more common in females than in males, particularly in populations reliant on agriculture (e.g., Hillson, 1979; Kelley *et al.*, 1991; Larsen *et al.*, 1991). There are a number of potential explanations for this pattern. First, female dentitions erupt earlier than males', so.the tooth surfaces of females are exposed to potential hazards in the oral environment for a longer period of time (Hillson, 1996).

If this were the only factor involved, the higher prevalence of caries in females would be consistent across all populations, which is not the case (e.g., Moore and Corbett, 1973; White, 1994). Other explanations are related to differences in food consumption patterns associated with sexual division of labor, food preparation practices, and pregnancy (see Larsen, 1999 for a review). Females tend to have longer life expectancies than males, and since caries is an age-progressive disease, females may tend to have more lesions. However, this may be counteracted by the bias against the preservation of female skeletal remains (Hillson, 2000). Studies have also found that social status may also have an impact on access to food and therefore affect caries prevalence among different members of society (e.g., Walker and Hewlett, 1990; White, 1994)

There has been a vast amount of research conducted on archaeological populations concerning the relationship between diet and dental caries. The general pattern that has emerged from these studies is the increase in caries prevalence with the introduction of carbohydrate-rich foods into the diet, although it is clear that other factors related to food preparation and consumption must be considered in the interpretation of caries prevalence.

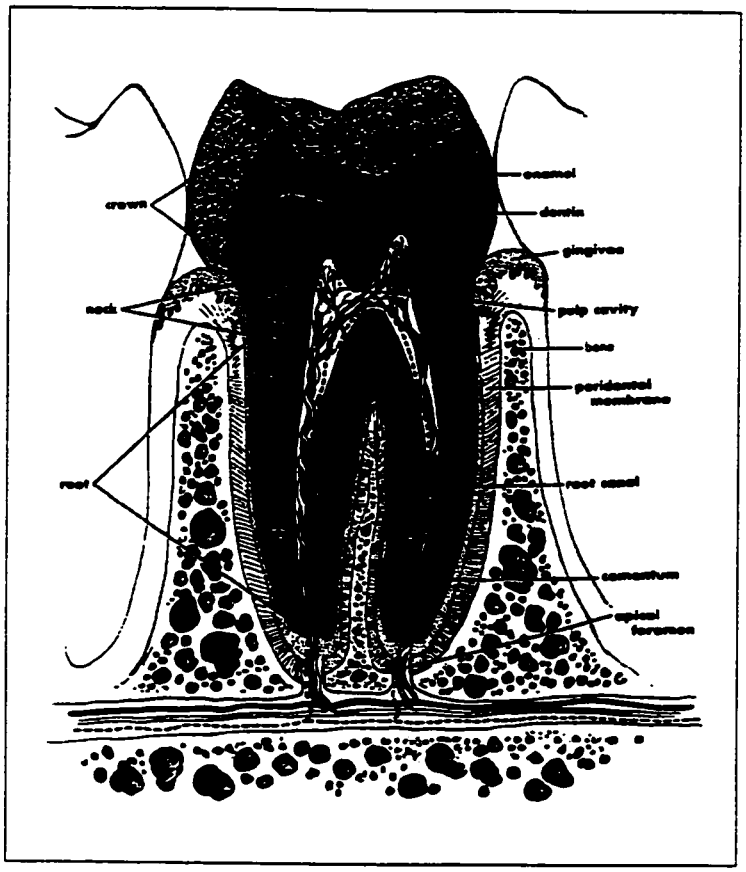
3.13 Abscesses

The pulp cavity of a tooth (Figure 3.1) can become exposed to the oral environment through the development of caries, trauma to the tooth (i.e., a chip or crack), or as the result of heavy wear. If one or a combination of these occurs, bacteria and other microorganisms can cause an inflammatory reaction, which may then travel down the

pulp cavity and further infect the surrounding tissue. The physiological response to infection is the accumulation of pus that may drain through existing gaps in the bone, or pressure may cause the bone to resorb, leaving a drainage channel through the alveolar bone. An abscess usually occurs on the thinner buccal (cheek) surface of the alveolus, but may also appear on the lingual surface, in the nasal cavity, or in the sinuses of the maxilla (Hillson, 1996). It is expected that abscesses will increase with age, due to the interaction with the development of caries and tooth wear (Jurmain, 1990). One problem with the macroscopic diagnosis of abscesses is that only those lesions that have perforated the bone will be recorded as present, so their actual prevalence in skeletal populations is likely underestimated (Lukacs, 1989).

In studies of archaeological populations, abscessing is usually attributed to severe attrition and/or caries (e.g., Costa, 1980; Macchiarelli, 1989; Jurmain, 1990; Kelley *et al.*, 1991). Like all the other indicators of oral health discussed in this chapter, there are always exceptions. In their study of dental pathology over time in the Arabian Gulf, Littleton and Frohlich (1993) found no consistent association between the number of abscesses and the number of pulp exposures caused by caries or attrition. These authors concluded that it is difficult to evaluate the relationship between abscesses due to "the complex relationship between attrition, caries, AMTL, and abscessing" (*ibid.*: 437).

Figure 3.3 – Molar tooth section, modified from Crouch (1978)



The pattern of sex-related abscessing is variable between populations. Costa (1980) found that there were only slight differences between males and females in three Eskimo samples from Alaska. A similar lack of sex-related differences in the prevalence of abscesses has been noted by Turner (1979) and Lukacs (1989). However, Jurmain (1990) found that dental abscesses were more common in males, although no explanation for this difference was provided.

3.14 Tooth Wear

The pattern and degree of tooth wear are valuable sources of information used in the reconstruction of subsistence practices and diet in past populations. Tooth wear reflects a combination of variables, including the properties (e.g., consistency and texture) of the food consumed, the methods of preparation, the function of teeth in chewing, as well as non-dietary uses of teeth that may affect wear (Molnar, 1972). Tooth wear is the normal consequence of the interaction between the teeth, their supporting structures, and the foods consumed, and is not considered a pathological process (Molnar, 1972; Powell, 1985). The rate and degree of tooth wear can, however, have a direct impact on the development of dental caries. Gradual wearing away of the tooth surface over time may slow the development of caries, since moderate wear removes fissures and pits from occlusal surfaces where carious lesions are prone to form. On the other hand, rapid, severe tooth wear can lead to infection, abscesses, tooth loss, and remodeling of supporting bony structures (Larsen, 1999).

There are three types of tooth wear. Attrition is caused by direct contact between teeth on both the occlusal and interproximal surfaces and produces facets at the point of contact. Abrasion is caused by contact between teeth and materials introduced into the mouth (e.g., food, grit) and results in a general loss of enamel with increasing age, particularly on the lingual, buccal, and labial surfaces of the teeth (Hillson, 2000). Erosion is caused by the chemical dissolution of the dental hard tissues.

An overall decline in the degree of occlusal surface wear has been observed in association with the transition from hunting & gathering to agriculture (e.g., Molnar,

1971; Hinton, 1981; Smith, 1984; Powell, 1985; Rose *et al.*, 1991; Lubell *et al.*, 1994). This trend is attributed to changing methods of food preparation and consistency of diet consumed, usually characterized by a shift from hard, abrasive foods to soft-textured foods. This pattern, however, is not universal. Molleson and Jones (1991) found an increase in occlusal surface wear in early agricultural populations compared to foraging groups, which they attributed to the coarseness of the grains consumed. Other studies have found increased levels of tooth wear in association with evidence for consumption of marine resources (e.g., Walker, 1978; Sealy *et al.*, 1992).

Developments in food preparation techniques can affect the degree of tooth wear. High rates of occlusal wear have been attributed to the use of coarse stone grinders for the processing of plants, especially grains, in both hunter-gatherer and early agricultural societies (Powell, 1985; Molleson and Jones, 1991). It is suggested that the gradual development of more refined grinding technologies and the cooking of food in water reduced the toughness of food, and ultimately led to a reduction in overall levels of wear (Smith, 1984; Larsen, 1999).

There is also a change in the patterns of wear between hunter-gatherer and agricultural societies. In hunter-gatherer groups there is greater interproximal wear, attributed to the greater mechanical loads placed on the teeth from chewing coarse, fibrous foods (Larsen, 1999; Hillson, 2000). Hinton (1982) compared foraging, mixed, and agricultural populations from Tennessee and found a decrease in interproximal wear with changes in diet and food preparation. A study of molar wear angles in hunter-gatherer and agricultural groups found that agriculturalists consistently displayed a more

oblique angle of occlusal wear in contrast to the flatter wear of the foraging groups (Smith, 1984). The higher angle of wear was attributed to the increased proportion of processed (i.e., ground) foods in the diet (*ibid.*).

The degree and pattern of wear may differ between the sexes. Greater anterior tooth wear has been observed in females from a number of archaeological samples, and is often associated with sex-specific use of the teeth as tools (reviewed by Larsen, 1999). It has also been suggested that sex differences in the degree of tooth wear may be due to differences in overall size and associated masticatory forces between males and females, or to differences in food choices (Molnar, 1972; Scott and Turner, 1988; Larsen, 1999). These differences, however, are not consistent across all populations and a number of studies have found no differences between males and females in either occlusal or interproximal wear (e.g., Turner and Machado, 1983; Whittaker *et al.*, 1987).

Finally, it is important to be able to distinguish non-dietary wear patterns from those caused by food consumption. Repeated and long-term use of teeth as tools produces specific wear patterns associated with the processing of fibrous plant material, animal sinew, or hides (Molnar, 1972; Cybulski, 1974; Turner and Machado, 1983; Larsen, 1985). Distinctive patterns of wear are associated with individual habits, such as the use of labrets (lip plugs) or habitual pipe smoking (Scott and Turner, 1988). There are numerous examples of intentional interproximal grooving, commonly attributed to the habitual use of a probe associated with dental hygiene practices (Formicola *et al.*, 1988). Larsen (1999) reviews the literature on extramasticatory wear in archaeological skeletal samples.

3.15 Antemortem Tooth Loss

The loss of teeth prior to death can, in most cases, be distinguished from postmortem loss by evidence of resorption of the alveolar bone in and around the empty tooth socket. However, teeth lost perimortem (at or near the time of death) cannot be distinguished from postmortem loss. During life, a tooth will fall out if there is loss or destruction of the alveolar bone surrounding the tooth. Severe caries, heavy tooth wear leading to pulp exposure and necrosis, continuous eruption, periapical abscesses, alveolar resorption, and heavy calculus leading to gingivitis (inflammation of the gums) and ultimately periodontal disease, are all factors that may ultimately result in AMTL (Scott and Turner, 1988; Lukacs, 1989; Clarke and Hirsch, 1991a; Littleton and Frohlich, 1993). Repeated inflammation of the tissues in the mouth can eventually damage the alveolar crest and periodontal ligament. If the connection between the root and the periodontal ligament is compromised, the alveolar bone will begin to resorb and the tooth will eventually fall out. Numerous studies have used AMTL as an indicator of dental health in past populations (e.g., Hartnady and Rose, 1991; Kelley *et al.*, 1991; Lukacs, 1992; Littleton and Frohlich, 1993; Nelson *et al.*, 1999). However, there has been relatively little specific focus on the study of AMTL. One of the problems is that there is a lack of agreement concerning the etiology of AMTL. Clarke and Hirsch (1991a) argue against the widely held view that high rates of AMTL in skeletal samples are caused by periodontal disease, based on the purportedly false assumption that large CEJ-AC (cemento-enamel junction - alveolar crest) distances represent bone loss. In a related

publication, the authors contend that severe localized destruction of alveolar bone is caused by the formation of dental abscesses, destroying the bony support for the teeth (Clarke and Hirsch, 1991b). In contrast, other researchers have argued that periodontal disease is a leading cause of tooth loss in both modern and archaeological populations (Hildebolt and Molnar, 1991). This assertion is based, in part, on the similarity of archaeological data to clinical evidence concerning the etiology of periodontal disease, and the location and pattern of AMTL, usually beginning with the molars (Hillson, 2000).

The pattern of changing oral health associated with the transition to agriculture is expressed through a general increase in tooth loss, often associated with increased caries and periodontal disease, which is in turn related to the increase of carbohydrates in the diet (e.g., Kelley *et al.*, 1991; Lukacs, 1992; Littleton and Frohlich, 1993). Nelson and coworkers (1999) found a high prevalence of caries and AMTL in an Iron Age sample from Oman, concluding that the widespread consumption of sticky foods, particularly dates, led to an increase in caries and subsequent tooth loss. More recently, however, Hillson (2000) has argued that the widely held assumption that dental caries is the primary cause of AMTL is unlikely because loosening of teeth is not commonly caused by caries, unless intentionally removed through extraction, but is more likely the loss of alveolar bone in association with periodontal disease. Antemortem tooth loss has also been found to be generally low in populations reliant on marine resources or those that have a high proportion of animal protein in their diet, so the simple distinction of forager versus farmer may not entirely explain differences in AMTL with different modes of subsistence (e.g., Costa, 1980; Macchiarelli, 1989; Littleton and Frohlich, 1993)

Sex differences in AMTL are, like caries, attributed to differences in dietary patterns between males and females, although there is not a consistent association between sex and AMTL in studies on archaeological samples (Larsen, 1999). Higher levels of AMTL among females have been found by Lukacs (1992) and Walker and Hewlett (1990), and are related to dietary differences associated with sex. In contrast, Turner and Machado (1983) and Whittaker *et al.* (1987) found no such differences. Higher rates of anterior AMTL among females have also been ascribed to the use of teeth as tools (e.g., Molnar, 1971, 1972; Costa, 1980). Various examples of the use of teeth as tools and related patterns of wear are reviewed by Molnar (1972). Regardless of the problems identifying the cause(s) of AMTL, it is still an extremely useful indicator of the interaction between the teeth and the diet consumed, but this evidence should be examined in conjunction with other dental pathological data.

3.16 Studies of Dental Health in the Deciduous Dentition

There are few studies of oral health in past populations that have specifically examined the deciduous dentition for evidence of dental pathology. This is likely due to problems with poor preservation and the recovery of subadult, and particularly infant, skeletal remains. Studies that have included deciduous teeth in the analysis of caries rates have found, as expected, a fairly low prevalence of caries, since caries is an age-progressive disease (Moore and Corbett, 1973; Lunt, 1986). Patterson's (1987) study of caries in prehistoric and historic samples from Ontario found that the prevalence of caries in deciduous teeth increased dramatically in association with historical and

archaeological evidence for the adoption of maize agriculture. A number of studies that have examined deciduous teeth have focused on the relationship between dental or skeletal indicators of stress and caries prevalence (e.g., Cook and Buikstra, 1979; Duray, 1990; O'Sullivan *et al.*, 1992). Research on prehistoric North American subadult skeletal samples has revealed a positive correlation between linear enamel hypoplasias, hypocalcifications, and caries prevalence on deciduous teeth (Cook and Buikstra, 1979; Duray, 1990). As mentioned previously, hypoplastic defects on the teeth may facilitate the accumulation of food and bacteria, and enamel hypocalcifications may increase porosity and decrease the mineral content of enamel, leaving the tooth susceptible to caries (Duray, 1990). O'Sullivan and coworkers (1992) examined the relationship between dental caries and cribra orbitalia in subadults from various pre-Roman to Late Medieval sites in England, and also found a positive association between caries and this skeletal indicator of stress.

Studies of subadult skeletal material have also investigated the relationship between oral health and the weaning process. Williams and Curzon (1986) found an association between dental erosion and caries on the lingual surfaces of deciduous maxillary incisors in a Medieval British sample. The authors suggest that the association between erosion and caries was due to a highly cariogenic weaning diet (e.g., honey and milk with bread), and through the use of feeding containers for nursing (*ibid.*). Bullington (1991) studied microwear patterns in two prehistoric infant samples and found that the age at which wear began to appear did not vary between populations, but the pattern of deciduous wear distinguished the agricultural (softer) from the horticultural

(harder) diets.

When conditions of preservation permit the investigation of dental pathology in subadult remains, it may be possible to use this evidence in the discussion of infant feeding practices, which can be used to supplement the isotopic data. Dental calculus, abscesses, and AMTL in subadults have not been widely studied, more than likely due to the extremely low prevalence of these conditions in deciduous teeth. In particular, it would be extremely difficult to distinguish AMTL from the natural evulsion of deciduous teeth during the eruption of the permanent dentition.

3.17 Studies of Dental Health in pre-Roman and Roman Skeletal Samples

Angel (1944; 1984) was one of the first to examine oral health in ancient Mediterranean skeletal samples. He focused primarily on temporal changes in oral health in Greece and the eastern Mediterranean, and observed the familiar trend of an increase in dental pathology with the transition from hunting & gathering to farming, reported by total lesions per mouth (including carious lesions, abscesses, and AMTL). Borgognini Tarli and Repetto (1985) compared Italian Epipalaeolithic, Mesolithic, and Neolithic samples, focusing on caries prevalence, and found generally low levels of caries in the earlier periods, and a trend towards increasing levels of carious lesions in the later samples. Repetto and coworkers (1988) compared the Bronze Age skeletal material of Toppo Daguzzo to later Neolithic and Mediaeval samples from the site of Matera. Levels of oral pathology (caries, abscesses and AMTL) were consistently lower in the Bronze

Age sample. The authors concluded that the relatively low levels reflect the absence of sugar in the diet and adequate nutritional status (*ibid.*). A similar increase in the prevalence of caries, AMTL and periapical abscesses from the Neolithic to Bronze Age periods was attributed to the intensification of grain-based agricultural activities and pastoralism, with an associated change in diet (Cucina *et al.*, 1999). Macchiarelli and Salvadei (1986) examined the maxillary dentition from the Iron Age (ca. 6^{th}-5^{th} centuries BC) site of Alfadena, comparing the prevalence of dental pathology, particularly dental caries, with other Iron Age samples from Italy. The frequency of carious lesions from this sample was higher than any of the earlier comparative Iron Age samples, and the authors concluded that this reflects a general decline in oral health of Italians over time (*ibid.*). Studies of Paleolithic, Neolithic, and Iron Age samples have also found patterns of heavy wear on the anterior dentition, associated with the use of teeth as tools (Minellono *et al.*, 1980; Salvadei and Macchiarelli, 1983; Macchiarelli and Salvadei, 1986; Fabbri and Mallegni, 1988, cited in Robb, 1993).

There are very few studies of dental health for Roman period skeletal samples in Italy. Those that do exist are parts of general skeletal reports of samples from the sites of Rome, Pompeii, and Herculaneum (Bisel, 1991; Henneberg *et al.*, 1996; Manzi *et al.*, 1999). Bisel (1991) examined the frequency of carious lesions, abscesses, periodontal disease and AMTL in the Herculaneum (79 AD) skeletal series and concluded that the low rate of caries was due to the absence of sugar and the abrasive quality of the Roman diet. Henneberg and coworkers (1996) examined the remains of six adults and seven subadults recovered from the "Casa di Polibio" at Pompeii (79 AD), recording evidence

of caries, calculus, AMTL, tooth wear, and periodontal disease. The relatively high prevalence of caries and calculus led the authors to conclude that these Romans consumed a sticky and non-abrasive diet and that there was an overall lack of oral hygiene (*ibid.*).

Recently, Manzi and colleagues (1999) examined a sub-sample of the Isola Sacra skeletal remains, and compared them to material from the Roman site of Lucus Feroniae (1^{st}-3^{rd} c. AD) and the mediaeval site of La Selvicciola (7^{th} c. AD) to investigate changes in health indicators from the Roman to mediaeval periods in Italy. They observed caries, abscesses, AMTL, calculus, alveolar resorption, and attrition. Their sample consists of 64 individuals, a small sub-sample of the entire skeletal series available for study, and is one-fifth the sample size used in this thesis. These authors observed increases in dental pathology, particularly caries, into the mediaeval period and attributed the change to a general decline in the overall level of health from the Roman to mediaeval period (*ibid.*).

There have been a number of dental health studies of Romano-British skeletal samples (Moore and Corbett, 1973, 1983), particularly material from the site of Poundbury (ca. 200-400 AD) (Whittaker *et al.*, 1981, 1985a, 1985b, 1987). Moore and Corbett (1973) examined changes in dental caries prevalence in Britain from the Iron Age to the mediaeval period. The Roman period samples used for their study were obtained from sites identified as towns and military settlements under Roman rule. The authors found very little change in the pattern and prevalence of caries, consistent with evidence for the stability of the diet in this region over time, and in particular the relatively small amount of sugar in the diet (*ibid.*). Whittaker and coworkers (1981) compared their data

from the Romano-British site of Poundbury to Moore and Corbett's (1973) earlier study. They found that both within specific age groups, and in the overall sample, caries prevalence was higher in the Poundbury material than in the other Romano-British samples (*ibid.*). More recent studies by Whittaker *et al.* (1985a, 1985b) and Whittaker (1987) examined tooth wear, AMTL, and adaptive changes using the Poundbury skeletal sample, but they did not relate these findings to diet. These studies demonstrated a correlation between occlusal surface wear and continuous eruption of dentition, but found no significant correlation between tooth wear and structural changes in the temporomandibular joint (Whittaker *et al.*, 1985a; 1985b). Finally, Whittaker (1987) examined patterns of interproximal wear in the Poundbury sample, and found the type and pattern of wear to be caused by tooth movements as a result of chewing forces (Whittaker, 1987).

Smith and Tau (1978) compared levels of dental pathology in Roman and Jewish skeletal samples from Israel (1st and 2nd centuries AD) to late Iron Age (600 BC) and Byzantine (400 AD) samples from the same area, to examine changing patterns of dental pathology with the Roman occupation of Israel. They attributed the increased frequency of caries in the Jewish samples to the effects of 'Romanization'; moreover, they found a slightly higher prevalence of caries in the Roman sample and attributed this to the consumption of a less abrasive, more cariogenic diet (*ibid.*). One problem with this study is that the archaeological context of the samples was not specified, so how the 'Roman' sample was identified is unclear.

3.18 Oral Hygiene in Ancient Rome

There is some evidence for the practice of 'dentistry' in pre-Roman and Roman Italy. Skeletal evidence from the Italian Neolithic period implies intentional removal of anterior teeth in women for ritual or cosmetic purposes (Robb, 1997). Further evidence for intentional dental treatment has been found mainly on Etruscan skeletons, most of which are gold dental bands used to fix teeth in place during the life of the individual (Corruccini and Pacciani, 1989; Becker, 1999). Dental prosthetics were commonly applied to the anterior dentition, usually in females, suggesting a cosmetic function (D'Amato, 1993; Becker, 1999). Other examples of gold and silver wiring of teeth are known from the eastern Mediterranean region, most likely done after death to secure teeth in place during funerary preparations (Corruccini and Pacciani, 1989). There is one reported case of an iron dental implant found in a 1st - 2nd century AD necropolis in France (Crubézy *et al.*, 1998), although the authenticity of the implant was subsequently called into question (Becker 1998).

Literary evidence suggests that the Romans were aware of the Etruscan dental practices and were conscious of the need for dental hygiene. Dentistry was not recognized as a specialized field, but was practiced by a wide range of professionals. Archaeological excavations at the Roman Forum uncovered eighty-six carious teeth under the floor of what was identified as a barbershop and/or pharmacy (2nd century B.C.) (Ginge *et al.*, 1989). The authors proposed that extraction of decayed teeth was a common practice in ancient Rome (*ibid.*).

Historical sources also provide some information on Roman beliefs concerning

dental disease that may help us to interpret the skeletal evidence. The medical writer Galen (ca. 2nd c. AD) recommended drilling teeth to allow medicines to penetrate the tooth, and Pliny the Elder (1st c. AD) wrote of a number treatments used to ease painful toothaches and to cause decayed teeth to fall out of the mouth (Borgognini Tarli and Repetto, 1987; Ginge *et al.*, 1989). It was assumed that cavities were caused by 'worms' and the resultant toothaches were treated with localized applications of medicinal ingredients, or by packing the decayed area with wax or lead (D'Amato, 1993). Extraction of the tooth was only undertaken as a last resort (Borgognini Tarli and Repetto, 1987). There are recipes for toothpaste in the Hippocratic corpus and in the writings of Pliny, although it is not clear if this was simply used to freshen breath. The poet Martial (1st c. AD) would describe characters with blackened or broken teeth (Borgognini Tarli and Repetto, 1987; Dosi and Schnell, 1992). Toothpicks made of wood, feathers, or metal (*dentiscalpium*) were commonly used by the Romans to clean their teeth (D'Amato, 1993). These scattered pieces of evidence suggest that the Romans had an appreciation for the aesthetic qualities of a bright, white smile. Unfortunately, it is not possible to identify intentional tooth extraction from the skeletal record, but the evidence presented here suggests that an unusually high prevalence of AMTL might be related to intentional removal of decayed teeth.

3.19 Roman Diet - Implications for Oral Health

It is expected that the Isola Sacra skeletal material will have a pattern of dental health comparable to other agricultural groups, but mediated by the potentially high

marine component in the diet of this maritime population. The prevalence of caries should reflect the high consumption of carbohydrates due to the reported predominance of grains in the Roman Imperial diet (Chapter 2). Moderate tooth wear should also reflect the reliance on processed grains, however the grinding process may introduce grit into the final product, and elevate levels of wear. Tooth wear may also be affected by the amount of seafood in the diet. It is more difficult to predict the prevalence of AMTL, abscesses and calculus in the inhabitants of *Portus Romae*, although it is expected that the levels are comparable to other data from Roman Italy. Status-based differences may exist, based on the preferential access to 'luxury' food items among elite members of the population, if it is assumed that those individuals buried in more elaborate tomb structures (e.g., sarcophagi and monumental tombs) at Isola Sacra can be considered 'elite'.

When using skeletal material to investigate patterns of diet, health and disease in past populations, one has to consider the limitations of the evidence. Wood and coworkers (1992) argued that the relationship between morbidity, mortality and skeletal lesions is complex. They questioned the assumption that a direct association can be made between data obtained from skeletal material and the health status of prehistoric populations. Individuals from a mortality sample had, during life, variable risks of disease and death, but these cannot necessarily be detected from skeletal remains. Further, a skeletal sample will never consist of all individuals who were at risk of dying at a particular age, only those who actually died, so samples will never be truly representative of the original living population *(ibid.)*. The presence of lesions indicates

that some sort of dental or skeletal reaction occurred, but the absence of lesions may mean that an individual was extremely healthy or that the person died before a skeletal response could occur. The problem is that it may not be possible to tell the difference based solely on the skeletal evidence. Additional contextual information is required in order to interpret the meaning of palaeopathological data derived from skeletal remains (*ibid.*). The use of dental, isotopic, archaeological and literary evidence used in this study will maximize the reliability of the data derived from the Isola Sacra skeletal sample.

3.20 Integration of Isotopic and Dental Data

A small number of anthropological studies have integrated dental and stable isotope data in the investigation of past diet. Most of these studies examine isotopic and pathological data in relation to transitions in subsistence strategies over time (e.g., Larsen *et al.*, 1991; Lubell *et al.*, 1994; White, 1994; White *et al.*, 1994; Lillie and Richards, 2000). Other studies have compared isotopic and dental data between populations exploiting different food resources, particularly marine versus terrestrial sources (Kelley *et al.*, 1991; Sealy *et al.*, 1992). Intrapopulational variability in relation to variables such as age, sex, and social status has also been explored (e.g., Sealy *et al.*, 1992; White, 1994). Few, however, have examined isotopic and palaeopathological data in conjunction with both written and archaeological evidence for diet.

Chapter 4

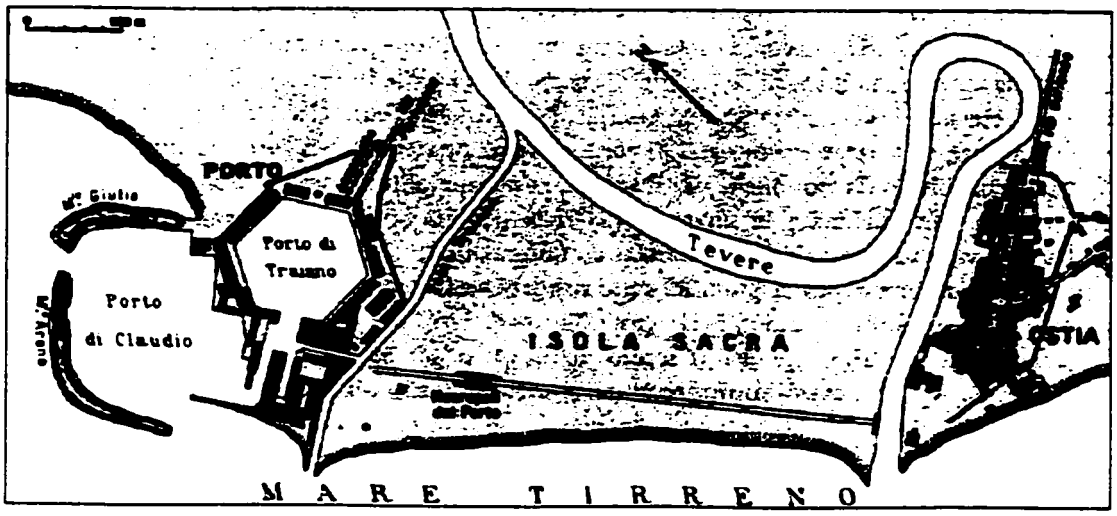
Materials and Methods

4.1 The Isola Sacra Cemetery

"*ode pausilypos*" (Here ends all pain)
Inscription from Tomb 43 at Isola Sacra

The necropolis of Isola Sacra is located approximately 23 km SW of Rome, Italy. It is situated on an artificial island that was created during the dredging of a canal, the *Fossa Traiana*, in AD 103 that connected the Tiber river with the coast (Figure 4.1) (Baldassarre, 1978).

Figure 4.1 – Map showing the location of *Portus Romae* ('Porto' on map), Ostia, and the necropolis of Isola Sacra (from Rossi *et al.*, 1998)



The necropolis extends approximately 1.5 km along the road that connects Ostia and *Portus Romae*, and was used by the inhabitants of *Portus* from the 1st to 3rd centuries AD. The cemetery eventually fell into disuse and was gradually covered over by encroaching sand (Sperduti, 1995). The area around *Portus* is now completely surrounded by land, and Fiumicino airport now occupies the area to the NE of Trajan's harbour.

The cemetery was first excavated between 1925 and 1940 by G. Calza, who uncovered some of the large monumental tombs (Figure 4.2) (*ibid.*). Between 1973 and 1982, the Archaeological Superintendency of Ostia, the University of Rome 'La Sapienza', and the University Institute of Oriental Studies of Naples undertook excavations at the site. This work focused on the restoration of the monumental tombs, as well as the recovery of human skeletal remains excavated by Calza that had been haphazardly dumped back into the tombs once his excavations were completed (Baldassarre, 1984, 1990; Rossi *et al.*, 1998). Systematic descriptions of this second excavation were published by Baldassarre *et al.* (1985) and Angelucci *et al.* (1990). Approximately 1,000 individuals were recovered, and now form part of the skeletal collection curated at the L. Pigorini Museum in Rome.

The most recent excavations at Isola Sacra in 1988 and 1989 were undertaken in conjunction with a large-scale water supply project in the region. Work focused on the areas between the monumental tombs and over 600 additional single and multiple burials were uncovered (Baldassarre, 1990). In 1992, all of the skeletal material recovered from

Isola Sacra was entrusted to members of the Anthropology Section of the L. Pigorini museum, who took on the task of identifying, cataloguing, and studying this large and important Roman period skeletal sample.

Figure 4.2 – View of some of the monumental tombs at the Isola Sacra cemetery (from Rossi *et al.*, 1998)

Figure 4.3 shows a plan of the cemetery with via Flavia passing between the tombs that are still standing today. Calza hypothesized that the burials found behind the second row of tombs was the 'field of the poor' (Angelucci *et al.*, 1990). Figure 4.4 illustrates this proposed field of the poor. Amphorae are visible in the foreground, inserted vertically into the soil. It is assumed that they were used for offering libations (*ibid.*).

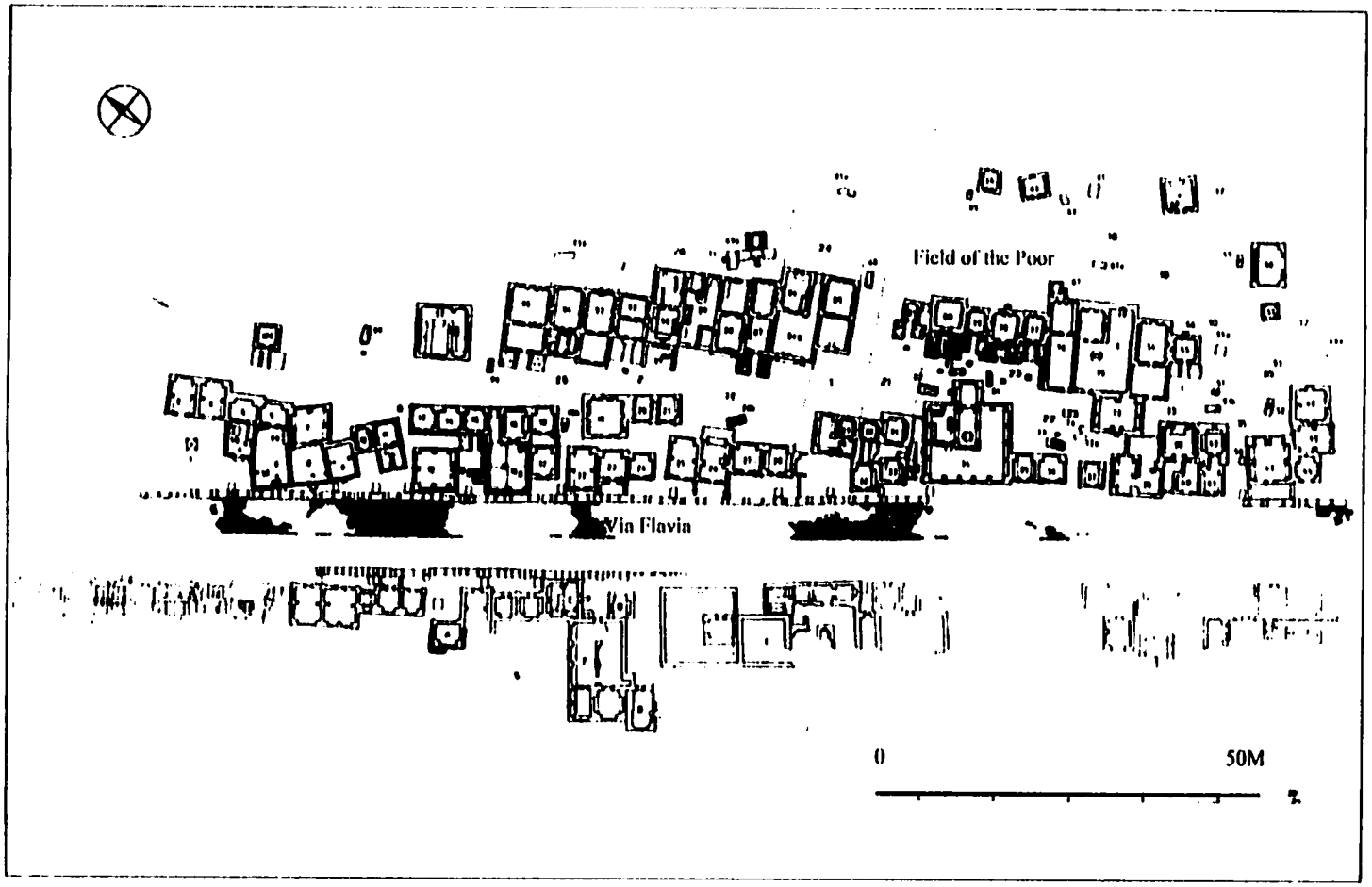
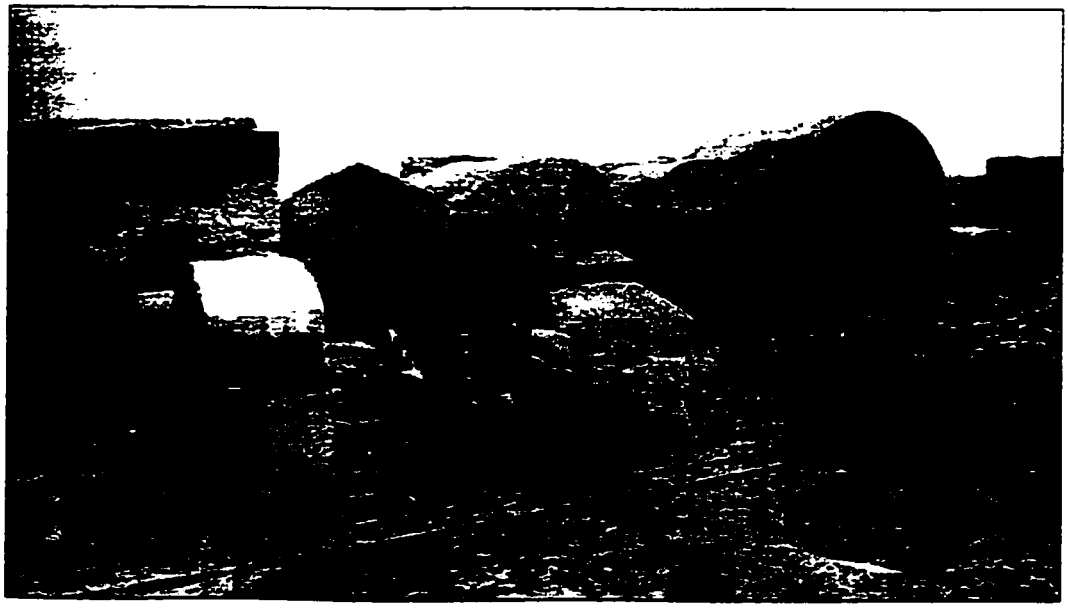


Figure 4.3 – Plan of the Isola Sacra necropolis (modified from Baldassarre, 1990)

The chronological relationship between different areas of the site is not well known because the final report of the excavations has not been published. It is known that the oldest tombs (1st century AD) are located closest to the road (Baldassare, 1984). The next phase of the cemetery is associated with the construction of tombs located further back, and near the end of the cemetery's use there is evidence for the reuse of existing structures (*ibid.*).

Angelucci and coworkers (1990) concluded that the distribution of burials between the tombs appeared to be fairly homogeneous, and that there is no evidence for a systematic expansion of the cemetery that implies a special location for 'poorer' burials. Most of the inhumations did not have any associated grave goods, with the exception of some coins, lamps, and 'female' ornaments (Sperduti, 1995).

Figure 4.4 – West end of cemetery behind the second row of monumental tombs, showing the hypothesized 'field of the poor' (from Angelucci *et al.*, 1990)



In addition to the 75 chamber tombs uncovered at Isola Sacra, there are a variety of other burial structures. Many of the infants and children were placed in 'amphorae' burials, consisting of the broken pieces of large storage vessels (amphorae) (Figure 4.5). There are also adult amphorae burials that have one or more relatively intact amphorae inserted vertically into the ground in association with the skeleton (Figure 4.6). Soil and sand burials are interments in the ground without any evidence of a protective structure (Figure 4.7). These are distinguished from 'inhumation' burials that are associated with coffins made of wood or terracotta bricks. 'Cappucina' burials are covered by a series of large terracotta tiles (*tegulae*) stacked to form a roof over the burial structure (Figure 4.8). Most of the descriptions in the archaeological reports focus on the architectural features of the monumental tombs, so there is comparatively little information on the secondary burial structures found at the site.

Figure 4.5 – Amphora Burial (from Angelucci *et al.*, 1990)

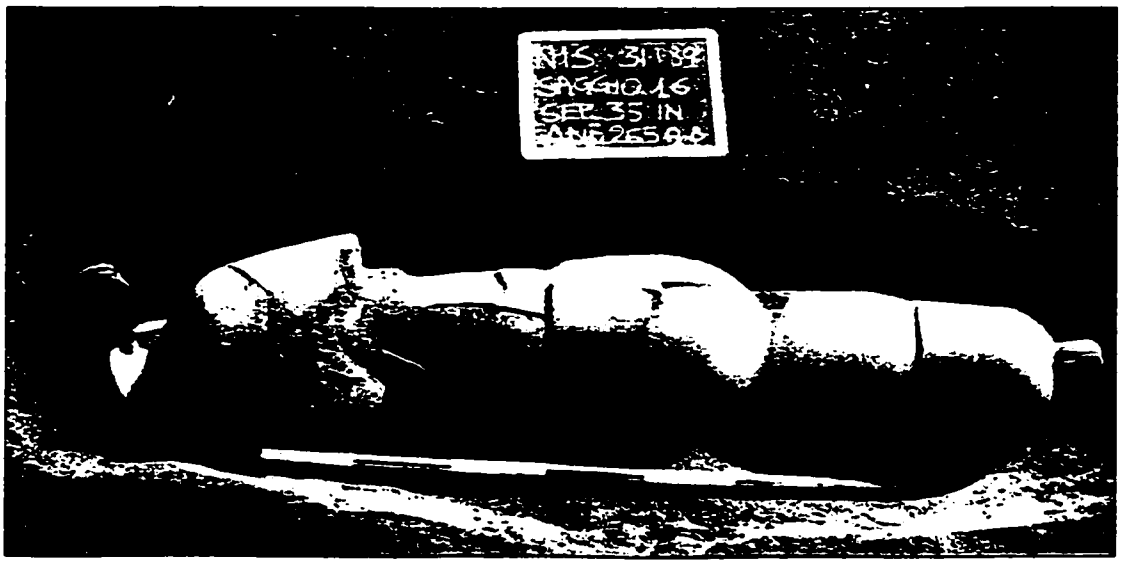


Figure 4.6 – Burial surrounded by a series of amphorae (from Angelucci *et al.*, 1990)

Figure 4.7 – Soil burial with no protective structure (from Angelucci *et al.*, 1990)

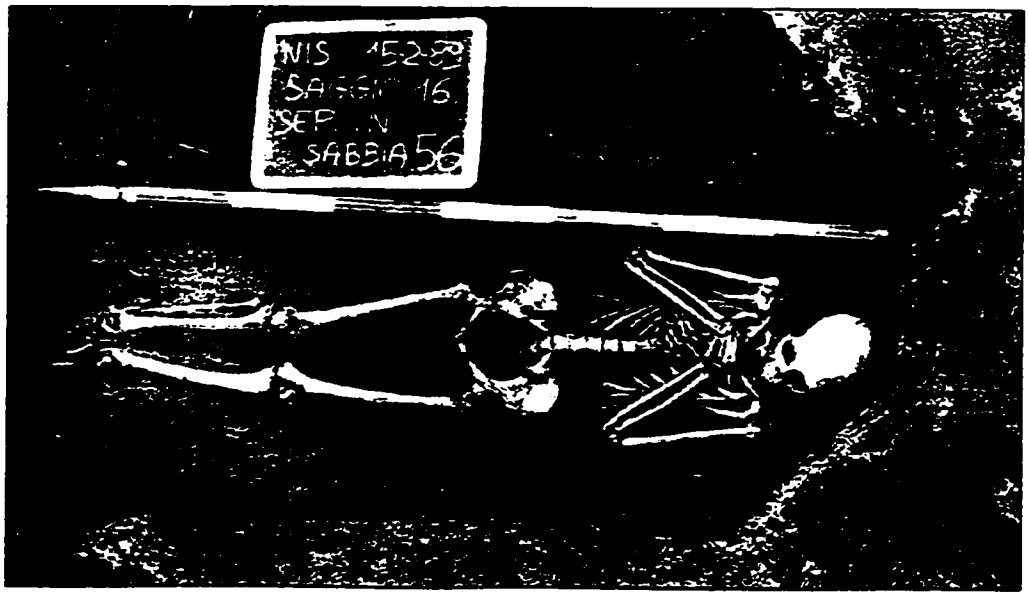


Figure 4.8 – Cappucina burial (from Angelucci *et al.*, 1990)

4.2 Human Skeletal Samples for Isotopic Analysis

The total number of individuals in the Isola Sacra sample is estimated to be around 2000 (Sperduti, 1995). Many of these are commingled remains from Calza's early excavations, but there are approximately 800 skeletons that have been individually catalogued and analyzed.

In 1996, 100 femur samples were sent from the Anthropology Section of the Pigorini Museum (Rome, Italy) to McMaster University for the purpose of stable isotope and DNA analysis. The samples were selected based on the availability of femur

fragments for study. Sixty infant and subadult rib samples were collected in 1997 during fieldwork at the Pigorini Museum. These samples were also chosen based on the availability of sufficient bone for stable isotope analysis (approximately 3-5 grams). In 1998, an additional 60 femur samples were sent from our colleagues at the Pigorini Museum, along with 14 samples from the Roman period ANAS cemetery.

The ANAS sample is from a small Roman cemetery located on via del Mare, running between modern Rome and Ostia. The graves were uncovered during construction of an underpass along via del Mare and were excavated by the Soprintendenza Archeologica di Ostia. The exact location of the excavation is not known. The cemetery probably belonged to a small rural center of farmers, based on the presence of a number of Roman period villas in the area (Macchiarelli, pers. comm., 2000). Little else is known about the cemetery or its occupants because the material was never systematically studied.

4.3 Estimation of Age and Sex of the Isola Sacra Skeletal Sample

The age and sex (for adults) of each skeleton was estimated by A. Sperduti (1995) for her PhD dissertation on the palaeodemography of the Isola Sacra sample (University of Rome, 'La Sapienza'). The following aging methods were used for the subadult skeletons: development and eruption of the deciduous and permanent dentition, development of the temporal and occipital bones, development and fusion of the epiphyses, and maximum long bone diaphyseal length (see Sperduti, 1995).

The adults were aged using the following methods: cranial suture closure, degree and pattern of tooth wear, morphological changes at the sternal rib ends, morphological changes of the pubic symphysis, changes on the auricular surface of the ilium, and trabecular structure of the proximal femur (*ibid.*). Long bone measurements and morphological characteristics of the cranium and os coxae were used to evaluate the sex of adult skeletons (Sperduti, 1995). The age and sex composition of the samples used for isotopic and dental analysis are presented in Chapters 5 and 6.

4.4 Extraction of Bone Collagen for Isotopic Analysis

The procedure used for the extraction of bone collagen is the method originally described by Longin (1971), and later modified by Chisholm and coworkers (1982). Samples were washed with tap water to remove dirt and broken into smaller pieces using a mortar and pestle. Remaining trabecular bone on internal surfaces was filed down with a metal file and visible dirt was removed.[1] Bone fragments were placed in beakers with distilled water and washed in three ultrasonic baths, or until the water remained clear. The water was poured off and the beakers were placed in a drying oven (at 60°C) overnight.

Approximately 3 grams of clean, dry bone was weighed out for each sample, and the fragments were placed into labeled 50 ml plastic centrifuge tubes. These samples were covered with 0.25 M HCl (hydrochloric acid), and left to sit for approximately 20 minutes until the pH was greater than 1. The acid was poured off and the procedure

[1] This could not be done for the rib samples, due to the small size of the bones and the small amount of trabecular bone present.

repeated until the bone mineral was dissolved. As the dissolution advanced, it was necessary to centrifuge the tubes for approximately 5 minutes before changing the acid to ensure that all organic material was conserved.

Once dissolution was complete (ca. 6-20 acid washes), the material in the tubes was rinsed 3 times with distilled water and 20 ml of 0.1 M NaOH (sodium hydroxide) was added to remove any remaining humic and fulvic acids. The samples were soaked in NaOH for approximately 20 minutes, after which time the tubes were centrifuged and rinsed 4 times with distilled water. If the NaOH solution remained dark after the initial wash, the procedure was repeated a second time. The samples were then placed in an acid wash of 0.25 M HCl for 2 minutes, centrifuged again, and the liquid was poured off.

The remaining material was washed from the centrifuge tubes into 50 ml glass vials using distilled water. These vials were topped up with distilled water, covered with plastic wrap, sealed with tape, and put into beakers. The beakers, each containing 4 vials, were placed in an oven (90°C) for a minimum of 6 hours (usually overnight) to convert the solid collagen into a liquid form. Next, the tubes were removed, centrifuged, and the liquid containing the soluble collagen was decanted into labeled teflon beakers. More distilled water was added to the remaining material in the glass centrifuge tubes, the tubes were covered, and placed in the oven again overnight. The teflon beakers were placed in a drying oven to evaporate the water, leaving a light to dark brown material (the dried collagen). After a second overnight heating, the liquid collagen in the glass tubes was recovered and added to the teflon beakers.

After drying, a small amount of distilled water (<5 ml) was added to the beakers and the dissolved collagen was transferred to pre-weighed plastic vials. The vials were placed in the drying oven until the collagen had completely dried, usually taking a few days. After drying, the vials were weighed again to calculate the dry weight of the collagen and to calculate the collagen yield. Collagen yield is determined with the following equation:

Equation 4.1 – **% Collagen Yield** = $\frac{\text{(weight of extracted collagen)}}{\text{(weight of cleaned bone)}} \times 100$

Approximately 2-3 mg (for Carbon) and 9-13 mg (for Nitrogen) of the dried collagen from each sample was loaded with CuO (cupric oxide) into separate 6 mm heat-treated pyrex tubes. The tubes were placed on a vacuum line for 4 hours to remove any air and water and then sealed with a torch. The sealed tubes were placed in an oven at 550 °C for 2.5 hours, causing a reaction to produce CO_2. Heating also causes the nitrogen in the collagen to break down into N_2. The samples were then analyzed using a VG SIRA 10 Series II mass spectrometer.

Diagenetic alteration of the bone collagen samples was examined by loading 1-2 mg of the collagen into small metal cups that were run in a Carlo-Erba analyzer. This machine measures the amount of carbon and nitrogen in each sample and C:N ratios can then be calculated.

4.5 Preparation of Bone Apatite for Isotopic Analysis

Sixty-six femur samples were analyzed for $\delta^{13}C$ in bone apatite. Preparation of the samples followed procedures developed by Sullivan and Krueger (1981) and Lee Thorp and van der Merwe (1987). Samples were washed with tap water and broken into smaller pieces using a mortar and pestle. The bone fragments were then put into beakers, rinsed in distilled water, and left overnight to dry (at 60°C).

Approximately 0.1 g of bone from each sample was weighed and placed in 50 ml plastic centrifuge tubes. Ten ml of 1M $C_2H_4O_2$ (acetic acid) was added to the tubes to remove surface carbonates. After 1 hour the acid was drained off and the samples were rinsed 3 times with distilled water. If the acid solution was still bubbling, fresh acid was added until the reaction was finished, and then the samples were repeatedly rinsed with water. The tubes were then placed in a drying oven (60°C) overnight. Dried samples were weighed to determine the amount of surface carbonates removed by the acid treatment. After weighing, 20 ml of NaOCl (sodium hypochlorite, or bleach) was added to the tubes to remove the organic material (i.e., collagen). The samples were soaked for 24 hours, rinsed with distilled water 6 times, dried overnight, and weighed again to determine how much organic material had been removed.

Bone from each sample was crushed to a fine powder and 20-40 mg was placed into a small glass sample cup. The samples were kept in a numbered sample holder and stored in a desiccator. Nine mm pyrex tubes were filled with 1 ml of 100% H_3PO_4 (phosphoric acid). One glass sample cup was placed carefully inside each tube without coming into contact with the phosphoric acid. Labeled tubes were then placed on the

vacuum line and air was slowly evacuated (~6 hours) so that the powder was not disturbed.

Tubes were sealed using a torch, placed in a plastic rack, and left in a 25°C distilled water bath for one hour. After 1 hour, they were quickly inverted to mix the bone powder and phosphoric acid together (to produce CO_2) and left for another hour. The tubes were inverted a second time so that the phosphoric acid would run into the sample cups and react with any remaining powder. The tubes were inverted every twelve hours until all the bone powder was dissolved. After removal from the bath, the CO_2 gas was transferred into 6 mm pyrex tubes for analysis. Samples were then analyzed on an Optima mass spectrometer.

4.5.1 FTIR Analysis

Diagenetic alteration of the carbonate was examined in 27 bone samples using Fourier transform infrared spectroscopy (FTIR). Samples were prepared according to the methods described by Wright and Schwarcz (1996). After cleaning, bone was ground into a fine powder and passed through a #200 mesh sieve. Approximately 2 mg of each sample was ground with 200 mg of KBr (potassium bromide), and the mixture was compressed at 15,000 psi into 12 mm pellets. The samples were analyzed using a Bio-Rad FTS-40 FTIR spectrometer to obtain absorbance spectra.

4.6 Faunal Remains and Garum Samples

Fourteen bone samples, representing seven different animal species, were analyzed isotopically for comparison with the Isola Sacra human samples. All of the faunal remains were recovered from stratified layers in the Isola Sacra necropolis. Two carnivore species (fox and dog), and five herbivore species (cow, horse, donkey, goat, and pig) are represented. The same procedures for extraction of bone collagen and apatite were used on these samples as for the human samples.

Ten *garum* samples were sent from the Pigorini Museum for isotopic analysis, provided by Dr. Barbara Wilkens, University of Sassari, Sardinia. These samples were obtained from amphorae found at sites in Sardinia and Italy. Sample 1 was taken from an African amphora that contained mainly sardines (2^{nd} c. AD) from the site of Olbia, Sardinia (Wilkens, pers. comm.). Samples 2 and 3 are also from Olbia, but were taken from locally produced amphorae (end of 4^{th}/beginning of 3^{rd} century BC), containing pickerels and mullet (*ibid*). Samples 4-10 were obtained from various amphorae recovered from a shipwreck (2^{nd} c. AD) near Grado, Italy, at the northern edge of the Adriatic Sea. These samples were obtained from amphorae originally used to transport wine and oil, and contained the remains of whole mackerels and sardines (*ibid.*).

The *garum* samples consisted of small fish bones, brown flakes (probably dried fish), shells, and sand. These were weighed and approximately 0.5 – 1 g was placed in a 50 ml plastic centrifuge tube. The samples were then covered with chloroform + methanol (to dissolve lipids) and left overnight. Additional chloroform and methanol were added to the tubes if all of the liquid had evaporated overnight. The liquid was

subsequently poured off and the samples were left to dry for 48 hours. Next, they were soaked in .25 M HCl (hydrochloric acid) for 20 minutes to remove surface carbonates, rinsed twice with distilled water, soaked in 0.1 M NaOH (sodium hydroxide) for 30 minutes, and rinsed another 4 times with distilled water. The samples were dried overnight (at 60°C), loaded into separate 6 mm quartz tubes (one for carbon, one for nitrogen), and placed on a vacuum line for 12 hours. After the tubes were sealed with a torch, they were placed in an oven at 450 °C for 4 hours, cooled, shaken to redistribute the CuO, and then heated for an additional 4 hours.

4.7 Dental Data Collection Standards

Data on tooth presence, tooth wear, caries, abscesses, and calculus were collected according to the standards recommended by Buikstra and Ubelaker (1994), and using the forms provided in their publication (Attachments 14-17). A total of 365 individuals were examined, and the age and sex distribution of the sample is presented in Section 6.1.1. Data were collected on all teeth in both dental arcades, if available. Age, sex, and burial information were collected from Sperduti's (1995) summaries. All raw data were entered into Microsoft Excel 2000 and then imported in to SPSS (Statistical Package for the Social Sciences) for statistical analysis.

4.7.1 Tooth Presence

The following codes were used to record tooth presence (after Buikstra and Ubelaker, 1994):

1 – present, but not in occlusion
2 – present, development completed, in occlusion
3 – missing, with no associated alveolar bone
4 – missing, with alveolus resorbing or fully resorbed (antemortem loss)
5 – missing, with no alveolar resorption (postmortem loss)
6 – missing, congenital absence
7 – present, damage renders measurement impossible, but other observations are recorded
8 – present, but unobservable (deciduous or permanent tooth in crypt)

4.7.2 Tooth Wear

Data on tooth wear for the incisors, premolars, and canines were collected using the Murphy (1959) system, as modified by Smith (1984), which assigns a score for each tooth on a scale from 1 (none) to 8 (severe), depending on the amount of exposed dentin. The Scott (1979) system was used to collect data from the molars. Each tooth is divided into four quadrants and a score from 1 to 10 is assigned to each quadrant, for a possible total score of 40. If any quadrants cannot be scored (e.g., due to destruction from a carious lesion), the tooth is recorded as 'unobservable'. Buikstra and Ubelaker (1994) provide illustrations and written descriptions to assist in evaluating the level of wear.

4.7.3 Caries

The presence of carious lesions was recorded using a modified version of the Moore and Corbett (1971) system. In this system a score is recorded for each tooth, and if a lesion is present, its location is drawn on a diagram of the dentition. Teeth were

examined under conditions of good light, and a dental probe or a lamp with a magnified lens was used when needed. The following codes were used to record carious lesions for each tooth (after Buikstra and Ubelaker, 1994):

0 – no lesion
1 – occlusal surface lesion
2 – interproximal lesion
3 – smooth surface lesion (buccal and lingual surfaces of teeth)
4 – cervical lesion (at the cemento-enamel junction, except in interproximal regions
5 – root lesion (below the cemento-enamel junction)
6 – large carious lesion (lesion that has destroyed so much of the tooth that a surface of origin cannot be determined)

4.7.4 Abscesses

The maxillae and mandibles were inspected visually for abscesses. If present, each abscess was scored according to its location (1 – buccal or labial; 2 – lingual) and drawn on diagrams of the dentition and alveoli.

4.7.5 Dental Calculus

Buikstra and Ubelaker (1994) recommend the scoring system of Brothwell (1981) for dental calculus. This method scores calculus as; 0 – absent, 1 – small amount, 2 – moderate amount, or 3 – large amount. After scoring a small number of the Isola Sacra specimens using this system, it became clear that the amount of calculus commonly observed on the teeth was smaller than the amount illustrated for a score of '1'. An additional score of '0.5' was added, to distinguish those teeth with small, sporadic patches of calculus.

Buikstra and Ubelaker (1994) also recommend that it should be noted whether calculus occurs on the buccal or lingual side of the tooth. This does not take into consideration the presence of calculus in interproximal spaces and on occlusal surfaces of some molar teeth. In this study, the presence of calculus is scored for 4 surfaces (buccal, labial, interproximal, occlusal) on molars, and for 3 surfaces (buccal, labial, interproximal) on all other teeth. This new method takes into account potential variability in the amount of calculus on the different surfaces of one tooth. When the data are entered onto spreadsheets, each side of a tooth has a separate score. A single score was assigned for the interproximal surfaces of each tooth.

4.8 Statistical Analysis of the Isotopic and Dental Data

SPSS Version 9.0 was used for the statistical analysis of the Isola Sacra data. All graphs were created using Microsoft Excel 2000. After all the data were entered, the spreadsheets were manually checked for errors.

The distribution of each data set was examined prior to statistical analysis, and statistical outliers were identified using z-scores (>3 standard deviations from the mean). T-tests and analyses of variance or covariance (ANOVA, ANCOVA) were used on the normally distributed data. Non-parametric tests (Mann-Whitney U and Kruskal-Wallis) were used on the non-normal data. In some cases, data that were not normally distributed were transformed so that parametric tests could be used.

Chapter 5

Results - Stable Isotope Analysis

5.1 Assessment of Bone Preservation

Before the data could be analyzed it was necessary to evaluate the preservation of the isotopic signal in the bone samples, through a comparison of collagen yield, bone histology, and C:N ratios (see Appendix A). Collagen yields greater than 5% of the original bone weights are considered to have reliable carbon and nitrogen values (Ambrose, 1990; Schwarcz and Schoeninger, 1991). Savorè (1996) identified four categories of bone preservation in histological thin sections of the Isola Sacra femora that will be used here. 'Normal' samples show no evidence of diagenetic alteration of the bone structure, and osteons are clearly visible. Samples identified as 'focalized' display foci of structural degradation, whereas 'amorphous' samples show more widespread evidence of degradation. Much of the destruction observed in both categories is attributed to microbial activity (*ibid.*). 'Mineralized' bone samples show evidence of crystallization of bone tissue. The C:N ratio measures the amount of carbon and nitrogen in the extracted collagen sample. If the ratio is between 2.9 to 3.6, the data from the sample are assumed to be reliable (DeNiro, 1985).

Bone samples identified as histologically 'normal' tend to have higher collagen yields (average 9.13%) than those categorized as 'focalized' (5.25%), 'amorphous' (3.89%), or 'mineralized' (2.32%). The average collagen yield is lower in the samples with histological evidence of diagenetic change, although there is considerable variation in yields. C:N ratios are higher in the 'focalized' category ($\bar{x}$ = 3.42), but are approximately equal in the 'normal' ($\bar{x}$ = 3.37) and 'amorphous' ($\bar{x}$ = 3.39) categories. This suggests that diagenetically altered bone can still have acceptable C:N ratios, and supports the use of multiple diagenetic indicators when assessing bone preservation for isotopic analysis. Individual samples with C:N ratios widely outside the accepted range (2.9-3.6) *and* collagen yields lower than 5% were excluded from subsequent analysis.

The data were further analyzed to investigate possible correlations between C:N ratios and $\delta^{13}C$ values, $\delta^{15}N$ values, or collagen yield. There are no significant correlations between the variables (at $p \leq 0.05$). If there is significant diagenetic alteration of the bone collagen, one would expect to see, for example, a shift in $\delta^{13}C$ values correlated with changes in C:N ratios. The C:N ratios are normally distributed, so an analysis of variance (ANOVA) was performed look for variability in ratios in relation to the type of burial structure. If diagenetic alteration is related to the type of burial structure, then there should be some variability in C:N ratios between different burial types. The results are not statistically significant ($p \leq 0.05$), so there does not appear to be a relationship between type of burial structure and C:N ratios.

The collagen yield data are not normally distributed, so a non-parametric test had to be applied. A Kruskal-Wallis test found no variability in yield related to burial type.

In samples without C:N ratios and with low yields, the $\delta^{13}C$ and $\delta^{15}N$ data were examined to see if they fell outside the normal range of variation for the entire sample (i.e., statistical outliers), and these samples were also excluded from further analysis.

Finally, to ensure that collagen yield does not affect interpretation of the results, the data were analyzed for correlations between $\delta^{13}C$, $\delta^{15}N$, and yield. A significant correlation exists for $\delta^{13}C$ values and yields lower than 5% ($r = .288$, $p = .033$), but there is no correlation with yields above 5%. These results are comparable to those of Ambrose (1990) and White and Schwarcz (1994). There is no significant correlation found between $\delta^{15}N$ values and % yield. Collagen yields are, on average, lower for females than males (♀ mean = 5.02%; ♂ mean = 6.26%), however a Mann-Whitney U test comparing yields for males and females indicated that the differences are not statistically significant. The correlation between $\delta^{13}C$ values and collagen yield will be controlled for in subsequent statistical analyses.

5.2 Variation of Isotopic Data Between Skeletal Elements

Four individuals were examined for reproducibility of isotopic data between skeletal elements (SCR 309, 310, 315, and 402). The differences in $\delta^{13}C$ values ($\Delta^{13}C_{rf} = \delta^{13}C_{rib} - \delta^{13}C_{femur}$) between rib and femur samples range from 0.0‰ to -0.4‰, with a mean value of –0.1‰. The variation of $\delta^{15}N$ values between skeletal elements ($\Delta^{15}N_{rf}$) is slightly larger, ranging from -0.3‰ to -1.3‰, with the data from the rib samples consistently higher in all cases. The mean $\Delta^{15}N_{rf}$ is –0.8‰. Table 5.1 presents the data

for all four cases, and in all but one (SCR 310), the femur samples have slightly lower values than the rib samples. The variation of isotopic values between skeletal elements within each individual cannot be explained by precision of analysis alone. Measurement precision for $\delta^{13}C$ is ± 0.1 ‰ and for $\delta^{15}N$ it is ± 0.2 ‰.

Table 5.1 – Differences in $\delta^{13}C$ and $\delta^{15}N$ values between rib and femur samples from the same individual

SCR #	Age (in years)	Rib $\delta^{13}C$ (‰)	Femur $\delta^{13}C$ (‰)	$\Delta\ ^{13}C_{rf}$	Rib $\delta^{15}N$ (‰)	Femur $\delta^{15}N$ (‰)	$\Delta\ ^{15}N_{rf}$
		PDB[1]	PDB[1]		AIR[2]	AIR[2]	
309	10-11	-18.8	-19.2	-0.4	10.2	9.2	-1.0
310	17-19	-18.9	-18.6	0.3	11.2	9.9	-1.3
315	8-9	-19.0	-19.3	-0.3	11.2	10.9	-0.3
402	5-6	-18.8	-18.8	0.0	11.8	11.3	-0.5

[1] PDB, Peedee belemnite
[2] AIR, atmospheric nitrogen

Controlled laboratory experiments have demonstrated that isotope levels in different skeletal elements vary by less than 1‰, and it was concluded that this variability would not affect interpretation of dietary differences in archaeological populations (DeNiro and Schoeninger, 1983). Dupras (1999) concluded that the range of variation in $\delta^{13}C$ and $\delta^{15}N$ values between femora, ilia, and ribs in six individuals from the Dakhleh Oasis, Egypt, was small enough to assume that isotopic data from one bone type could be considered representative of the entire skeleton ($\delta^{15}N$ range - 0.1 to 1.1‰; $\delta^{13}C$ range - 0.1 to 1.2‰).

In the Isola Sacra sample, the range of variation between skeletal elements for $\delta^{13}C$ is fairly low, however there is considerable variability in the $\delta^{15}N$ data that exceeds measurement precision, so it was decided that data from different elements could not be collapsed together for statistical analysis. The rib values come primarily from younger subadults, still in the process of bone growth, so it may be that physiological factors are responsible for variability in isotopic values between different bones in the body. It cannot be determined how this operates from this sample, but further testing of the isotopic values in different bones within different age groups is required. Consequently, this chapter reports the rib and femur data separately, although the data are presented together in Figures 5.6 and 5.7 to show the general relationship between age-at-death and isotope levels.

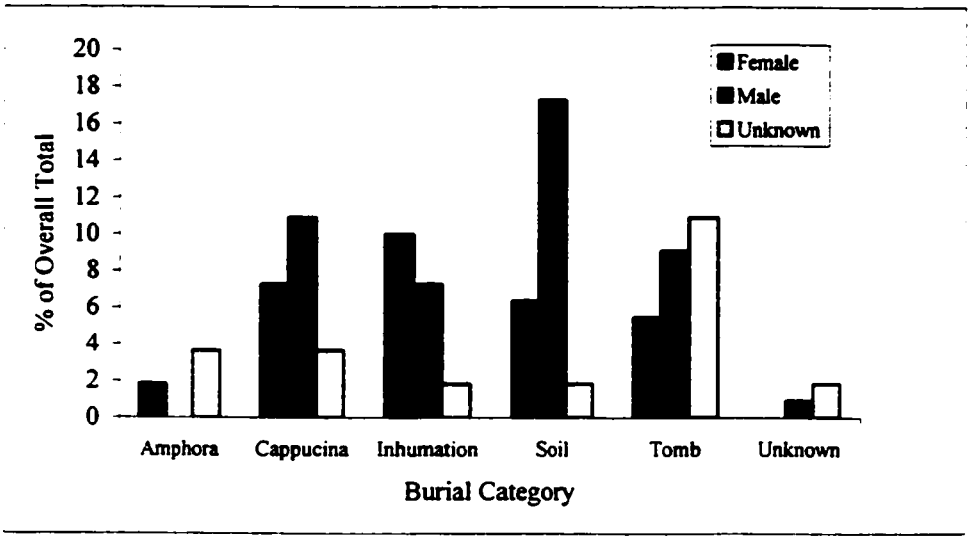
5.3 Sample Size and Distribution

A total of 110 femur and 52 rib samples were analyzed for $\delta^{13}C$ and $\delta^{15}N$ of bone collagen. The majority of infants and children in this study are represented by rib samples (n = 52) to keep the femora intact for age estimations. The age distribution of the rib sample will be discussed in Section 5.9. Demographic information for the femur sample is presented in Appendix B, and is summarized in Table 5.2. Figure 5.1 shows the distribution of the sample by burial type and sex.

Table 5.2 – Age and sex distribution of the Isola Sacra femur sample

	Unknown	Male	Female	Total
Age Category	(n)	(n)	(n)	(n)
5-15 years	15	*	*	15
15-30 years	*	18	12	30
30-45 years	*	13	9	22
>45 years	*	19	13	32
Adult	11	*	*	11
Total	**26**	**50**	**34**	**110**

Figure 5.1 – Distribution of the Isola Sacra femur sample by sex and burial category



5.4 Bone Collagen Data - Femur Samples

The isotopic data for the femora are presented in Appendix B, and summary statistics for the total sample and the sample divided by sex are presented in Table 5.3. Z-scores were calculated for both the carbon and nitrogen data to check for outliers. One outlier (>3 standard deviations from the mean), SCR 050, was removed from subsequent

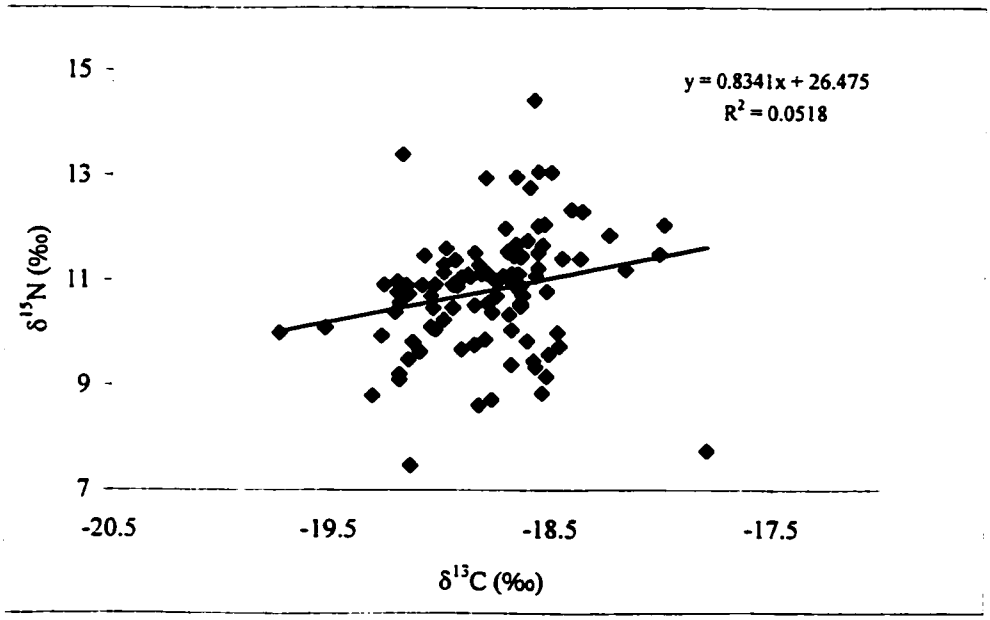
analyses. The $\delta^{13}C$ data range from -17.8‰ to -19.7‰, with a mean value of -18.8 ± 0.3‰. Nitrogen values range from 7.5‰ to 14.4‰, with a mean value of 10.8 ± 1.2‰. Figure 5.2 shows the distribution of the $\delta^{13}C$ and $\delta^{15}N$ data for the sample. Partial correlation analysis (controlling for yield) between $\delta^{13}C$ and $\delta^{15}N$ found a weak, but significant relationship between the two sets of data ($r = .215$, $p = .035$).

Table 5.3 - Mean $\delta^{13}C$ and $\delta^{15}N$ isotope values for the Isola Sacra femur sample and for the sample divided by sex

Sample	n	$\delta^{13}C$ (‰) PDB[1]	S.D.	n	$\delta^{15}N$ (‰) AIR[2]	S.D.
Total	105	-18.8	0.3	103	10.8	1.2
Female	32	-18.9	0.3	30	10.7	1.1
Male	48	-18.7	0.3	49	11.0	1.2
Unknown	25	-18.8	0.4	24	10.7	1.1

[1] PDB, Peedee belemnite
[2] AIR, atmospheric nitrogen

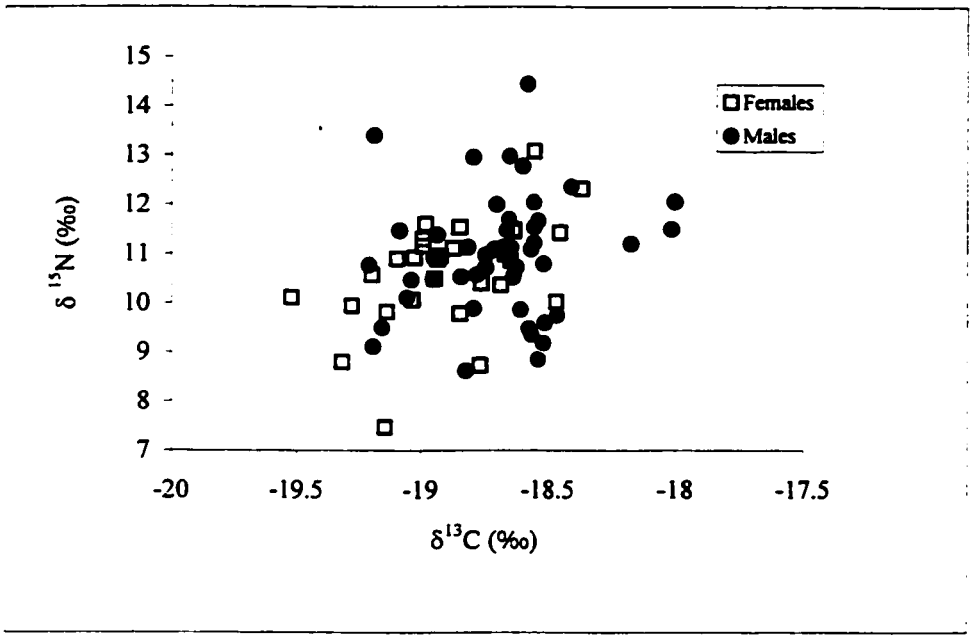
Figure 5.2 – Scatter plot showing Isola Sacra δ13C and δ15N femur data (total sample)



5.4.1 - Variation in Isotopic Data in Relation to Sex

For those individuals in the sample of known sex, a T-test was performed to compare $\delta^{13}C$ and $\delta^{15}N$ values between males and females. The level of significance was set at $p \leq 0.05$. The female $\delta^{13}C$ values are significantly more negative than those of the males ($t = 2.819$; $p = .006$), whereas the $\delta^{15}N$ values show no significant difference between the sexes ($t = 1.116$; $p = .268$).

Figure 5.3– Scatter plot showing Isola Sacra $\delta^{13}C$ and $\delta^{15}N$ femur data by sex



To control for the effect of yield on $\delta^{13}C$ values, an analysis of co-variance (ANCOVA) was performed, with similar significant results between males and females for $\delta^{13}C$ ($F = 8.492$, $p = .005$). Figure 5.3 illustrates the $\delta^{13}C$ and $\delta^{15}N$ data,

differentiated by sex. Table 5.3 indicates that the mean $\delta^{13}C$ values for males and females are quite close. The variability in the $\delta^{13}C$ data between males and females appears to be caused by the clustering of male $\delta^{13}C$ values around –18.5‰, whereas the female data appear to be more evenly dispersed.

5.4.2 - Variation in Isotopic Data in Relation to Age-at-Death

Table 5.4 presents the mean $\delta^{13}C$ and $\delta^{15}N$ data divided by age and sex. Due to the observed variability in $\delta^{13}C$ values between males and females, both $\delta^{13}C$ and $\delta^{15}N$ were analyzed with the sexes divided for ease of comparison. For the purposes of statistical analysis, the midpoint of the age range for each individual was used. Individuals with unspecified 'adult' ages were excluded from statistical analysis, but their mean values are reported in Table 5.4.

The data were first analyzed to look for a relationship between isotopic values and increasing age-at-death. Partial correlation analysis of $\delta^{13}C$ and age-at-death (controlling for yield) produced an r-value of .263 ($p = .011$), indicating a weak but significant correlation between age-at-death and the carbon data. The relationship between $\delta^{15}N$ and age-at-death is also significant ($r = .324$, $p = .002$).

Table 5.4 shows that there is a progressive increase in mean $\delta^{15}N$ values between successive adult age categories, with the exception of females in the 15-30 year age range, who have the lowest mean $\delta^{15}N$ values of the entire sample. This is shown graphically in Figure 5.4. This figure also shows that the subadult $\delta^{15}N$ values tend to be lower in the 10-15 year range. It is interesting to note that in all adult age categories the

mean $\delta^{15}N$ values are consistently higher in males than in females. The carbon data show a similar consistent pattern of change, with the females in each age category having lower mean $\delta^{13}C$ values than males (Figure 5.5). In addition, the subadults (5-15 years of age) have more negative $\delta^{13}C$ values than the rest of the sample. This consistent pattern of more negative $\delta^{13}C$ values among females in all age categories helps to clarify the earlier T-test results of the overall isotopic levels for males and females (Section 5.4.1). The small, but significant, overall variability is caused by the consistently more negative $\delta^{13}C$ values among females. The mean difference in $\delta^{13}C$ values between males and females does not distinguish this variability.

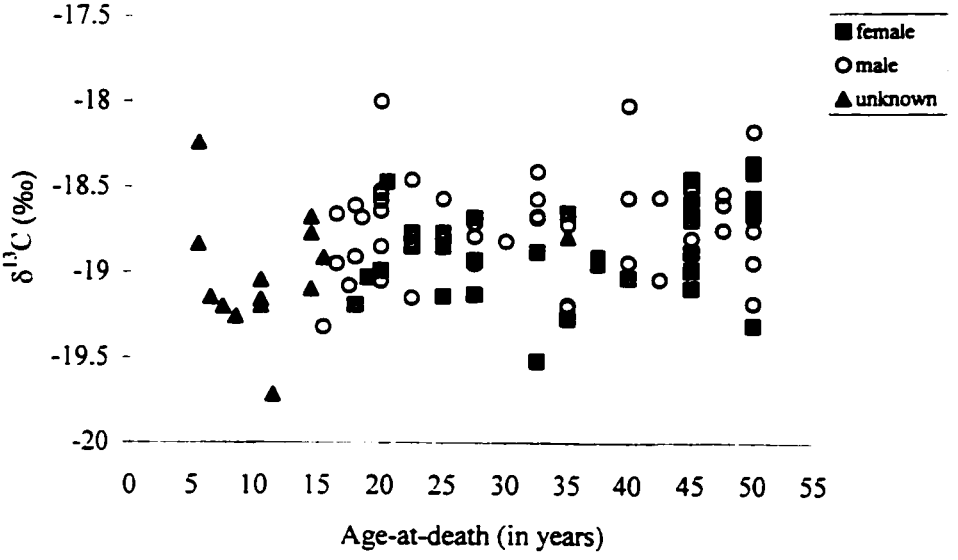
Table 5.4 - Mean $\delta^{13}C$ and $\delta^{15}N$ isotope values for the Isola Sacra femur sample divided by age and sex.

Age & Sex Category	n	$\delta^{13}C$ ‰ PDB[1]	S.D.	n	$\delta^{15}N$ ‰ AIR[2]	S.D.
5-15 years (U)	14	-19.0	0.3	13	10.4	0.8
15-30 years (M)	18	-18.7	0.3	18	10.5	0.9
15-30 years (F)	11	-18.9	0.2	12	10.1	1.2
30-45 years (M)	13	-18.7	0.3	13	11.0	0.9
30-45 years (F)	8	-19.0	0.3	7	10.7	0.6
>45 years (M)	17	-18.7	0.2	18	11.4	1.5
>45 years (F)	13	-18.7	0.3	11	11.2	1.1
Adult (U)	11	-18.6	0.3	11	11.0	1.4

[1] PDB, Peedee belemnite
[2] AIR, atmospheric nitrogen

Figure 5.4 - $\delta^{15}N$ plotted against age-at-death

Figure 5.5 – $\delta^{13}C$ plotted against age-at-death

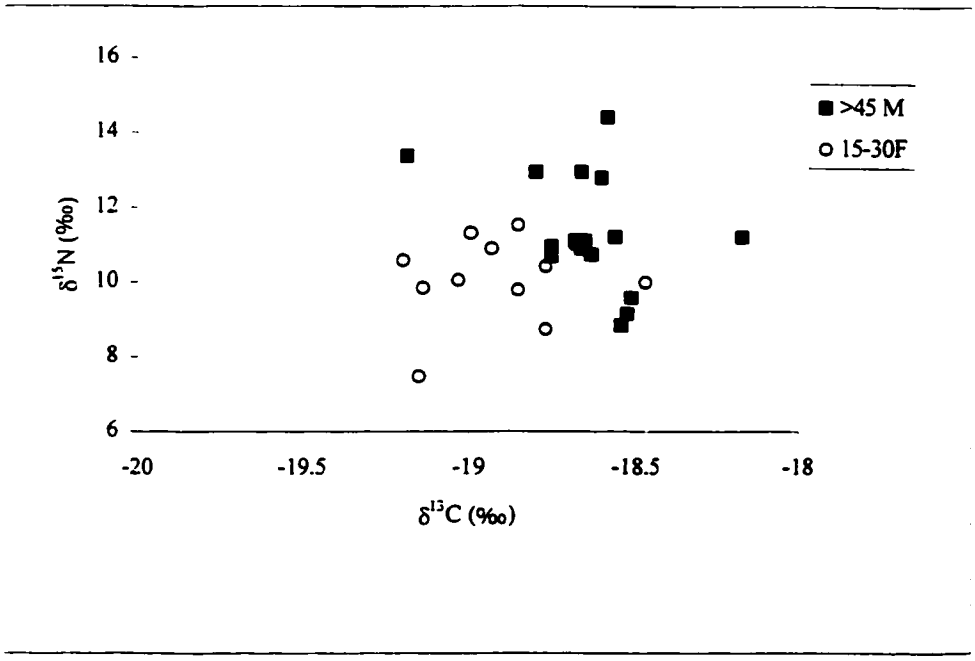


An analysis of variance (ANOVA) on the $\delta^{15}N$ data demonstrates significant variation between the age/sex groups ($F = 2.799$, $p = .016$). Post-hoc Tukey HSD comparisons determined that 15-30 year-old females have significantly lower $\delta^{15}N$ values than > 45 year-old males ($p = .018$).

An analysis of co-variance (ANCOVA) was performed on the $\delta^{13}C$ data, controlling for collagen yield. The results of this analysis are also statistically significant ($F = 3.869$, $p = .002$). Post-hoc Tukey HSD comparisons indicate that subadults in the 5-15 age category have significantly lower $\delta^{13}C$ values than males in two older categories (15-30 years $p = .019$; and >45 years $p = .009$). These results also approach statistical significance with males in the 30-45 age category ($p = .067$). Figure 5.5 shows that the youngest subadult individuals tend to have more negative $\delta^{13}C$ values than the rest of the sample, clustering around –19.25‰.

Figure 5.6 illustrates the 15-30 and female data and the >45 male data. As noted in Figure 5.3, the male data tend to be restricted in their $\delta^{13}C$ values, yet there is a very wide range (~ 6‰) of $\delta^{15}N$ data. The female data tend to have more negative $\delta^{13}C$ values, and the $\delta^{15}N$ values vary between ~ 8 to 12‰.

Figure 5.6 - $\delta^{13}C$ plotted against $\delta^{15}N$, showing age/sex categories with significant variability



5.4.3 - Variation in Isotopic Data in Relation to Burial Type

Once the analysis of variability by age and sex was completed, the data were then divided by burial categories. The nine categories used by the excavators were collapsed into five for statistical analysis. These were also the categories used by Savorè (1996) for her histological assessment of the Isola Sacra femur samples. 'Soil' burials include those individuals who were found in 'pit' or 'sand' interments, with no evidence of a protective burial structure. 'Tomb' burials include monumental tombs, colombario, and sarcophagi. 'Cappucina' burials include both semicappucina and cappucina interments. The mean $\delta^{13}C$ and $\delta^{15}N$ values, by burial category, are presented in Table 5.5. Individuals of

unknown burial type were excluded from statistical analysis, but are also reported below.

Table 5.5 – Mean $\delta^{13}C$ and $\delta^{15}N$ isotope values for the Isola Sacra femur sample divided by burial type

Burial Type	n	$\delta^{13}C$ (‰) PDB[1]	S.D.	n	$\delta^{15}N$ (‰) AIR[2]	S.D.
Amphora	6	-19.1	0.1	5	10.1	0.7
Tomb	28	-18.7	0.4	27	10.7	1.4
Cappucina	22	-18.8	0.3	23	11.1	1.3
Soil	28	-18.8	0.3	25	10.7	0.9
Inhumation	19	-18.8	0.3	20	10.9	1.0
Unknown	3	-18.6	0.1	3	11.5	0.7

[1] PDB, Peedee belemnite
[2] AIR, atmospheric nitrogen

An analysis of variance (ANOVA) performed on the $\delta^{15}N$ data found no significant variation between burial types ($F = 1.152$, $p = .337$). An analysis of co-variance (ANCOVA) performed on the $\delta^{13}C$ data, controlling for yield, also found no variation between burial types ($F = 1.513$, $p = .204$). As males and females are not evenly distributed among the different burial types (i.e., more females in inhumations; more males in soil burials), the data were re-analyzed with the sexes separated, with similar results. The low $\delta^{13}C$ and $\delta^{15}N$ values of individuals in amphorae burials are likely age-related, since the majority of individuals buried in amphorae are subadults, with an average age of 16.7 years.

5.4.4 - Combined Rib and Femur Data

Figures 5.7 and 5.8 illustrate the trends in the $\delta^{13}C$ and $\delta^{15}N$ data with increasing age-at-death for the combined rib and femur samples. From both graphs it is clear that

extremely young individuals have higher $\delta^{13}C$ and $\delta^{15}N$ values than the rest of the sample, and these values decrease between approximately 0 and 2 years of age. This pattern is discussed in more detail in section 5.9.

Even taking into consideration the discrepancy in $\delta^{15}N$ values between the ribs and femora (discussed in section 5.2) there is a clear distinction between individuals under 2 years of age and the rest of the sample. After 2 years of age, the values tend to level out, although there is a gradual trend towards more positive $\delta^{13}C$ and $\delta^{15}N$ values with increased age-at-death (Table 5.6). Since it was decided that the femur and rib data should not be combined, statistical analyses were not performed on these data.

Table 5.6 - Mean $\delta^{13}C$ and $\delta^{15}N$ isotope values for the combined rib and femur sample divided by age category

Age Category	n	$\delta^{13}C$ (‰) PDB[1]	S.D.	n	$\delta^{15}N$ (‰) AIR[2]	S.D.
0-2 yrs	24	-18.5	0.5	25	13.5	1.4
2-5 yrs	13	-19.1	0.2	14	11.5	1.6
5-15 yrs	20	-18.9	0.5	19	10.6	0.7
15-30 yrs	34	-18.8	0.3	33	10.5	1.3
30-45 yrs	22	-18.8	0.3	21	10.9	0.8
>45 yrs	30	-18.7	0.3	29	11.4	1.3

[1] PDB, Peedee belemnite
[2] AIR, atmospheric nitrogen

Figure 5.7 – Scatter plot showing Isola Sacra femur and rib $\delta^{13}C$ data versus estimated age-at-death

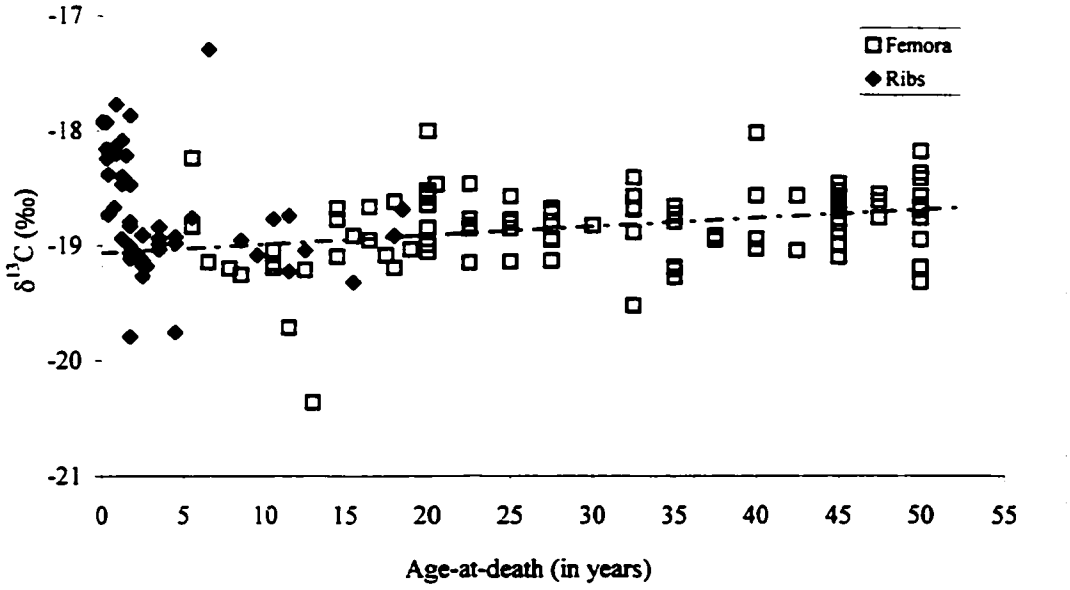
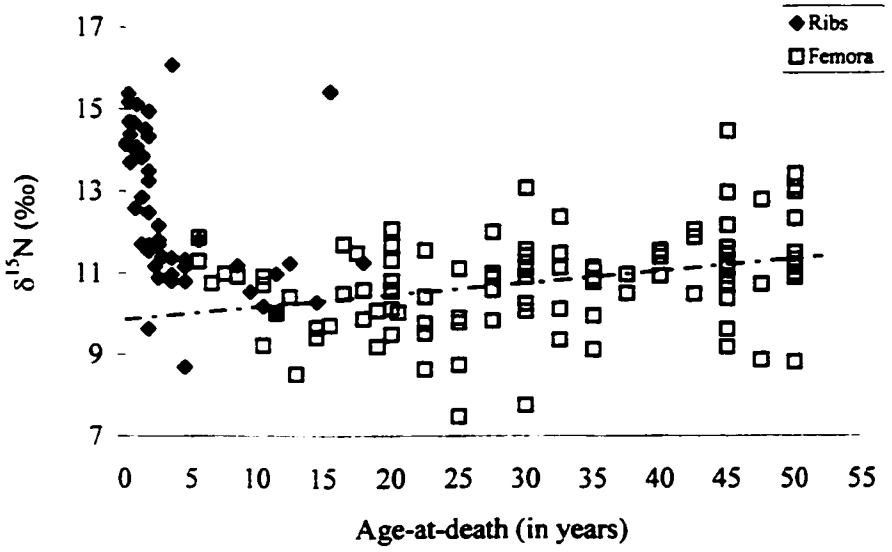


Figure 5.8 – Scatter plot showing Isola Sacra femur and rib $\delta^{15}N$ data versus estimated age-at-death



5.5 Bone Apatite - Femur Samples

5.5.1 Diagenesis

A subset (n=27) of the Isola Sacra femur series was analyzed for diagenetic alteration of bone apatite using Fourier Transform Infrared Spectroscopy. This technique measures the absorbance spectra of powdered bone samples and is used to evaluate alterations in the crystalline structure of bone. The 'Crystallinity Index' (CI) of each sample was calculated, using the following formula:

Equation 5.1- **Crystallinity Index** $CI = \{ A_{565} + A_{605} \} / A_{595}$

A_x represents the absorbance at a specified wavenumber (x). The CI is a measure of the separation between the two phosphate (PO_4) peaks at 565 and 605 cm^{-1}, divided by the 'trough' between them at 595 cm^{-1}. The peaks represent the vibrational frequency of the PO_4 molecule. The data are summarized in Appendix C. The indices of the samples range from 2.85 to 4.12, with an average of 3.31 ± .28. High crystallinity indices in archaeological bone are considered to be indicative of post-mortem crystal growth or dissolution of more soluble crystals (Wright and Schwarcz, 1996). When these data were compared to Savorè's (1996) bone histology evaluations, mineralized samples had the highest CI (4.12), focalized and amorphous samples had intermediate CI (3.57-3.96), and normal samples had the lowest CI values (<3.28). Modern human bone has a CI of 3.1 (Wright and Schwarcz, 1996). The CI data were normalized using a logarithm transformation and an analysis of variance (ANOVA) was run to explore the variability in CI related to burial type. No significant difference was found between burial types.

5.5.2 $\delta^{13}C$ of Bone Apatite

Sixty-six femur samples were analyzed for $\delta^{13}C$ of apatite. Precision of analysis is 0.1‰. Z-scores were calculated for the $\delta^{13}C_{apatite}$ data to check for outliers (>3 standard deviations away from the mean). One sample, SCR 029, was identified as a statistical outlier ($z = -3.4$), and was removed from subsequent analysis. The range of $\delta^{13}C_{apatite}$ is –9.5 to –14.1‰, with a mean of -11.4 ± 1.1‰.

The data are not normal, so a Mann-Whitney U test was performed to detect variability in $\delta^{13}C_{apatite}$ values between males (-11.5 ± 1.2‰) and females (-11.4 ± 1.0‰), but no significant difference was found. The mean value for individuals of unknown sex is -11.1 ± 1.0‰. Kruskal-Wallis statistics were calculated to examine variability in the $\delta^{13}C_{apatite}$ data in relation to age-at-death and burial type, using the same age and burial categories as the collagen data. There is no statistically significant variability between $\delta^{13}C_{apatite}$ and the different burial types (Table 5.7). However, variability for the age categories is statistically significant ($X^2 = 11.628$, $p = .009$). Mean values for each age category are summarized in Table 5.8, and shows a trend of decreasing $\delta^{13}C_{ap}$ values with increased age-at-death.

Table 5.7 – Mean $\delta^{13}C_{apatite}$ values by burial type

Burial Type	n	δ^{13}Cap (‰) PDB[1]	S.D.
Amphora	6	-10.9	0.5
Tomb	14	-11.7	1.0
Cappucina	13	-12.0	1.3
Soil	21	-11.0	0.9
Inhumation	10	-11.2	1.4
Unknown	1	-11.0	*

[1] PDB, Peedee belemnite

Table 5.8 – Mean $\delta^{13}C_{apatite}$ values by age category

Age Category	n	$\delta^{13}C_{ap}$ ‰ PDB[1]	S.D.
5-15 years	11	-10.7	0.5
15-30 years	22	-11.1	1.0
30-45 years	13	-11.2	1.0
>45 years	15	-12.2	1.3
Adult	4	-12.4	1.2
Total	65	-11.4	1.2

[1] PDB, Peedee belemnite

Figure 5.9 shows an interesting pattern in the $\delta^{13}C_{apatite}$ data when they are plotted against age-at-death. First, the younger subadults (5-10 years of age) have $\delta^{13}C_{apatite}$ values that cluster between –10 and –11‰. The range of $\delta^{13}C_{apatite}$ data remains fairly consistent (between –10 to –13‰) up to approximately 40 years, after which some of the $\delta^{13}C_{apatite}$ values become more negative. The subadult values appear to be less variable than the adult values, suggesting that total dietary carbon was coming from a more restricted source. This is similar to the collagen $\delta^{13}C$ data of the subadults (Figure 5.5), which also show a fairly restricted distribution.

Figure 5.10 graphs $\delta^{13}C_{apatite}$ against $\delta^{13}C_{collagen}$ results by age alone. A correlation test found no significant correlation between the Isola Sacra collagen and apatite data. This graph also shows that most of the subadults (5-15 years) cluster together for both $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values. There is a cluster of >45 year-olds with restricted $\delta^{13}C_{collagen}$ values, but a wide range of $\delta^{13}C_{apatite}$ values. The behavior of $\delta^{13}C_{apatite}$ is similar to that of $\delta^{15}N$, in that we see a wider range of values for individuals in the >45 year age category.

Figure 5.9 – Scatter plot of $\delta^{13}C_{apatite}$ versus age-at-death, with sexes separated

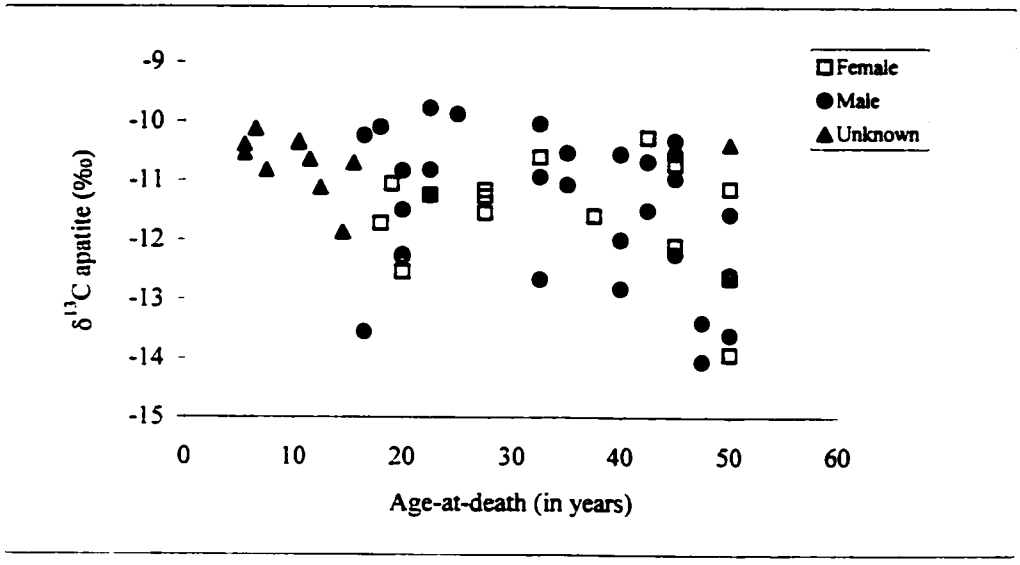
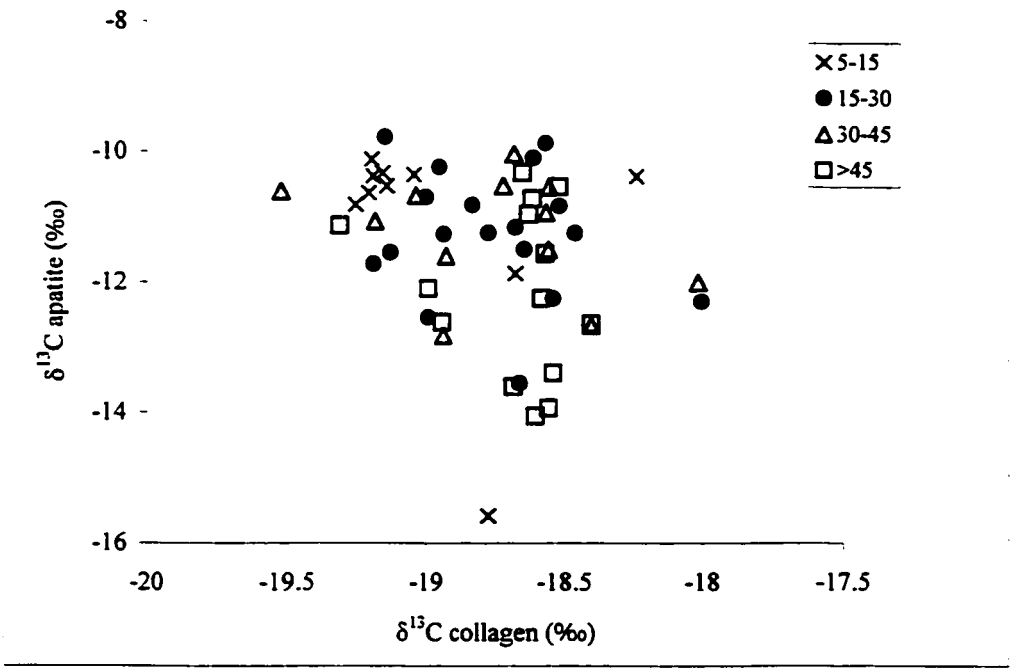


Figure 5.10 – Scatter plot of $\delta^{13}C_{collagen}$ versus $\delta^{13}C_{apatite}$ by age category (in years)



The lack of a linear correlation between the $\delta^{13}C$ of collagen and apatite is expected if there are extreme differences in trophic levels between different individuals in a sample (Wright and Schwarcz, 1996). Trophic level differences can be explored by looking at the variability between the $\delta^{13}C$ values in collagen and apatite ($\Delta^{13}C_{a-c}$) as well as the $\delta^{15}N$ levels of collagen. The mean difference between $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ ($\Delta^{13}C_{a-c}$) in this study is 7.4‰, close to the value expected for an omnivorous diet (~7‰) (Krueger and Sullivan, 1984).

Figure 5.11 plots $\Delta^{13}C_{a-c}$ against $\delta^{15}N$ of collagen. Low $\delta^{15}N$ values and high $\Delta^{13}C_{a-c}$ differences indicate a mainly herbivorous diet, whereas high $\delta^{15}N$ values and low $\Delta^{13}C_{a-c}$ differences indicate a predominantly carnivorous diet. Nearly all of the subadults

cluster in the high $\Delta^{13}C_{a-c}$, low $\delta^{15}N$ region on this graph (circled).

Wright and Schwarcz (1996) contend that if the lack of a linear correlation between $\delta^{13}C$ of collagen and apatite is due to differences in trophic level, then there should be a correlation between $\Delta^{13}C_{a-c}$ and $\delta^{15}N$. This is, in fact, the case for the Isola Sacra sample, with a negative correlation of r = -.386; p = .005. This is to be expected because as the $\Delta^{13}C_{a-c}$ spacing gets smaller (indicating a shift from herbivore – omnivore – carnivore), the $\delta^{15}N$ values become more positive, as seen in Figure 5.11.

Figure 5.11 - Scatter plot of $\Delta^{13}C_{apatite-collagen}$ versus $\delta^{15}N$, by age category, with the subadult (5-15 yrs) cluster circled

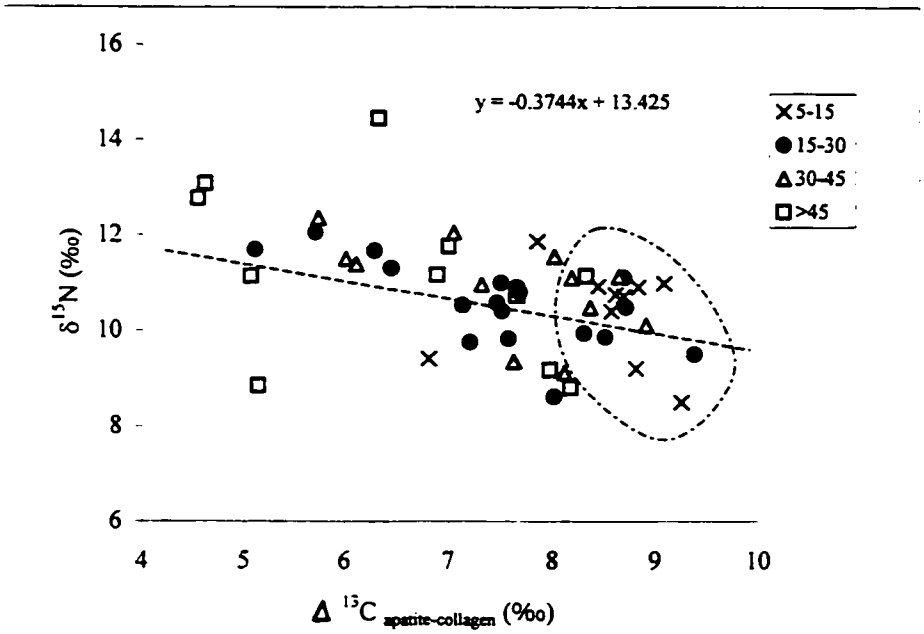
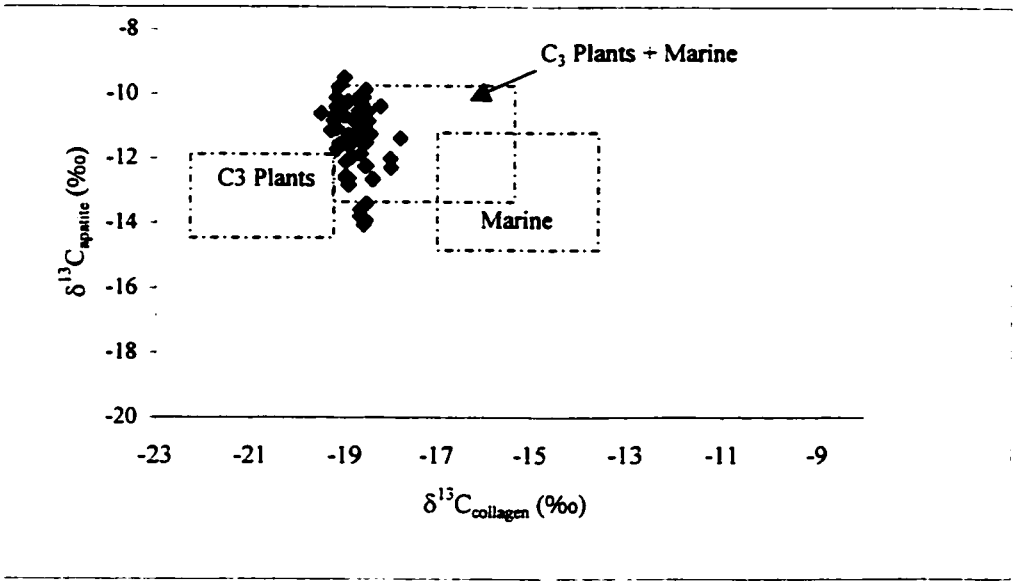


Figure 5.12 plots the Isola Sacra data against expected ranges of $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$, after Krueger and Sullivan (1984). The Isola Sacra data fall within the range of a diet composed of C_3 plants and marine foods.

Figure 5.12 – Scatter plot of $\delta^{13}C_{apatite}$ versus $\delta^{13}C_{collagen}$, with expected ranges of carbon values for different diets (after Krueger and Sullivan, 1984)



5.6 Isotopic Analysis of Faunal Remains

Bone samples from two omnivore species (fox and dog), and five herbivore species (cow, horse, donkey, goat, and pig) were analyzed. The raw data for these samples are presented in Appendix D, and are summarized in Table 5.9.

Figure 5.13 plots the collagen data of the faunal remains along with the Isola Sacra data. The graph shows a clear isotopic distinction between the herbivores and the

Isola Sacra humans. The omnivore values cluster at the lower range of the human data, although the small sample size (n = 2) makes any generalization difficult. The human samples are enriched in both $\delta^{13}C$ and $\delta^{15}N$ with respect to the herbivores, and the $\delta^{13}C$ levels of the herbivores are what would be expected of organisms consuming diets consisting primarily of terrestrial C_3 plants. The $\delta^{13}C$ levels of the omnivores overlap with the Isola Sacra sample, but most of the human $\delta^{15}N$ values are enriched over the omnivore data. The $\delta^{15}N$ levels of the humans are clearly enriched over the herbivores, by an average of ~ 5.5‰ (see Table 5.9).

Table 5.9 – Comparison of human and faunal isotopic data from Isola Sacra

Sample	n	$\delta^{13}C_{col}$ (‰) PDB[1]	S.D.	n	$\delta^{13}C_{ap}$ (‰) PDB	S.D.	n	$\delta^{15}N$ (‰) AIR[2]	S.D.
Isola Sacra	105	-18.8	0.3	66	-11.4	1.1	103	10.8	1.2
Herbivores	14	-20.8	0.9	4	-10.7	0.8	12	5.3	1.5
Omnivores	3	-19.2	0.1	1	-10.4	*	2	9.3	0.1

[1] PDB, Peedee belemnite
[2] AIR, atmospheric nitrogen

When the $\Delta^{13}C_{apatite\text{-}collagen}$ data of the human and animal species are plotted against $\delta^{15}N$ (Figure 5.14), the herbivores (horse, cow, pig, and goat) cluster in the lower right section of the graph, as would be expected for species with diets consisting mainly of C_3 plants. The dog sample approaches the human values, but is still not as enriched in $\delta^{15}N$ as the humans.

Figure 5.13 – Scatter plot of Isola Sacra human and faunal $\delta^{13}C$ and $\delta^{15}N$ data

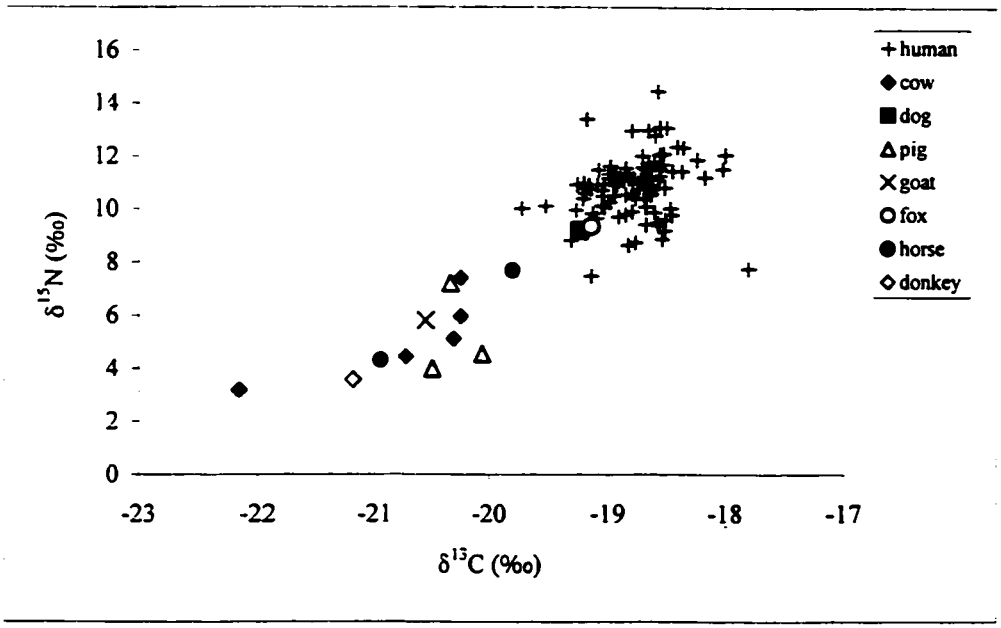
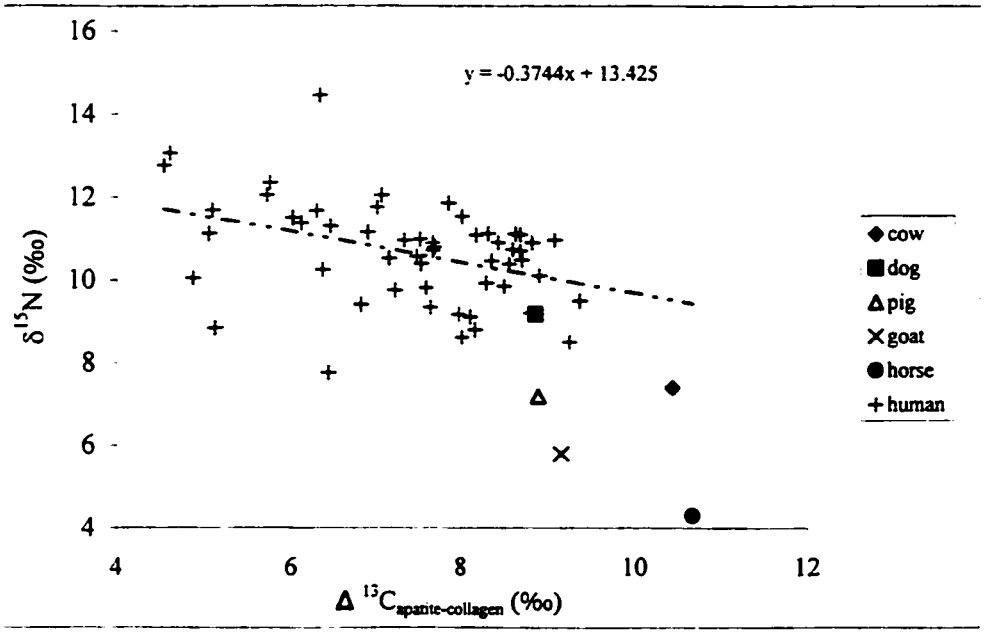


Figure 5.14 – Scatter plot of $\Delta^{13}C_{apatite\text{-}collagen}$ values versus $\delta^{15}N$, including faunal samples



5.7 Isotopic Analysis of Garum Samples

Ten *garum* samples were analyzed for $\delta^{13}C$ and $\delta^{15}N$ and the data are presented in Table 5.10 with their C:N ratios. Samples 4 and 5 have extremely high C:N ratios, suggesting that these data are probably not reliable, so they are not included in the calculation of the mean. The mean $\delta^{13}C$ value is $-14.7 \pm 0.6‰$ and the mean $\delta^{15}N$ value is $6.5 \pm 1.7‰$. Five of the original nitrogen samples prepared for analysis exploded in the furnace when they were being combusted with CuO and there was only enough garum remaining in five of the prepared samples to re-run the nitrogen analysis.

Table 5.10 – Isotopic data for Isola Sacra garum samples

Sample ID	$\delta^{13}C$ (‰) PDB[1]	$\delta^{15}N$ (‰) AIR[2]	C:N Ratio
1	-13.6	9.4	4.7
2	-15.3	*	5.6
3	-12.2	*	4.5
4	-19.7	*	18.6
5	-6.5	*	34.0
6	-17.8	4.9	6.8
7	-16.3	5.9	*
8	-14.3	6.2	4.1
9	-14.3	*	4.0
10	-13.5	5.9	4.6

[1] PDB, Peedee belemnite
[2] AIR, atmospheric nitrogen

Even though the carbon data are presented, carbon values actually reflect both the collagen and carbonate values of these samples, so only the nitrogen data are considered reliable. No other samples of garum have been analyzed isotopically, so there are no comparative samples for discussion. The data are plotted along with the Isola Sacra

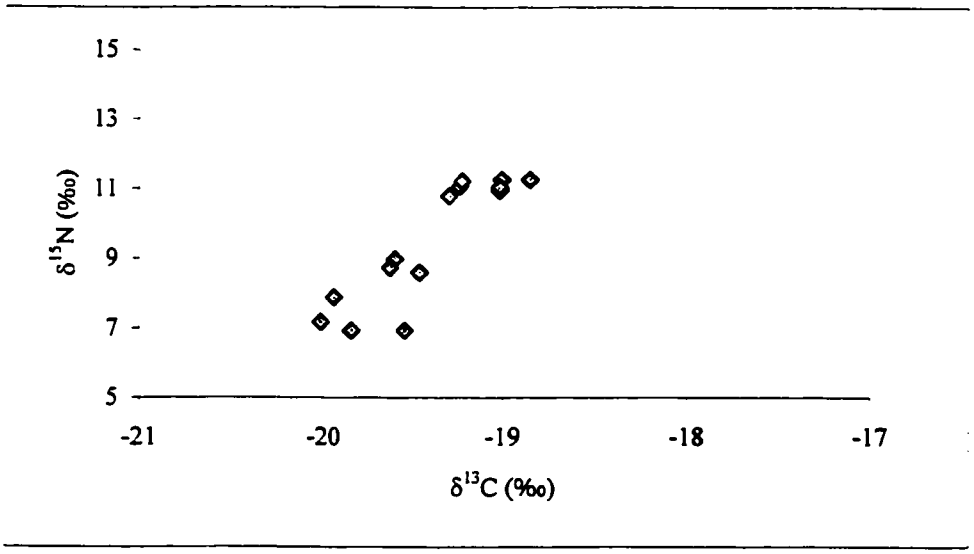
sample and the ANAS cemetery sample in Figure 5.16, showing the $\delta^{15}N$ levels relative to expected values for other marine consumers. These data indicate that the garum samples have low $\delta^{15}N$ values, slightly lower than expected values for marine herbivores.

5.8 The ANAS Cemetery

Fourteen samples from the 'ANAS' Cemetery were analyzed for $\delta^{13}C$ and $\delta^{15}N$ of bone collagen. The data are presented in Figure 5.15 and in Appendix E. Unfortunately, age, sex and burial treatment are not known for this sample, due to the nature of their recovery from a salvage excavation during construction of a modern road between Rome and Ostia (Macchiarelli, pers. comm.). The $\delta^{13}C$ data range from –18.9 to –20.0‰, with a mean value of –19.4 ± 0.4‰. The $\delta^{15}N$ data range from 6.9 to 11.3, with a mean value of 9.5 ± 1.8‰. Figure 5.15 shows that there is a clear separation of the ANAS data into 2 subgroups. A T-test comparing the two clusters of ANAS data confirmed that the variability is statistically significant ($\delta^{13}C$ t = -6.196, p = .000; $\delta^{15}N$ t = -9.341, p = .000). The ANAS cemetery data are plotted together with the Isola Sacra data in Figure 5.16 (both corrected for diet-bone collagen spacing), along with expected isotopic values of terrestrial- and marine-based diets (after Lubell *et al.*, 1994).[1]

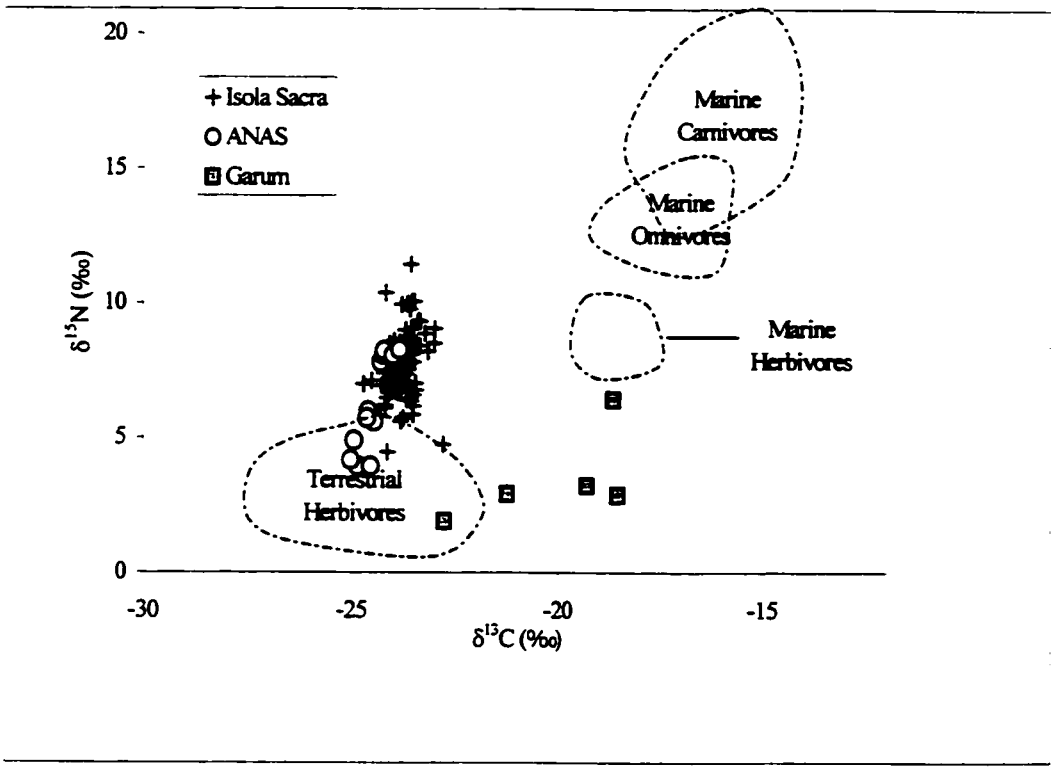
[1] Diet-bone collagen correction is 5‰ for carbon and 3‰ for nitrogen. These estimates are derived from studies of diet-collagen spacing in natural, wild animal populations (Vogel, 1978; Vogel *et al.*, 1990).

Figure 5.15 – ANAS sample, $\delta^{13}C$ plotted against $\delta^{15}N$



The cluster of ANAS individuals with higher $\delta^{13}C$ and $\delta^{15}N$ values fall within the same range as the Isola Sacra sample. The other subgroup has lower $\delta^{13}C$ and $\delta^{15}N$ values that are distinct from the other ANAS subgroup, and from the Isola Sacra sample. These latter data fall within the range expected for a terrestrial herbivore diet.

Figure 5.16– Inferred isotopic signal of Isola Sacra and ANAS diets, from $\delta^{13}C$ and $\delta^{15}N$ of bone collagen, and expected isotopic values of pure terrestrial and marine-based diets



5.9 Isola Sacra Rib Data

A total of 52 ribs, mainly of infants and children, were analyzed for $\delta^{13}C$ and $\delta^{15}N$ of bone collagen. The $\delta^{13}C$ results range from –17.3 to –19.8‰, with a mean value of -18.7 ± 0.5‰. The $\delta^{15}N$ results range from 8.7 to 16.1‰, with a mean value of 12.5 ± 1.8‰. These data are presented graphically in Figures 5.16-5.19 and the raw values are listed in Appendix F. Z-scores were calculated for both sets of data and no outliers were identified. There is no significant correlation found between the isotopic data and C:N

ratios or collagen yields. There is also no variability in the isotopic data in relation to burial type.

5.9.1 Variation in Isotopic Data in Relation to Age-at-Death

Table 5.11 presents the mean $\delta^{13}C$ and $\delta^{15}N$ values for the rib sample, separated by age-at-death categories. For the purposes of statistical analysis, the midpoint of the age range for each individual was used. The data were not divided by sex, since most of the individuals in this sample could not be assigned to either sex due to the lack of distinguishing sex-related characteristics in their skeletons.

Table 5.11 - Mean $\delta^{13}C$ and $\delta^{15}N$ isotope values for the rib sample divided by age category

Age Category	n	$\delta^{13}C$ (‰) PDB[1]	S.D.	n	$\delta^{15}N$ (‰) AIR[2]	S.D.
0-2 yrs	24	-18.5	0.5	25	13.5	1.4
2-10 yrs	17	-19.0	0.5	17	11.4	1.4
10-20 yrs	7	-19.0	0.3	7	11.3	1.9

[1] PDB, Peedee belemnite
[2] AIR, atmospheric nitrogen

The data in the three age categories were examined for significant variability between the subsets. Analysis of variance (ANOVA) found that there is significant variability between the age categories for both $\delta^{13}C$ ($F = 6.520$, $p = .003$) and $\delta^{15}N$ ($F = 12.256$, $p = .000$). Post-hoc Tukey HSD comparisons revealed that the variability exists between the 0-2 year-old category and the two older age groups for both $\delta^{13}C$ and $\delta^{15}N$, but not between the two older age categories (see Table 5.12).

Table 5.12 - Post-hoc Tukey HSD results showing mean differences of $\delta^{13}C$ (upper right) and $\delta^{15}N$ (lower left) isotope values between age categories*

Age Category	0-2 yrs	2-10 yrs	10-20 yrs
0-2 yrs	-	**0.5 (p=.005)**	**0.5 (.049)**
2-10 yrs	**2.1 (p=.000)**	-	0.0
10-20 yrs	**2.2 (p=.004)**	0.1	-

*Significant results are bolded.

Figures 5.17 and 5.18 illustrate the pattern of higher $\delta^{15}N$ and $\delta^{13}C$ levels in individuals younger than two years of age-at-death. There is a clear decrease in isotopic values in progressively older individuals. After 2 years of age, the $\delta^{15}N$ data fluctuate around the adult female mean for the femur sample, indicated by the horizontal line, with exception of one individual. It is interesting to note that most $\delta^{13}C$ values fall below the adult mean after 2 years of age and are still low in some of the older subadults. This is similar to the subadult femur $\delta^{13}C$ results, which showed that subadults have a more negative average $\delta^{13}C$ value than most of the adults (Table 5.4).

The adult female mean calculated from the femur data is $-18.9 \pm 0.3‰$ for $\delta^{13}C$, and $10.7 \pm 1.1‰$ for $\delta^{15}N$. An adult female mean could not be calculated from the rib data, because the oldest individuals are approximately 18 years of age, and sex could only be determined for a small number of individuals. However, the results in Section 5.2 suggest that $\delta^{15}N$ isotopic values from ribs are consistently higher than those obtained from femora, so the adult female average from the femur data must be interpreted with caution.

Figure 5.17 – Scatter plot of the Isola Sacra rib data, showing $\delta^{15}N$ versus estimated age-at-death

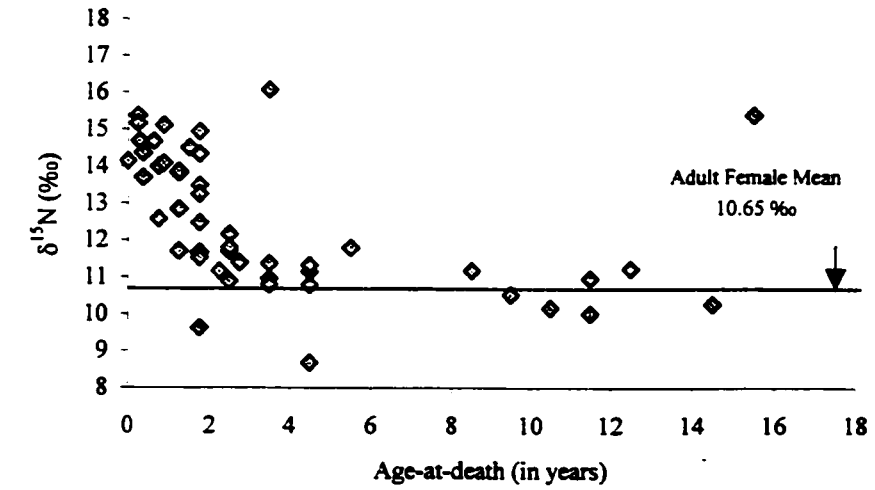
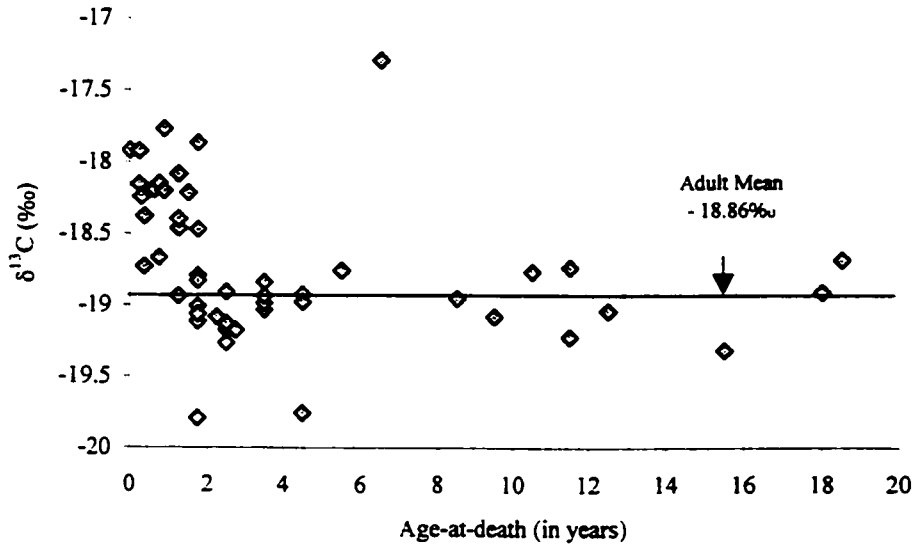
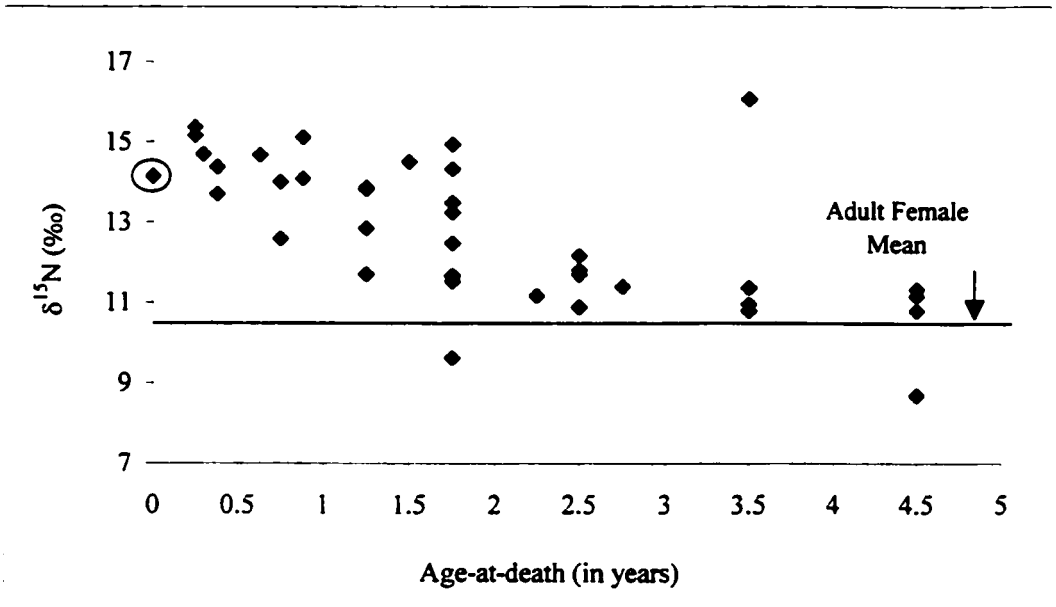


Figure 5.18 – Scatter plot of the Isola Sacra rib data, showing $\delta^{13}C$ versus estimated age-at-death



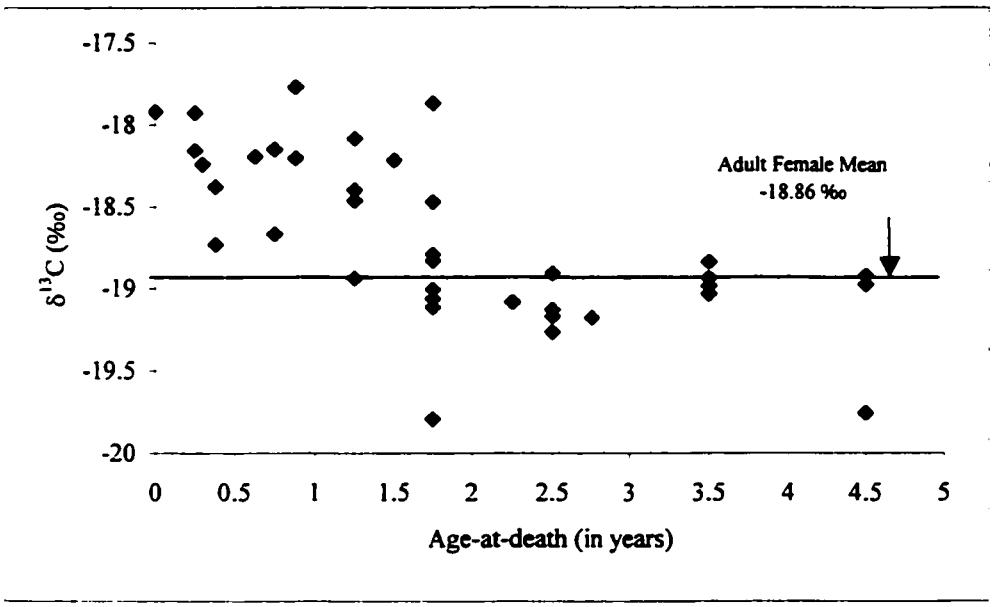
Figures 5.19 and 5.20 present a closer examination of the isotopic data in individuals less than 5 years of age. Figure 5.19 shows a peak of $\delta^{15}N$ values around 3 months of age, with decreasing $\delta^{15}N$ values with increased age-at-death. The graph shows that there is considerable variability in the $\delta^{15}N$ data prior to 2 years of age. The mean value of nitrogen for individuals under the age of 2 years is 13.5 ± 1.4‰ and that of individuals over ten years is 11.3 ± 1.9‰. The maximum range of $\delta^{15}N$ values is approximately 4‰, which is slightly larger than the expected trophic level shift of 3‰ associated with the removal of breast milk from the infant diet. One further observation of interest is that the single neonate analyzed has a slightly lower $\delta^{15}N$ value than the older infants, but it is still higher than the average adult value.

Figure 5.19 – Scatter plot showing the $\delta^{15}N$ rib data for 0 to 5 year-old individuals; neonate is circled



The $\delta^{13}C$ data show a smaller, but definite increase in the isotopic levels for nursing infants, by approximately 1‰, which corresponds to the expected trophic level effect. As with the nitrogen data, there is no clear pattern of increased $\delta^{13}C$ values in the youngest infants (i.e., < 3 months) categories. Between birth and 18 months of age, the isotopic values are scattered, although the data do appear to decrease between 1 and 2.5 years of age, after which the values approximate (but are generally below) the adult mean.

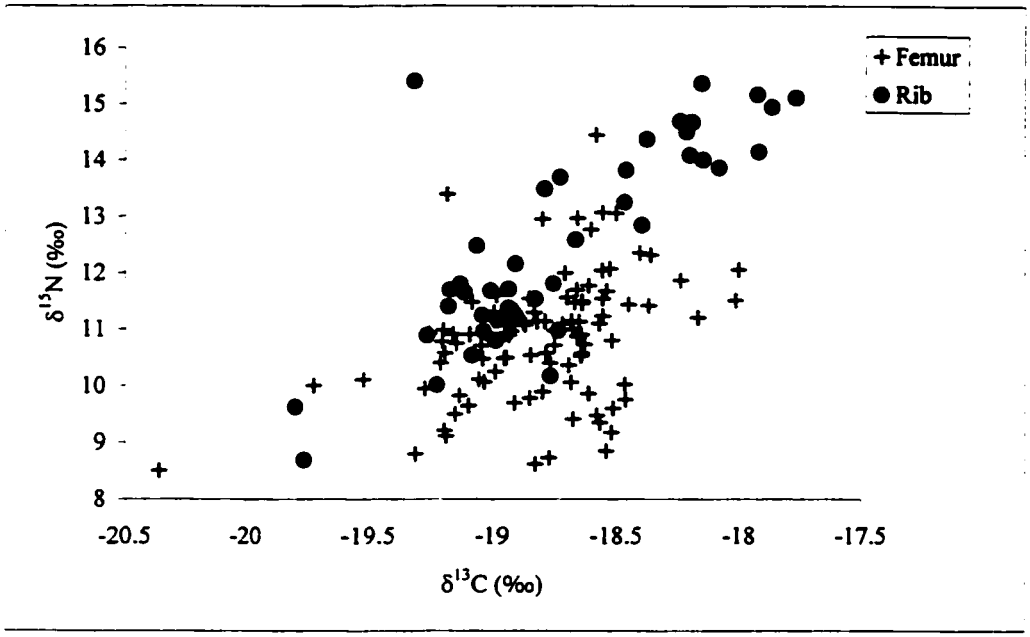
Figure 5.20 – Scatter plot showing $\delta^{13}C$ rib data for 0 to 5 year-old individuals



Correlation analysis of the $\delta^{13}C$ and $\delta^{15}N$ rib data reveals a strong relationship between the two variables ($r = .768$, $p=.000$), much stronger than that found for the adult femora data ($r = .215$, $p = .030$) (Figure 5.21). The youngest individuals are clustered in

the upper right corner of the graph, and there is a gradual overlap of the two sets of data as both the nitrogen and carbon values of the rib sample decrease with increased age-at-death. Regardless of the variability observed in the rib data for the youngest individuals (i.e., less than 2 years), this graph shows the consistent linear relationship between $\delta^{13}C$ and $\delta^{15}N$ values. This pattern suggests that the data can be considered reliable, because diagenesis has not altered the isotopic 'signatures' of these bones.

Figure 5.21 – Rib $\delta^{13}C$ and $\delta^{15}N$ data plotted with the femur data



5.10 Summary

Statistical analysis of the femur data indicates that overall $\delta^{13}C$ mean of males is significantly higher than females, but no differences exist in mean $\delta^{15}N$ values. When the data are further divided into age and sex categories, females in the 15-30 age category have the lowest mean $\delta^{15}N$ values, and their values are significantly lower than those of >45 year-old males. The $\delta^{13}C$ values of subadults (5-15 years) are significantly lower than those of males in two older age categories. In general, there is a small, but significant, correlation between $\delta^{13}C$, $\delta^{15}N$, and age-at-death.

The bone apatite results of the femur sample show no significant differences between the sexes. The $\delta^{13}C_{apatite}$ data, examined by age categories, do show a significant age-related trend, with decreasing apatite values in progressively older age categories. Subadult bone apatite values tend to cluster together. When collagen and apatite data are analyzed with respect to burial type, there are no statistically significant associations.

Examination of the total sample also reveals some interesting associations. When $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ are plotted against expected ranges of $\delta^{13}C$, they fall within the range of a mixed marine and terrestrial C_3 plant diet. Analysis of the faunal $\delta^{13}C$ collagen and carbonate data demonstrates that omnivores are isotopically enriched over the herbivores, as expected, and the Isola Sacra human samples are slightly more enriched than the animal omnivore values. $\Delta^{13}C_{a\text{-}c}$ correlated with $\delta^{15}N$, as both variables are an indication of trophic level. Most of the Isola Sacra data tend to fall in the 'herbivore' range, although there is considerable dispersion of the data. Comparison of the Isola Sacra data with the contemporaneous ANAS cemetery data indicates that a

subset of the ANAS data are isotopically similar to the Isola Sacra data, while the majority are clearly distinct with more negative $\delta^{13}C$ and $\delta^{15}N$ values.

Finally, the data for both $\delta^{13}C$ and $\delta^{15}N$ indicate that individuals under 2 years of age-at-death have significantly higher values than those older than 2 years. There is clear trend of declining isotope levels between the ages of 3 months and 2 years. The $\delta^{15}N$ data tend to level out after 2 years, while the $\delta^{13}C$ data at the same age are slightly more negative than the expected adult mean. There is also a strong positive correlation between $\delta^{13}C$ and $\delta^{15}N$ for individuals less than five years of age. This is a much stronger correlation than exists for the adult femur values, indicating the reliability of the data and a linear trend between different food sources.

Chapter 6

Results – Dental Data

6.1 Introduction

Evidence of antemortem tooth loss, caries, calculus, abscesses, and tooth wear was examined in 365 individuals. There are 6461 teeth and 8516 observable sockets in the total sample. The data from the permanent and deciduous dentitions are reported separately. For those individuals with mixed dentitions (6-12 years), the permanent and deciduous teeth were analyzed separately, so there is some overlap of individuals between the separate analyses. The total number of individuals with permanent teeth is 325 and the total number of individuals with deciduous teeth is 78; 38 individuals have some permanent and deciduous teeth. In this chapter, the age categories are set at 10-year intervals instead of 15-years. This was done because there are considerably more data available for dental analysis, so a finer age distinction could be made.

6.1.1 Sample Size and Distribution

Of the 365 individuals in this sample, there are 141 males, 128 females, and 96 individuals of unknown sex, most of whom are subadults and children. The age and sex distribution of the sample is presented in Table 6.1. Age, sex, and burial information for each individual are presented in Appendix G. The relatively equal age and sex

distribution of the adult portion (i.e., >20 years) of the sample is a reflection of the intentional selection of approximately equal numbers of males and females within each age category. Figure 6.1 presents the age and sex distribution of the entire sample. Figure 6.2 shows the distribution of the sample by sex and burial category, illustrating that most individuals of 'unknown' sex are from amphorae burials. The mean age for individuals in amphorae burials is lower than all other burial types ($\bar{x}$ = 22.52; S.E. = 2.78) due to the large number of subadults in this category. The mean ages for all other burial categories are similar, ranging from 30.64 (S.E. 1.62) in tombs to 32.38 (S.E. 1.59) in soil burials. Chi-square analysis of the difference between the number of males and females in the 10-20 year age category is significant ($X^2 = 4.83$; $p = .028$), but there are no significant size differences in all other age categories. Chi-square analysis of the sample distribution by sex and burial type found that the differences in the number of males and females in each burial category are not statistically significant.

Table 6.1 – Age and sex distribution of the Isola Sacra dental sample

Age Category	Unknown (n)	Male (n)	Female (n)	Total (n)
0-10 years	66	-	-	66
10-20 years	29	24	11	64
20-30 years	1	27	30	58
30-40 years	0	29	34	63
40-50 years	0	35	34	69
50+ years	0	26	19	45
Total	**96**	**141**	**128**	**365**

Figure 6.1 – Age and sex distribution of the Isola Sacra dental sample

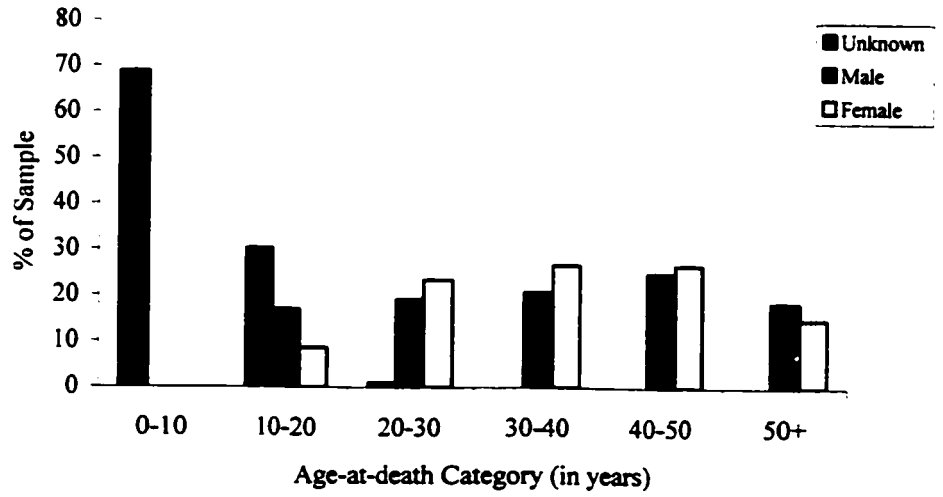
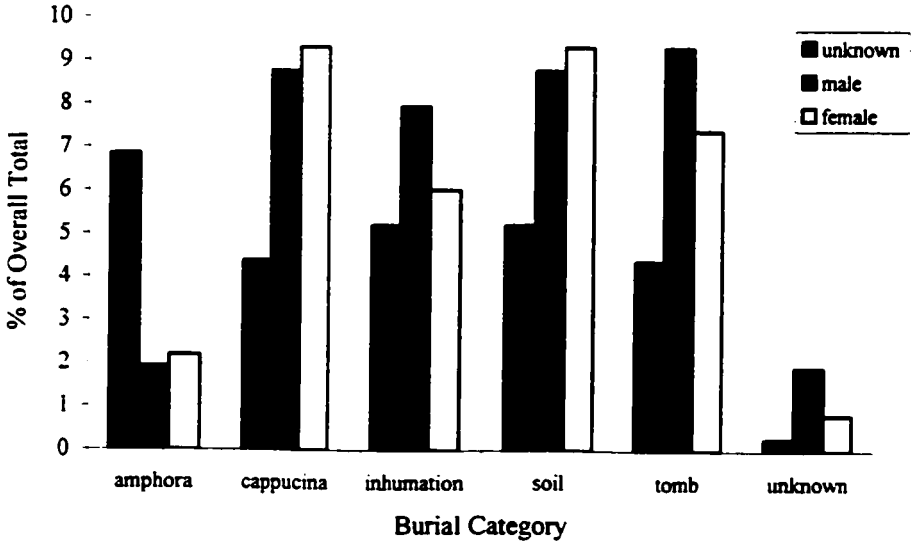


Figure 6.2 – Distribution of the Isola Sacra dental sample by sex and burial category



6.1.2 Postmortem Tooth Loss

There are a total of 7474 observable sockets for the permanent dentition. The number of observable sockets is calculated as the sum of teeth present, teeth lost antemortem, and teeth lost postmortem. Table 6.2 presents data on tooth presence and postmortem loss by tooth type and by dental arcade. Data by individual tooth is presented in Appendix H, including data on congenital absence of teeth. Congenital absence occurred most frequently in the 3rd molars (7.38%).

A total of 1150 teeth were lost postmortem (15.39%), indicated by the presence of a tooth socket with no evidence of alveolar resorption. When postmortem loss was examined by tooth type and arcade, the teeth most frequently lost were the mandibular and maxillary incisors, followed by the mandibular premolars. Postmortem loss was only .1% higher in the mandible than in the maxilla (summarized in Table 6.2). The lowest levels of postmortem loss were found in the maxillary and mandibular molars, probably due to the presence of multiple roots that help to anchor the tooth in the alveolus even after death.

Table 6.2 – Permanent dentition: tooth presence, total observable sockets, and postmortem loss by tooth type and by dental arcade

	Teeth Present (n)	Total # of Sockets (n)	Postmortem Loss (PL) (n)	% PL
Tooth Type				
Maxilla				
Molars	936	1204	75	6.23
Premolars	632	860	151	17.56
Canines	343	435	72	16.55
Incisors	634	880	220	25.00
Mandible				
Molars	1158	1478	76	5.14
Premolars	749	1007	184	18.27
Canines	403	534	94	17.60
Incisors	694	1076	278	25.84
Arcade				
Maxilla	2545	3379	518	15.33
Mandible	3004	4095	632	15.43
Total	**5549**	**7474**	**1150**	**15.39**

6.2 Permanent Dentition – Calculus

6.2.1 Number of Teeth Affected by Calculus

The data were then examined to explore the number of teeth with calculus in the maxilla and mandible, and a number of interesting patterns emerged (Table 6.3). The percentage of teeth with calculus in the sample is 72.87%, and females have more teeth with calculus (79.23%) than males (72.92%). There is very little difference in the number of teeth affected on the right (72.97%) and left (72.72%) sides of the mouth.

Calculus was found most often on the interproximal surfaces of the teeth, followed by the buccal surfaces.

A significantly higher number of teeth are affected by calculus in the mandible (78.42%) than in the maxilla (66.30%) (X^2 = 72.58; p = .000). When each tooth type is examined, all teeth in the mandible show a higher percentage of calculus, with the exception of the 1st molars (Appendix H). The heaviest calculus deposits (score = '3') are on the maxillary and mandibular molars and 2nd premolars. Even though there are more teeth affected by calculus in the mandible, the largest calculus deposits by size are more frequent on the maxillary posterior dentition (maxilla – 19 teeth; mandible – 5 teeth) (see Figure 6.3).

Figure 6.3 – SCR 186 (male, 50+ years old). Heavy calculus deposits (score = 3) on the left maxillary molars and premolars

Photo – T. Prowse

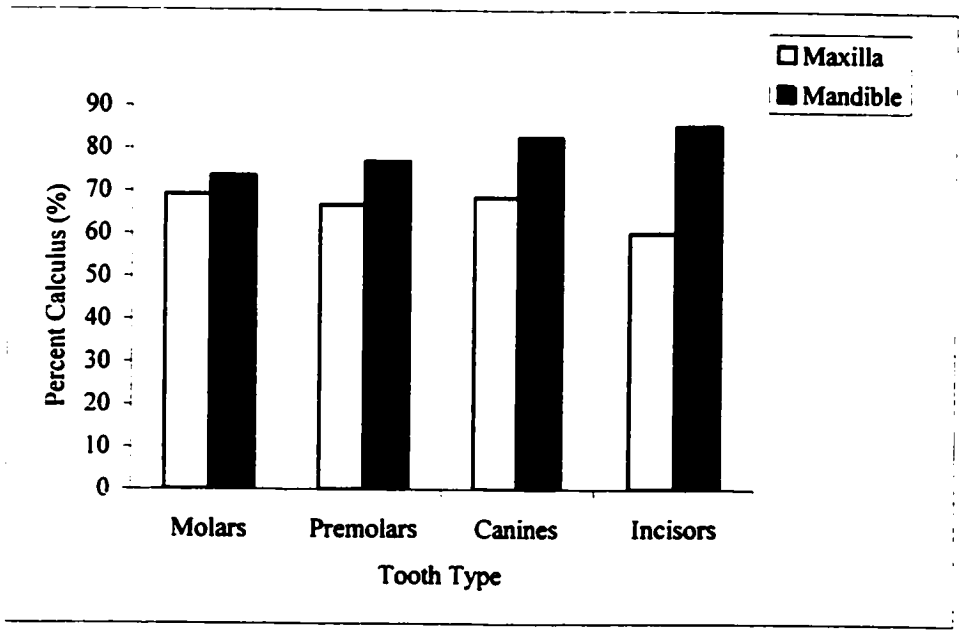
Table 6.3 – Percentage of teeth with calculus, by tooth type, in the maxilla and mandible

	Observable Teeth	Teeth with Calculus	% Calculus
Tooth Type	**(n)**	**(n)**	
Maxilla			
Molars	934	646	69.16
Premolars	622	415	66.72
Canines	341	234	68.62
Incisors	619	373	60.26
TOTAL	**2516**	**1668**	**66.30**
Mandible			
Molars	1155	850	73.59
Premolars	735	566	77.01
Canines	398	329	82.66
Incisors	691	591	85.53
TOTAL	**2979**	**2336**	**78.42**

There is a marked arcade difference in the pattern of teeth affected by calculus. In the maxilla, more posterior teeth are affected by calculus, and the teeth least affected by calculus are the maxillary incisors. In contrast, more anterior teeth (canines and incisors) in the mandible have calculus (shown in Figure 6.4).

The location of the salivary glands in the mouth explains the observed pattern of calculus in the permanent dentition. The formation of calculus is dependent upon saliva, both for covering the tooth with a surface that bacteria can adhere to, and for providing minerals used for calculus formation (Hillson, 1996). The teeth closest to the three main salivary glands in the mouth are the anterior teeth (lingual surfaces) and the molars (buccal surfaces), so these are the teeth most often found with heavy calculus deposits (*ibid.*).

Figure 6.4 – Percent of teeth with calculus, by tooth type, in the maxilla and mandible



6.2.2 Calculus by Sex and Age Categories

Calculus is present in 288 of 321 (89.72%) individuals with permanent teeth. When the sample is divided by age and sex, approximately equal numbers of males and females have calculus in the younger age categories (< 40 years), but in the older age categories (>40 years) more females have calculus on their teeth (Table 6.4). A X^2 analysis of the difference in the number of males and females with calculus approaches statistical significance ($X^2 = 3.71$, $p = .054$). Within each age group, the same test revealed that these differences are only statistically significant in the 40-50 year age category ($X^2 = 6.382$, $p = .012$). It is also interesting to note that even in the youngest

age group (< 10 years), 40% of the individuals have some calculus on their teeth, suggesting that calculus was common in the Isola Sacra teeth from a very young age.

Table 6.4 – Number of individuals with calculus, by age and sex category

	Males	%	Females	%	Unknown	%	Total	%
	(n)		(n)		(n)		(n)	
Age Category								
<10 years	*	*	*	*	9/22	40.91	9/22	40.91
10-20 years	22/24	91.67	10/11	90.91	28/29	96.55	60/64	93.75
20-30 years	26/27	96.30	29/30	96.67	1/1	100	56/58	96.55
30-40 years	28/29	96.55	32/34	94.11	*	*	60/63	95.24
40-50 years	**29/35**	**82.86**	**34/34**	**100.00**	*	*	63/69	91.30
50+ years	22/26	84.62	18/19	94.74	*	*	40/45	88.89
TOTAL	127/141	90.07	123/128	96.09	*	*	250/269	92.94

Bold – indicates statistically significant at the $p \leq 0.05$ level

While these data provide some information on the number of people in the Isola Sacra sample with *some* degree of calculus on their permanent teeth, they do not give any indication of the relative number of teeth affected for each individual. For example, two individuals with calculus 'present' may have different numbers of teeth affected by calculus.

To explore these differences in more detail, a 'Calculus Rate' (Equation 6.1) was calculated for each individual, similar to the formula used to calculate 'Caries Rate'. This produces a score for each individual, based on the number of tooth sides affected by calculus divided by the total number of observable sides (e.g., buccal, lingual, interproximal). 'Interproximal' was only counted once for each tooth to simplify the calculations, even though there are two interproximal surfaces on each tooth, with the

exception of the 3rd molar. The "number of sides with calculus" must be divided by the "total number of observable sides", in order to produce comparable averages for individuals with different numbers of teeth (and sides of teeth). The usefulness of quantifying calculus for each individual in this way is that it permits a more detailed analysis of differences between sexes, age groups, and burial types.

Equation 6.1 - **Calculus Rate** = $\frac{\text{\# of tooth sides with calculus}}{\text{total \# of observable sides}} \times 100$

Calculus Rates for each individual are presented in Appendix I. Averages were calculated for each age and sex category (summarized in Table 6.5). The mean Calculus Rate for males is 34.00 and for females it is 39.26. A Mann-Whitney U test indicates that this difference is statistically significant ($p = .033$). A non-parametric test was used because the calculus rates are not normally distributed. Table 6.5 shows that with the exception of the 30-40 year age category, females have a consistently higher mean Calculus Rates than males. These results indicate that females have more surfaces of their teeth affected by calculus than males, however the differences between males and females within age categories are not statistically significant at the $p \leq 0.05$ level (Mann-Whitney U test).

Table 6.5 – Mean Calculus Rates by age and sex category (standard error in brackets)

Age Category (in years)	Males	Females	Unknown sex
<10	*	*	6.20 (1.99)
10-20	21.17 (3.29)	21.20 (3.39)	20.66 (3.02)
20-30	27.64 (2.88)	35.08 (3.43)	12.00 (0.00)**
30-40	39.59 (4.05)	37.08 (3.20)	*
40-50	38.71 (3.74)	47.97 (2.35)	*
50+	41.30 (3.76)	44.56 (4.69)	*
TOTAL	**34.00 (1.73)**	**39.26 (1.65)**	**14.38 (2.11)**

**1 individual

An alternative method was developed to examine the data by calculating actual *scores* recorded for each side of any tooth (e.g., .5 + 1 + .5) per individual, not only the number of sides affected by calculus. This modified score provides an indication of the relative *amount* of calculus present for each individual, and is calculated in a similar manner to Calculus Rate for each individual (Equation 6.2). This is different from the Calculus Rate because it quantifies the amount of calculus on each tooth side, not only the number of sides affected.

Equation 6.2 – **Modified Calculus Rate** = $\frac{\Sigma \text{ scores for all tooth sides}^{1}}{\text{Total \# of observable sides}} \times 100$

[1] Four sides were scored for molars; buccal, lingual, interproximal, and occlusal. All other teeth only had three sides scored; buccal, lingual, and interproximal. Interproximal was only scored once, even though there are two interproximal spaces for each tooth.

These modified scores are also presented in Appendix I. The highest possible score for the Modified Calculus Rate would be 324. The mean 'Modified Calculus Rate' for males is 25.32 and for females it is 30.74. A Mann-Whitney U test indicates that this difference is statistically significant ($p = .010$). These results demonstrate that not only do females tend to have more surfaces of their teeth affected by calculus (Table 6.5), but when calculus is present, females also tend to have more calculus on their teeth (Table 6.6). The only exception to this is in the 30-40 year-old category, however, none of the differences between males and females within each age category are statistically significant (at $p \leq 0.05$) (Mann-Whitney U test).

Table 6.6 – Modified Calculus Rate by age and sex category (standard error in brackets)

Age Category (in years)	Males	Females	Unknown sex
<10	*	*	3.83 (1.32)
10-20	13.18 (2.37)	14.38 (2.64)	15.00 (2.99)
20-30	17.03 (1.72)	22.70 (2.94)	7.00 (0.00)**
30-40	29.41 (3.83)	26.29 (2.52)	*
40-50	31.72 (3.94)	40.21 (3.53)	*
50+	33.56 (4.65)	43.72 (6.62)	*
TOTAL	**25.32 (1.70)**	**30.74 (1.87)**	**10.12 (1.91)**

**1 individual

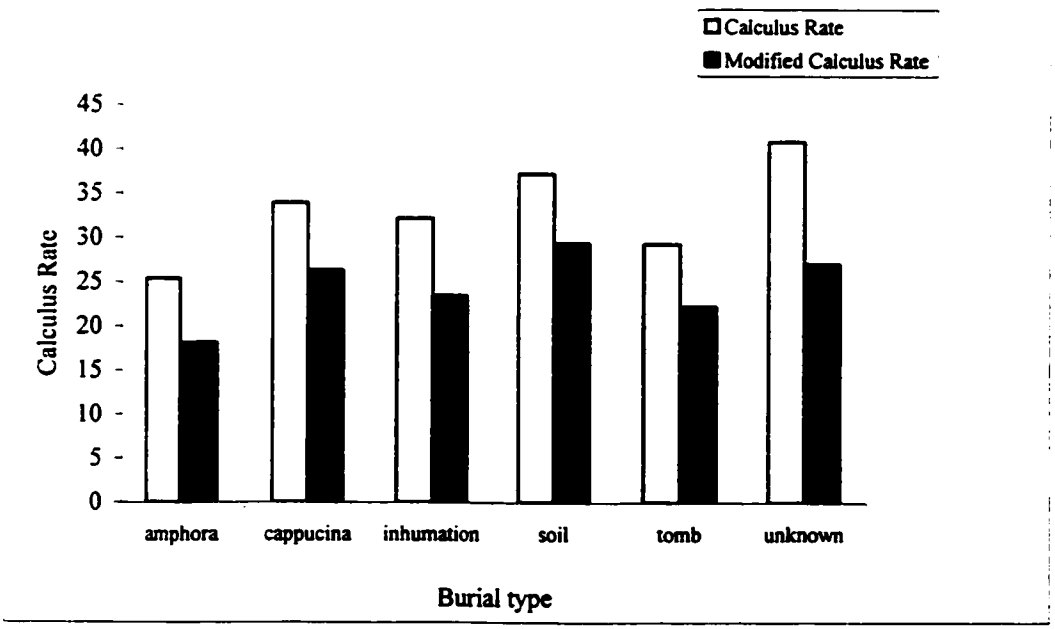
6.2.3 Calculus by Burial Type

Analysis of the Calculus Rate and Modified Calculus Rate by burial type indicates that the average values for individuals in each burial category are similar, with the exception of amphorae and soil burials (Table 6.7 and Figure 6.5). The low rates for the amphorae burials are likely related to the large number of young individuals represented in this subset. The average age for the amphorae burials is 22.5 years, while the average age for all other burial types is 30.6 to 32.4 years. These younger individuals have comparatively lower levels of calculus on their teeth (refer back to Figure 6.2). The highest rates occur among individuals buried in the soil; however, none of the differences between burial types are statistically significant for either Calculus Rate or Modified Calculus Rate (Kruskal-Wallis test, $p = .067$ and $p = .089$, respectively). Rates for 'Unknown' burials were excluded from the statistical analyses, but are presented in the tables.

Table 6.7 – Calculus Rates and Modified Calculus Rates burial category (standard error in brackets)

Burial Type	Calculus Rate	Modified Calculus Rate
Amphora	25.41 (3.99)	18.14 (3.15)
Cappucina	33.89 (2.30)	26.33 (2.72)
Inhumation	32.17 (2.82)	23.48 (2.63)
Soil	37.24 (2.44)	29.42 (2.53)
Tomb	29.35 (2.29)	22.31 (2.08)
Unknown	40.98 (6.14)	27.15 (6.18)

Figure 6.5 – Calculus Rate and Modified Calculus Rate by burial type



6.3 Permanent Dentition – Caries

The total number of carious permanent teeth in the Isola Sacra sample is 297, out of a total of 5548 observable teeth, so the Total Percent Caries for the sample is 5.35%. The caries prevalence data for the total sample by tooth is presented in Appendix J. The prevalence of root caries is reported separately here, and was not included in the statistical analysis of caries prevalence for the sample because of differences in the etiology of root caries. Root caries develops in association with exposure of the root caused by periodontal disease (Hillson, 1996). The number of teeth in this sample with root caries is 15 and the posterior teeth (premolars and molars) are most often affected (86.67%).

There are a number of ways that caries can be reported for skeletal samples. Many early studies reported the number of carious teeth as a percentage of the total number of observable teeth (Total Percent Caries) and in order to compare the Isola Sacra sample with other contemporaneous skeletal samples this statistic was calculated. This is not the best method to quantify the level of caries in a sample because it does not account for individual variability, antemortem loss of teeth, or biased postmortem preservation of teeth in the archaeological record.

'Caries Rate' calculates a score for each individual and permits the analysis of caries in a sample based on demographic variables (e.g., age, sex, burial type) (after Moore and Corbett, 1971):

Equation 6.3 – **Caries Rate by Individual** = $\frac{\text{number of carious teeth}}{\text{number of teeth present}} \times 100$

The Caries Rates for each individual are presented in Appendix J. If this calculation is used, then Caries Rates can also be calculated by individual for each tooth type (e.g., incisors, canines). The overall mean Caries Rate for the sample was calculated using the following equation:

Equation 6.4 - **Overall Caries Rate** = $\frac{\sum \text{individual caries rates}}{\text{Total \# of individuals}} \times 100$

The overall Caries Rate for the Isola Sacra sample is 6.39 (S.E. = .70), which is higher than the Total Percent Caries calculation of 5.35%. Variability between the two

statistics can be caused by poor postmortem preservation, or if a strong negative correlation exists between the number of carious teeth and the total number of observable teeth (Saunders *et al.*, 1997). More specifically, if a large number of individuals have high levels of AMTL, and also have many carious teeth, this would create more variability in the sample and ultimately affect the overall Caries Rate (*ibid.*). A correlation test of the number of carious teeth versus the total number of observable teeth yields a significant positive correlation between the two variables ($r = .199$, $p = .000$). This suggests that individuals with high numbers of carious teeth actually have more teeth in total. A frequency distribution of the Caries Rate values shows that 56.4% of individuals have rates less than 3.00; more than half of the individuals in the permanent sample with caries have a small number of carious teeth in relation to the total number of teeth present.

One of the limitations of the Caries Rate calculation is that it may underestimate the true caries prevalence in the sample because it does not take into account that teeth lost antemortem may have been lost as the result of caries (Lukacs, 1995). The 'Diseased Missing Index' (DMI) is an alternative calculation that attempts to correct this by incorporating AMTL into the calculation of the caries prevalence for each individual in a sample:

Equation 6.5 - **DMI** = $\dfrac{(\#\text{ of carious teeth} + \#\text{ of teeth lost antemortem})}{(\#\text{ of observable teeth} + \#\text{ of teeth lost antemortem})} \times 100$

The DMI for the Isola Sacra sample is 13.17 (S.E. = 1.12), which is more than twice the calculated Caries Rate. The DMI distribution reveals that 42.8% of individuals have DMI values below 3.0. The limitation of this calculation is that it may actually *overestimate* the level of caries in a sample, because it assumes that all AMTL is due to caries, but tooth loss is not always the direct consequence of caries (Hillson, 2000). AMTL can be caused by a combination of many factors, including caries, heavy tooth wear, and periodontal disease. Both Caries Rate and DMI will be reported here in order to give both estimates of the caries prevalence in the Isola Sacra permanent dentition.

Additional methods have been proposed to more accurately estimate the true caries prevalence in skeletal samples. Lukacs (1995) proposed a 'Caries Correction Factor' that estimates the actual number of teeth lost due to caries, instead of assuming that all teeth lost antemortem are lost due to caries. This method multiplies the number of teeth lost antemortem by the proportion of teeth with pulp exposure caused by caries, which must be differentiated from pulp exposure caused by attrition (*ibid.*). When collecting the dental data from the Isola Sacra material, caries-induced pulp exposure was not recorded, so this correction factor cannot be applied to the Isola Sacra data. Pulp exposure caused by caries should be added as an additional category in the Buikstra and Ubelaker (1994) dental data collection standards.

More recently, Erdal and Duyar (1999) have proposed an additional correction factor, called the 'Proportional Correction Factor', for the calculation of caries prevalence. This method takes into account the postmortem loss of anterior teeth (incisors and canines) due to their single-root morphology, and is designed for use in

conjunction with Lukacs' (1995) Caries Correction Factor. The Caries Rates of the anterior and posterior tooth classes are multiplied by a ratio representing the proportion of anterior (3/8) to posterior (5/8) teeth on one side of the mouth. It is expected that the ratio between anterior and posterior teeth in a 'normal' mouth (i.e., all teeth present) would be three (2 incisors, 1 canine) to five (2 premolars, 3 molars), producing an expected ratio of 0.6.

Erdal and Duyar (1999) argued that their correction factor is most useful in those samples with large deviations from the expected ratio through postmortem loss of anterior teeth. The ratio of anterior (2074) to posterior (3475) teeth in the Isola Sacra sample is 0.60. As it appears that postmortem loss in this sample has not caused a deviation from the expected ratio of anterior to posterior teeth, the application of the 'Proportional Correction Factor' should not change the calculated Total Percent Caries for the entire sample (5.35%).

6.3.1 Caries by Age and Sex Categories

Table 6.8 summarizes the Total Percent Caries, Caries Rate, and DMI for the total sample and for the sample divided by sex. There is no difference between Caries Rate and DMI in the 'Unknown' category because there is no AMTL in this subset of the sample. Regardless of the statistic used, males always have slightly higher levels of caries in the sample.

Table 6.8 – Comparison of different statistical measures to quantify caries prevalence in the total sample, and in the sample divided by sex

	Total Sample (n =365)	Females (n =128)	Males (n =141)	Unknown (n = 96)
Total Percent Caries	5.35	5.49	5.99	1.69
Caries Rate	6.39	6.57	7.79	2.17
DMI	13.17	15.26	15.34	2.17

Table 6.9 presents the Caries Rate and Diseased Missing Index by sex and age categories. When the sample is examined by sex, the mean Caries Rate for females (6.57) is found to be lower than that for males (7.79). When AMTL is factored into the calculation of the DMI, the values are very close for both females (15.26) and males (15.34). Caries Rate and DMI values are also reported for individuals of unknown sex, but these data were not included in the statistical analyses. A Mann-Whitney U test indicates that the differences between the sexes are not statistically significant for either Caries Rate or DMI (at $p \leq .05$).

When Caries Rate and DMI are examined by age-at-death, there is a clear pattern of increased caries prevalence with increased age (Figure 6.6). This is to be expected, as caries is an age-progressive disease, so there should be more carious lesions in older members of the sample. The higher DMI values, particularly in the older age categories, reflect higher levels of AMTL in the > 40 year age categories. However, when the data are examined by both age and sex, the pattern of Caries Rate and DMI are slightly different.

Table 6.9– Caries Rate and Diseased Missing Index (DMI) by age and sex category (standard error in brackets)

Caries Rate				
	Total Sample	**Females**	**Males**	**Unknown**
Age (in years)				
<10	1.45 (1.13)	*	*	1.45 (1.13)
10-20	2.99 (.86)	2.27 (1.09)	3.50 (1.43)	2.85 (1.48)
20-30	3.67 (.83)	3.65 (1.01)	3.82 (1.38)	0.00**
30-40	6.86 (1.29)	6.48 (1.54)	7.37 (2.26)	*
40-50	8.02 (1.85)	8.29 (2.19)	7.77 (2.98)	*
50+	14.14 (2.91)	10.74 (3.41)	16.63 (4.37)	*
Mean	**6.39 (.70)**	**6.57 (.93)**	**7.79 (1.28)**	**2.17 (.94)**
DMI				
Age (in years)	**Total Sample**	**Females**	**Males**	**Unknown**
<10	1.45 (1.13)	*	*	1.45 (1.13)
10-20	2.99 (.86)	2.27 (1.09)	3.50 (1.42)	2.85 (1.48)
20-30	6.07 (1.44)	4.87 (1.37)	7.51 (2.63)	0.00**
30-40	11.34 (1.72)	9.75 (2.06)	13.51 (2.93)	*
40-50	20.01 (2.80)	21.59 (3.56)	18.52 (4.31)	*
50+	34.63 (4.00)	37.75 (6.66)	32.36 (4.98)	*
Mean	**13.17 (1.12)**	**15.26 (1.81)**	**15.34 (1.82)**	**2.17 (.94)**

**1 individual

Figure 6.7 is a graph of Caries Rate by sex and age category, and illustrates that Caries Rates are similar between males and females in all age groups, except for the 50+ age category, in which males have a markedly higher mean Caries Rate (16.62, S.E. = 4.37) than the females (10.74, S.E. = 3.41). In all but one age category (40-50 years), males have slightly higher Caries Rates than females. A Mann-Whitney U test for each age category shows that none of the differences in Caries Rates between the sexes are statistically significant (at $p \leq .05$).

Figure 6.6 – Caries Rate and DMI by age-at-death

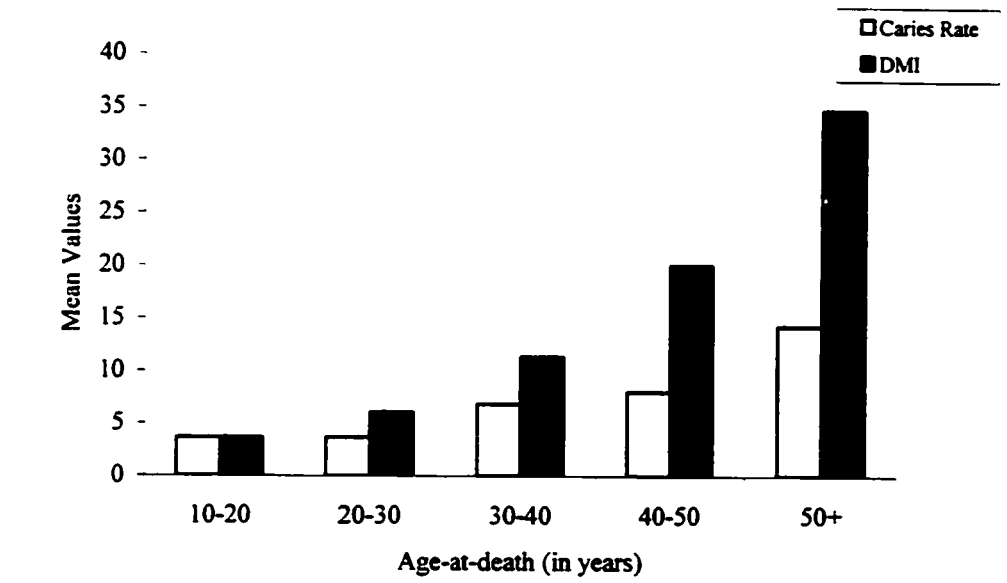


Figure 6.7 – Caries Rate by age and sex category

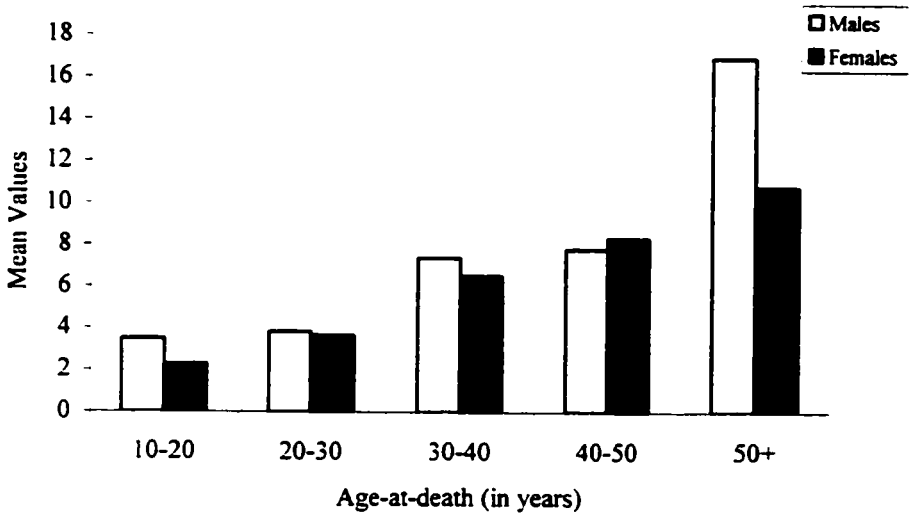
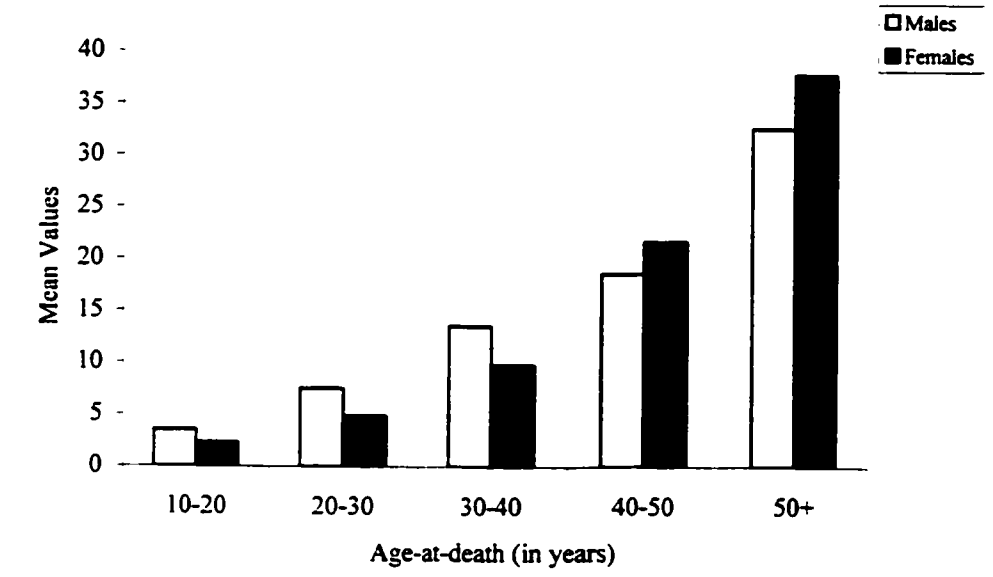


Figure 6.8 graphs the relationship between DMI values and age and sex. These results suggest that males have higher mean DMI's in the younger age categories (10-40 years), but that females have a higher prevalence in the two older age categories (>40 years). The mean Caries Rate and DMI values in the younger age categories are close, because AMTL levels are low in the younger age categories. In the >40 year age categories, females have considerably higher levels of AMTL (21.46%) than males (14.00%). This is reflected in the shift to higher DMI levels in older females; however, a Mann-Whitney U test indicates the difference in DMI values between the sexes is not statistically significant (at $p \leq .05$).

Figure 6.8 – Diseased Missing Index (DMI) by age and sex category



The DMI and Caries Rata data are not normally distributed, so in order to examine the interaction of age and sex for these variables it was necessary to transform the data using a logarithmic transformation. Saunders and coworkers (1997) used a square root transformation for their caries data, but this did not normalize the Isola Sacra data sufficiently for parametric statistical analysis (i.e., measures of skewness and kurtosis still indicated that the data were not normally distributed). The logarithmic transformation excluded the zero values so that the subsequent analysis investigates differences only in those individuals who actually have carious lesions on their teeth.

An analysis of covariance (ANCOVA) was calculated, with sex as the fixed factor and age as the covariate, for both Caries Rate and DMI. For both variables, with age controlled for, there is still no statistically significant difference between the sexes. These results indicated that age, not sex, is the controlling factor in the development of carious lesions in the Isola Sacra sample.

6.3.2 Caries by Burial Type

Caries Rate and DMI were then examined by burial type (Table 6.10). Individuals with the lowest Caries Rate and DMI are from the amphora burials. As was the case for calculus, the low caries prevalence in amphorae burials is probably related to the large number of young individuals represented in this burial category. As with calculus, caries prevalence is highest among individuals in the 'soil' category. The differences between burial types are statistically significant for both measures of caries prevalence (Kruskal-

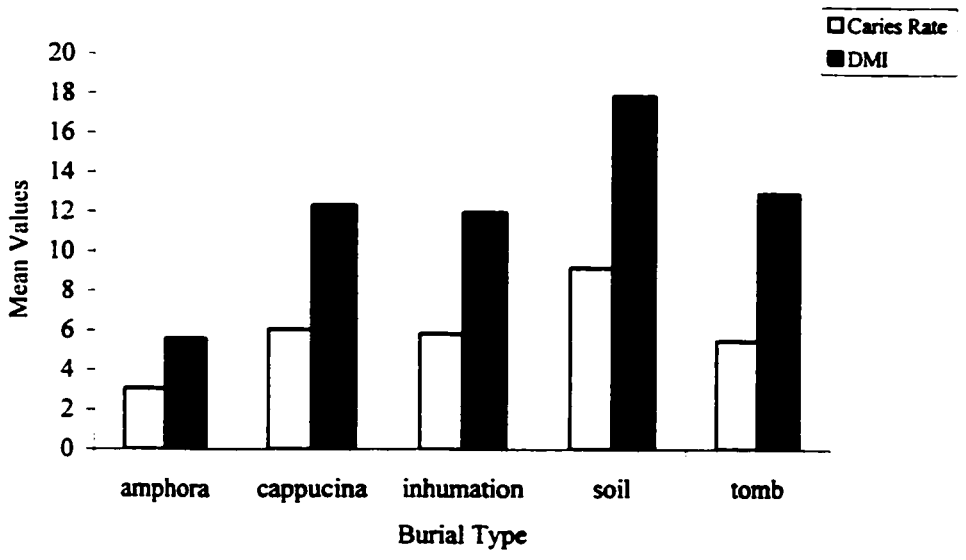
Wallis test, Caries Rate - p = .009 and DMI - p = .029, respectively). The 'Unknown' burial category was excluded from statistical analysis.

Table 6.10 – Caries Rate and DMI by burial type (standard error in brackets)

Burial Type	Caries Rate	DMI
Amphora	3.06 (1.18)	5.60 (1.88)
Cappucina	6.05 (1.28)	12.32 (2.28)
Inhumation	5.83 (1.30)	11.97 (2.30)
Soil	9.17 (1.66)	17.87 (2.53)
Tomb	5.48 (1.69)	12.93 (2.47)
Unknown	6.37 (4.49)	12.12 (7.99)

Caries Rate and DMI by burial type are shown in Figure 6.9. The Kruskal-Wallis test does not indicate the source of variability in the sample, but since the mean values in the other burial categories are similar, it can be assumed that the statistically significant variation arises from individuals in the amphora and soil burial categories. An analysis of variance (ANOVA) on the log-transformed data found no statistically significant difference between tomb types, but this is applies only to those individuals who have carious lesions, and not the total sample.

Figure 6.9 – Caries Rate and DMI by burial type



6.3.3 Caries Rate and DMI by Tooth Type and Arcade

For the total sample, Caries Rates are highest among the molars, followed by the premolars, canines, and incisors (Table 6.11). The more complex posterior teeth, the molars and premolars, have higher Caries Rates than the anterior teeth because there are more pits and fissures on the surfaces of the posterior dentition where bacterial plaque can accumulate. There are only 26 cases of multiple lesions on the permanent dentition, and most of those occur on the posterior dentition (84.61%). The DMI calculations show a similar pattern of higher mean levels in molars and premolars, however incisors have a higher DMI than canines. Caries Rates and DMI by tooth are presented in Appendix H. The relatively high rate of antemortem tooth loss among incisors in this sample (see

Table 6.23) is likely the reason for the increased DMI of incisors. In modern populations, carious lesions most frequently affect molars; the anterior teeth (canines and incisors) are the least affected (Hillson, 1996). This suggests that the DMI calculation may overestimate the number of incisors lost due to caries, because these teeth are not as susceptible to caries as the posterior dentition.

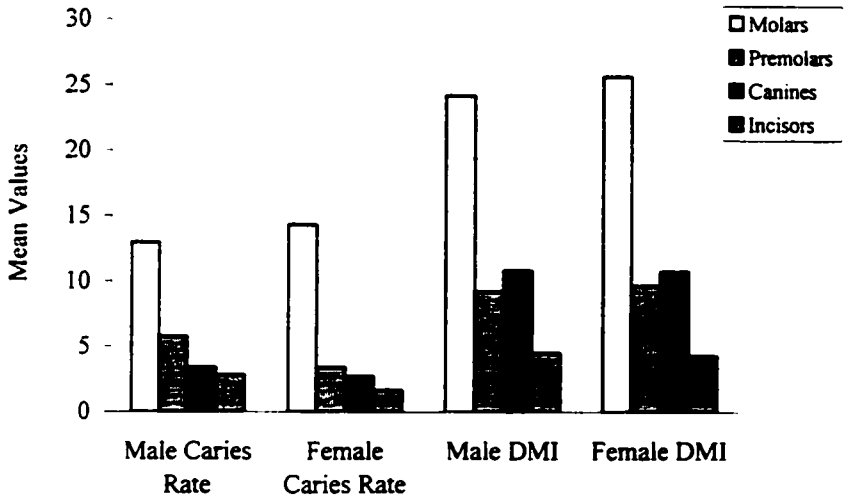
Table 6.11 presents the Caries Rate and DMI for the total sample, and for the sample divided by sex. Individuals of unknown sex only have carious lesions on the molars (Caries Rate and DMI = 5.29, S.E. = 2.36). All other tooth categories have zero values because there are no carious lesions present, so they are not presented in Table 6.11, but they were included in the calculations for the total sample.

There is no clear pattern by tooth type and sex in Caries Rate and DMI values, and the differences between males and females are small. Statistical analysis of Caries Rate and DMI between the sexes, by tooth type, found no statistically significant differences between any of the tooth types (Mann-Whitney U test), although the difference in Caries Rate of incisors between males and females approaches statistical significance ($p = .058$).

Table 6.11 – Caries Rate and DMI by tooth type for the total sample, and for the sample divided by sex (standard error in brackets)

Tooth Type	Caries Rate	DMI
Total Sample		
Molars	12.19 (1.21)	21.58 (1.61)
Premolars	4.29 (.80)	4.07 (.93)
Canines	2.84 (.83)	10.00 (1.35)
Incisors	1.90 (.66)	8.04 (1.41)
Males		
Molars	12.97 (1.85)	24.13 (2.50)
Premolars	5.77 (1.43)	9.19 (2.26)
Canines	3.39 (1.37)	10.79 (2.04)
Incisors	2.82 (1.13)	4.47 (1.50)
Females		
Molars	14.29 (2.03)	25.57 (2.61)
Premolars	3.39 (.91)	9.65 (2.37)
Canines	2.71 (1.13)	10.72 (2.04)
Incisors	1.65 (1.06)	4.27 (1.31)

Figure 6.10 – Caries Rate and DMI, by tooth type, for males and females



When caries prevalence in the Isola Sacra permanent dentition is examined by dental arcade, the Caries Rate calculations indicate that caries is more common in the maxillary dentition for all tooth types and for the total dental arcade (Table 6.12). In contrast, the DMI calculations for each arcade indicate that the mandibular dentition has a higher overall caries prevalence, however not all teeth in the mandible have the highest DMI. The marked discrepancy between the DMI (9.46) and Caries Rate (0.81) values for the mandibular incisors is related to the high AMTL in the mandibular incisors (5.39%) relative to other anterior teeth in both the maxilla and the mandible (see Appendix H). Once again, Caries Rates probably underestimates the true caries prevalence in the sample and DMI values overestimates it. A Mann-Whitney U test, comparing Caries Rate and DMI values between the maxilla and mandible, determined that the only statistically significant difference was the Caries Rate for maxillary versus mandibular incisors ($p = .025$).

When the dental data were collected, the location, or type, of carious lesion was also recorded (after Buikstra and Ubelaker, 1994). Table 6.13 reports the total number of carious lesions by individual type. The types of carious lesions most frequently observed are interproximal lesions (45.82%) and occlusal surface lesions (31.12%). These two categories make up more than three-quarters of the lesions observed (Figures 6.11 and 6.12).

Table 6.12 – Caries Rate and DMI by tooth type in the maxilla and mandible (standard error in brackets)

	Caries Rate	DMI
Tooth Type		
Maxilla		
Molars	12.53 (1.59)	20.33 (1.89)
Premolars	5.41 (1.11)	10.74 (1.65)
Canines	3.46 (1.19)	5.80 (1.55)
Incisors	2.34(.81)	4.43 (1.17)
Total	**7.07 (.96)**	**11.85 (1.23)**
Mandible		
Molars	11.36 (1.34)	21.54 (1.74)
Premolars	3.20 (.87)	9.27 (1.53)
Canines	2.33 (.96)	3.80 (1.13)
Incisors	.81 (.51)	9.46 (1.78)
Total	**5.98 (.81)**	**13.79 (1.26)**

Table 6.13 – Prevalence of carious lesions, by type, for males, females and individuals of unknown sex

	Male (n)	%	Female (n)	%	Unknown (n)	%
Type of Lesion						
Interproximal	85	50.90	69	40.35	5	55.56
Occlusal	50	29.94	55	32.16	3	33.33
Large	14	8.38	15	8.77	0	0
Smooth	4	2.40	15	8.77	0	0
Root	7	4.19	9	5.26	0	0
Cervical	7	4.19	8	4.68	1	11.11
Total	**167**	**100.00**	**171**	**100.00**	**9**	**100.00**

Figure 6.11 – SCR 037 (Male, 50+ years, left mandible). Large interproximal carious lesions between 2nd premolar and 1st molar

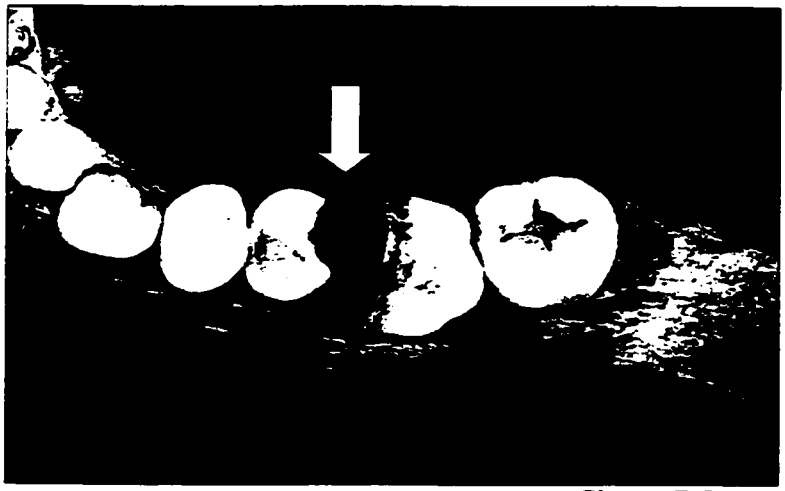


Photo – T. Prowse

Figure 6.12 – SCR 097 (Male, 40-50 years, left mandible). Detail of occlusal surface carious lesion on 2nd molar

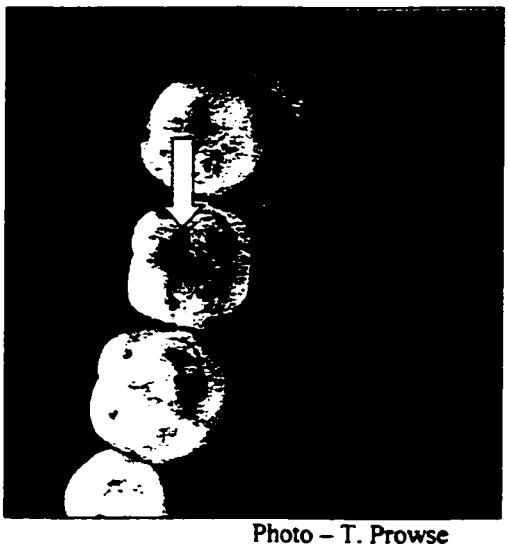
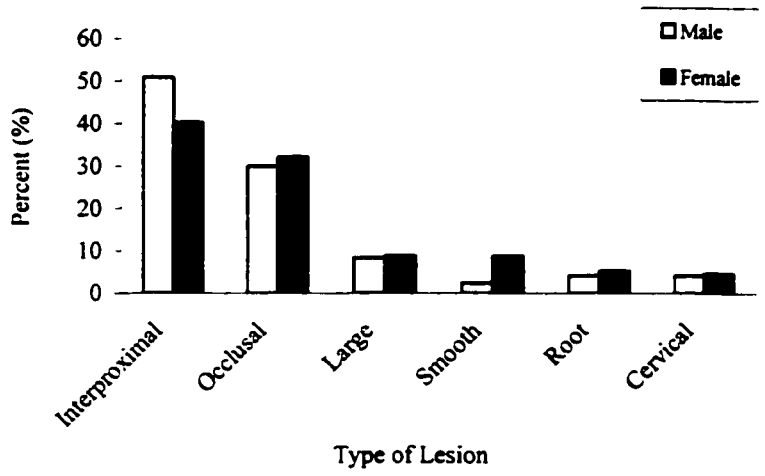


Photo – T. Prowse

There is little difference in the pattern of lesions between males and females, although interproximal lesions are more common in males, and females have a higher percentage of smooth and occlusal surface lesions (Table 6.13 and Figure 6.13). None of the differences in the frequency of carious lesions between the sexes are significant (Mann-Whitney U test), although the difference for smooth surface lesions does approach statistical significance ($p = .052$).

Figure 6.13 – Percentage of carious lesions, by type, for males and females



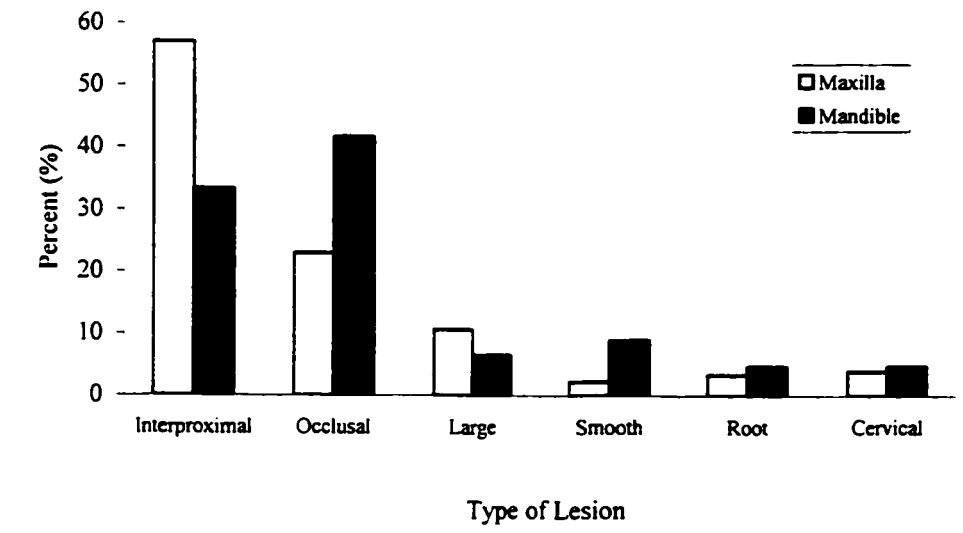
When the pattern of carious lesions is examined by tooth arcade, two interesting contrasts emerged. Interproximal lesions are more common on the maxilla, whereas occlusal lesions are more common on the mandible (see Figure 6.14). Smooth surface

lesions are also more common on the mandible. These results are summarized in Table 6.14.

Table 6.14 – Prevalence of carious lesions, by category, between the mandible and maxilla

	Maxilla (n)	%	Mandible (n)	%
Interproximal	102	56.98	56	33.33
Occlusal	41	22.91	70	41.67
Large	19	10.61	11	6.55
Smooth	4	2.23	15	8.93
Root	6	3.35	8	4.76
Cervical	7	3.91	8	4.76
TOTAL	**179**	**100**	**168**	**100**

Figure 6.14 – Percentage of carious lesions, by category, for the maxilla and mandible



6.4 Permanent Dentition – Abscesses

There are a total of 55 abscesses on the maxillae and mandibles of the permanent dentition, out of a total of 6224 observable sockets (0.88%). The percentage of individuals with one or more abscesses is 12.81%. Abscesses are found more frequently on the buccal, or labial side of the alveolus (94.64%) (Figure 6.15). This is consistent with the expected pattern because of the comparatively thinner bone on the buccal surface of the alveolus. Although the number of overall abscesses is low, they are more common on the maxilla (1.42%) than on the mandible (0.50%) (Table 6.15). The data for abscesses, by individual tooth, are presented in Appendix H. Figure 6.16 shows the consistently higher prevalence of abscesses in the maxillae of the Isola Sacra sample.

Figure 6.15 – SCR 295 (female, 40-50 years, anterior view of mandible). Large abscess in association with heavily worn right 2nd incisor

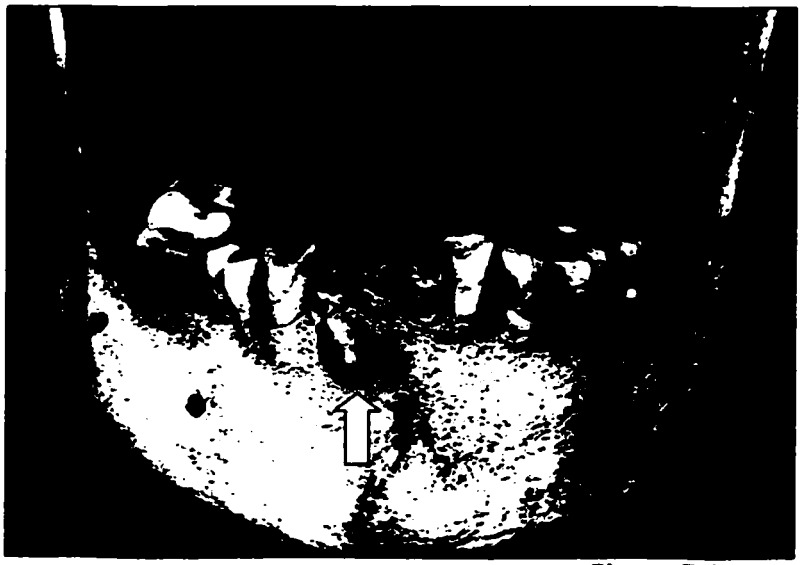
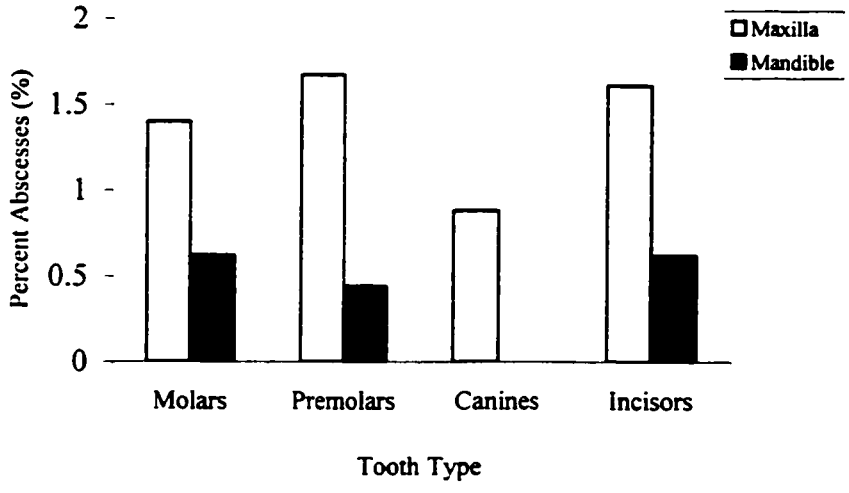


Photo – T. Prowse

Table 6.15 – Prevalence of abscesses, by tooth type, in the maxilla and mandible

	Observable Sockets	Abscesses (n)	Percent %
Maxilla			
Molars	857	12	1.40
Premolars	718	12	1.67
Canines	342	3	0.88
Incisors	683	11	1.61
Mandible			
Molars	1290	8	0.62
Premolars	913	4	0.44
Canines	459	0	0.00
Incisors	962	6	0.62
Arcade			
Maxilla	2600	38	1.46
Mandible	3624	18	0.50
Total	**6224**	**56**	**0.90**

Figure 6.16 – Percent of abscesses, by tooth type, in the maxilla and mandible



6.4.1 Abscesses by Age and Sex Categories

There are an almost equal proportion of females (14.96%) and males (14.89%) affected by abscesses. Only one individual of unknown sex has an abscess (1.92%). There is also no difference in the pattern of abscesses, that is, females and males have similar distributions of single and multiple abscesses. When the data are examined by age and sex, there is a clear age-related trend in the prevalence of abscesses within the total sample (Table 6.16). Only two individuals under the age of twenty have any abscesses, and the prevalence of abscesses increases to approximately the same levels in the 20-40 year range (~ 8%). Above 40 years, there is a sharp increase in the number of individuals affected by abscesses, reaching a peak in the 50+ age group. When males and females are considered separately, males appear to have more abscesses in the youngest (10-20) and oldest (50+) age categories. Females have a higher prevalence of abscesses in all other age categories, and the difference is particularly large in the 20-30 year age category. Chi-square analysis of the differences in the number of males and females with abscesses in each age category could not be run due to the small number of cases within each subgroup.

Inflammation of the alveolar bone has been related to infection of the tooth by bacteria, caused by trauma, caries, or heavy wear, yet the development of a visible hole in the bone may take years (Hillson, 1996). One problem with determining the prevalence of abscesses in any sample is that the true number of abscesses is likely underestimated, since openings may exist within the alveolus but a visible abscess has not yet developed on the surface of the bone.

Table 6.16 – Percentage of abscesses by age category for the total sample and separately for males and females

	# with Abscesses	# of Individuals	Percent
Age (in years)	**(n)**	**(n)**	**(%)**
Total Sample			
<10	0	22	0.00
10-20	2	64	3.13
20-30	5	58	8.62
30-40	5	60	8.33
40-50	14	71	19.72
50+	15	45	33.33
Males			
<10	*	*	*
10-20	1	24	4.17
20-30	1	27	3.70
30-40	2	28	7.14
40-50	7	36	19.44
50+	10	26	38.46
Females			
<10	*	*	*
10-20	0	11	0.00
20-30	4	30	13.33
30-40	3	32	9.38
40-50	7	35	20.00
50+	5	19	26.32

6.4.2 Abscesses by Burial Type

The abscess data were analyzed by burial category and the results are presented in Table 6.17. The largest percentage of individuals with abscesses is in the cappucina category and the lowest is in the tomb category, but the difference between the two extremes is not large (6.07%). A Kruskal-Wallis test was performed (with 'unknown' burial types excluded), and there is no statistically significant difference in the number of individuals affected between different burial types.

Table 6.17 – Percentage of individuals with abscesses, by burial category

	# with Abscesses	# of Individuals	Percent
Tomb Type	**(n)**	**(n)**	**(%)**
Amphora	4	27	14.81
Cappucina	12	76	15.79
Inhumation	6	58	10.34
Soil	11	76	14 47
Tomb	7	72	9.72
Unknown	1	11	9.09

6.5 Permanent Dentition - Tooth Wear

6.5.1 Tooth Wear by Individual Tooth

Buikstra and Ubelaker (1994) recommend collecting tooth wear data only on the left side of the mouth, and substituting information from a right tooth if the left one is missing. In this study, data were collected from both sides of the mouth to see if there was any marked difference in the level of wear between the right and left. To do this, the individual scores for each tooth (e.g., all right upper 3rd molars, all left lower 2nd premolars) were added up and then divided by the total of observable teeth to come up with an 'average' value for each tooth. The raw data are presented in Appendix K, including sample sizes, and the results are summarized in Table 6.18.

Table 6.18 – Average tooth wear scores for each tooth, by dental arcade (standard error in brackets)

Tooth Type	Average Wear		Tooth Type	Average Wear
Maxilla*			**Mandible**	
R upper 3rd molar	10.18 (.62)		R lower 3rd molar	11.53 (.57)
R upper 2nd molar	12.26 (.42)		R lower 2nd molar	13.83 (.41)
R upper 1st molar	15.04 (.55)		R lower 1st molar	16.41 (.49)
R upper 2nd premolar	3.07 (.14)		R lower 2nd premolar	3.01 (.10)
R upper 1st premolar	2.69 (.13)		R lower 1st premolar	2.61 (.11)
R upper canine	3.17 (.14)		R lower canine	3.18 (.12)
R upper 2nd incisor	2.78 (.17)		R lower 2nd incisor	3.16 (.14)
R upper 1st incisor	3.78 (.15)		R lower 1st incisor	3.80 (.13)
L upper 1st incisor	3.67 (.16)		L lower 1st incisor	3.86 (.13)
L upper 2nd incisor	2.92 (.17)		L lower 2nd incisor	2.97 (.14)
L upper canine	3.09 (.14)		L lower canine	3.08 (.13)
L upper 1st premolar	2.74 (.14)		L lower 1st premolar	2.53 (.12)
L upper 2nd premolar	3.00 (.13)		L lower 2nd premolar	3.11 (.11)
L upper 1st molar	15.59 (.56)		L lower 1st molar	16.89 (.52)
L upper 2nd molar	13.08 (.45)		L lower 2nd molar	14.01 (.43)
L upper 3rd molar	10.03 (.78)		L lower 3rd molar	11.63 (.58)

R = right; L = left

One limitation of this analysis is that the degree of wear on the molars cannot be compared directly to the degree of wear in the other tooth types because different scoring systems were used for the molars (Scott, 1979) than for the premolars, canines, and incisors (Smith, 1984). The scores for the molars are considerably higher than those for the other teeth, due to the quadrant scoring system used, which produces a possible score out of 40. The maximum possible score, or stage, for the premolars, canines, and incisors is 8. The score for the molars cannot simply be divided by four to produce an average, because an average score of 2 (for example) for a molar would not necessarily correspond

to a '2' in the Smith (1984) scoring system. Littleton and Frohlich (1993) attempted to integrate different scoring systems for tooth wear, but they recognized that in some cases it is difficult to correlate categories between different scoring methods.

Clearly, if mandibular incisors have an average score of 7.8 (out of 8), this would indicate very heavy wear according to the Smith (1984) scoring system. If molars have an average score of 35.99 (out of 40), this would also indicate extremely heavy wear on these teeth according to the Scott (1979) system, so conclusions can still be reached about the relative levels of wear between molars and the other tooth types. If any molar had one or more quadrant that was not observable (e.g., due to caries), the entire tooth was scored as 'unobservable'.

There are a number of patterns that emerge from the analysis of average wear for each tooth type. The 1st molars (the first teeth to erupt in the mouth) have higher wear scores than the 2nd and 3rd molars, which have successively lower levels of occlusal wear. This is expected because the 1st molars are exposed to the oral environment for a longer period of time than the other molars. In addition, there are consistently higher tooth wear scores in the mandibular versus maxillary molars (Figure 6.17). This may also be related to a pattern of slightly earlier eruption of the mandibular molars (Hillson, 1996). Heavier mandibular attrition has been noted in other studies (e.g., Powell, 1985; Hartnady and Rose, 1991). When tooth wear scores between corresponding teeth in the maxilla and mandible are compared (e.g., right upper 3rd molar versus right lower 3rd molars), there are only two tooth types that have significantly different tooth wear scores between arcades. The data are not normally distributed so non-parametric tests were used. A

Mann-Whitney U test reveals that the right 2nd molars (p = .004) and the right 1st molars (p = .021) are significantly different between the maxilla and mandible (Figure 6.17).

Figure 6.17 – Comparison of average tooth wear scores for the right maxilla and mandible

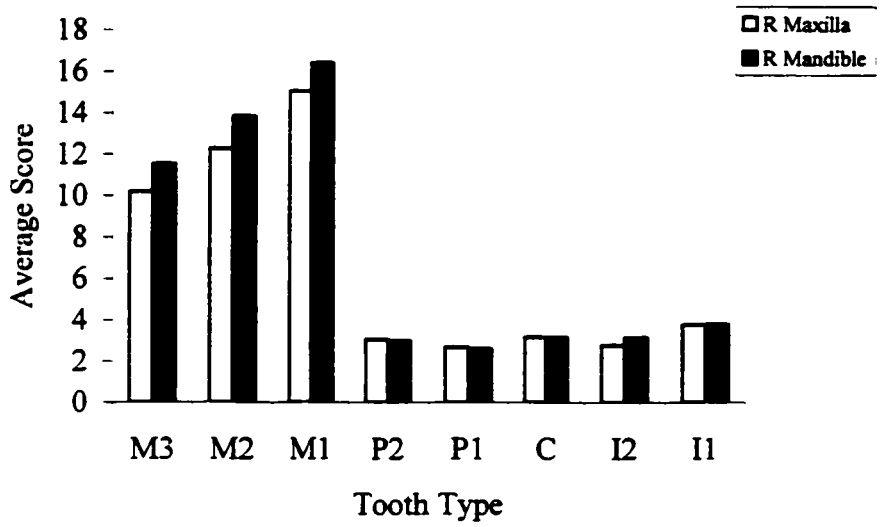


Table 6.18 shows that the range of average scores for the molars is 10.03 to 16.89, out of a possible score of 40, indicating a low to moderate level of wear on the molars. The premolars, canines, and incisors all have mean scores lower than 4 (out of 8), again suggesting moderate overall wear. Interestingly, the central incisors on both the maxilla and mandible have the highest scores of all the anterior dentition and premolars (Figure 6.18).

Figure 6.18 – SCR 127 (male, 40 – 50 years, inferior view of maxilla). Moderately heavy wear on incisors and canines

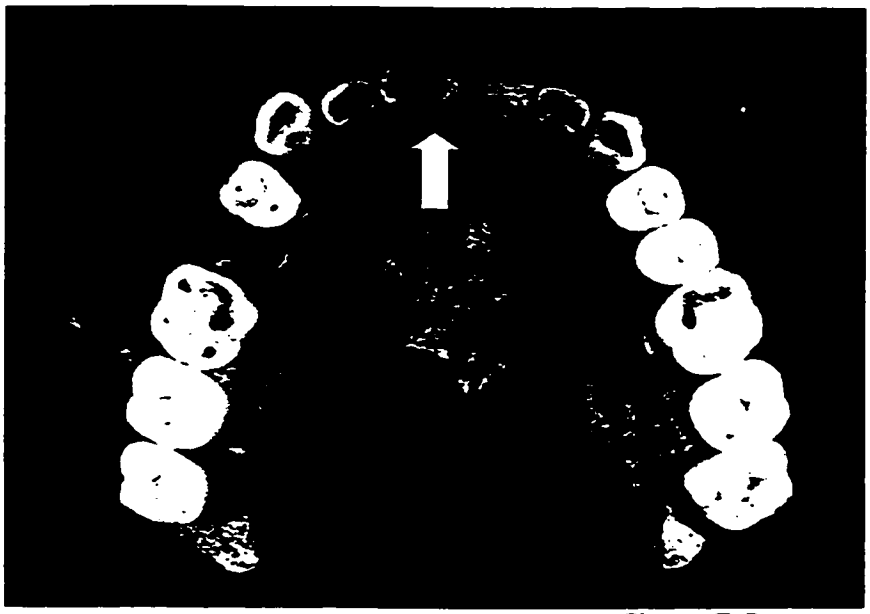
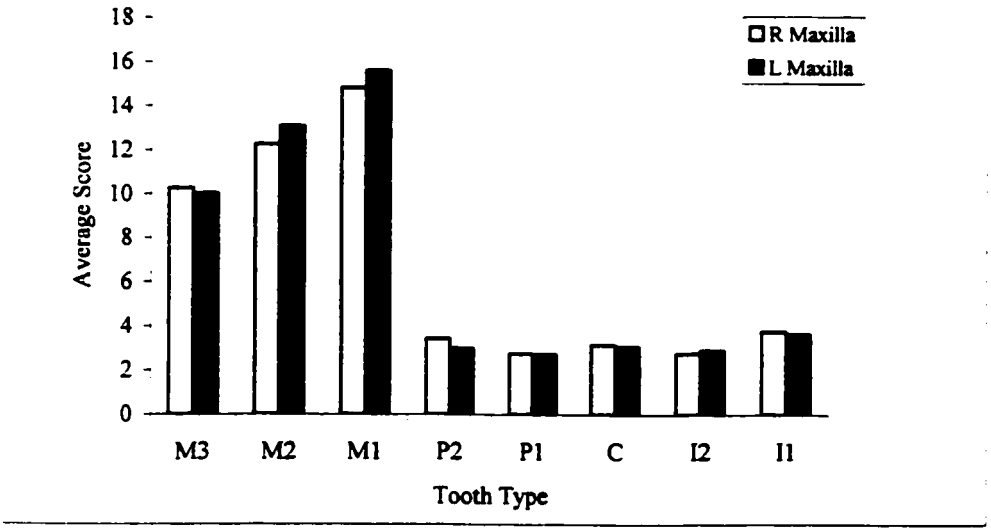


Photo – T. Prowse

When the average tooth wear scores are compared between right and left sides of each arcade, the 1st and 2nd molars on the left side of the mouth tend to have slightly higher scores than those on the right. Figure 6.19 shows the average scores for the right and left maxilla, and the pattern is the same for the right side of the mouth. A Mann-Whitney U test on the averages scores, comparing right and left sides of the maxilla, confirmed that none of the differences are statistically significant. The same is true for the mandible. These results suggest that the tooth wear scores from the right and left sides of the mouth can be combined for further analysis.

Figure 6.19 – Comparison of average tooth wear scores for the right and left sides of the maxilla



6.5.2 Tooth Wear by Age and Sex Categories

In order to investigate variability within the Isola Sacra permanent dentition, tooth wear scores were added up for each individual in the sample, by individual tooth type (e.g., molars, premolars). The total number of observable teeth in each category is divided into this aggregate score, otherwise an individual with more teeth would have a higher score than one with fewer teeth. The equation is the same as that used to calculate 'Caries Rate' for each individual:

Equation 6.6 – **Tooth Wear Score** = $\frac{\Sigma \text{ scores for each tooth type}}{\#\text{ of observable teeth for each tooth type}}$

Consequently, each individual has an average 'Tooth Wear Score' for molars, premolars, canines, and incisors. These scores are summarized in Appendix K. Table 6.19 reports Tooth Wear Scores for each tooth type by sex. In all tooth categories, males have higher Tooth Wear Scores than females; however, none of the differences between males and females are statistically significant (Mann-Whitney U test).

Table 6.19 – Tooth wear scores by tooth type and by sex (standard error in brackets)

	Male	Female	Unknown	Total
Tooth Type				
Molars	15.76 (.55)	14.64 (.47)	7.12 (.59)	13.87 (.36)
Premolars	3.24 (.14)	2.89 (.13)	.95 (.25)	2.92 (.09)
Canines	3.48 (.15)	3.06 (.16)	.98 (.25)	3.11 (.11)
Incisors	3.89 (.16)	3.67 (.15)	.90 (.17)	3.34 (.12)
TOTAL	**8.48 (.37)**	**7.59 (.26)**	**3.73 (.35)**	**7.36 (.22)**

When the data are examined by age category, a clear age-related pattern emerges (see Table 6.20 and Figure 6.20). For all tooth types, there is an increase in the amount of tooth wear with age, which is expected as tooth wear is an age-progressive process. A Kruskal-Wallis test shows that the differences between the age categories are statistically significant ($p = .000$), even when the youngest age category (0-10 years) is removed. To ensure that the molars are not responsible for the differences between each age group, tooth wear scores were recalculated for premolars, canines, and incisors only. The Kruskal-Wallis test on this subset also indicates that there are statistically significant differences between the age groups ($p = .000$).

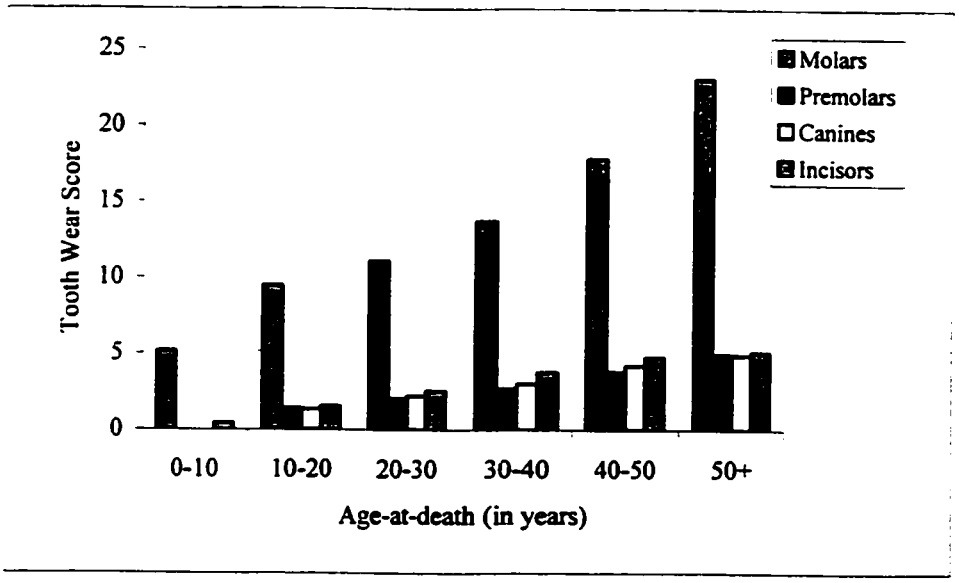
Table 6.20 - Tooth wear scores by tooth type and age category (standard error in brackets)

Age Category (in years)	n	Molars	Premolars	Canines	Incisors
<10	21	5.17 (.87)	0.00	0.00	0.43 (.21)
10-20	64	9.47 (.39)	1.41 (.14)	1.35 (.17)	1.56 (.16)
20-30	55	11.10 (.35)	2.06 (.16)	2.24 (.17)	2.57 (.18)
30-40	62	13.72 (.37)	2.72 (.10)	3.03 (.20)	3.79 (.18)
40-50	63	17.83 (.57)	3.83 (.13)	4.25 (.15)	4.78 (.14)
50+	41	23.06 (.95)	4.97 (.17)	4.92 (.17)	5.12 (.18)

The data were then normalized using a logarithmic transformation, so that an analysis of variance (ANOVA) could be used to explore the sources of variability in the sample. As with the normalized caries data, the logarithmic transformation excluded those individuals with no wear from the analysis (n=22). Thus, the ANOVA test examines variability only in those individuals who have some degree of tooth wear, which is most of the sample. Post-hoc Tukey HSD tests of the normalized data show that the differences between each age category are all statistically significant, with one exception. There are no significant differences in tooth wear scores between the 40-50 and 50+ age categories.

To ensure that the differences between Tooth Wear Scores in the maxillary and mandibular 1st and 2nd molars do not affect the interpretation of these results, the age and sex data were re-analyzed with maxillary and mandibular molars separated. Again, males have higher overall levels than females, and tooth wear is progressively higher from the youngest to oldest age categories.

Figure 6.20– Tooth Wear Scores by tooth type and age category



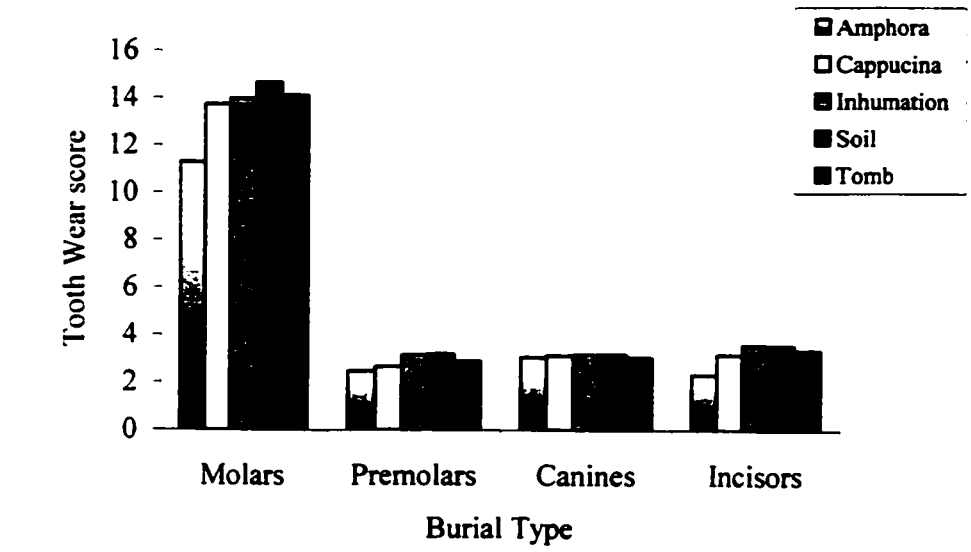
6.5.3 Tooth Wear by Burial Type

Analysis of tooth wear by burial type indicates that the lowest Tooth Wear Scores occur in the amphorae burials and the highest scores occur in the soil burials, with the exception of the incisors, (Table 6.21). Figure 6.21 illustrates this relationship, however the differences in tooth wear scores between burial types are not statistically significant (Kruskal-Wallis test). An ANOVA on the normalized tooth wear scores also found no significant differences between burial types.

Table 6.21- Tooth wear scores by tooth type and burial category (standard error is reported in brackets)

	Molars	Premolars	Canines	Incisors
Burial Type				
Amphora	11.28 (.97)	2.47 (.31)	3.04 (.47)	2.32 (.47)
Cappucina	13.73 (.65)	2.65 (.17)	3.12 (.23)	3.17 (.24)
Inhumation	13.98 (.93)	3.15 (.23)	3.16 (.26)	3.57 (.26)
Soil	14.66 (.77)	3.19 (.20)	3.18 (.22)	3.56 (.24)
Tomb	14.11 (.82)	2.88 (.21)	3.04 (.23)	3.36 (.24)
Unknown	13.15 (1.85)	2.65 (.56)	2.89 (.58)	3.72 (.47)

Figure 6.21 – Tooth Wear Scores by tooth type and burial category



6.6 Permanent Dentition - Antemortem Tooth Loss (AMTL)

6.6.1 AMTL by Tooth Type

AMTL by individual tooth is presented in Appendix H, along with the previously reported data on postmortem loss, and congenital absence of teeth. Congenital absence occurs most frequently in the 3rd molars (7.38%). AMTL for the permanent dentition is 6.32%, with a slightly higher rate of loss in the mandible than in the maxilla (Table 6.22). For individual teeth, the highest rate of AMTL is in the mandibular molars (12.79%), followed by the maxillary molars and the mandibular canines. There is a considerably higher rate of AMTL in mandibular incisors (5.39%) than in the maxillary incisors (1.14%). AMTL of mandibular molars is also higher than that of the maxillary molars. A non-parametric test (Mann-Whitney U) was run to see if the differences in AMTL between teeth in the maxilla and the mandible are statistically significant. Results show that statistically significant differences exist between the maxillary and mandibular molars ($p = .025$) and the maxillary and mandibular incisors ($p = .001$). The overall difference in AMTL between the maxilla and mandible is also statistically significant ($p = .010$).

Table 6.22 – Tooth presence, total observable sockets, and antemortem tooth loss by tooth type and by dental arcade

	Teeth Present (n)	Total Obs. Sockets (n)	Antemortem Loss (n)	% AMTL
Tooth Type				
Maxilla				
Molars	936	1204	121	10.05
Premolars	632	860	41	4.78
Canines	343	435	5	1.15
Incisors	634	880	10	1.14
Mandible				
Molars	1158	1478	189	12.79
Premolars	749	1007	41	4.07
Canines	403	534	7	1.31
Incisors	694	1076	58	5.39
Arcade				
Maxilla	2545	3379	177	5.24
Mandible	3004	4095	295	7.20
Total	**5549**	**7474**	**472**	**6.32**

6.6.2 AMTL by Age and Sex Categories

Table 6.23 presents the AMTL data for males and females. There is no AMTL in individuals of unknown sex (0/857 observable sockets), so they are not listed here, but AMTL for all individuals is listed in Appendix L. Females have a slightly higher overall rate of AMTL (7.81%, versus 6.45% for males), and higher rates in all tooth categories; however, a Mann-Whitney U test found no significant difference in the overall % AMTL between males and females.

Table 6.23 – AMTL by tooth type by sex

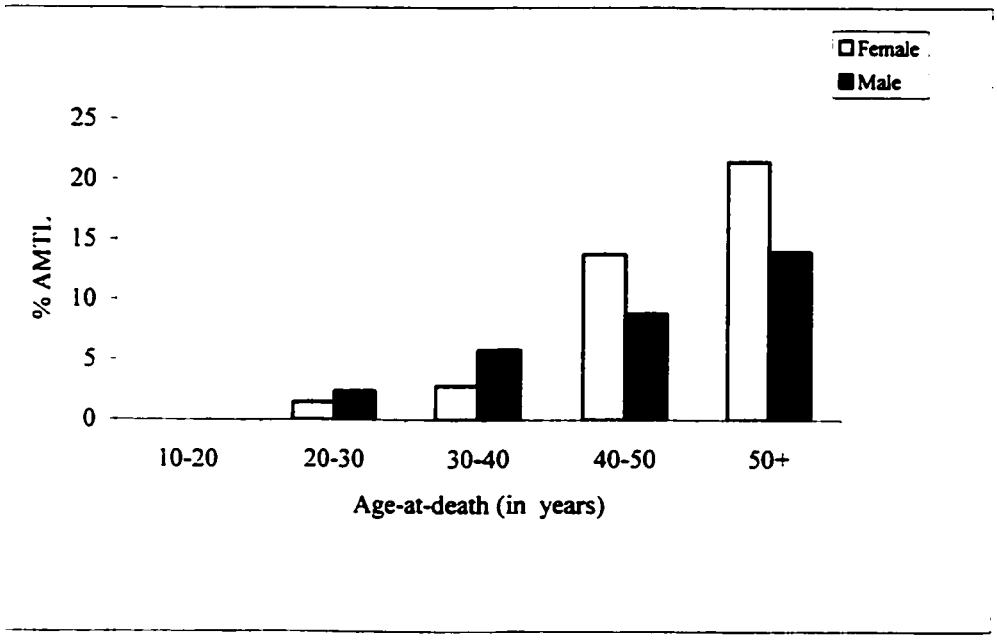
	Total Observable Sockets	Teeth Lost Antemortem	AMTL
	(n)	(n)	(%)
Tooth Type			
Males			
Molars	1193	149	12.49
Premolars	849	34	4.00
Canines	438	5	1.14
Incisors	836	26	3.11
TOTAL	**3316**	**214**	**6.45**
Females			
Molars	1183	161	13.61
Premolars	852	48	5.63
Canines	431	7	1.62
Incisors	835	42	5.03
TOTAL	**3301**	**258**	**7.81**

The data were then collapsed into age categories. As with tooth wear and caries, there is an age-progressive pattern of AMTL. There is no AMTL in individuals under 20 years of age and prevalence is low in the younger adult categories (Table 6.24). In the older adult categories there is a marked increase in % AMTL. This age progressive pattern is presented in Figure 6.22. The difference in % AMTL between males and females is only statistically significant for the 40-50 year-old group, with a higher prevalence among females (Mann-Whitney U test, $p = .036$). The pattern of AMTL loss between maxilla and mandible is consistent throughout all age categories, with mandibular AMTL loss slightly higher in each age group.

Table 6.24 – Percentage of teeth lost antemortem

	Total # of sockets	Teeth Lost Antemortem	AMTL
Age Category (in years)	**(n)**	**(n)**	**(%)**
FEMALE			
<10	*	*	*
10-20	316	0	0.00
20-30	749	11	1.47
30-40	876	25	2.85
40-50	908	125	13.77
50+	452	97	21.46
MALE			
<10	*	*	*
10-20	540	0	0.00
20-30	628	15	2.39
30-40	705	41	5.82
40-50	850	75	8.82
50+	593	83	14.00

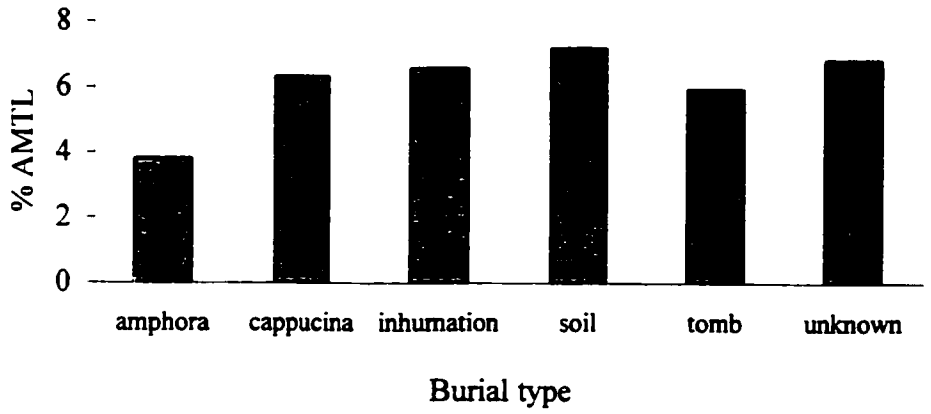
Figure 6.22 – Percent Antemortem tooth loss (AMTL) by sex and age category



6.6.3 AMTL by Burial Type

The levels of AMTL are fairly consistent between all burial types; cappucina (6.32%), inhumation (6.57%), soil (7.19%), and tomb (5.93%) (Figure 6.23). The only exception is in the amphorae category, with 3.81% AMTL. The reason for this low rate of AMTL is likely age-related, since many of the individuals who show no evidence of AMTL are younger than 20 years of age. A Kruskal-Wallis test indicates no statistically significant differences for % AMTL and different burial types (p = .343).

Figure 6.23 – Percent AMTL by burial type



6.7 Dental and Isotopic Data

The isotopic data were examined in relation to Caries Rate, DMI, and, Calculus Rate and tooth wear, using the 15-year age categories (Table 6.25). It is apparent that the mean $\delta^{13}C$ values between different age groups are not dramatically different. When the youngest age category is ignored, because the permanent teeth have not been in the mouth long enough to develop large numbers of carious lesions, there is even less variability in the Caries Rate data for the adult age groups.

Table 6.25 – Mean isotopic values for each age category compared to mean Caries Rate, DMI and Tooth Wear

Age (in years)	$\delta^{13}C_{col}$ (‰)	$\delta^{13}C_{ap}$ (‰)	$\delta^{15}N$ (‰)	Tooth Wear	Caries Rate	DMI	Calculus Rate
5-15	-19.04 (± .35)	-11.10 (± 1.64)	10.50 (± .80)	2.84 (S.E. .60)	0.36 (S.E. .36)	0.36 (S.E. .36)	17.73 (S.E. 6.71)
15-30	-18.78 (± .26)	-11.28 (± .98)	10.27 (± .99)	5.17 (S.E. .35)	8.44 (S.E. 2.01)	10.30 (S.E. 2.47)	26.79 (S.E. 4.84)
30-45	-18.83 (± .33)	-11.19 (± .89)	10.93 (± .82)	8.17 (S.E. .78)	8.41 (S.E. 4.73)	14.02 (S.E. 5.11)	33.39 (S.E. 4.40)
45+	-18.69 (± .25)	-12.21 (± .1.29)	11.35 (± 1.31)	10.89 (S.E. .92)	9.21 (S.E. 4.31)	25.64 (S.E. .04)	33.74 (S.E. 4.41)

Correlation analyses were performed, using Spearman's rho coefficient (r_s), because the dental scores are not normally distributed. Results of this analysis indicate that there is a positive correlation between $\delta^{13}C_{collagen}$ and DMI ($r_s = .298$, $p = .001$), tooth wear ($r_s = .336$, $p = .004$), and Calculus Rate ($r_s = .257$, $p = .033$). There is also a correlation between tooth wear and $\delta^{15}N$ ($r_s = .311$; $p = .009$). There are no significant

associations between $\delta^{13}C_{apatite}$ and the dental data, probably because of the small amount of variation in the isotopic data. These results suggest that when $\delta^{13}C_{collagen}$ increases there is a slight tendency for tooth wear, calculus, and DMI to increase as well. The same is true for $\delta^{15}N$ and tooth wear.

6.8 The Deciduous Dentition

6.8.1 Antemortem and Postmortem Tooth Loss

There are 78 individuals with deciduous teeth. The youngest individuals from which data were collected are 1-1.5 years of age, and the oldest are 11-12 years of age. There are a total of 609 teeth and 1042 observable sockets in the deciduous dentition (Table 6.26). The raw data are presented in Appendix M. Postmortem loss is very high in teeth with only one root (canines = 15.07%, and incisors = 20.35%), and postmortem loss is slightly higher in the maxilla (42.67%) than in the mandible (39.93%). Antemortem loss is extremely low (0.38%), occurring in only two individuals (SCR 162 and SCR 165). As the number of individuals with AMTL is so low, no statistical analysis was performed.

Table 6.26 – Deciduous dentition: Tooth presence, antemortem tooth loss, postmortem tooth loss and total observable sockets by tooth type and by dental arcade

	# of Obs. Teeth	Antemortem Loss	AMTL	Postmortem Loss	PMTL	# Total Sockets
	(n)	(n)	(%)	(n)	(%)	(n)
Tooth Type						
Molar	442	0	0.00	60	5.76	**502**
Canine	55	2	0.19	157	15.07	**214**
Incisor	112	2	0.19	212	20.35	**326**
Arcade						
Maxilla	270	0	0.00	201	42.67	**471**
Mandible	339	4	0.70	228	39.93	**571**
Total	**609**	**4**	**0.38**	**429**	**41.17**	**1042**

6.8.2 Deciduous Dentition – Calculus

Thirty-two of the 78 individuals (41.03%) have some degree of calculus. As expected, Calculus Rates are much lower than in the permanent dentition, with a mean score of 9.28 (S.E. = 1.95) (see Appendix M for individual scores). The mean Modified Calculus Rate is 7.79 (S.E. = 2.21). One interesting pattern is that calculus deposits are present on individuals as young as 2.5 years of age, and calculus is present in all ages over two (Table 6.27). The calculus that is present is almost always found on the molars, and only infrequently on the canines or incisors.

Table 6.27 – Number of individuals affected by calculus, Calculus Rate, and Modified Calculus Rate, by age category (standard error in brackets)

Age Category	Individuals	# with Calculus	%	Calculus Rate	Modified Calculus Rate
(in years)	(n)	(n)			
<2	10	0	0	0.00	0.00
2-4	19	6	31.58	2.47 (1.37)	1.29 (.70)
4-6	13	6	46.15	8.28 (4.14)	6.52 (3.87)
6-8	11	4	36.36	9.91 (6.15)	8.45 (5.97)
8-10	13	7	53.85	9.83 (4.27)	5.97 (2.90)
10-12	12	9	75.00	28.53 (7.22)	28.05 (10.91)
TOTAL	**78**	**32**	**41.03**	**9.28 (1.95)**	**7.79 (2.21)**

6.8.3 Deciduous Dentition - Caries

There are a total of 22 carious lesions in the deciduous dentition, out of a total of 554 observable teeth. Total Percent Caries for the deciduous dentition is 3.97%. The only teeth affected by caries are the mandibular and maxillary molars (Figure 6.24), and there are more carious lesions present in the maxilla (5.69%) than in the mandible (2.60%). Eighteen of the total carious lesions observed are interproximal lesions, and the remaining four lesions are on smooth surfaces (2) and occlusal surfaces (2).

The Caries Rate was calculated for each individual (Appendix M), but DMI was not calculated because there is so little AMTL in the deciduous teeth (n = 4), this would not have changed the overall interpretation of the pattern of caries in this sample. The overall Caries Rate for the deciduous dentition is 5.79 (S.E. =1.64). The results in Table 6.28 show that caries is an age-progressive disease, as was observed in the permanent teeth. The decline in Caries Rate in the oldest age category (10-12 years) is probably

related to the decreased number of deciduous teeth left in the mouth because they were being replaced by permanent teeth. Any deciduous teeth that might have had carious lesions were lost through the normal eruption of the permanent dentition.

Figure 6.24 – SCR 519 (11-12 years, anterior view of left mandible). Interproximal carious lesion on left deciduous m1, and occlusal surface wear of 1st and 2nd molars

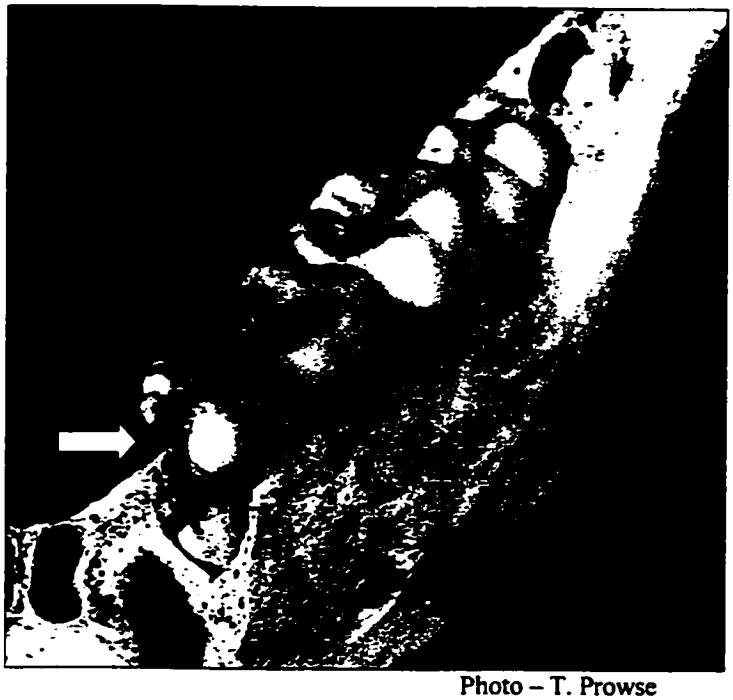


Photo – T. Prowse

As with calculus, the pattern of caries prevalence indicates that even young children were consuming a diet that promoted caries. The prevalence of caries is quite low in the younger children, but is present in those as young as 2.5 years of age. By 6 years of age these levels increase considerably.

Table 6.28 – Number of carious teeth and Caries Rate, by age category (standard error in brackets)

Age (in years)	# of Observable Teeth (n)	# of Carious Teeth (n)	Caries Rate
0-2	62	0	0.00
2-4	167	2	1.00 (.69)
4-6	136	5	3.05 (2.29)
6-8	72	4	12.23 (8.93)
8-10	70	7	12.97 (4.39)
10-12	47	4	7.50 (3.23)
TOTAL	**554**	**22**	**5.79 (1.64)**

6.8.4 Deciduous Dentition - Abscesses

There is only one individual with an abscess in the deciduous sample. SCR 225 (8-9 years old) has a lingual abscess associated with a deciduous 1st molar. The permanent premolar has not yet erupted, so the abscess is attributed to the deciduous dentition.

6.8.5 Deciduous Dentition - Tooth Wear

Seventy-four of the 78 deciduous dentitions show some degree of tooth wear, for a total of 450 out of 566 observable teeth with wear (79.51%). The data used to calculate average tooth wear scores, by tooth type, are presented in Appendix M, and the results are summarized in Table 6.29.

Table 6.29 – Average Tooth Wear Scores for each tooth type, by dental arcade

	Observable Teeth	Cumulative Score	Average
Tooth Type	**(n)**		
Maxilla			
Molars	184	1414	7.68
Canines	29	91	3.14
Incisors	42	109	2.60
Mandible			
Molars	219	1933	8.83
Canines	20	39	1.95
Incisors	71	155	2.18
Maxilla	255	1614	6.33
Mandible	310	2127	6.86
Total	**565**	**3741**	**6.62**

Analysis of tooth wear by tooth type reveals that there is no consistent tendency for teeth on one side of the mouth to have heavier wear than on the other. Maxillary molars have slightly higher wear on the left side, but mandibular 2nd molars have higher wear on the right side. The overall difference between right and left sides is very small. The mandibular molars have higher levels of wear than do their maxillary counterparts. In contrast, both the canines and incisors show higher levels of wear in the maxilla for both sides of the mouth.

The analysis of the deciduous dentition reveals a pattern of increased tooth wear in the older age categories, but like calculus, the age at which tooth wear begins to develop is of particular interest. This may provide some indication of when food other than mother's milk was starting to become a regular component of the diet of the Isola

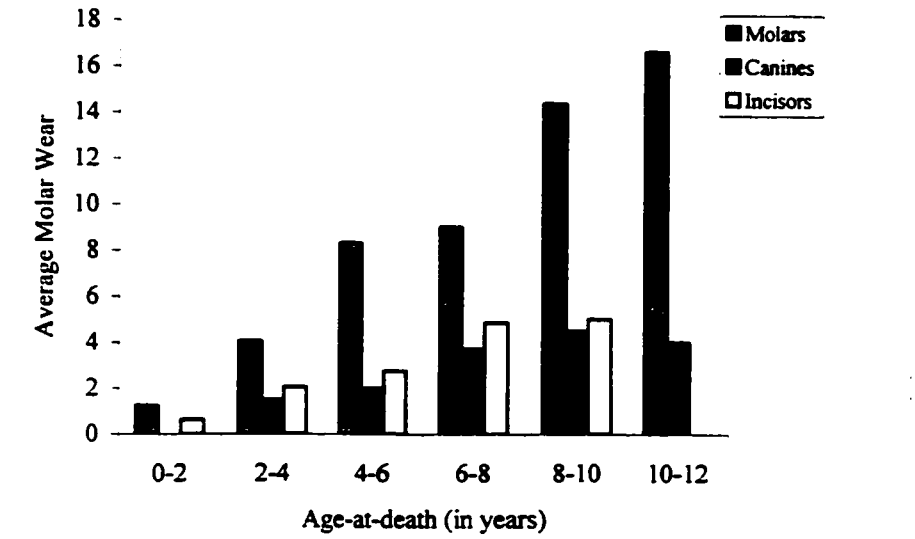
Sacra infants and children. Table 6.30 shows that there are extremely low levels of tooth wear in infants as young as 1.5 years of age. There is a progressive increase in molar wear in the successive age categories. The difference in scales between the scoring methods for molars versus incisors and canines makes it difficult to directly compare the changes between the different tooth types, but it does appear that there is a consistent increase in levels of wear between successive age categories.

Table 6.30 – Tooth Wear Scores by tooth type and age category (standard error in brackets)

Age Category (in years)	Sample (n)	Tooth Wear Molars	Tooth Wear Canines	Tooth Wear Incisors
< 2	10	1.24 (.52)	-	.63 (.20)
2-4	19	4.05 (.64)	1.50 (.50)	2.04 (.32)
4-6	13	8.30 (1.03)	1.98 (.42)	2.75 (.27)
6-8	11	9.00 (.93)	3.71 (.83)	4.85 (1.48)
8-10	13	14.36 (1.32)	4.50 (.22)	5.00 (.00)*
10-12	12	16.60 (1.91)	4.00 (.00)*	N/A
TOTAL	**78**	**8.94 (.75)**	**2.60 (.32)**	**2.23 (.29)**

*one individual

Figure 6.25 – Average Tooth Wear Scores by age category for each tooth type



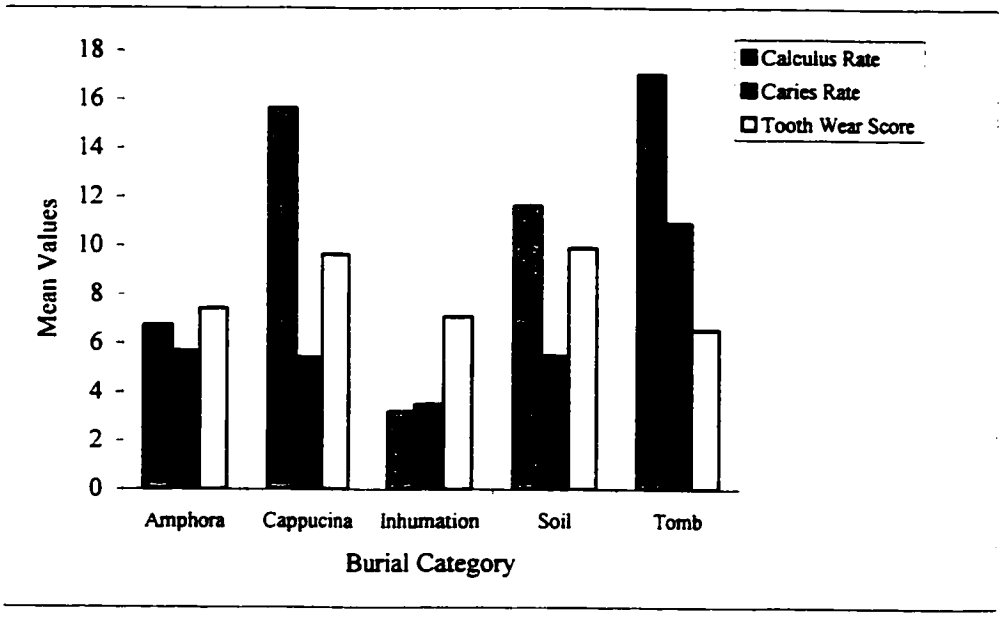
6.8.6 Deciduous Dental Data by Burial Type

Table 6.31 presents the mean scores for calculus, caries, and tooth wear for each of the five burial types. Analysis by burial type shows that individuals in tomb burials have the highest mean Calculus Rate and Caries Rate. Figure 6.26 illustrates this relationship graphically without the Modified Calculus Rate. Tooth Wear Scores are highest in the soil burials, but are only slightly higher than the mean for cappucina burials. Tooth Wear Scores show the least amount of variability. A Kruskal-Wallis test indicates that the prevalence of dental pathology between tomb types is not statistically significant ($p \leq .05$).

Table 6.31 – Measures of dental health for calculus, caries, and tooth wear by burial type (standard error in brackets)

	Calculus Rate	Modified Calculus Rate	Caries Rate	Tooth Wear Score
Burial Type				
Amphora	6.75 (2.75)	3.97 (1.78)	5.68 (2.72)	7.43 (1.30)
Cappucina	15.64 (7.40)	13.01 (6.57)	5.42 (2.85)	9.63 (1.48)
Inhumation	3.20 (1.56)	1.86 (.97)	3.50 (2.00)	7.09 (1.16)
Soil	11.62 (4.96)	13.42 (8.37)	5.48 (2.05)	9.89 (2.45)
Tomb	17.01 (7.72)	13.92 (7.05)	10.91 (9.94)	6.56 (1.27)

Figure 6.26 – Calculus Rate, Caries Rate, and Tooth Wear Score by burial category



One problem, however, is that the distribution of age categories between the burial types is not even. For example, there are more 10-12 year-olds in the soil burials than in any other category, and more 2-4 year-olds in the inhumation category (Table

6.32). It is therefore possible that the patterns observed may be related to the age distribution between burial types. In some burial categories there are no individuals in particular age groups, so sample size may also be a factor in these differences.

Table 6.32 – Number of individuals with deciduous teeth in each burial category

	Amphora	Cappucina	Inhumation	Soil	Tomb
Age (in years)	(n)	(n)	(n)	(n)	(n)
0-2	5	2	0	3	0
2-4	3	1	8	3	4
4-6	4	2	4	2	1
6-8	4	1	2	1	3
8-10	5	3	3	2	0
10-12	2	3	0	5	2
Total	**23**	**12**	**17**	**16**	**10**

6.9 Summary

The dental health status of males and females in the Isola Sacra sample are quite similar. Females tend to have higher rates of calculus, and this is more pronounced in the older age category (50+). Collectively, the results suggest that a greater proportion of females have some calculus on their teeth, although this is not statistically significant. The Calculus Rate and Modified Calculus Rate, however, do indicate that females have both a higher number of tooth sides affected by calculus and greater amounts of calculus when it is present. Antemortem tooth loss affects males more often in the younger age categories and females in the older age categories. Without more precise age estimates, it is difficult to ascertain if the reason for the higher levels of AMTL in older females is

because they actually survived longer than males (i.e., had longer life expectancies) and lost more teeth over time. Males have a higher overall prevalence of caries in the sample, and it may be that the higher levels of calculus in the females provided some protection against caries. However, overall differences between males and females are not statistically significant. Males also have heavier occlusal wear, but the prevalence of abscesses is approximately the same in both sexes.

An examination of dental health with respect to burial type did not reveal any statistically significant differences, but there are patterns in the data. Individuals in soil burials tend to have higher levels of calculus, tooth wear, and caries. AMTL is very similar between all burial types, although individuals in soil burials again have the highest overall level of AMTL.

The deciduous dental data show that the overall levels of calculus, caries, and tooth wear are low, which is to be expected in young individuals whose teeth have not been exposed to the oral environment for a long time. However, even though the overall levels are not high, both calculus and caries are present in individuals aged 2.5 years, and tooth wear is present in individuals as young as 1.5 years. The pattern of deciduous dental health by burial type, in contrast to the permanent data, indicates that infants and children in the tomb burials had higher levels of calculus and caries, and lower levels of tooth wear.

Chapter 7

Integrating the Evidence for Diet of the People from Isola Sacra

7.1 Isotope Analysis

7.1.1 Total Sample

The isotopic data can now be examined in relation to the food choices available to the ancient Romans and possible social factors that may have influenced access to food resources. The overall pattern of the Isola Sacra isotopic data suggests the consumption of a largely terrestrial diet, with a significant contribution of marine resources. Figure 5.12 illustrates the tendency of the $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ isotopic values toward a C_3 plant diet, but still within the expected ranges for a combined C_3 plant and marine diet. The combined $\delta^{13}C$ and $\delta^{15}N$ values also confirm the combined contribution of marine and terrestrial resources to the diet.

What about the contribution of terrestrial animals to the diet of people from Isola Sacra? If a significant proportion of the daily protein intake was obtained from the consumption of, for example, the meat of goats or pigs, one would expect to see a trophic level enrichment of 3‰ in $\delta^{15}N$ values and a 1‰ enrichment in $\delta^{13}C$ values over faunal

levels. Table 5.9 shows that the mean $\delta^{15}N$ values for the humans are enriched by more than 5‰ over the herbivores and approximately 1.5‰ enriched over the omnivores (dog and fox). The human $\delta^{13}C_{collagen}$ values are also enriched over the herbivores by approximately 2‰. This suggests that something in the diet of the inhabitants of *Portus Romae* is increasing both their $\delta^{15}N$ and $\delta^{13}C$ values higher than would be expected if they were consuming a purely terrestrial diet. It appears that a marine contribution to the diet is 'pulling' the data towards more positive isotopic levels.

If a significant proportion of the diet consisted of lipid-rich animal by-products like milk or cheese, it is expected that $\delta^{13}C$ values would be depleted. This effect would likely be more pronounced in the apatite values because they reflect total dietary carbon (including lipids). The collagen results indicate that human $\delta^{13}C$ values are consistently more positive than herbivore values, again likely reflecting the contribution of marine resources (Figure 5.13). In contrast, the $\delta^{13}C_{apatite}$ values of the humans are slightly more negative than the animals (Table 5.9). This may indicate that a portion of the total dietary carbon was coming from a source depleted in ^{13}C, like lipid-rich cheese, which was reportedly a popular food item among the ancient Romans.

Another reportedly popular constituent of the Roman diet was olive oil. Olive oil should have a negative $\delta^{13}C_{apatite}$ value because of its high lipid content. Unfortunately, the isotopic 'signature' of olive oil is not known, nor do we have a clear understanding of how much olive oil was consumed on a daily basis. The apatite results, however, suggest that these people did consume lipid-rich food items like cheese and olive oil. It is also interesting to note the tendency for $\delta^{13}C_{apatite}$ values to decrease with increased age-at-

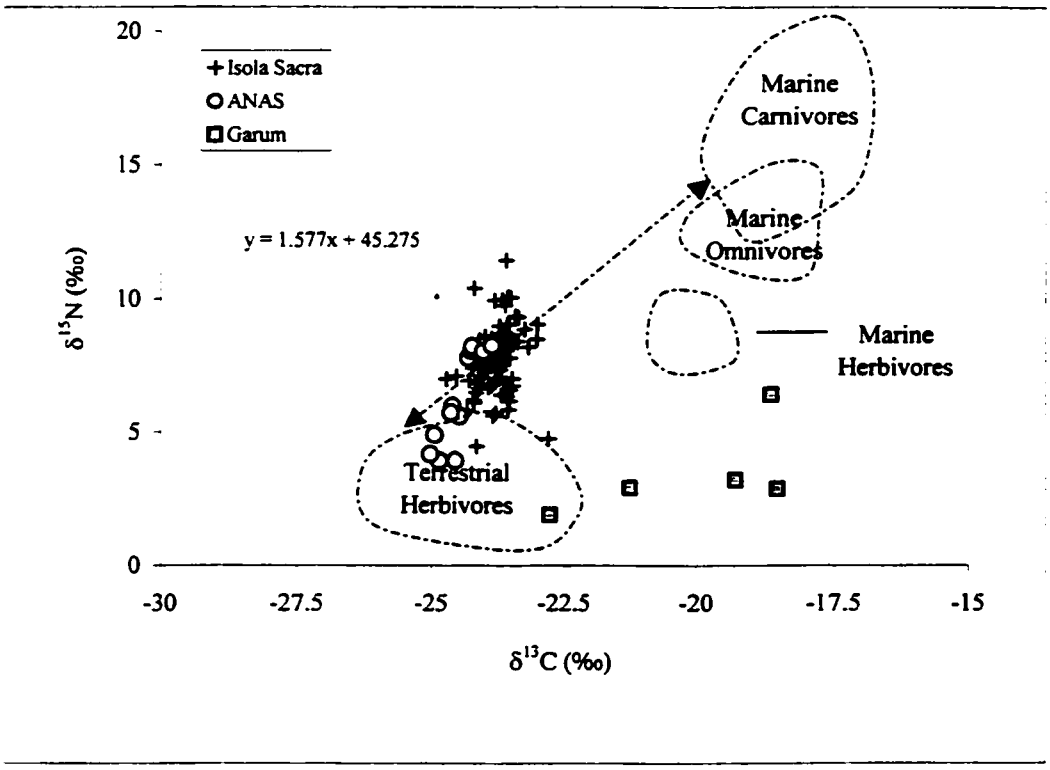
death (Figure 5.9), suggesting that older members of the population consumed more ^{13}C-depleted foods.

The isotopic data also suggest that legumes (with extremely low $\delta^{15}N$ values) do not appear to have been a staple for the people of *Portus Romae*. It has been proposed that legumes were an important source of protein, particularly for the urban and rural poor of Roman society (Corbier, 1989; Garnsey, 1991, 1999). The Isola Sacra $\delta^{15}N$ values are considerably higher than would be expected if legumes constituted a significant proportion of the diet. These results may be related to the 'middle-class' status of the *Portus Romae* population.

Figure 5.14 plots the Isola Sacra and ANAS cemetery data in relation to expected isotopic values of terrestrial and marine-based diets (after Schwarcz, 1991). The expected values for marine organisms are based on levels obtained from Atlantic ocean samples. These values should be shifted to the left for the present study, because isotopic analysis of Mediterranean waters has revealed that surface waters are not as enriched in ^{13}C as other bodies of water (Pierre, 1999); consequently, organisms at the base of the marine food chain in the Mediterranean have slightly lower $\delta^{13}C$ levels, and this is transferred up the food chain. Figure 7.1 illustrates the $\delta^{13}C$ estimates of marine values, which have been shifted slightly to the left to compensate for the depletion of $\delta^{13}C$ in the Mediterranean.

The ANAS and Isola Sacra data, representing terrestrial herbivore consumers and combined terrestrial and marine consumers, respectively, show a directional trend between terrestrial herbivores and marine omnivores and carnivores in Figure 7.1.

Figure 7.1 –Inferred isotopic signal of Isola Sacra and ANAS diets, from $\delta^{13}C$ and $\delta^{15}N$ of bone collagen, showing trend of data between terrestrial herbivores and marine omnivores and carnivores* (offset by diet-bone collagen spacing)



*Marine faunal estimates have been shifted by -2‰ to represent the low $\delta^{13}C$ of Mediterranean dissolved inorganic carbon (after Pierre, 1999).

The isotopic distinction between some of the ANAS values and the Isola Sacra values is remarkable given the reportedly close geographic proximity of the samples. The second subgroup in the ANAS sample has isotope levels that cluster closely with the Isola Sacra data. A possible explanation is that the individuals with isotopic values similar to the Isola Sacra sample were migrant workers (sex unknown) who worked on the coast and consumed a diet composed of a greater proportion of marine resources.

Curtis (1991) described Roman fishermen who would be hired to work for traders and merchants, but who lived in nearby towns. These individuals would have worked for long periods of time on the coast or on ships during peak seasons, and would have consumed a diet that distinguished them isotopically from the other ANAS members, who were probably involved in agricultural activities and whose isotopic values indicate the consumption of a large proportion of terrestrial resources.

Table 7.1 presents $\delta^{15}N$ and $\delta^{13}C$ data for selected marine organisms to show the range of values for diverse species (with standard deviations, if reported), and also includes the average values for the *garum* samples analyzed in this study. It would be ideal to have isotopic data for all the marine foods reportedly consumed by the ancient Romans (e.g., mullet, turbot, brill, eel), but the data are not available.

Table 7.1 – $\delta^{15}N$ and $\delta^{13}C$ (if reported) values for *garum* and selected marine organisms

Species Name	$\delta^{15}N$ (‰)	δ13C (‰)
Garum	6.5 ± 1.7	-14.7 ± 0.6
Shrimp[1]	7.7 ± 0.5	.
Mussels[1]	9.0 ± 0.6	.
Abalone[2]	7.1*	.
Crayfish[2]	11.8*	.
Squid[3]	11.7 ± 0.4	-18.4 ±0 .2
Pink Salmon[4]	9.6	-17.2
King Salmon4	12.7	-19.3
Tuna[4]	11.4	-14.2
Squirrel fish[4]	14.4	-13.6
Walleye[4]	14.7	-12.4
Needle fish[4]	16.0	-11.1

[1]Minagawa and Wada, 1984
[2]Sealy *et al.*, 1987 (* - tissue samples)
[3]Gould *et al.*, 1997
[4]Schoeninger and DeNiro, 1984

The low $\delta^{15}N$ values of the *garum* indicate that these samples were probably prepared with small fish like sprat (small herring), sardines, or smelt, and perhaps some shellfish. The important point about the isotopic composition of the *garum* samples is that the reportedly widespread use of *garum* by the ancient Romans does not account for the ^{15}N-rich isotopic distribution of the Isola Sacra sample, because the $\delta^{15}N$ values of the *garum* samples are quite low. The people from Isola Sacra were consuming marine organisms from higher trophic levels, with isotopic values similar to salmon and tuna. The reason for the extremely wide range of $\delta^{15}N$ values in marine ecosystems is due to the larger number of trophic levels found in these food webs. People from the Isola Sacra sample appear to have been eating high trophic level feeders, unlike some of their neighbors at the ANAS cemetery. The result is that the Isola Sacra data are shifted towards these higher $\delta^{15}N$ levels.

Having said this, if the inhabitants of *Portus Romae* were consuming a 50% marine omnivore/carnivore and 50% terrestrial diet, the data would cluster roughly in the center of the two extremes. As can be seen in Figure 7.1, the data are closer to the terrestrial herbivore range, suggesting that a greater overall proportion of the diet was C_3 plants and either the flesh or byproducts (e.g., milk, cheese) of C_3 plant consumers. An estimate of the proportion of marine versus terrestrial resources in the diet would be approximately 60% terrestrial and 40% marine.

Richards and Van Klinken (1997) examined average human $\delta^{13}C$ values from a variety of European Holocene sites, including sites from Italy (ca. 12,000 BP and later). The $\delta^{13}C$ average obtained for human samples from Italy was –21.3‰ (standard

deviation not reported), based on data derived from sites "in the Alps as well as the south" (*ibid.*: 364).[1] This is even more negative than the $\delta^{13}C$ levels from the ANAS individuals who were apparently eating a largely terrestrial diet (approx. –19.7‰). This suggests that even the ANAS population was getting a small amount of dietary carbon from marine resources. The enriched $\delta^{13}C$ values from the Isola Sacra skeletal sample are likely due to a greater contribution of marine foods in the diet. Climatic variation in Italy between the two time periods was not significant, so the variation in the $\delta^{13}C$ values can be attributed to dietary differences.

It is also possible that enriched $\delta^{13}C$ values can be caused by the consumption of C_4 plants in the diet. There are references in the literary sources to the use of millet (a C_4 plant) as animal fodder, but it was considered unsuitable for human consumption under normal conditions of food availability (White, 1976; Spurr, 1983). This C_4 plant signal would be passed on to humans through the consumption of these animals or their byproducts; however, the graph of the Isola Sacra faunal data (Figure 5.13) shows that most of the animal species have more negative $\delta^{13}C$ values than humans (with the exception of the omnivore species). Their isotopic values fall within the range expected for terrestrial herbivores consuming C_3 plants. These results suggest that the higher $\delta^{13}C$ values of the humans are related to the consumption of marine foods, since C_4 plants do not appear to have been an important food source for humans or animals.

[1] Sample sizes were not reported, although the authors only included data from countries with 10 or more samples.

It is difficult to compare the Isola Sacra isotope data with other samples, because isotopic studies of historic samples from Italy, and the Mediterranean region in general, are rare. One study that has investigated isotopic variation in Roman samples was an analysis of forty-one samples from the site of Poundbury, England, by Richards and coworkers (1998). Individuals interred in mausolea from the late Roman phase (4th c. AD) of the site have an average $\delta^{13}C$ value of $-18.2 \pm 0.3‰$ and an average $\delta^{15}N$ value of $10.1 \pm 1.0‰$. The authors proposed that the diet of these individuals was composed primarily of terrestrial foods, but with a marine contribution to the overall protein in the diet (*ibid.*). In addition, they concluded that individuals in the mausolea were higher status members of the population, consuming a more 'Roman' diet composed of marine fish, oysters, or *garum* (*ibid.*). A direct comparison between the Isola Sacra and Poundbury data is not possible without correcting for climate variation in $\delta^{13}C$ values, which can vary by 1-2‰ between northern and southern Europe (Richards and Van Klinken, 1997). What can be said, however, is that the isotopic values between two Roman sites are remarkably similar and the consumption profiles suggest similar diets.

Stable isotope analysis has also been undertaken on eleven individuals from a Neolithic ossuary at Alepotrypa Cave, Diros, Greece (Papathanasiou *et al.*, 2000). This site on the southwestern coast of Greece is closer geographically to Isola Sacra, but is much earlier in date (5000-3200 BC). It is used for comparison here because it is a coastal site in the Mediterranean region. The authors hypothesized that the isotopic data would reveal a heavy marine component in the diet, but instead found $\delta^{13}C$ (-19.9‰) and $\delta^{15}N$ (7.2‰) averages that reflect a more terrestrial C_3 diet, even though the remains of

fish and shellfish were recovered from the site (*ibid.*). The Isola Sacra data, with more positive $\delta^{13}C$ and $\delta^{15}N$ values, show a much stronger influence of marine resources on the isotopic values. The isotopic values from Alepotrypa Cave more closely resemble the 'terrestrial plant consumer' subgroup from the ANAS cemetery.

A study of the dietary transition between the Mesolithic and Neolithic periods in Portugal found a similar trend between marine and terrestrial foods (Lubell *et al.*, 1994). Their Mesolithic sample (ca. 7000 BP) showed a wide range of $\delta^{15}N$ values, interpreted to indicate that these individuals were eating a wide range of marine resources at various trophic levels (*ibid.*). This pattern is similar to that found in the Isola Sacra data, showing a trend between two main food sources with the data dispersed along a line, depending on the amount of marine foods in an individual consumer's diet. Walker and DeNiro (1986) also found a similar linear trend between terrestrial and marine resources in prehistoric samples from the coast of California, although most of the data clustered more towards marine resources. The authors hypothesized that the diet was composed of mixed marine and terrestrial resources, with seafood making up the majority of the diet (*ibid.*).

7.1.2 Variations due to Sex, Age, and Burial Type

Sex

Statistical analysis of variability in $\delta^{13}C$ values between males and females in the Isola Sacra sample found that there is significant variability between sexes, even though the overall variation is small. Females tend to have more negative $\delta^{13}C$ values than

males. Figure 5.3 shows that the pattern of isotopic values among males and females is slightly different, with the female data showing a more dispersed distribution, while the male data 'cluster' around –18.5‰.

The distribution of the $\delta^{15}N$ data is not significantly different between males and females for the total sample, although male values tend to be, on average, slightly higher. Figure 5.3 illustrates that while the range of $\delta^{15}N$ values is similar between the sexes, there are more males with high $\delta^{15}N$ values (i.e., > 12‰). The combined $\delta^{13}C$ and $\delta^{15}N$ data suggest that females were consuming a slightly greater proportion of terrestrial animals and C_3 plants in their diet and that marine foods made up a comparatively larger proportion of the males' diet.

Access to food in any society is not simply a matter of physical necessity. It is influenced by social relationships and the importance placed on food by members of society (Bradley, 1998). Garnsey (1999) has pointed out that in addition to the physiological needs of the individual, status and the associated control over resources (both within the household and in society) has considerable influence on access to food. The head of the Roman family was the *pater familias*, usually the father or oldest male member, and all other members of the household were under his legal authority, even as adults (Casson, 1998). Male members of the household, and of Roman society, generally had higher status and power than did female members and, consequently, likely had greater access to food or at least greater varieties of food. The grain dole instituted by Gaius Gracchus in 123 BC was made available to 'citizens' of Rome at a reduced price, but this usually referred to adult males of a certain social status (Stambaugh, 1988).

The preferential treatment of males over females started from birth. According to a law attributed to Romulus, fathers were required to take care of all their male offspring, but only care for the first female born into the family (Pomeroy, 1995). Young male children were also given preference in social assistance programs (Casson, 1998). Both private and state-run *alimenta* schemes existed during the Roman Imperial period. These were funds designed to support children, but more support was usually reserved for male children in the community (Casson, 1998; Rawson, 1991). Roman dining practices also reflected and reinforced the status of males, with males reclining comfortably on *triclinia* (couches), while women and children (if even present), were often seated upright in 'inferior' or 'subordinate' positions below or off to the side of the *triclinia* (Nielsen, 1998).

There is considerable evidence from ancient written records concerning the attitudes of Greeks and Romans to women's health and access to food. Doctors considered it prudent to restrict the food consumption of women; in order to maintain the proper balance of body 'humours' it was recommended that they avoid 'cold and wet' foods like, eel, sturgeon, turbot, river fishes, and fatty meats (among others) (Garnsey, 1999). Individuals with higher status in Roman society might have greater access to these desirable foods, so males would consume comparatively more expensive items like seafood than women and children, which agrees with the pattern found in the isotopic data.

Fish and fishing were important economic resources at the ports of Rome, indicated by the existence of a corporation of fishermen and fishmongers at Ostia, and the

discovery of metal fishing hooks and an intact fishing boat in the port of Claudius (Pavolini, 1996). It was not only the fish, but also their byproducts, like *garum*, that were the focus of major economic activity along the coastal regions of Italy and the Mediterranean (reviewed by Curtis, 1991). As fishermen and merchants involved in the production and trade of fish and fish products, it is therefore not surprising that males would have had greater access to marine resources. The $\delta^{13}C$ and $\delta^{15}N$ values of the females in the Isola Sacra sample do not indicate a pure terrestrial diet; rather, their isotopic levels also suggest the consumption of marine foods. The overall isotopic variability between males and females at Isola Sacra is quite small, particularly when considered in conjunction with the ANAS data that show clear dietary differences. The lack of striking variability in the Isola Sacra isotopic data is also reflected in the dental evidence.

Age

Previous studies of skeletal samples have not found age-related effects in isotopic data, and it appears that there is no physiological reason for age differences in the incorporation of carbon and nitrogen isotopes into the body's tissues (Lovell *et al.*, 1986; Schwarcz and Schoeninger, 1991). The exceptions are studies that have found negative correlations between $\delta^{15}N$ values and increased age, due to the large number of infants in the samples, and/or decreases in $\delta^{15}N$ values associated with the weaning process (e.g., Herring *et al.*, 1998; Katzenberg *et al.*, 1993). Consequently, if age-related variations in

$\delta^{13}C$ and $\delta^{15}N$ levels exist within a sample, it may be inferred that they are related to variability in diet.

When the Isola Sacra femur data are examined by age, a slight but significant correlation is found between age and both $\delta^{13}C$ and $\delta^{15}N$ values. The rate of bone turnover in adults is estimated to be quite slow, requiring a minimum of 10 years, so collagen levels represent an average of the food consumed over that time (Stenhouse and Baxter, 1979; Manolagas, 2000). This slow rate of turnover means that the variation in the collagen values is less than the actual change in the diet. Therefore, the slight correlation with age in the isotopic data reflects a much larger dietary gradient over time.

Figure 5.4 shows the trend for the $\delta^{15}N$ data, and statistical analysis indicates that 15-30 year-old females have lower $\delta^{15}N$ values than > 45 year-old males. The reason for the distinction between young females and older males is not clear, unless it is considered within the context of one's status within Roman society. As discussed above, the perspective of medical and philosophical writers was that the diet of women should be restricted for 'health' reasons. The 15-30 age group also represents women in their peak reproductive years, and perhaps these differences reflect dietary restrictions surrounding pregnancy and childbirth. Greek and Roman writers appeared to have recognized the need of pregnant women to eat well and exercise regularly, although 'eating well' was not clearly defined, other than the recommendation to eat 'hot and dry' instead of 'cold and wet' foods (Pomeroy, 1995; Garnsey, 1999). The higher $\delta^{15}N$ values of the older males are, again, likely related to the status of older males, affording them the opportunity to consume a larger proportion of ^{15}N-enriched foods in their diet.

The carbon data from collagen indicate that the subadults (5-15 years) have $\delta^{13}C$ values that are consistently more negative than males in nearly all the older age categories, and that $\delta^{13}C$ values are also depleted among females in the 30-45 year-old category (Table 5.4). The isotopic values of the subadults can again be understood in terms of the social relationships and status of children in Roman society. Nielsen (1998) argued that children were not widely discussed with respect to 'family life' and dining practices in the pre-Christian literature, because the idea of the family unit was not prevalent until Christianity became more widespread and the ideal of the parent-child bond was strongly developed. Interestingly, Nielsen (1998) used inscriptions found on tombs at Isola Sacra to support her argument that the 'nuclear family' (i.e., father, mother, and children) was only infrequently commemorated on tombs; moreover, the inscriptions more commonly mentioned relationships between the patron of the tomb, his extended family, freedmen, and slaves. This is not to say that the commemoration of deceased children was rare and, in fact, there are many examples of elaborate memorials to children from the Roman period (see discussions by Saller and Shaw, 1984; Walker, 1985; Montanini, 1991; and Huskinson, 1996).

There are a number of comprehensive reviews of childhood that examine the role that children played in Roman social life (e.g., Néraudau, 1984; Wiedemann, 1989; Rawson, 1991). There is, however, very little discussion of specific dietary practices related to children after they had been weaned, other than the occasional reference to foods for young children. What can be gleaned from this information is that children, like women, were perceived as weak and feeble-minded, and that they had similar

'humours' (Wiedemann, 1989). According to the Roman historian Tacitus, children were expected to eat a more frugal type of food in keeping with their inferior status, although specific foods were not mentioned (Bradley, 1998).

Childhood ended when individuals reached the age of marriage, 12-15 years for girls and slightly older for boys, although some ancient authors recommended marriage as late as 18 years of age (Casson, 1998; Garnsey, 1999). One might expect to see a gradual shift in dietary patterns in association with the changing roles of young adults in Roman society. It was recommended, however, that young girls be kept on a simple and restricted diet in order to control their sexual development (Garnsey, 1999). Unfortunately, sex-related differences in children and pre-pubescent young adults cannot be examined because of the lack of sexually dimorphic characteristics in the skeletons.

The overall age-related pattern of the isotopic data is seen clearly in Figures 5.7 and 5.8, which show the combined rib and femur data plotted against age-at-death. Even with the reported variability between the different skeletal elements (Section 5.2), there is a clear isotopic distinction between individuals younger than 2 – 3 years of age and the rest of the sample. The reasons for this are discussed in Section 7.1.4.

Burial Type

The $\delta^{15}N$ and $\delta^{13}C$ values (Table 5.5) indicate that individuals in different burial types have similar isotopic values. The only exception is the group from the amphorae burials, who are largely represented by subadults, so the variability in isotopic values is probably age-related. The $\delta^{13}C$ values are remarkably consistent between burial types, with a maximum variation of 0.1‰, excluding the 'unknown' and 'amphorae' categories. The $\delta^{15}N$ data are slightly more variable, with the highest values among individuals in the 'cappucina' burials, and the lowest in the 'soil' burials (with the 'amphorae' burials excluded).

If different burial types accurately reflect the status of individuals during their lives, then either social status at *Portus Romae* did not differentially affect access to food, or the isotopes do not distinguish the differences, because all individuals had similar isotopic values regardless of burial type. Isotopes have been able to distinguish 'elite' versus 'non-elite' diets in previous studies of archaeological samples. White (1994) found that a male and female from 'elite' tomb burials at Lamanai, Belize, had distinct $\delta^{13}C$ values from the rest of the non-elite individuals, and the male also had a distinct $\delta^{15}N$ value. Richards and coworkers (1998) also found that individuals buried in late Roman (4^{th} c. AD) mausolea and lead-lined coffins from Poundbury, England, were isotopically distinct from individuals buried in simple wooden coffins. This evidence suggests that status-based differences in diet can be detected isotopically.

Alternatively, if individuals buried both within and between the tombs represent all levels of Roman society, then there is no clear status-based distinction between

different burial types. The lack of variability related to burial type would, therefore, not be surprising. There is evidence from the Isola Sacra cemetery that the latter is more likely the case, and is related to burial practices of the Roman period. Inscriptions on some of the tombs indicate that the individuals buried therein were patrons of the tomb along with their family members, but sometimes freedmen and slaves were included (Calza and Becatti, 1974). Large tombs, like those found at Isola Sacra, were costly to build and maintain and sometimes were built by *collegia*, groups of individuals who would contribute funds for a collective tomb (Morris, 1992). In these cases, it would still be necessary to have the funds to reserve spaces within a tomb, but those who eventually ended up in the tomb were interred there at the discretion of the patron(s).

This highlights a general issue concerning the interpretation of burial structures and commemorative styles and what we can truly interpret about wealth and status in past societies. Nielsen and coworkers (1989) argue that 'middle class' or 'common' people could have afforded the cost of Athenian grave monuments, so the assumption that grave monuments are indicative of wealth or high social status may be misleading. The use of grave monuments may also more accurately reflect status aspirations rather than actual status possessed. Morris (1992) proposed that variability in tombstone styles from different areas or time periods may reflect diversity in ritual, or religious ideology, but can be misinterpreted as indicative of social status. The use of grave markers in ancient Greece as expressions of status and status aspirations has also been examined by Cannon (1989). He argued that there were cycles of increased status distinction in mortuary display through the elaboration of grave markers followed by trends towards restraint

(*ibid.*). In addition, changes in mortuary styles over time represent competitive display between social classes, with the lower status members of society emulating the styles of those in the upper classes (*ibid.*). The implication for the Isola Sacra sample is that it may not be possible to infer the status of individuals based on burial type, particularly when the information concerning the chronological relationship between different burial types is unclear.

7.1.3 The Apatite Data

The lack of variability between males and females in $\delta^{13}C_{apatite}$ values is not surprising since mean $\delta^{13}C_{apatite}$ values vary by only 0.1‰ between the sexes. Similarly, the lack of a positive correlation between the collagen and carbonate data is not unexpected due to the comparatively small amount of variation in the $\delta^{13}C$ values in the Isola Sacra sample. If there is relatively little variability in a data set, then there may not be any correlation between the data. Another reason for the lack of correlation between the $\delta^{13}C$ collagen and apatite values is related to differences in trophic levels between individuals in the same sample. It has been suggested that the amount of spacing between bone collagen and apatite can be used as an indicator of trophic level differences within a sample (Kreuger and Sullivan, 1984). Large $\delta^{13}C_{apatite\text{-}collagen}$ spacing reflects a more herbivorous diet, whereas small $\delta^{13}C_{apatite\text{-}collagen}$ spacing reflects a more carnivorous diet. The average $\delta^{13}C_{apatite\text{-}collagen}$ spacing in the Isola Sacra femur sample is 7.4‰, which

approximates the value expected for an omnivorous diet (7‰) (Krueger and Sullivan, 1984).

The $\delta^{13}C_{apatite\text{-}collagen}$ spacing of most of the subadult (5-15 years) data tends to be the largest in the sample (~ 8-9‰), and at the same time subadults have low $\delta^{15}N$ values. This pattern appears to suggest, like the collagen data, that subadults were consuming a predominantly C_3–based terrestrial diet. This suggests that the subadults from *Portus Romae* were eating a 'simple and frugal' diet in accordance with their status in Roman society.

The older members of the sample show more variable $\delta^{13}C_{apatite\text{-}collagen}$ spacing. These results suggest that the most of the Isola Sacra subadults were eating at a lower trophic level than many of the adults in the sample. If individuals within a sample are eating at different trophic levels, there will be a correlation between $\Delta^{13}C_{a\text{-}c}$ and $\delta^{15}N$ (Wright and Schwarcz, 1996). There is a significant negative correlation between $\Delta^{13}C_{a\text{-}c}$ and $\delta^{15}N$ ($r = -.386$, $p = .005$). These results do not necessarily indicate that the subadults were eating a purely plant-based diet. Figures 5.13 and 5.14 illustrate that the subadult values, characterized by relatively low $\delta^{15}N$ levels and large $\Delta^{13}C_{a\text{-}c}$ spacing, are still not as low as the data from the faunal samples. This suggests that subadults may have been getting their protein from animal sources, either as meat or as animal byproducts, like eggs or cheese.

Studies of other human skeletal samples have found similar overall differences between the $\delta^{13}C$ of apatite and collagen. Dupras' (1999) study of diet in the Dakhleh Oasis, Egypt, found a $\delta^{13}C_{apatite\text{-}collagen}$ spacing of 6.0‰, and concluded that the population

consumed an omnivorous diet. Wright and Schwarcz (1996) found an average $\delta^{13}C_{apatite-collagen}$ spacing of 3.4‰, an unexpected result from a population of maize consumers. The authors concluded that diagenetic alteration of bone apatite had affected the $\delta^{13}C$ values (*ibid.*). In general, the apatite data from the Isola Sacra sample indicate that the sources of carbon in the adult diet were much more varied than those in the subadult diet.

7.1.4 Pattern of Breast-feeding and Weaning of Infants at *Portus Romae*

The isotopic analysis of the ribs found a clear pattern of enriched $\delta^{13}C$ and $\delta^{15}N$ values in the youngest members of the skeletal sample. Statistical analysis indicates that $\delta^{13}C$ and $\delta^{15}N$ are significantly higher among individuals younger than 2 years of age than among those older than 2 years of age (Table 5.12).

Previous studies of weaning patterns in skeletal samples have found increasing $\delta^{15}N$ levels between individuals aged '0' (fetal/neonate) and slightly older infants, reaching a plateau that is approximately 3‰ over maternal levels. This is interpreted as a breast-feeding signal (e.g., Herring *et al.*, 1998; Katzenberg and Pfeiffer, 1995). This pattern represents the onset of breast-feeding and a leveling-off while the infant is being breast-fed, followed by a decline in isotopic values as breast milk is gradually removed from the infant diet (*ibid.*). The higher $\delta^{15}N$ values in infants is related to the trophic level effect. Nursing infants are enriched by approximately 3‰ over maternal $\delta^{15}N$ levels, because they are consuming the tissues of the mothers through breast milk (Fogel *et al.*, 1989). As infants begin to breast-feed at birth, their $\delta^{15}N$ levels become more positive until they are approximately one trophic level above their mothers. The decline

in $\delta^{15}N$ values reflects the gradual drop in trophic level with the removal of breast milk from the diet.

The maximum range of $\delta^{15}N$ values in the rib data is approximately 4‰, which is slightly larger than the expected trophic level shift of 3‰. The reason for this discrepancy is unclear and may be related to physiological factors, although higher trophic level shifts have been observed in other animal species (e.g., Minagawa and Wada, 1984). Another explanation is that mothers of infants with high $\delta^{15}N$ values have higher-than-average $\delta^{15}N$ values themselves, which would raise the infants' overall $\delta^{15}N$ levels. However, the $\delta^{15}N$ data from the adult femur sample indicates that females in the 15-30 year-old age category have the lowest $\delta^{15}N$ values of the entire sample (Table 5.4). One further observation of interest is that the single neonate analyzed has a slightly lower $\delta^{15}N$ value than the older infants, but it is still higher than the average adult value. Postmortem degradation of the collagen may have altered the isotopic signal in this individual, and the effect of diagenesis is to increase $\delta^{15}N$ levels in bone. No C:N ratio could be obtained because all of the sample was used for stable isotope analysis, so it possible that diagenesis has increased this $\delta^{15}N$ value. The collagen yield for this individual (SCR 459) is high (16.75%), which suggests that collagen preservation is good, so the reason for the higher level is still unclear.

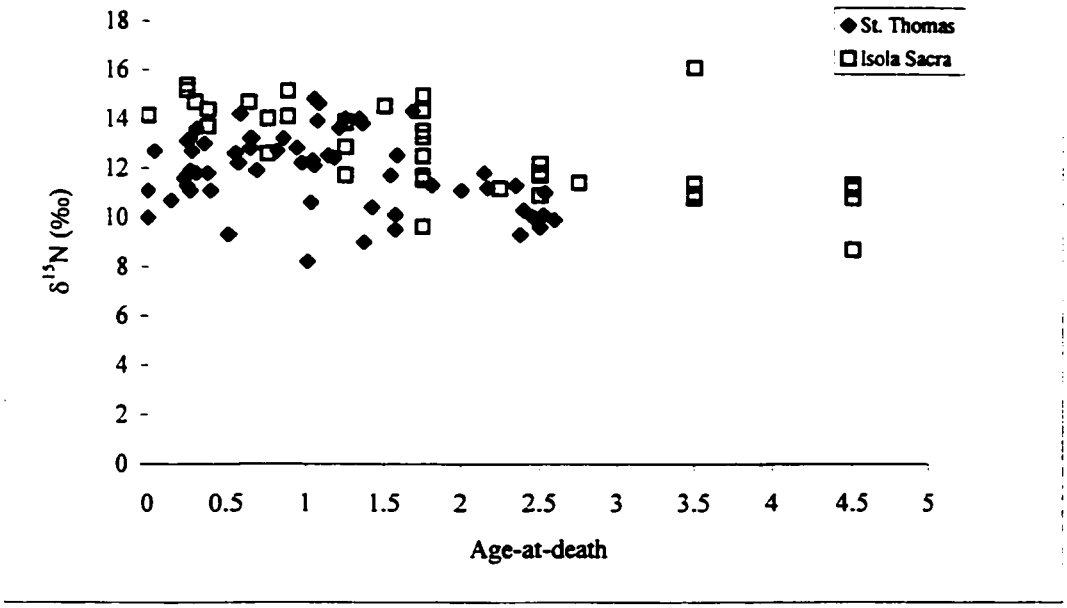
The rib $\delta^{15}N$ data show a slight increase in $\delta^{15}N$ values between the individual aged '0' (fetal/neonate) to 'peak' values at approximately 3 months of age. After this, there is a progressive decline in the values up to 2 years of age, but there is no apparent 'plateau' of the isotopic data. This suggests that breast milk alone was the only food

source in the infants' diet for a short period of time, followed by an extended period of weaning. Figure 7.2 compares the pattern of $\delta^{15}N$ data of the Isola Sacra sample to a 19th century sample from Belleville, Ontario (data from Herring *et al.*, 1998). Both studies use ribs for the analysis, but only values up to three years of age were reported for the Belleville sample.

The interpretation of the $\delta^{15}N$ pattern from the Belleville data, in conjunction with parish records, was that by the age of 14 months there was evidence of reduced levels of breast milk in the diet, and that the transition from breast milk to solid foods occurred over a 9-month period (*ibid.*). The Isola Sacra data indicate that there was a different pattern of weaning, characterized by a shorter period of breast-feeding, followed by a longer stage during which breast milk was gradually removed from the diet, lasting from just after 3 months to 2 years. Those individuals with low (i.e., close to the adult mean) $\delta^{15}N$ values during this period may have been weaned at an extremely young age, or were never breast-fed at all.

It is possible that the small sample of infants in the 0 - 6 month age range (n = 6) in this study was not large enough to pick up the trend observed in other studies. Alternatively, this pattern may reflect a slightly different pattern of mortality in the Isola Sacra sample, and the observed variability of the $\delta^{15}N$ data is related to the inability of the infants to nurse due to a variety of factors.

Figure 7.2 - $\delta^{15}N$ versus age-at-death for the St. Thomas cemetery sample[1] and the Isola Sacra sample



[1]Herring *et al.*, 1998

The limitation of this analysis is that it is not known if the cause of death was related to the inability of the infants to feed even though breast milk was available, or due to the absence of maternal breast milk associated with complications during childbirth (Herring *et al.*, 1998). Infant mortality is also related to the exposure of infants to new pathogens with the introduction of new foods and other sources of infection. The process of weaning compounds the effects of inadequate nutrition, infectious disease, and stress on the infant (McElory and Townsend, 1989). A further limitation is that we do not know the rate of bone turnover in infants and young children, so it is not clear how much time is required for the bones of an infant to register the introduction or removal of breast milk from the diet. It is known that infants will increase in length by 50% and triple in

weight during the 1st year of life, so collagen is obviously being deposited at a rapid rate (Herring *et al.*, 1998).

The $\delta^{13}C$ levels are also higher in infants under 2 years of age, which is interpreted to be the carbon trophic level effect of 1‰ between consumer and the food consumed (i.e., breast milk). As with the nitrogen data, there is considerable variability in the $\delta^{13}C$ data for individuals under 2 years (Figure 5.20), although the total range of variation of $\delta^{13}C$ values in this range is approximately 1‰. Wright and Schwarcz (1998), however, found depleted $\delta^{13}C_{apatite}$ values in teeth from Guatemala formed during the first year of life (1st molars) compared to teeth formed later in childhood (premolars and 3rd molars). They proposed that the depleted $\delta^{13}C$ values were caused by the ingestion of lipid-rich breast milk (*ibid.*).

The explanation for this contrasting pattern is related to the tissues being analyzed, and what portion of the diet those tissues represent. Recall that collagen represents the protein component of the diet, and apatite represents the total diet (protein, carbohydrate, and lipids) (Ambrose and Norr, 1993). The apatite data in Wright and Schwarcz's (1998) study therefore reflect the presence of $\delta^{13}C$-depleted lipids in the breast milk. Infants that are nursing are getting all of their nutrients from protein-rich breast milk, so they do not need to get material for collagen synthesis from any other portion of the diet (e.g., lipids). The result is that the $\delta^{13}C$ levels in collagen are not depleted, because of the special conditions of breast-feeding infants. Thus, infants follow the pattern proposed by Ambrose and Norr (1993) whereby collagen represents the protein component of the diet. This is not necessarily the case for adults, who may not

obtain all the amino acids they need from their diet, and need to synthesize non-essential amino acids from other nutrient sources (Schwarcz, 2000).

Another interesting observation about the carbon data is that they are, at the same time, reflecting the introduction of ^{13}C-depleted weaning foods into the infant diet. After 2 years, the $\delta^{13}C$ values are closer to the adult female mean ($-18.9 \pm 0.3‰$), which must be interpreted with caution, but an interesting pattern is that the data from infants aged 2 to 3 years have $\delta^{13}C$ values that are slightly lower than the adult mean. This pattern suggests that infants who were being weaned were fed foods depleted in ^{13}C, producing more negative $\delta^{13}C$ values. What was the composition of these isotopically depleted weaning foods?

Wet-nursing contracts in Roman Egypt and medical texts recommended cows' milk as a weaning food between 6 and 18 months of age (Fildes, 1986). There are also literary references to the use of mares' milk as a supplemental source of food for infants (*ibid.*). The faunal data indicate that cows have an average $\delta^{13}C$ value of -20.7‰ (from bone collagen), so the 2-3 year-old infant values are still enriched by 1.6‰. If they were consuming only cereals in their weaning diet, it would be expected that their $\delta^{13}C$ values would be closer to the levels of herbivores. Unfortunately, there was not enough bone to analyze the $\delta^{13}C_{apatite}$ levels in these infants, which might further clarify the pattern found in the collagen data. Even in the older age categories, the $\delta^{13}C$ values are sometimes below the adult mean, similar to the pattern observed for subadults in the femur sample (see Figure 5.16). This suggests that from infancy through childhood, the Isola Sacra children were fed a diet with low $\delta^{13}C$ values, probably from C_3 plants and perhaps some

dairy foods. The $\delta^{15}N$ data approach the adult mean at the 2-3 year age range and the levels are more than 5‰ enriched over the mean levels of herbivores.

In general, the isotopic data agree well with the written evidence that we have for the weaning practices of the ancient Romans. The medical writer Soranus warned that infants should not be weaned too early and be fed only breast milk until 6 months of age (Garnsey, 1999). The isotopic data for Isola Sacra sample show that by 6 months of age the trend towards decreasing $\delta^{13}C$ and $\delta^{15}N$ levels is already underway, which suggests that weaning began prior to 6 months of age. A potential risk for newborns was the belief by ancient medical writers that infants should not be fed until two days after birth and that colostrum initially produced by mothers was unhealthy for the infant (*ibid.*). However, Aritsotle also wrote that breast-feeding should begin on the first day, but not necessarily by the mother (Fildes, 1986). It is now known that colostrum and breast milk are essential to the health and survival of the infant, providing immunoglobin A, antibodies, hormone, proteins, and other substances necessary for development and resistance to pathogens (Stuart-Macadam, 1995). It is clear that Romans were familiar with, if not accustomed to, high infant mortality in the first few weeks of life. The actual naming of the infant did not occur until eight (for females) or nine (for males) days after birth, since it was considered pointless to name a child until it had survived the first week of life (Wiedemann, 1989).

It was recommended by Galen and Soranus that the duration of weaning last until approximately 2 to 3 years of age (Fildes, 1986). There is a great deal of variability in the isotopic data prior to 2 years of age, but after that point the data reflect the absence of

breast milk and the consumption of isotopically depleted foods like C_3 plants and animal products. Soranus recommended initially feeding infants bread mixed with milk, honey and water, or wine, later followed by porridge made from spelt (a species of wheat) or an egg (Garnsey, 1999). Again, this is consistent with the evidence from the isotopic data.

Garnsey (1999) contends that there was a high incidence of morbidity and mortality in children under the age of five in Graeco-Roman society, which he attributes in part to infant feeding practices. The pattern and timing of breast-feeding and weaning clearly have an impact on the health and survivorship of infants and young children. It cannot be determined from the isotopic data whether or not the weaning foods were nutritionally inadequate. What can be said is that the pattern of breast-feeding and weaning is consistent with descriptions in the ancient sources, and this may have had implications for health. Studies of modern human populations have shown that protein is particularly important during the weaning process when the protein-rich breast milk is being removed from the infant diet, because infants and children need more protein by body weight than adults for growth and development (McElroy and Townsend, 1989).

One of the most striking contrasts between the rib and femur data is the consistent linear relationship between $\delta^{13}C$ and $\delta^{15}N$ in the subadult rib sample (Figure 7.3). The linear distribution of points in the rib data is characteristic of a diet consisting of varying proportions of two main food sources (Schwarcz, 1991). The data appear to show the transition from a pure breast milk diet to a fully weaned diet of childhood foods. The limitation is that we do not know the isotopic 'signatures' of breast milk or of the foods

consumed by children after they were fully weaned, so it can only be hypothesized that the two extreme points are represented by these two food sources.

Figure 7.3 – $\delta^{13}C$ plotted against $\delta^{15}N$ for the rib and femur (sexes separated) data

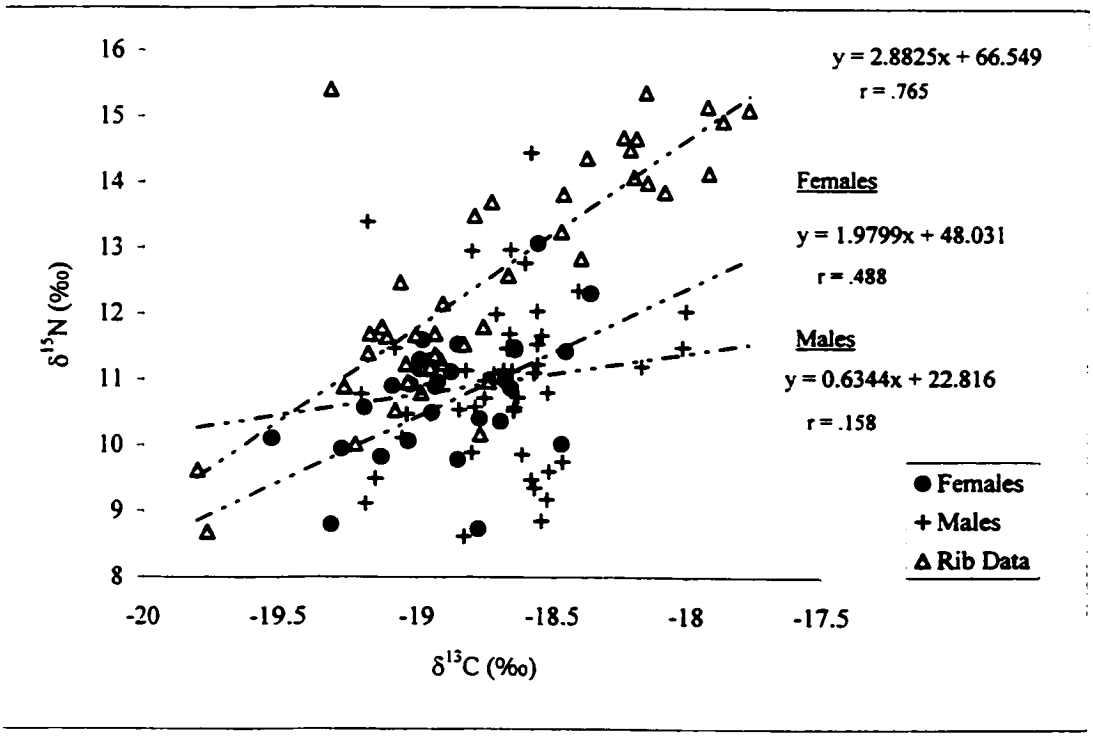


Figure 7.3 is reproduced from Figure 5.21, but with the sexes separated. There is a strong correlation between $\delta^{15}N$ and $\delta^{13}C$ in the rib data (r = .768). The femur data of the adult males show a much more scattered dispersion, which probably reflects a greater diversity of foods in the diet. Interestingly, the slope of the female data more closely resembles the slope of the rib data. The decreased correlation between $\delta^{13}C$ and $\delta^{15}N$ in

the adult data (both males and females) may be because they are no longer getting all their protein from one abundant source (i.e., breast milk), like the infants. Consequently, the production of amino acids may require that carbon atoms are obtained from a variety of sources, including lipids and carbohydrates, which means that collagen may actually reflect more than just dietary protein under these conditions. What this suggests is that Krueger and Sullivan's (1984) model that collagen = dietary protein may be more applicable to the infants. Adults may need to derive carbon atoms from a variety of dietary sources, and not just protein (Schwarcz, 2000).

7.2 Dental Analysis

7.2.1 Comparing the Isola Sacra data with Other Skeletal Samples

A perpetual problem in skeletal studies is that age-related pathological conditions, like caries and AMTL, require that the age distribution of comparative samples is known, so that differences in the composition of the samples do not affect the interpretation of results. Consequently, there are only a limited number of studies that can be compared with the Isola Sacra sample.

Manzi and coworkers (1999) analyzed a subset of the Isola Sacra skeletal sample (n = 65), and compared the results with the sites of Lucus Feroniae (1^{st} – 3^{rd} c. AD) and La Selvicciola (7^{th} c. AD). There are a number of problems with the subset of the Isola Sacra sample they used that should be identified. First, the determination of sex was based on cranial morphology alone, which is not as reliable as some of the postcranial

elements (e.g., the os coxa) for sexing human skeletal remains. It is also possible that the small size and considerably larger proportion of males (n = 42) over females (n = 21) may have affected their results. The methods used by Sperduti (1995) to determine age and sex of the entire sample involved a combination of morphological characteristics from the both the cranial and postcranial remains. The samples used by Manzi and coworkers (1999) had a greater proportion of adults in the 20-30 age category (30-39%) than in this study, which has 18% in the 20-30 year range. The distribution in the older age categories is approximately the same, but Manzi and coworkers (1999) did not include any permanent teeth from individuals younger than 20 years of age. The data from this previous study will be discussed in order to examine discrepancies in the findings.

7.2.2 Calculus

Calculus is the only condition studied that shows a statistically significant difference between males and females. If only the percentage of teeth with calculus is considered, females (79.23%) have more teeth affected by calculus than males (72.92%); however, as with Total Percent Caries, this does not take into account individual variation in the number of teeth present and how many teeth are affected by calculus.

The 'Calculus Rate' and 'Modified Calculus Rate' used in this study are an attempt to quantify the calculus experience within the Isola Sacra sample. Both the mean Calculus Rate and Modified Calculus Rate indicate that the differences between males and females are statistically significant, with females having consistently higher rates in

all age categories, except in the 30-40 year category (Tables 6.5 and 6.6). The actual amount of calculus on the Isola Sacra teeth is actually quite small, even though almost 75% of the teeth in the sample had some degree of calculus. The isotopic data suggest that the Isola Sacra males ate a higher proportion of marine foods in their diet, while females and children probably consumed a more terrestrial diet composed of C_3 plants and animals. It may be that the combination of carbohydrates and protein from terrestrial food sources encouraged the formation of a low level of calculus, especially for females.

In general, the diet of the people at *Portus Romae* did not appear to promote significant amounts of calculus on the teeth, although there was something responsible for the greater prevalence of calculus among the women. Lieverse (1999) pointed out that assuming a direct association between levels of protein and carbohydrate in a diet and the formation of calculus may be too simplistic, and that high fat and high carbohydrate diets may also lead to calculus formation. Littleton and Frohlich (1993) proposed a multifactorial explanation for variability in the amount of calculus between populations, including the composition of the 'meal', food preparation techniques, and levels of oral hygiene. Other studies of dental health in past populations have compared overall levels of calculus (low, moderate, high) between different skeletal samples, in association with evidence for differences in subsistence practices (e.g., Hillson, 1979; Allison, 1984; Lukacs, 1989). Lieverse's (1999) survey of these studies showed that calculus levels cannot be predicted based on the general dietary characteristics of a population (i.e., hunting/gathering versus agriculture), and that factors like saliva flow and mineral content of water may also have an impact on calculus formation.

The only other study that has looked at calculus in Roman period populations is the one by Manzi and coworkers (1999). It is unwise to compare the results of the two studies because of the different methods used to collect dental calculus data. Manzi *et al.* (1999) used the scoring system by Dobney and Brothwell (1987) and the present study used a modified version of Brothwell's (1981) system to calculate 'Calculus Rate' and 'Modified Calculus Rate'.

Part of the problem is that the method of scoring calculus using Brothwell's (1981) 'low', 'medium', and 'high' scoring system does not adequately quantify the amount of calculus present. An improvement on this method is to score each side of the tooth separately, and develop aggregate scores for each tooth, which was done in this study. Of course, developing another scoring system restricts the amount of comparison that can be made with other studies, but is necessary to work towards a better understanding of the true prevalence of calculus in a sample.

7.2.3 Dental Caries

Caries Rate and DMI calculations reveal that there are no statistically significant differences between males and females in the Isola Sacra sample. This is consistent with other dental health indicators in this study that show little difference in the prevalence of dental lesions between the sexes. There is, however, a slightly different pattern of carious lesions between males and females. Females tend to have more smooth surface and occlusal surface lesions, while males have more interproximal surface lesions. The slightly lower levels of tooth wear in females (Section 7.2.5) may explain the higher

prevalence of occlusal surface caries, because less wear leaves the pits and fissures on the occlusal surface intact, which are prime locations for bacteria to accumulate.

Caries is an age-progressive disease process, so the increase in Caries Rates and DMI with increased age-at-death is to be expected. Caries Rates are similar between the sexes in all age categories, except in the 50+ age category, where males have a much higher Caries Rate (Figure 6.7). The pattern of DMI is slightly different with increasing age. Males have higher DMI values in the young age categories, but after 40 years of age females have higher DMI values (Figure 6.8). This pattern can be explained by the increase in AMTL among females in the older age categories. Both non-parametric and parametric statistical analyses of the data confirm that these differences are age-related.

Manzi and coworkers (1999) reported that Isola Sacra females had a higher number of carious teeth (4.38%) than males (3.86%). In contrast, the present study shows that there is a slightly lower prevalence in females (5.49%) than in males (5.99%), but that the levels are very close. The discrepancy between the two sets of data is not large, although there is clearly a lower estimated prevalence in the earlier study. The lack of variability between males and females in the dental health data is consistent with the low level of variability in the diet represented by the isotopic data.

Caries Rate and DMI have not been reported for samples from the ancient Mediterranean. Instead, the prevalence of caries is commonly reported as Total Percent Caries. As mentioned above, a problem arises when the age compositions of possible comparative samples are unknown, so there are only a limited number of studies that can

be directly compared to the Isola Sacra sample. Table 7.2 presents comparative data from sites in Italy and Greece.

Table 7.2 – Total Percent Caries in the Isola Sacra permanent dentition and other skeletal samples from Italy and Greece

Sample	Sample (n)	Period	Obs. Teeth (n)	Carious Teeth (n)	Total % Caries
Alepotrypa Cave, Greece[1]	15	5000-3200 BC	81	4	4.94
Isola Sacra	**365**	**1st - 3rd c. AD**	**5548**	**297**	**5.35**
Isola Sacra[2]	64	1st - 3rd c. AD	872	35	4.01
Lucus Feroniae[2]	25	1st - 3rd c. AD	942	57	6.05
Herculaneum[3]	96	79 AD	***	***	♀ - .92 ♂ - .68
Pompeii[4]	11	79 AD	133	12	9.02
La Selvicciola[2]	31	7th century AD	912	115	12.61

[1]Papathanasiou *et al.*, 2000
[2]Manzi *et al.*, 1999
[3]Bisel, 1999
[4]Henneberg *et al.*, 1996

All of the samples, with the exception of La Selvicciola, have levels of Total Percent Caries under 10%. The extremely low number of carious teeth in the sample from Herculaneum may reflect the unique mortality profile of the skeletal sample. All of these skeletons were recovered from caves at the coastal edge of the town, and were presumably all killed at exactly the same time by the eruption of Vesuvius in 79 AD (Bisel, 1991).

Averages calculated from Turner's (1979) survey of world-wide caries rates indicate that mixed foraging/agriculture populations have frequencies of approximately 4.4%, whereas agricultural communities have almost double the amount, at 8.9% (in Larsen, 1999). The prevalence of caries reported in samples practicing maize agriculture ranges from 15 to 48% (Kelley *et al.*, 1991; Larsen *et al.*, 1991). The levels from Isola Sacra and most of the other samples from the Roman period are clearly at the low end of the range expected for agricultural societies.

The isotopic evidence for the consumption of marine resources in the Isola Sacra sample may partially explain the low levels of caries in the people from *Portus Romae*. Sealy and coworkers (1992) concluded that lower carbohydrate intake and the potentially cariostatic effects of marine foods (i.e., high levels of fluoride in fish) were responsible for lower levels of dental caries in populations with a significant dietary marine component. The quality and texture of the carbohydrates consumed may also play a role in the lower prevalence of caries. Commercially produced bread was made from different types of flour, the quality of which depended on the number of grindings and siftings (White, 1988). Few people could afford the highest quality bread, so the majority of the population was probably eating 'secondary' bread, made from the coarser products of the milling process (*ibid.*). This dense, possibly gritty, bread was probably not as cariogenic as softer foods made from grains, like porridge.

7.2.4 Abscesses

The development of an abscess is the result of a complex interaction between tooth wear, caries, and AMTL (Littleton and Frohlich, 1993). The Isola Sacra skeletal sample has generally low to moderate levels of all three variables, so it not surprising that the prevalence of abscesses is also fairly low, occurring in 0.88% of observable sockets, and in 12.81% of the individuals studied. In contrast, the study by Manzi and coworkers (1999) found a considerably smaller number of sockets (0.2%) and individuals (4.7%) with alveolar abscesses. The discrepancy is, again, likely related to the characteristics of the sample used in the earlier study, and the result is an underestimation of the prevalence of abscesses. The number of individuals with abscesses was larger in the other Roman sample from Lucas Feroniae (12.0%), which is comparable to the results of the present study. The reported prevalence (by tooth) from the site of Herculaneum is also comparable to the Isola Sacra data (♀ - 0.66%; ♂ - 0.73%).

As with the other pathological lesions examined here, the prevalence of abscesses is age-related, characterized by a sharp increase in the number of individuals with abscesses after 40 years of age (Table 6.16). The prevalence of abscesses between the sexes is almost identical (♀ - 14.96%; ♂ - 14.89%). Previous studies of abscesses have also found very little variation in the prevalence of abscesses between males and females (e.g., Costa, 1980; Turner, 1979; Lukacs, 1989). Again, these results are consistent with the low levels of variability in the other dental health indicators and with the isotopic data.

7.2.5 Tooth Wear

The overall level of wear in the Isola Sacra permanent dentition is moderate for all teeth. A tooth wear score was calculated for each individual and for each tooth type, so that variability between sex and age categories could be examined (Tables 6.19 and 6.20). This analysis shows that males have slightly higher tooth wear scores for all teeth, but none of the differences are statistically significant. The average score for males is 8.48 (S.E. = .37) and the average for females is 7.59 (S.E. = .26).

Tooth wear is not a pathological process, but rather a normal consequence of the interaction of teeth with the foods consumed (Powell, 1985). The Isola Sacra results show that levels of wear increase in each successive age category (Table 6.20), and that these differences are statistically significant. The one limitation of the Kruskal-Wallis test is that while it determines if the variation is statistically significant, it cannot identify the source of variability in the sample. Normalizing the data using a logarithm transformation permits the analysis of the data using a parametric test (ANOVA) that can pinpoint which groups within the sample are significantly different from each other. These results indicate that significant variation exists between all age groups, except in the 40-50 and 50+ age categories. Individuals in the 50+ age group still have higher levels than those in the 40-50 age range, but the difference is not significant. Perhaps by this age, the choices of foods consumed did not cause as much wear on the dentition. As with caries, the quality and consistency of the food consumed influences the level of tooth wear. The generally moderate levels of wear in the Isola Sacra sample suggests that some grit may have been introduced into the diet through the consumption of 'gritty'

foods, such as bread. In addition, higher levels of tooth wear have also been attributed to an increased reliance on seafood and the presence of sand and grit in foods (e.g., Walker, 1978; Sealy *et al.*, 1992). The marine component of the Isola Sacra diet, as indicated by the stable isotope evidence, may be partially responsible for the observed levels of tooth wear.

Once again, the problem of comparison with other skeletal samples is compounded by the age-progressive pattern of tooth wear and by the use of different standards for scoring tooth wear. Manzi and coworkers (1999) used the Smith (1984) system for scoring all teeth, and reported the scores as percentages of tooth types with light (1-2), medium (3-4), or heavy (5-8) wear. The average scores for each tooth type are not reported, so it is difficult to make any direct comparisons. They did not find any dramatic differences in wear between Isola Sacra, Lucus Feroniae, and La Selvicciola, although anterior tooth wear was slightly higher in the two Roman period samples and was attributed to a diet rich in meat (*ibid.*).

In this study, average tooth wear scores indicate that the anterior teeth do have slightly higher average scores than the posterior dentition (Table 6.19). Incisors have an average score of 3.34 out of 8 (= 48.6%), when compared to canines (38.9%), and premolars (36.5%). Molars have an average score of 15.76 out of 40 (= 39.4%). This general comparison indicates that the wear on the incisors is higher than on any of the other teeth. Hinton (1981) found that anterior tooth wear was equal to, or more severe than, posterior wear in prehistoric hunter-gatherers, and that intensive agricultural populations had the opposite pattern.

It is not clear why individuals in the Isola Sacra sample have heavier anterior tooth wear, because they clearly were not hunter-gatherers. A pattern of greater anterior tooth wear has also been found in skeletal samples from coastal Holocene sites in South Africa (Sealy *et al.*, 1992). Patterns of heavier anterior wear have been observed in other prehistoric and modern populations, and are attributed to dietary and non-dietary use of the teeth (i.e., abrasion caused by using teeth as tools) (Molnar, 1972; Larsen, 1999). Studies of Paleolithic, Neolithic, and Iron Age samples from Italy have found heavy anterior tooth wear, which has also been attributed to the use of teeth as tools (e.g., Salvadei and Macchiarelli, 1983; Minellono *et al.*, 1980; Fabbri and Mallegni, 1988, cited in Robb, 1993). It is possible that the heavy anterior tooth wear in the Isola Sacra sample, particularly among the males (see Figure 6.18), may be related to the extra-masticatory use of teeth.

Hartnady and Rose (1991) compared molar wear scores for prehistoric North American samples, using the scoring system developed Scott (1979). Once again, it is difficult to make direct comparisons between samples when the age structures of the skeletal series are not similar, or are not known, yet the Isola Sacra sample has lower molar wear levels than all of the samples studied. Lower overall levels of tooth wear have been associated with the increased consumption of cultivated plants and changes in associated food preparation techniques (see Larsen, 1999).

7.2.6 Antemortem Tooth Loss

The AMTL data indicate that females have slightly higher levels of AMTL (7.81%) than males (6.45%), but this is not statistically significant (Table 6.24). AMTL is age-progressive, and when the data are examined by age category, males actually have higher levels of AMTL in the 20-40 age range, and females have higher levels in the older age categories (Figure 6.22). It is in these older age categories that the differences between males and females become quite large, but are only statistically significant for the 40-50 year group.

AMTL can be caused by a number of pathological processes, including severe caries, heavy tooth wear, and calculus, but it is often difficult to identify the cause(s). The prevalence of caries and levels of tooth wear are higher in the Isola Sacra males, so this does not help to explain the higher prevalence of AMTL in the females. Heavy amounts of calculus can lead to gingivitis, periodontal disease, and can ultimately lead to AMTL (Lukacs, 1989). The dental data indicate that females have higher levels of calculus, based on the number of individuals affected, Calculus Rate, and Modified Calculus Rate (Section 6.2.2). It is not clear how much calculus must be on the teeth before it will have a significant impact on oral health, but most of the individuals in the Isola Sacra sample have only low to moderate levels of calculus, so this was probably not the only factor responsible for AMTL.

Survivorship may also play a role, since the largest differences in AMTL occurred in the older age categories. If females from *Portus Romae* lived longer than males, then we might expect to see higher levels of age-progressive pathological conditions in the

older age categories. It may be that levels of AMTL are reflecting the relatively longer lives of females in the sample, who survived long enough to have more teeth fall out. The limitations of aging adult skeletons at this time make it virtually impossible to tell if females in the 50+ age category are significantly older than males. If females did live longer than males, this would suggest that the overall health of females was not severely compromised by the preferential treatment of males in Roman society.

The age and sex distribution of the Isola Sacra dental sample (Figure 6.1) indicates that there are approximately equal numbers of males and females in the adult age categories. There are other samples available for comparison, but some have been compiled from different sites and the age/sex structures of the samples are not reported, so the data cannot be used. This is the case for Italian Epipalaeolithic and Mesolithic samples reported by Borgognini Tarli and Repetto (1985). Smith and Tau (1978) reported that age and sex was determined for a Roman legion sample from Israel, but the distribution was not reported, so the data are not used.

Table 7.3 compares AMTL in the Isola Sacra permanent dentition with samples from Greece and Italy with reported age distributions. The samples from Pompeii and Alepotrypa Cave are very small, but there is a generally equal distribution of individuals in the adult age categories. Manzi and coworkers (1999) found a slightly higher level of AMTL (6.8%), but is close to the calculated value from the current study (6.32%). There is no AMTL among individuals under 20 in this study, so both percentages reflect AMTL in individuals over the age of 20 years. The reported prevalence of AMTL is much larger

between the sexes (females 9.4%; males 5.7%) in Manzi *et al.*'s (1999) study than in the current study, although the pattern is still the same.

Table 7.3 –Antemortem tooth loss (AMTL) in the Isola Sacra permanent dentition and other skeletal samples from Italy and Greece

Sample	Sample Size (n)	Period	Obs. Sockets (n)	AMTL (n)	AMTL %
Isola Sacra	**285**	**1st - 3rd c. AD**	**7474**	**472**	**6.3**
Alepotrypa Cave, Greece[1]	15	5000-3200 BC	***	***	4.0
Isola Sacra[2]	64	1st - 3rd c. AD	1325	90	6.8
Lucus Feroniae[2]	25	1st - 3rd c. AD	1085	134	12.4
Herculaneum[3]	96	79 AD	***	***	♀ - 2.07 ♂ - 1.79
Pompeii[4]	11	79 AD	247	14	5.7
La Selvicciola[2]	31	7th century AD	1097	200	18.2

[1]Papathanasiou *et al.*, 2000
[2]Manzi *et al.*, 1999
[3]Bisel, 1999
[4]Henneberg *et al.*, 1996

The level of AMTL in the Isola Sacra sample is comparable to the other urban Roman population from Pompeii, however both are higher than the level found among individuals from Herculaneum (Table 7.3). The higher levels of AMTL in the Lucus Feroniae and La Selvicciola samples are attributed to lower socioeconomic conditions and poor oral hygiene (Manzi *et al.*, 1999). In general, levels of AMTL are reportedly high (e.g., up to 35%) in agricultural populations consuming a high proportion of plant carbohydrates or processed foods and are usually attributed to an increase in periodontal

disease and dental caries (reviewed by Larsen, 1999). The levels from all the Roman period populations are relatively low. It is interesting to note that most of these samples are from coastal populations, with the exception of Lucus Feroniae and La Selvicciola, which also happen to have higher levels of AMTL. An investigation of the isotopic values of these two inland populations would help to clarify the relationship between isotopic and dental data.

7.2.7 Dental Health in Relation to Burial Type

Individuals in different burial types do not have significantly different levels of dental health, with the exception of amphorae burials. The relatively large proportion of subadults in amphorae burials is most likely responsible for this variability (Figure 7.4). Although not significantly different from other burial types, individuals found in soil burials did have slightly higher levels of AMTL, caries, tooth wear and calculus (Figure 7.5). If amphorae burials are excluded, individuals in soil burials have the lowest mean $\delta^{15}N$ levels and, together with inhumation burials, have the lowest $\delta^{13}C$ levels (see Table 5.5). The multiple indicators suggest that people buried in soil graves are slightly different from the rest of the sample in terms of diet and dental health, even though each independent line of evidence is not statistically significant.

As discussed in the previous section on isotopes, it may not be possible to ascribe social status on the basis of burial structure alone. The mean ages for the different burial types are approximately the same, ranging from 30.63 (S.E. = 1.62) in tombs to 32.38 (S.E. = 1.59) in soil burials, but the actual age distributions in each burial type are

different. It is possible that the slightly older average age of the individuals in the soil burials is responsible for the pattern of higher levels of dental pathology, many of which are age-related.

Figure 7.4 – Age distribution of the Isola Sacra sample (permanent dentition) by burial type

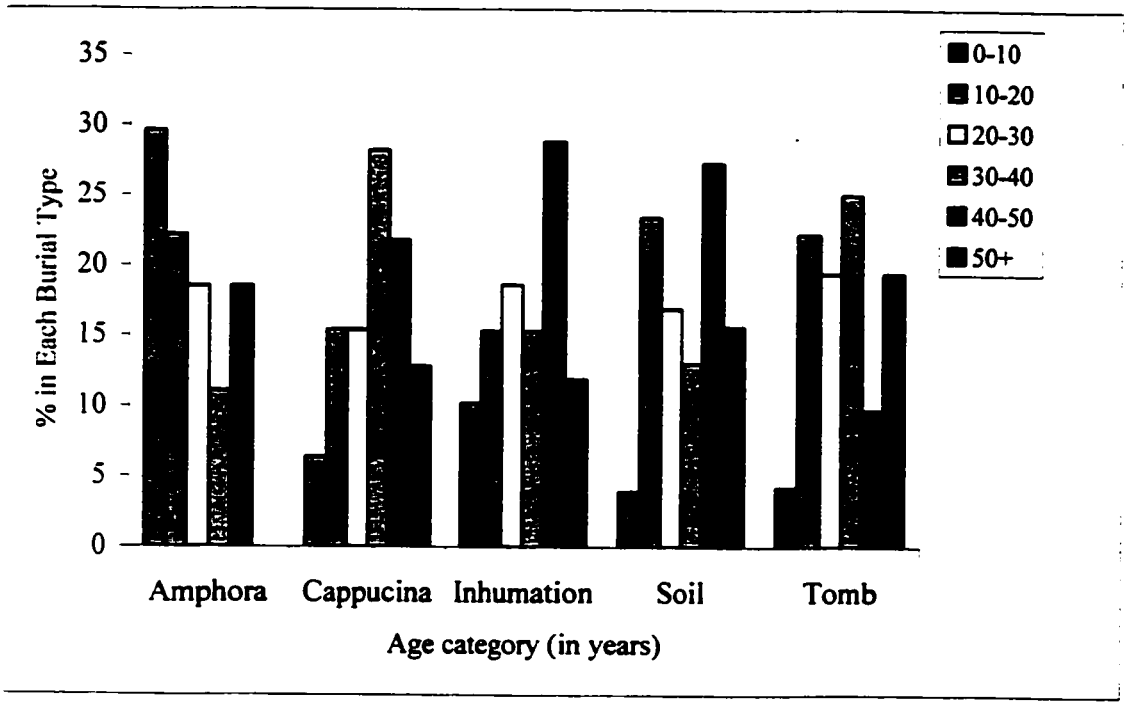
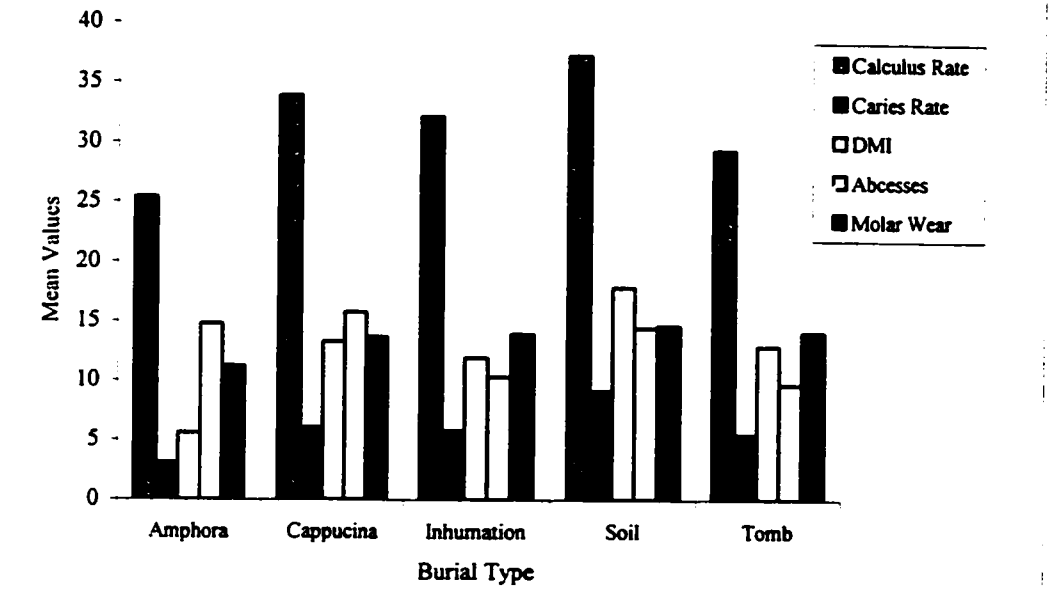


Figure 7.5 – Mean values of dental health indicators by burial type



7.2.8 Deciduous Teeth

There is no evidence of calculus or caries in individuals under 2 years of age, probably due to the relatively short amount of time that the teeth have been exposed to conditions in the oral environment. The deciduous incisors start erupting around 6 months of age and the 1st molars by 18 months (Ubelaker, 1989). All the deciduous teeth are fully erupted by approximately 2-3 years of age. However, there is already evidence of tooth wear in individuals as young as 1.5 years of age in the Isola Sacra sample, both on the incisors and the 1st molars. The isotopic evidence from the rib data suggests that the process of weaning began as early as 3 - 6 months of age, characterized by the progressive removal of breast milk and the concomitant introduction of weaning foods,

so it is not surprising to see tooth wear at a young age. The weaning foods reportedly fed to infants were soft foods like bread with milk or porridge, but some grit may have been present. Children from mediaeval England were given wood, bones, leather, or rags to chew on to ease the discomfort of teething (Williams and Cruzon, 1986), so tooth wear in infants may also be caused be non-dietary factors. In addition, Roman children were also probably being weaned with the aid of ceramic feeding vessels with spouts, like those described by Fildes (1986). It is possible that early weaning and the use of feeding vessels and teething aides may have contributed to the early onset of wear.

Both calculus and caries are present in individuals aged 2.5 years and older, which suggests that the weaning diet was composed of foods that promoted the formation of carious lesions and calculus. The calculus that is present is almost always found on the molars, and only infrequently on the canines or incisors. A weaning diet of soft foods, particularly carbohydrates, could contribute to the formation of carious lesions. These results support the infant and subadult isotopic data, which suggest that the introduction of weaning foods began early in life and children were fully weaned by around 2 years of age. Erupting deciduous teeth were exposed to soft foods that encouraged the development of calculus and caries.

Total Percent Caries for the Isola Sacra deciduous teeth is 3.97%. Table 7.4 presents comparative data, and shows that Isola Sacra has the lowest Total Percent Caries. However, if the youngest age category (0-2 years) is removed, because not all of the deciduous teeth are erupted in the mouth until 2-3 years of age, then the Total Percent Caries is 4.47%. This is comparable to a number of the samples from Iron Age and

Mediaeval Britain. One caution in interpreting these results is that although the age range is fairly restricted (2-12 years) for deciduous teeth, the age structure of the comparative samples may affect the reported caries prevalence. In most of these studies the age structure of the sample was not reported, so the results must be interpreted with caution. Studies of oral health in archaeological samples of deciduous teeth from Europe and North America have found associations between enamel defects (e.g., hypocalcifications and enamel hypoplasias) or cribra orbitalia and caries (Cook and Buikstra, 1979; Duray, 1990; O'Sullivan *et al.*, 1992). The prevalence of enamel defects in the Isola Sacra sample has not yet been systematically studied, but could potentially shed some light on these relationships.

Table 7.4 – Comparative caries prevalence data for the deciduous dentition

Sample	Time Period	# of observable teeth (n)	# of carious teeth (n)	Total Percent Caries (%)
Isola Sacra	1st – 3rd c. AD	554	22	3.97/4.47*
Romano-British[1]	55 BC – 410 AD	172	28	16.30
Anglo-Saxon[1]	9th – 11th c. AD	186	16	8.60
Kirkhill, Scotland[2]	Mediaeval	231	10	4.33
Hirsel, England[3]	Mediaeval	229	20	6.80
Iron Age British[4]	550 BC – 43 AD	137	6	4.38
Romano-British[4]	43 AD – 410 AD	212	9	4.26
Mediaeval British[4]	1066 – 1500 AD	662	35	5.29
Libben site, Ohio[5]	800-1100 AD	596	109	18.29
Prehistoric Ontario[6]	ca. 1200 – 1650 AD	.	.	13.6-29.2

[1]O'Sullivan *et al.*, 1992 – reported first primary molars only
[2]Lunt, 1986
[3]Williams and Curzon, 1986
[4]Moore and Corbett, 1973
[5]Duray, 1990
[6]Patterson, 1987

The pattern of deciduous dental health by burial type indicates that infants and children in the tomb burials have higher levels of calculus and caries, and lower levels of tooth wear (Figure 6.26). However, the differences in the prevalence of caries, calculus, and tooth wear between burial types are not statistically significant. As mentioned in Chapter 6, the age distribution of the different burial types is not the same (see Table 6.32). The absence of young infants (0-2 years) in the tomb category does not adequately explain the higher caries and calculus rates for this group, because there are also no young infants in the inhumation burials, and both calculus and caries rates are the lowest for the entire sample in this category. This suggests that random factors are likely responsible for the high calculus, high caries, and relatively low tooth wear observed in infants and children buried in the tombs at Isola Sacra.

7.3 Correlation of Isotopic and Dental Data

There are 76 individuals that have both dental pathology data and isotopic data from bone collagen (Appendix N). The typical pattern found in studies of caries in past populations is that the consumption of a carbohydrate-rich diet is related to an increase in the prevalence of caries (see Section 3.12). Kelley and colleagues (1991) found a weak positive correlation between $\delta^{13}C$ and caries prevalence in relation to the adoption of maize agriculture. In their study, a positive correlation was hypothesized because maize consumption would increase $\delta^{13}C$ values (maize is a C_4 plant) and at the same time increases the number of carious lesions. In the Isola Sacra sample, there is no evidence for the contribution of C_4 plants to the diet, so it would be expected that if there is an

association between caries and carbohydrate consumption, then individuals with more negative $\delta^{13}C$ values should have higher levels of caries, resulting in a negative correlation between the variables.

As mentioned in Chapter 6, there is only a small amount of variation in the range of $\delta^{13}C$ values (~ 1.5‰). Correlation analysis of the data indicates that there is a weak positive correlation between $\delta^{13}C_{collagen}$ and DMI ($r_s = .358$; $p = .002$). This suggests that individuals with enriched $\delta^{13}C$ values tend to have slightly higher DMI values, which is not the correlation expected. It is not clear what this implies with respect to diet. A clearer association appears to exist between $\delta^{13}C$, $\delta^{15}N$, and tooth wear. As the levels of both $\delta^{13}C$ and $\delta^{15}N$ increase, tooth wear also increases. This seems to suggest that individuals in the Isola Sacra consuming more marine-based diets, characterized by comparatively higher $\delta^{13}C$ and $\delta^{15}N$ levels, have more tooth wear.

Sealy and coworkers (1992) found that individuals from coastal regions of South Africa who consumed large amounts of seafood, identified by more positive $\delta^{13}C$ values, also had teeth that were more heavily worn than other individuals in the sample. Walker (1978) also found higher levels of wear in prehistoric samples consuming greater quantities of seafood. This pattern is attributed to sand and grit in the diet of coastal populations (*ibid.*). These results tend to confirm the relationship between increased marine foods and higher levels of tooth wear.

7.4 Summary

The isotopic data indicate that the diet of the people from *Portus Romae* was a combination of 40% marine and 60% terrestrial resources. Their diet consisted of terrestrial C_3 plants and animals, supplemented with marine foods, probably fish. This is not the 'typical' Roman diet described in the historical sources, but the people of *Portus Romae* were probably not a typical Roman population. Comparison of the human and faunal data shows that the human samples are enriched over the herbivores by more than the 3‰ expected from the trophic level effect, confirming that there is a contribution to the diet that is increasing $\delta^{15}N$ levels. These data also indicate that millet was probably not used as animal fodder for the animals studied, because they have a strong C_3 plant signal. The isotopic data from the *garum* samples, fish, and other marine organisms provides a possible range of isotopic values for the types of foods that might have been eaten. It is clear from this comparison that *garum*, the fish sauce reportedly in widespread use by the ancient Romans, is not responsible for the nitrogen isotope values in the Isola Sacra bones.

After comparison with other human skeletal studies, the pattern observed in the Isola Sacra sample appears consistent with a population consuming a mixed marine and terrestrial diet. Within the sample, the slight isotopic variability between males and females suggests that females were probably consuming more terrestrial resources in their diet and that males were consuming a greater proportion of marine foods. The overall variability, however, is not large. The apatite data suggest that the subadults, in particular, were consuming a predominantly herbivorous diet and were eating at a lower

trophic level than many of the other members of the sample. This variability is interpreted in terms of social relations and access to food, based on the status of individuals both within the household and in Roman society.

The pattern of $\delta^{13}C$ and $\delta^{15}N$ values appear to agree with the information available on breast-feeding and weaning patterns in ancient Rome. The data suggest that weaning may have begun as early as 3-6 months, and lasted until approximately 2 years of age. The $\delta^{13}C$ data also indicate that the diet of young children after they had been weaned is more negative than the adult mean values, and suggests that these children were being fed a diet that was high in carbohydrates and animal byproducts. The deciduous dental data also indicate that caries and calculus were present in individuals as young as 2.5 years of age, and the soft, sticky weaning foods reportedly fed to Roman infants appears to have contributed to the early appearance of dental disease. The strong linear relationship between the $\delta^{13}C$ and $\delta^{15}N$ data of the subadults suggests a dietary trend between two main resources, breast milk and carbohydrate-based weaning foods.

The pattern of weaning seen in the Isola Sacra sample is slightly different than the expected pattern observed in previous studies. Comparison of the data with a historic North American sample may suggest a different pattern of weaning in the Isola Sacra sample, or it may actually reflect different mortality patterns between the two samples. One of the problems is that the sample is composed of the non-survivors, and it is not known if the cause of death is related to problems with breast-feeding, disease, or other factors.

The dental data reveal generally low levels of oral pathology in the Isola Sacra sample; the only significant difference between males and females is in the level of dental calculus. This pattern of dental health is consistent with the overall low level of variability in the isotopic data between the sexes, although there are trends in both sets of data. All other dental indicators show no significant intra-sample variability, but patterns in the data suggest that the slight differences between the sexes may be related to differential access to resources and possibly overall life expectancy. Correlations between the isotope and tooth wear data reveal an association between increased $\delta^{13}C$ and $\delta^{15}N$ levels and tooth wear, which can be related to the contribution of marine foods to the diet.

Another pattern is the lack of variability in the isotopic and dental data between different burial types. Some of the inscriptional evidence from the site of Isola Sacra indicates that the tombs were not only used exclusively by 'elite' members of *Portus Romae* society, and there is also evidence to suggest that grave monuments may not accurately reflect social status, but rather status aspirations. Individuals in soil burials are distinguished in both the isotopic and dental data, but it is not certain that this difference can be attributed to 'status'.

Chapter 8

Conclusions

The results of the isotopic and dental analysis of the Isola Sacra remains provide us with substantial information about the diet and lives of the people at *Portus Romae*. The size and composition of the sample offered a relatively rare opportunity to explore, in great detail, the variation between different members of a mortality population.

The isotopic data indicate that a mixture of marine and terrestrial resources characterized the diet of the people at *Portus Romae*. This is not surprising considering its location on the coast of Italy and the role that its inhabitants played in maritime trade for the Imperial city of Rome. The data do, however, suggest that terrestrial resources (C_3 plants and animals) still formed the bulk of the diet. This pattern may not be representative of the 'typical' Roman diet, but the objective of this research was not to identify *the* Roman diet. While the overall variability between males and females is not large, there are patterns in the distribution of the data, with consistently lower $\delta^{13}C$ and $\delta^{15}N$ levels among females. These results suggest that males were eating a larger proportion of marine foods and females were consuming more terrestrial resources. Age-related differences were also found, particularly between the older males and younger females and subadults. The literary sources provide valuable insight into some of the

potential reasons for the differences in dietary patterns between sexes and age groups, which can be explained in the context of the status of women and children in Roman society.

The $\delta^{13}C$ and $\delta^{15}N$ data from the infants imply a pattern of weaning that is consistent with written records from the Graeco-Roman period, and indicate that the process of weaning began at a very young age, as early as 3-6 months, and was probably completed by 2 years of age. The data clearly show the trophic level effect associated with breastfeeding, and the decrease in isotopic values with the weaning process. There is, however, little information in the ancient written sources and from the archaeological record on the diet of infants and children in ancient Rome after the weaning period. The isotopic data from both the rib and femur samples has contributed to filling this gap by showing that around 2-3 years of age, the Isola Sacra children have depleted $\delta^{13}C$ levels relative to adult members of the sample. This pattern is also seen in the subadult femur data, both in collagen and apatite, which clearly show that individuals 5-15 years of age were consuming a diet that was quite distinct (i.e., depleted in both $\delta^{15}N$ and $\delta^{13}C$) from the adult members of the sample. They likely consumed a predominantly terrestrial diet. This may, in fact, support Garnsey's (1999) contention that children in the Graeco-Roman world were nutritionally disadvantaged, with serious potential implications for health. What is not known is the nutritional adequacy of the diet consumed by the subadults from Isola Sacra. The next logical step is to look at the prevalence of palaeopathological indicators (e.g., enamel hypoplasias, rickets, and cribra orbitalia) in the sample.

The pattern of dental health in the Isola Sacra sample suggests that males and females had generally similar levels of dental health, consistent with the dietary pattern inferred from the isotopic data. The only indicator of dental health with significant differences between males and females is calculus; females have a greater number of teeth affected by calculus and heavier amounts of calculus when present. The investigation of calculus and tooth wear using quantified 'scores' for each individual permitted the statistical examination of intra-sample variation. The combined higher tooth wear scores among males, and the positive correlation between $\delta^{15}N$, $\delta^{13}C$ and tooth wear, supports the hypothesis that marine foods made up a greater proportion of the males' diet. The large number of subadults in the sample provided an opportunity to look at patterns of dental pathology in young infants and children. These data are interesting because they show that caries, calculus, and tooth wear begin quite early and are probably related to the weaning process. Comparison of the Isola Sacra results with other archaeological samples indicates that the levels of oral health are consistent with other Roman period populations, and the isotopic distribution is characteristic of a coastal population relying on a combination of marine and terrestrial resources.

The archaeological context of the Isola Sacra sample, and the varied burial structures at the site, also presented an opportunity to examine variability in diet related to burial type. The almost complete absence of variation between the different burial types supports inscriptional evidence from the site, which indicates that patrons, freedmen, slaves, and family members were placed in these tombs. These results also

confirm the archaeologists' conclusion that Calza's 'field of the poor' is not a collection of graves representing the poorer members of society.

The written and archaeological evidence provided useful insight into the potential variability of the diet, and supplied invaluable historical context for understanding the patterns seen in the skeletal and dental remains. The isotopic and dental evidence quantify the relative importance of certain dietary components, and also contribute to the understanding of dietary patterns among women and children in this skeletal sample, who are not well represented in the ancient literature. The various sources of information do not blend together seamlessly, but without the various lines of evidence, the interpretation would be lacking.

This study is the first large-scale isotopic and dental paleopathological analysis of a Roman period skeletal sample from the Mediterranean region. In order to better understand the diversity of dietary patterns in Italy and the Mediterranean, further samples need to be analyzed isotopically. The comparative data from the ANAS cemetery provides a clue to the potential diversity that might be present within a small geographic area. The other important sources of isotopic information that need to be explored for the Mediterranean region, and that may shed further light on dietary patterns, are foods like oil, wine, fish, meat, and plant remains. These data would contribute significantly to our understanding the distribution of the Isola Sacra values with respect to reportedly important components of the Roman diet. The dental and isotopic data should also be integrated with palaeopathological data from the Isola Sacra sample to gain some insight into the nutritional adequacy of the diet consumed.

References Cited

Allison MJ. 1984. Paleopathology in Peruvian and Chilean populations. In: Cohen MN, Armelagos GJ, editors. Paleopathology at the Origins of Agriculture. Orlando: Academic Press. p 515-529.

Alston R. 1998. Aspects of Roman History (AD 14-117). London: Routledge.

Ambrose SH, DeNiro MJ. 1986. Reconstruction of African human diet using bone collagen carbon and nitrogen isotope ratios. Nature 319:321-324.

Ambrose SH. 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. Journal of Archaeological Science 17:431-451.

Ambrose SH, Norr L. 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: Lambert JB, Grupe G, editors. Prehistoric Human Bone: Archaeology at the Molecular Level. Berlin: Springer-Verlag. p 1-36.

Ambrose SH. 1993. Isotopic analysis of paleodiets: methodological and interpretive considerations. In: Sandford MK, editor. Investigations of Ancient Human Tissue: Chemical Analyses in Anthropology. Langhorne, PA: Gordon & Breach Scientific Publishers. p 59-130.

Amouretti MC. 1986. Le Pain et l'Huile dans la Grèce Antique; de l'Arraire au Moulin. Paris: Les Belles Lettres.

André J. 1981. L'alimentation et la Cuisine à Rome. Paris: Société d'Edition les Belles Lettres.

Angel JL. 1944. Greek teeth: ancient and modern. Human Biology 16:283-297.

Angel JL. 1984. Health as a crucial factor in the changes from hunting to developed farming in the eastern Mediterranean. In: Cohen MN, Armelagos GJ, editors. Paleopathology at the Origins of Agriculture. Orlando: Academic Press. p 51-73.

Angelucci S, Baldassarre I, Bragantini I, Lauro MG, Mannucci V, Mazzoleni A, Morselli C, Taglietti F. 1990. Sepolture e riti nella necropoli dell'Isola Sacra. Bollettino di Archeologia 5-6:50-113.

Aufderheide AC, Tieszen LL, Allison MJ, Wallgren J, Rapp G. 1988. Chemical reconstruction of components in complex diets: a pilot study. In: Kennedy BV, LeMoine GM, editors. Diet and Subsistence: Current Archaeological Perspectives. Calgary: The University of Calgary, Archaeological Association.

Baldassarre I. 1978. La necropoli dell'Isola Sacra. Quaderni de 'La Ricerca Scientifica' 100:3-20.

Baldassarre I. 1984. Una necropoli imperiale Romana: proposte di lettura. Annali di Archeologia e Storia Antica VI:141-149.

Baldassarre I, Bragantini I, Dolciotti AM, Morselli C, Taglietti F, Taloni M. 1985. La necropoli dell'Isola Sacra. Campagne di scavo 1976-1979. Quaderni de 'La Ricerca Scientifica' 112:261-302.

Baldassarre I. 1990. Nuove ricerche nella necropoli dell'Isola Sacra. Quaderni di Archeologia Etrusco-Italica 19:164-172.

Barker G. 1995. A Mediterranean Valley: Landscape Archaeology and Annales History in the Biferno Valley. London: Leicester University Press.

Barnish SJB. 1987. Pigs, plebeians and *potentes*. Papers of the British School at Rome 55:157-185.

Becker MJ. 1998. A Roman "implant" reconsidered. Nature 394:-534.

Becker MJ. 1999. Etruscan gold dental appliances: three newly "discovered" examples. American Journal of Archaeology 103:103-111.

Bisel S. 1991. The human skeletons of Herculaneum. International Journal of Anthropology 6:1-20.

Boardman J. 1976. The olive in the Mediterranean: its culture and use. Philosophical Transactions of the Royal Society, London.Series B, 275:187-196.

Borgognini Tarli SM, Repetto E. 1985. Diet, dental features and oral pathology in the Mesolithic samples from Uzzo and Molara caves (Sicily). In: Malone C, Stoddart S, editors. Papers in Italian Archaeology IV (II): Prehistory. BAR International Series #244. Oxford: British Archaeological Reports. p 87-100.

Borgognini Tarli SM, Repetto E. 1987. Igiene orale, usura e patologia dentaria nella preistoria. Federazione Medica XL:501-508.

Bradley KR. 1998. The Roman family at dinner. In: Nielsen I, Sigismund Nielsen H, editors. Meals in a Social Context. Aarhus: Aarhus University Press. p 36-55.

Braun T. 1995. Barley cakes and emmer bread. In: Wilkins J, Harvey D, Dobson M, editors. Food in Antiquity. Exeter: University of Exeter Press. p 25-37.

Brothwell DR. 1981. Digging up Bones. Ithaca, New York: Cornell University Press.

Brothwell DR. 1988. Foodstuffs, cooking, and drugs. In: Grant M, Kitzinger R, editors. Civilization of the Ancient Mediterranean: Greece and Rome. New York: Charles Scribner's Sons. p 247-261.

Brothwell DR, Brothwell P. 1998. Food in Antiquity. Baltimore: The Johns Hopkins University Press.

Buikstra JE. 1984. The lower Illinois river region: a prehistoric context for the study of ancient diet and health. In: Cohen MN, Armelagos GJ, editors. Paleopathology at the Origins of Agriculture. Orlando: Academic Press, Inc. p 215-234.

Buikstra JE, Ubelaker DH. 1994. Standards for Data Collection from Human Skeletal Remains. Arkansas Archeological Survey Research Series No. 44. Fayetteville, Arkansas: Arkansas Archeological Survey.

Bullington J. 1991. Deciduous dental microwear of prehistoric juveniles from the lower Illinois river valley. American Journal of Physical Anthropology 84:59-73.

Bumsted MP. 1985. Past human behavior from bone chemical analysis - respects and prospects. Journal of Human Evolution 14:539-551.

Calza G, Becatti G. 1974. Ostia. Rome: Istituto Poligrafico e Zecca dello Stato.

Cannon A. 1989. The historical dimension in mortuary expressions of status and sentiment. Current Anthropology 30:437-458.

Carandini A, Panella C. 1970. Ostia III, Parte Seconda. Studi Miscellanei. Rome: De Luca Editore.

Carter JC, Costantini L, D'Annibale C, Jones JR, Folk RL, Sullivan D. 1985. Population and agriculture: Magna Grecia in the fourth century BC. In: Malone C, Stoddart S, editors. Papers in Italian Archaeology IV. Part I: The Human Landscape. Oxford: British Archaeological Reports. p 281-312.

Caselitz P. 1998. Caries - ancient plague of humankind. In: Alt KW, Rosing FW, Teschler-Nicola M, editors. Dental Anthropology: Fundamentals, Limits, and Prospects. New York: Springer Wien. p 203-226.

Casson L. 1998. Everyday Life in Ancient Rome. Baltimore: The Johns Hopkins University Press.

Chisholm BS, Nelson DE, Schwarcz HP. 1982. Stable-carbon isotope ratios as a measure of marine versus terrestrial protein in ancient diets. Science 216:1131-1132.

Chisholm BS, Nelson DE, Hobson KA, Schwarcz HP, Knyf M. 1983. Carbon isotope measurement techniques for bone collagen: notes for the archaeologist. Journal of Archaeological Science 10:355-360.

Chisholm BS. 1989. Variation in diet reconstructions based on stable carbon isotope evidence. In: Price DT, editor. The Chemistry of Prehistoric Human Bone. Cambridge: Cambridge University Press. p 10-37.

Clarke NG, Hirsch RS. 1991a. Physiological, pulpal, and periodontal factors influencing alveolar bone. In: Kelley MA, Larsen CS, editors. Advances in Dental Anthropology. New York: Wiley-Liss, Inc. p 241-266.

Clarke NG, Hirsch RS. 1991b. Tooth dislocation: the relationship with tooth wear and dental abscesses. American Journal of Physical Anthropology 85:293-298.

Cohen MN, Armelagos GJ. 1984. Paleopathology at the Origins of Agriculture. Orlando: Academic Press.

Cook DC, Buikstra JE. 1979. Health and differential survival in prehistoric populations: prenatal dental defects. American Journal of Physical Anthropology 51:649-664.

Corbier M. 1989. The ambiguous status of meat in ancient Rome. Food and Foodways 3:223-264.

Cornell TJ. 1995. The Beginnings of Rome. London: Routledge.

Corruccini RS, Pacciani E. 1989. "Orthodontistry" and dental occlusion in Etruscans. Angle Orthodontist 59:61-64.

Costa RL Jr. 1980. Age, sex, and antemortem loss of teeth in prehistoric Eskimo samples from Point Hope and Kodiak Island, Alaska. American Journal of Physical Anthropology 53:579-587.

Crouch JE. 1978. Functional Human Anatomy. Philadelphia: Lea & Febiger.

Crubezy E, Murail P, Girard L, Bernadou JP. 1998. False teeth of the Roman world. Nature 391:29

Cucina A, Lucci M, Vargiu R, Coppa A. 1999. Dental evidence of biological affinity and environmental conditions in prehistoric Trentino (Italy) samples from the Neolithic to the Early Bronze Age. International Journal of Osteoarchaeology 9:404-416.

Curtis RI. 1991. Garum and Salsamenta. New York: E.J. Brill.

Cybulski JS. 1974. Tooth wear and material culture: precontact patterns in the Tsimshian area, British Columbia. Syesis 7:31-35.

D'Amato C. 1993. La Medicina. Rome: Edizioni Quasar.

Davidson J. 1998. Courtesans and Fishcakes: The Consuming Passions of Classical Athens. London: Fontana Press.

Deines P. 1980. The isotopic composition of reduced organic carbon. In: Fritz P, Fontes JC, editors. Handbook of Environmental Isotope Geochemistry. Amsterdam: Elsevier. p 329-406.

DeNiro MJ, Epstein S. 1978. Influence of diet on the distribution of carbon isotopes in animals. Geochimica et Cosmochimica Acta 42:495-506.

DeNiro MJ, Schoeninger MJ. 1983. Stable carbon and nitrogen isotope ratios of bone collagen: variations within individuals, between sexes, and within populations raised on monotonous diets. Journal of Archaeological Science 10:199-203.

DeNiro MJ. 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature 317:806-809.

DeNiro MJ. 1987. Stable isotopy and archaeology. American Scientist 75:182-191.

DeNiro MJ, Weiner S. 1988. The use of collagenase to purify collagen from prehistoric bones for stable isotopic analysis. Geochimica et Cosmochimica Acta 52:2425-2431.

Dosi A, Schnell F. 1986. I Romani in Cucina. Rome: Edizioni Quasar.

Dosi A, Schnell F. 1992. Le Abitudini Alimentari dei Romani. Rome: Edizioni Quasar.

Drinkwater JF, Drummond D. 1993. The World of the Romans. New York: Oxford University Press, Inc.

Dupras TL. 1999. Dining in the Dakhleh Oasis, Egypt: Determination of Diet Using Documents and Stable Isotope Analysis. Unpublished PhD Thesis, Department of Anthropology, McMaster University, Hamilton, Ontario, Canada.

Duray SM. 1990. Deciduous enamel defects and caries susceptibility in a prehistoric Ohio population. American Journal of Physical Anthropology 81:27-34.

Erdal YS, Duyar I. 1999. A new correction procedure for calibrating dental caries frequency. American Journal of Physical Anthropology 108:237-240.

Evans DT. 1973. A preliminary evaluation of tooth tartar among the preconquest Maya of the Tayasal area, El Peten, Guatemala. American Antiquity 38:489-493.

Evans JK. 1980. Plebs Rustica. The peasantry of classical Italy. American Journal of Ancient History 5:134-173.

Fabbri P, Mallegni F. 1988. Dental anthropology of the Upper Paleolithic remains from Romita Cava at Papasidero (Cosenza, Italy). Bulletin et Memoire de la Societe' d'Anthropologie de Paris 5:163-178.

Fajans J. 1988. The transformative value of food: a review essay. Food and Foodways 3:143-166.

Farrar L. 1998. Ancient Roman Gardens. Thrupp, Stroud, Gloucestershire: Sutton Publishing Limited.

Fidanza F. 1979. Diets and dietary recommendation in ancient Greece and Rome and the School of Salerno. Progress in Food Nutrition and Science 3:79-99.

Fildes V. 1986. Breasts, Bottles, and Babies: A History of Infant Feeding. Edinburgh: Edinburgh University Press.

Fogel ML, Tuross N, Owsley DW. 1989. Nitrogen isotope tracers of human lactation in modern and archaeological populations: implications for palaeodiet studies. Carnegie Institution, Annual Report of the Director: Geophysical Laboratory.

Formicola V, Turner CG II, Puech PF, Cianfarani F, Eckhardt RB, Piermarini AL. 1988. Interproximal grooving of teeth: additional evidence and interpretation. Current Anthropology 29:663-671.

Foxhall L, Forbes HA. 1982. Sitometria: The role of grain as a staple food in classical antiquity. Chiron 12:41-90.

Francey RJ, Farquhar GD. 1982. An explanation of $^{13}C/^{12}C$ variations in tree rings. Nature 297:28-31.

Frayn JM. 1975. Wild and cultivated plants: A note on the peasant economy of ancient Italy. Journal of Roman Studies 65:32-39.

Frayn JM. 1993. Markets and Fairs in Roman Italy. Oxford: Clarendon Press.

Fyfe DM, Chandler NP, Wilson NHF. 1993. Alveolar bone status of some pre-seventeenth century inhabitants of Taumako, Solomon Islands. International Journal of Osteoarchaeology 3:29-35.

Gallo L. 1990. Demografia e alimentazione. In: Settis S, editor. Civilita' dei Romani: il Rito e la Vita Privata. Milan: Electa. p 246-259.

Garnsey P. 1983. Grain for Rome. In: Garnsey P, Hopkins K, Whittaker CR, editors. Trade in the Ancient Economy. London: Chatto and Windus. p 118-130.

Garnsey P. 1991. Mass diet and nutrition in the city of Rome. In: Giovannini A, editor. Nourrir la Plebe: Actes du Colloque tenu à Geneve les 28 et 29 IX, 1989 en Hommage à Denis van Berchen. Kassel: Friedrich Reinhart Verlag Basel. p 67-101.

Garnsey P. 1999. Food and Society in Classical Antiquity. Cambridge: Cambridge University Press.

Ginge B, Becker MJ, Guldager P. 1989. Of Roman extraction. Archaeology 42:34-37.

Gould P, Ostrom P, Walker W. 1997. Trophic relationships of albatrosses associated with squid and large-mesh driftnet fisheries in the North Pacific ocean. Canadian Journal of Zoology 75:549-562.

Grant M. 1974. Ancient History Atlas: 1700 BC to AD 565 (2nd edition). London: Weidenfeld and Nelson.

Grant M. 1978. History of Rome. London: Faber and Faber.

Grant M. 1995. Greek and Roman Historians: Information and Misinformation. New York: Routledge.

Gumerman G. 1997. Food and complex societies. Journal of Archaeological Method and Theory 4:105-139.

Hartnady P, Rose JC. 1991. Abnormal tooth-loss patterns among archaic-period inhabitants of the Lower Pecos region, Texas. In: Kelley MA, Spencer Larsen C, editors. Advances in Dental Anthropology. New York: Wiley-Liss, Inc. p 267-278.

Henneberg M, Henneberg R, Ciarallo A. 1996. Skeletal material from the house of C Iulius Polybius in Pompeii, 79 AD. Human Evolution 11:249-259.

Herring DA, Saunders SR, Katzenberg MA. 1998. Investigating the weaning process in past populations. American Journal of Physical Anthropology 105:425-439.

Hildebolt CF, Molnar S. 1991. Measurement and description of periodontal disease in anthropological studies. In: Kelley MA, Larsen CS, editors. Advances in Dental Anthropology. New York: Wiley-Liss, Inc. p 225-240.

Hillson S. 1979. Diet and dental disease. World Archaeology 11:147-162.

Hillson S. 1996. Dental Anthropology. Cambridge: Cambridge University Press.

Hillson S. 2000. Dental pathology. In: Katzenberg MA, Saunders SR, editors. Biological Anthropology of the Human Skeleton. New York: Wiley-Liss Inc. p 249-286.

Hinton RJ. 1981. Form and patterning of anterior tooth wear among aboriginal human groups. American Journal of Physical Anthropology 54:555-564.

Hinton RJ. 1982. Differences in interproximal and occlusal tooth wear among prehistoric Tennessee Indians: implications for masticatory function. American Journal of Physical Anthropology 57:103-115.

Holt CA. 1991. Plants, humans, and culture: an edible model of consuming behavior. Historical Archaeology 25:46-61.

Huskinson J. 1996. Roman Children's Sarcophagi. Oxford: Clarendon Press.

Jackson WTH. 1966. Roman Civilization. Sourcebook II: The Empire. New York: Harper and Row.

Joshel SR. 1986. Nurturing the master's child: slavery and the Roman child-nurse. Journal of Women in Culture and Society 12:3-22.

Jurmain R. 1990. Paleoepidemiology of a central California prehistoric population from CA-Ala-329: dental disease. American Journal of Physical Anthropology 81:333-342.

Katzenberg MA, Schwarcz HP, Knyf M, Melbye FJ. 1985. Stable isotope evidence for maize horticulture and paleodiet in southern Ontario, Canada. American Antiquity 60:335-350.

Katzenberg MA. 1992. Advances in stable isotope analysis of prehistoric bones. In: Saunders SR, Katzenberg MA, editors. Skeletal Biology of Past Peoples: Research Methods. New York: Wiley-Liss. p 105-119.

Katzenberg MA. 1993. Age differences and population variation in stable isotope values from Ontario, Canada. In: Grupe G, Lambert JB, editors. Prehistoric Human Bone: Archaeology at the Molecular Level. Berlin: Springer-Verlag. p 39-62.

Katzenberg MA, Saunders SR, Fitzgerald WR. 1993. Age differences in stable carbon and nitrogen isotope ratios in a population of prehistoric maize horticulturists. American Journal of Physical Anthropology 90:267-281.

Katzenberg MA, Pfeiffer S. 1995. Nitrogen isotope evidence for weaning age in a nineteenth century Canadian skeletal sample. In: Grauer AL, editor. Bodies of Evidence: Reconstructing History through Skeletal Analysis. New York: Wiley-Liss. p 221-235.

Katzenberg MA, Herring DA, Saunders SR. 1996. Weaning and infant mortality: evaluating the skeletal evidence. Yearbook of Physical Anthropology 39:177-199.

Katzenberg MA. 2000. Stable isotope analysis: a tool for studying past diet, demography, and life history. In: Katzenberg MA, Saunders SR, editors. Biological Anthropology of the Human Skeleton. New York: Wiley-Liss Inc. p 305-327.

Keegan WF, DeNiro MJ. 1988. Stable carbon- and nitrogen-isotope ratios of bone collagen used to study coral-reef and terrestrial components of prehistoric Bahamian diet. American Antiquity 53:320-336.

Keegan WF. 1989. Stable isotope analysis of prehistoric diet. In: Iscan MY, Kennedy KAR, editors. Reconstruction of Life from the Skeleton. New York: Alan R. Liss, Inc. p 223-236.

Kelley MA, Levesque DR, Weidl E. 1991. Contrasting patterns of dental disease in five early northern Chilean groups. In: Kelley MA, Larsen CS, editors. Advances in Dental Anthropology. New York: Wiley-Liss, Inc. p 203-213.

Klepinger LL, Kuhn JK, Thomas J Jr. 1977. Prehistoric dental calculus gives evidence for coca use in early coastal Ecuador. Nature 269:507

Klepinger LL. 1984. Nutritional assessment from bone. Annual Review of Anthropology 13:75-96.

Krueger HW and Sullivan CH. 1984. Models for carbon isotope fractionation between diet and bone. Stable Isotopes in Nutrition, ACS Symposium. Washington: American Chemical Society, pp. 205-220

Larsen CS. 1984. Health and disease in prehistoric Georgia: the transition to agriculture. In: Cohen MN, Armelagos GJ, editors. Paleopathology at the Origins of Agriculture. Orlando: Academic Press, Inc. p 367-392.

Larsen CS. 1985. Dental modifications and tool use in the western Great Basin. American Journal of Physical Anthropology 67:393-402.

Larsen CS, Shavit R, Griffin MC. 1991. Dental caries evidence for dietary change: an archaeological context. In: Kelley MA, Larsen CS, editors. Advances in Dental Anthropology. New York: Wiley-Liss. p 179-202.

Larsen CS, Schoeninger MJ, van der Merwe NJ, Moore KM, Lee Thorp JA. 1992. Carbon and nitrogen stable isotopic signatures of human dietary change in the Georgia Bight. American Journal of Physical Anthropology 89:197-214.

Larsen CS. 1995. Biological changes in human populations with agriculture. Annual Review of Anthropology 24:185-213.

Larsen CS. 1999. Bioarchaeology: Interpreting Behavior from the Human Skeleton. Cambridge: Cambridge University Press.

Lee Thorp JA, van der Merwe NJ. 1987. Carbon isotope analysis of fossil bone apatite. South African Journal of Science 83:712-715.

Lee Thorp JA, Sealy JC, van der Merwe NJ. 1989. Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. Journal of Archaeological Science 16:585-599.

Lefkowitz MR, Fant MB. 1982. Women's Life in Greece and Rome. Toronto: Samuel-Stevens.

Lieverse AR. 1999. Diet and the aetiology of dental calculus. International Journal of Osteoarchaeology 9:219-232.

Lillie MC, Richards M. 2000. Stable isotope analysis and dental evidence of diet at the Mesolithic-Neolithic transition in Ukraine. Journal of Archaeological Science 27:965-972.

Littleton J, Frohlich B. 1993. Fish-eaters and farmers: dental pathology in the Arabian Gulf. American Journal of Physical Anthropology 92:427-447.

Longin R. 1971. New method for collagen extraction for radiocarbon dating. Nature 230:241-242.

Lovell NC, Nelson DE, Schwarcz HP. 1986. Carbon isotope ratios in paleodiet: lack of age or sex effect. Archaeometry 28:51-55.

Lubell D, Jackes M, Schwarcz HP, Knyf M, Meiklejohn C. 1994. The Mesolithic-Neolithic transition in Portugal: isotopic and dental evidence of diet. Journal of Archaeological Science 21:201-216.

Lukacs JR. 1989. Dental paleopathology: methods for reconstructing dietary patterns. In: Iscan MY, Kennedy KAR, editors. Reconstruction of Life from the Skeleton. New York: Alan R. Liss. p 261-286.

Lukacs JR. 1992. Dental paleopathology and agricultural intensification in South Asia: new evidence from Bronze Age Harappa. American Journal of Physical Anthropology 87:133-150.

Lukacs JR. 1995. The 'Caries Correction Factor': a new method of calibrating dental caries rates to compensate for antemortem loss of teeth. International Journal of Osteoarchaeology 5:151-156.

Lunt DA. 1986. Mediaeval dentitions from St. Andrews. BAR International Series, No. 291. In: Cruwys E, Foley RA, editors. Teeth and Anthropology. Oxford: British Archaeological Reports. p 215-224.

Macchiarelli R, Salvadei L. 1986. Topographic distribution of maxillary carious lesions at Alfedena (VI-V cent. B.C., central Italy). Antropologia Contemporanea 9:210-206.

Macchiarelli R. 1989. Prehistoric "fish-eaters" along the Eastern Arabian coasts: dental variation, morphology, and oral health in the Ra's al-Hamra community (Qurum, Sultanate of Oman, 5th-4th millenia BC). American Journal of Physical Anthropology 78:575-594.

Mandel ID. 1979. Dental caries. American Scientist 67:680-688.

Mannucci V, Verduchi P. 1996. Il porto imperiale di Roma: le vicende storiche. In: Mannucci Vanni, editor. Il Parco Archeologico Naturalistico del Porto di Traiano. Roma: Gangemi Editore. p 15-28.

Manolagas S. 2000. Birth and death of bone cells: basic regulatory mechanisms and implications for the pathogenesis and treatment of osteoporosis. Endocrine Reviews 21:115-137.

Manzi G, Salvadei L, Vienna A, Passarello P. 1999. Discontinuity of life conditions at the transition from the Roman Imperial Age to the Early Middle Ages: example from central Italy evaluated by pathological dento-alveolar lesions. American Journal of Human Biology 11:327-341.

Marino BD, McElroy MB. 1991. Isotopic composition of atmospheric CO_2 inferred from carbon in C_4 plant cellulose. Nature 349:127-131.

Mattingly DJ. 1988. Oil for export? A comparison of Libyan, Spanish and Tunisian olive oil production in the Roman empire. Journal of Roman Archaeology 1:33-56.

Mattingly DJ. 1996. First fruit? The olive in the Roman world. In: Shipley G, Salmon J, editors. Human Landscapes in Classical Antiquity. London: Routledge. p 213-253.

McCann AM. 1988. The Roman port of Cosa. Scientific American 258:102-109.

Meiggs R. 1960. Roman Ostia. Oxford: Clarendon Press.

Minagawa M, Wada E. 1984. Stepwise enrichment of ^{15}N along food chains: Further evidence and the relation between $\delta^{15}N$ and animal age. Geochimica et Cosmochimica Acta 48:1135-1140.

Minellono F, Pardini E, Fornaciari G. 1980. Le sepolture epigravettiane di Vado all'Arancio (Grosseto). Rivista di Scienze Preistoriche 35:3-44.

Molleson T, Jones K. 1991. Dental evidence for dietary change at abu Hureyra. Journal of Archaeological Science 18:525-539.

Molnar S. 1971. Human tooth wear, tooth function and cultural variability. American Journal of Physical Anthropology 34:175-190.

Molnar S. 1972. Tooth wear and culture: a survey of tooth functions among some prehistoric populations. Current Anthropology 13:511-526.

Montanini L. 1991. Nascita e morte del bambino. In: Criniti N, editor. Gli Affanni del Vivere e del Morire: Schiavi, Soldati, Donne, Bambini nella Roma Imperiale. Brescia: Grafo Edizioni. p 89-107.

Moore WJ, Corbett ME. 1971. Distribution of dental caries in ancient British populations: I Anglo-Saxon period. Caries Research 5:151-168.

Moore WJ, Corbett ME. 1973. The distribution of dental caries in ancient British populations. Caries Research 7:139-153.

Moore WJ, Corbett ME. 1983. Dental and alveolar infection. In: Hart GD, editor. Disease in Ancient Man. Toronto: Clarke Irwin. p 139-155.

Morris I. 1992. Death-ritual and Social Structure in Classical Antiquity. Cambridge: Cambridge University Press.

Murphy TR. 1959. Gradients of dentine exposure in human tooth attrition. American Journal of Physical Anthropology 17:179-185.

Nelson BK, DeNiro MJ, Schoeninger MJ, De Paolo DJ. 1986. Effects of diagenesis on strontium, carbon, nitrogen and oxygen concentration and isotopic composition of bone. Geochimica et Cosmochimica Acta 50:1941-1949.

Nelson GC, Lukacs JR, Yule P. 1999. Dates, caries, and early tooth loss during the Iron Age of Oman. American Journal of Physical Anthropology 108:333-344.

Néraudau JP. 1984. Être Enfant à Rome. Paris: Societe d'Edition Les Belles Lettres.

Nielsen HS. 1998. Roman children at mealtimes. In: Nielsen I, Nielsen HS, editors. Meals in a Social Context. Aarhus: Aarhus University Press. p 56-66.

Nielsen TH, Bjertrup L, Hansen MH, Rubinstein L, Vestergaard T. 1989. Athenian grave monuments and social class. Greek, Roman, and Byzantine Studies 30:411-420.

O'Sullivan EA, Williams SA, Curzon MEJ. 1992. Dental caries in relation to nutritional stress in early English child populations. Pediatric Dentistry 14:26-29.

Ortner DJ, Putschar WGJ. 1981. Identification of Pathological Conditions in Human Skeletal Remains. Washington: Smithsonian Institution Press.

Papathanasiou A, Spencer Larsen C, Norr L. 2000. Bioarchaeological inferences from a Neolithic ossuary from Alepotrypa cave, Diros, Greece. International Journal of Osteoarchaeology 10:210-228.

Patterson DK. 1987. Changes in oral health among prehistoric Ontario populations. Canadian Review of Physical Anthropology 5:3-13.

Pavolini C. 1996. La Vita Quotidiana a Ostia. Rome: Gius. Laterza & Figli.

Pierre C. 1999. The oxygen and carbon isotope distribution in the Mediterranean water masses. Marine Geology 153:41-55.

Pomeroy SB. 1995. Goddesses, Whores, Wives, and Slaves: Women in Classical Antiquity. New York: Schocken Books.

Powell ML. 1985. The analysis of dental wear and caries for dietary reconstruction. In: Gilbert RI Jr, Mielke JH, editors. The Analysis of Prehistoric Diets. Orlando: Academic Press. p 307-338.

Prowse TL, Schwarcz HP, Macchiarelli R, Bondioli L. 1997. Infra-red, fluorescence, and stable isotope studies of bones from Isola Sacra. Poster presented at 'Humans from the Past: Advancement in Research and Technology'. Rome, December, 1997.

Purcell N. 1985. Wine and wealth in ancient Italy. Journal of Roman Studies 75:1-19.

Purcell N. 1995. Eating fish: The paradoxes of seafood. In: Wilkins J, Harvey D, Dobson M, editors. Food in Antiquity. Exeter: University of Exeter Press. p 132-149.

Radcliffe W. 1974. Fishing from the Earliest Times. Chicago: Ares Publishers Inc.

Rathbun TA. 1984. Skeletal pathology from the Paleolithic through the Metal Ages in Iran and Iraq. In: Cohen MN, Armelagos GJ, editors. Orlando: Academic Press. p 137-167.

Rau GH, Mearns AF, Young DR, Olson RJ, Schafer HA, Kaplan IR. 1983. Animal $^{13}C/^{12}C$ correlates with trophic level in pelagic food webs. Ecology 64:1314-1318.

Rawson B. 1991. Adult-child relationships in Roman society. In: Beryl Rawson, editor. Marriage, Divorce, and Children in Ancient Rome. Oxford: Clarendon Press. p 7-30.

Repetto E, Canci A, Borgognini Tarli SM. 1988. Indicatori scheletrici e dentari dello stato di salute nel campione dell'Eta' del Bronzo di Toppo Daguzzo, Basilicata. Rivista di Antropologia 66:89-112.

Richards M, van Klinken GJ. 1997. A survey of European human bone stable carbon and nitrogen isotope values. In: Sinclair AGM, Slate EA, Gowlett JAJ, editors. Archaeological Sciences 1995. Oxford: Oxbow Archaeological Monograph. p 363-368.

Richards MP, Hedges REM, Molleson TI, Vogel JC. 1998. Stable isotope analysis reveals variations in human diet at the Poundbury Camp cemetery site. Journal of Archaeological Science 25:1247-1252.

Rickman GE. 1996. Portus in perspective. In: Zevi AG, Claridge A, editors. 'Roman Ostia' Revisited. London: The British School at Rome. p 281-291.

Robb J. (1993). Skeletal signs of activity in the Italian Metal Ages. Paper presented at the 10th congress of Italian Anthropologists.Pisa, September, 1993.,

Robb J. 1997. Intentional tooth removal in Neolithic Italian women. Antiquity 71:659-669.

Robinson C, Kirkham J, Weatherell JA, Strong M. 1986. Dental enamel: a living fossil. BAR International Series, No. 291. In: Cruwys E, Foley RA, editors. Teeth and Anthropology. Oxford: British Archaeological Reports. p 31-54.

Rose JC, Burnett BA, Nassaney MS, Blaeuer MW. 1984. Paleopathology and the origins of maize agriculture in the lower Mississippi Valley and Caddoan culture areas. In: Cohen MN, Armelagos GJ, editors. Paleopathology at the Origins of Agriculture. Orlando: Academic Press. p 393-424.

Rose JC, Marks MK, Tieszen LL. 1991. Bioarchaeology and subsistence in the central and lower portions of the Mississippi Valley. In: Powell ML, Bridges PS, Mires AMW, editors. What Mean These Bones? Studies in southeastern Bioarchaeology. Tuscaloosa: University of Alabama Press. p 7-21.

Rossi PF, Bondioli L, Geusa G, Macchiarelli R. 1998. Enamel Microstructure and Developmental Defects of the Primary Dentition. Osteodental Biology of the People of *Portus Romae* (Necropolis of Isola Sacra, 2nd-3rd Cent. AD). I (CD-ROM). Roma: Soprintendenza Speciale al Museo Nazionale Preistorico Etnografico "L. Pigorini".

Saller R, Shaw B. 1984. Tombstones and Roman family relations in the principate: civilians, soldiers and slaves. Journal of Roman Studies 74:124-156.

Salvadei L, Macchiarelli R. 1983. Osservazioni sullo scheletro proveniente da Masseria Valente. In: Cassano SM, Manfredini A, editors. Studi sul Neolitico del Tavoliere della Puglia: Indagine Territoriale in Un'area-campione. BAR International Series No. 160. Oxford: BAR Archaeological Reports. p 253-262.

Sandford MK. 1992. A reconsideration of trace element analysis in prehistoric bone. In: Saunders SR, Katzenberg MA, editors. Skeletal Biology of Past Peoples: Research Methods. New York: Wiley-Liss, Inc. p 79-103.

Sandford MK. 1993. Understanding the biogenic-diagenetic continuum: interpreting elemental concentrations of archaeological bone. In: Sandford MK, editor. Investigations of Ancient Human Tissue: Chemical Analyses in Anthropology. Langhorne, PA: Gordon & Breach Science Publishers. p 3-55.

Saunders SR, DeVito C, Katzenberg MA. 1997. Dental caries in nineteenth century Upper Canada. American Journal of Physical Anthropology 104:71-87.

Savorè C. 1996. I Resti Scheletrici Umani di Isola Sacra: Stimà dell'Eta alla Morte con Metodo Istomorfometrico ed Analisi Paleoistologica di un Campione. Unpublished M.A. Thesis, Universita di Pavia, Pavia, Italy.

Scarra C. 1995. Chronicle of the Roman Emperors: The Reign-by-Reign Record of the Rulers of Imperial Rome. New York: Thames and Hudson, Inc.

Schneider KN. 1986. Dental caries, enamel composition, and subsistence among prehistoric Amerindians of Ohio. American Journal of Physical Anthropology 71:95-102.

Schoeller DA. 1999. Isotope fractionation: why aren't we what we eat? Journal of Archaeological Science 26:667-673.

Schoeninger MJ, DeNiro MJ. 1982. Carbon isotope ratios of apatite from fossil bone cannot be used to reconstruct diets of animals. Nature 297:577-578.

Schoeninger MJ, DeNiro MJ, Tauber H. 1983. Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. Science 220:1381-1383.

Schoeninger MJ, DeNiro MJ. 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochimica et Cosmochimica Acta 48:625-639.

Schoeninger MJ, Moore KM, Murray ML, Kingston JD. 1989. Detection of bone preservation in archaeological and fossil samples. Applied Geochemistry 4:281-292.

Schoeninger MJ, Moore K. 1992. Bone stable isotope studies in archaeology. Journal of World Prehistory 6:247-296.

Schoeninger MJ. 1995. Stable isotope studies in human evolution. Evolutionary Anthropology 4:83-98.

Schurr MR. 1997. Stable nitrogen isotopes as evidence for the age of weaning at the Angel site: a comparison of isotopic and demographic measures of weaning age. Journal of Archaeological Science 24:919-927.

Schurr MR. 1998. Using stable nitrogen-isotopes to study weaning behavior in past populations. World Archaeology 30:327-342.

Schwarcz HP, Melbye J, Katzenberg MA, Knyf M. 1985. Stable isotopes in human skeletons of southern Ontario: reconstructing palaeodiet. Journal of Archaeological Science 12:187-206.

Schwarcz HP, Schoeninger MJ. 1991. Stable isotope analyses in human nutritional ecology. Yearbook of Physical Anthropology 34:283-321.

Schwarcz HP. 1991. Some theoretical aspects of isotope paleodiet studies. Journal of Archaeological Science 18:261-275.

Schwarcz HP, Dupras TL, Fairgrieve SI. 1999. ^{15}N enrichment in the Sahara: in search of a global relationship. Journal of Archaeological Science 26:629-636.

Schwarcz HP. 2000. Some biochemical aspects of carbon isotopic paleodiet studies. In: Ambrose SH, Katzenberg MA, editors. Biogeochemical Approaches to Paleodietary Analysis. Kluwer Academic/Plenum Press. p 189-210.

Scott EC. 1979. Dental wear scoring technique. American Journal of Physical Anthropology 51:213-218.

Scott GR, Turner CG II. 1988. Dental anthropology. Annual Review of Anthropology 17:99-126.

Scullard HH. 1982. From the Gracchi to Nero: A History of Rome from 133 B.C. to A.D. 68 (5th Edition). London: Routledge.

Sealy JC, van der Merwe NJ, Lee Thorp JA, Lanham JL. 1987. Nitrogen isotopic ecology in southern Africa: implications for environmental and dietary tracing. Geochimica et Cosmochimica Acta 51:2707-2717.

Sippel DV. 1987. Dietary deficiency among the lower classes of late Republican and early Imperial Rome. The Ancient World 16:47-54.

Smith BH. 1984. Patterns of molar wear in hunter-gatherers and agriculturalists. American Journal of Physical Anthropology 63:39-56.

Smith P, Tau S. 1978. Dental pathology in the period of the Roman Empire: a comparison of two populations. Ossa 5:35-41.

Sobolik KD. 1994. Paleonutrition: The Diet and Health of Prehistoric Americans. Carbondale, Il: Center for Archaeological Investigations.

Sperduti A. 1995. I Resti Scheletrici Umani della Necropoli di Età Romano-Imperiale di Isola Sacra (I-III sec. d.C.). Unpublished PhD dissertation. Roma: Department of Animal and Human Biology, Universita 'La Sapienza'.

Spurr MS. 1983. The cultivation of millet in Roman Italy. Papers of the British School at Rome 51:1-15.

Spurr MS. 1986. Arable Cultivation in Roman Italy, c. 200 B.C. - c. A.D. 100. London: The Society for the Promotion of Roman Studies.

Stambaugh JE. 1988. The Ancient Roman City. Baltimore: The Johns Hopkins University Press.

Stenhouse MJ, Baxter MS. 1979. The uptake of bomb ^{14}C in humans. In: Berger R, Suess H, editors. Radiocarbon Dating. Berkeley: University of California Press. p 324-341.

Stout S. 1978. Histological structure and its preservation in ancient bone. Current Anthropology 19:601-604.

Sullivan CH, Krueger HW. 1981. Carbon isotope analysis of separate chemical phases in modern and fossil bone. Nature 292:333-335.

Tieszen LL, Boutton TW, Tesdahl KG, Slade NA. 1983. Fractionation and turnover of stable carbon isotopes in animal tissues: implications for delta ^{13}C analysis of diet. Oecologia32-37.

Tieszen LL. 1991. Natural variation in the carbon isotope values of plants: implications for archaeology, ecology, and paleoecology. Journal of Archaeological Science 18:227-248.

Tieszen LL, Fagre T. 1993. Effect of diet quality and composition on the isotopic composition of respiratory CO_2, bone collagen, bioapatite, and soft tissues. In: Lambert JB, Grupe G, editors. Prehistoric Human Bone: Archaeology at the Molecular Level. Berlin: Springer-Verlag. p 121-155.

Turner CG II. 1979. Dental anthropological indications of agriculture among the Jomon people of central Japan: X. Peopling of the Pacific. American Journal of Physical Anthropology 51:619-636.

Turner CG II, Machado LMC. 1983. A new dental wear pattern and evidence for high carbohydrate consumption in a Brazilian archaic skeletal population. American Journal of Physical Anthropology 61:125-130.

Ubelacker DH. 1989. Human Skeletal Remains: Excavation, Analysis, Interpretation. Washington: Taraxacum.

van der Merwe NJ, Vogel JC. 1978. ^{13}C content of human collagen as a measure of prehistoric diet in woodland North America. Nature 276:815-816.

van der Merwe NJ. 1982. Carbon isotopes, photosynthesis, and archaeology. American Scientist 70:596-606.

van der Merwe NJ, Medina E. 1991. The canopy effect, carbon isotope ratios and foodwebs in Amazonia. Journal of Archaeological Science 18:249-259.

Vehling JD. 1977. Apicius: Cookery and Dining in Imperial Rome (2nd Edition). New York: Dover Publications Inc.

Vogel JC. 1978. Isotopic assessment of the dietary habits of ungulates. South African Journal of Science 74:298-301.

Vogel JC, Talma AS, Hall-Martin AJ, Viljoen PJ. 1990. Carbon and nitrogen isotopes in elephants. South African Journal of Science 86:147-150.

Walker PL. 1978. A quantitative analysis of dental attrition rates in the Santa Barbara channel area. American Journal of Physical Anthropology 48:101-106.

Walker PL, DeNiro MJ. 1986. Stable nitrogen and carbon isotope ratios in bone collagen as indices of prehistoric dietary dependence on marine and terrestrial resources in southern California. American Journal of Physical Anthropology 71:51-61.

Walker PL, Hewlett BS. 1990. Dental health diet and social status among central African foragers and farmers. American Anthropologist 92:383-398.

Walker S. 1985. Memorials to the Roman Dead. London: British Museum Publications.

White CD, Schwarcz HP. 1989. Ancient Maya diet at Lamanai, Belize: as inferred from isotopic and chemical analysis of human bone. Journal of Archaeological Science 16:451-474.

White CD. 1993. Isotopic determination of seasonality in diet and death from Nubian mummy hair. Journal of Archaeological Science 20:657-666.

White CD, Schwarcz HP. 1994. Temporal trends in stable isotopes for Nubian mummy tissues. American Journal of Physical Anthropology 93:165-187.

White CD. 1994. Dietary dental pathology and cultural change in the Maya. In: Herring DA, Chan L, editors. Strength in Diversity: A Reader in Physical Anthropology. Toronto: Canadian Scholars' Press. p 279-302.

White CD, Wright LE, Pendergast DM. 1994. Biological disruption in the early Colonial period at Lamanai. In: Larsen CS, Milner GR, editors. In the Wake of Contact: Biological Responses to Conquest. New York: Wiley-Liss. p 135-145.

White KD. 1976. Food requirements and food supplies in classical times in relation to the diets of the various classes. Progress in Food Nutrition and Science 2:143-191.

White KD. 1988. Farming and animal husbandry. In: Grant M, Kitzinger R, editors. Civilization of the Ancient Mediterranean. New York: Charles Scribner's Sons. p 211-246.

Whittaker DK, Molleson TI, Bennett RB, Edwards I, Jenkins PR, Llewelyn JH. 1981. The prevalence and distribution of dental caries in a Romano-British population. Archives of Oral Biology 26:237-245.

Whittaker DK, Molleson TI, Daniel AT, Williams JT, Rose P, Resteghini R. 1985a. Quantitative assessment of tooth wear, alveolar-crest height and continuing eruption in a Romano-British population. Archives of Oral Biology 30:493-501.

Whittaker DK, Davies G, Brown M. 1985b.Tooth loss, attrition and temporomandibular joint changes in a Romano-British population. Journal of Oral Rehabilitation 12:407-419.

Whittaker DK, Ryan S, Weeks K, Murphy WM. 1987. Patterns of approximal wear in cheek teeth of a Romano-British population. American Journal of Physical Anthropology 73:389-396.

Wiedemann T. 1989. Adults and Children in the Roman Empire. London: Routledge.

Wilkins J, Hill S. 1995. The sources and sauces of Athenaeus. In: Wilkins J, Harvey D, Dobson M, editors. Food in Antiquity. Exeter: University of Exeter Press. p 429-438.

Williams SA, Curzon MEJ. 1986. Observations on dental caries in primary teeth in some medieval British skull material. In: Cruwys E, Foley RA, editors. Teeth and Anthropology. Oxford: British Archaeological Reports. p 201-214.

Wood JW, Milner GR, Harpending HC, Weiss KM. 1992. The osteological paradox: problems in inferring prehistoric health from skeletal samples. Current Anthropology 33:343-358.

Wright LE, Schwarcz HP. 1996. Infrared and isotopic evidence for diagenesis of bone apatite at Dos Pilas Guatemala: paleodietary implications. Journal of Archaeological Science 23:933-944.

APPENDIX A –

COMPARISON OF COLLAGEN YIELD, BONE HISTOLOGY, AND C:N RATIOS

SCR #	% Yield	Histology	C:N Ratio		SCR #	% Yield	Histology	C:N Ratio
34	8.54	Normal	3.49		127	3.03	Amorphous	3.40
38	18.08	Normal	3.42		142	2.79	Amorphous	3.11
1045	10.15	Normal			178	6.34	Amorphous	3.40
1230	9.27	Normal/Foc.			223	0.13	Amorphous	
132	0.48	Normal			326	4.46	Amorphous	3.37
145	12.23	Normal	3.23		A211	5.73	Amorphous	3.46
177	9.04	Normal	3.16		A249	3.58	Amorphous	3.58
208	6.25	Normal	3.39		A463	5.02	Amorphous	3.43
239	4.09	Normal	3.28		**Average**	**3.89**		**3.39**
242	10.22	Normal	3.59					
265	12.26	Normal	3.34					
322	9.53	Normal	3.37		28	2.96	Focalized	3.52
524	1.46	Normal/Min.	3.42		73	7.39	Focalized	3.65
A139	13.19	Normal	*		89	3.34	Focalized	3.52
A236	19.22	Normal	*		1091	4.15	Focalized	*
A329a	7.02	Normal	3.42		1112	3.67	Focalized	*
A422	4.22	Normal/Foc.	*		1210	5.42	Focalized	*
Average	**9.13**		**3.37**		172	9.66	Focalized	3.39
					211	9.35	Focalized/Min.	3.26
					213	4.83	Focalized	3.43
253	0.42	Mineralized	*		258	3.28	Focalized	3.40
502	4.21	Mineralized	*		280	5.86	Focalized	*
Average	**2.32**		*		289	0.35	Focalized	*
					299	3.88	Focalized	3.42
					336	0.01	Focalized	*
					A144	7.62	Focalized/Amor.	*
					A190	3.87	Focalized	3.38
					A202	10.79	Focalized	*
					A206	0.23	Focalized	*
					A222	0.86	Focalized	3.34
					A247	7.23	Focalized	3.40
					A357	2.9	Focalized	*
					A362	12.24	Focalized	3.50
					A364/1	9.51	Focalized	3.38
					A364/2	12.01	Focalized	3.40
					A380	1.63	Focalized	3.34
					A412	3.56	Focalized	*
					A418	5.09	Focalized	*
					Average	**5.25**		**3.42**

APPENDIX B -

ISOLA SACRA SAMPLE – RAW DATA

SCR #	Alt. SCR #	Zone	Burial Type	Age	Sex	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C_{ap}$ (‰)	C:N ratio	% Yield	Histology
SCR 002		24	inhumation	7-8	U	-19.2	11.0	-10.1	3.35	3.10	
SCR 005		23	inhumation	18-20	F		9.2	-11.1	3.25	3.10	
SCR 015		20	cappucina	50+/-	F	-18.6	13.1	-13.9	3.43	8.50	
SCR 018		2	amphora	25-30	F	-18.9	10.9	-11.3	3.60	4.26	
SCR 020		2	semicappucina	20-30	F	-18.9	9.8		3.31	11.41	
SCR 027		21	inhumation	35-40	F	-18.9				0.16	
SCR 028		26	inhumation	50+/-	F	-18.6	11.5		3.52	2.96	Focalized
SCR 029		22	pit	14-15	U	-18.8		-15.6	3.37	3.83	
SCR 032		**20**	**cappucina**	**18-20**	**F**	**-18.8**	**11.1**		**3.67**	**2.85**	
SCR 034		26	cappucina	40-50	F	-18.7	10.4		3.49	8.54	Normal
SCR 035		24	sand	20-25	M	-18.8	8.6	-10.8	3.55	4.11	
SCR 038		14	inhumation	45-50	M	-18.6	12.8	-14.1	3.42	18.08	Normal
SCR 044		**24**	**inhumation**	**40-45**	**M**	**-19.4**	**15.3**		**3.61**	**3.74**	
SCR 050		22	amphora	12-14	U	-20.4	8.5	-11.1		0.47	
SCR 057		22	inhumation	25-30	F	-18.7	11.0	-11.2	3.44	1.68	
SCR 073		26	cappucina	40+/-	M	-18.9	11.4	-12.8	**3.65**	7.39	Focalized
SCR 079		20	inhumation	40-50	F	-18.5	11.4		3.46	4.17	
SCR 089		21	sand	20+/-	M	-18.5	11.7	-12.3	3.52	3.34	Amorphous
SCR 090		24	inhumation	25-35	M	-18.8	11.1		3.50	2.45	
SCR 097		20	cappucina	40-50	M	-18.6	11.1	-10.3	3.42	5.28	
SCR 098		14	cappucina	20-25	F	-18.9	11.5		3.46	3.35	
SCR 099		*	cappucina	40-50	M	-18.5	9.2	-10.6	3.45	2.75	
SCR 124		20	cappucina	15-16	U	-18.9	9.7		3.37	1.24	
SCR 124A		**same**	**same**	**same**	**same**	**-19.0**	**9.9**	**-10.7**	**3.64**	**2.76**	
SCR 127		1	inhumation	40+/-	M	-18.0	11.5	-12.0	3.40	3.03	Amorphous
SCR 134		**16**	**sand**	**50+**	**M**	**-18.6**	**11.8**	**-11.6**	**3.84**	**5.94**	
SCR 142		10	cappucina	30-35	M	-18.7	11.1	-10.1	3.11	2.79	Amorphous
*** Bold =**	**Excluded**	**from**	**analysis**								

SCR #	Alt. SCR #	Zone	Burial Type	Age	Sex	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C_{ap}$ (‰)	C:N ratio	% Yield	Histology
SCR 145		1	cappucina	45-50	M	-18.5	8.9	-13.4	3.23	12.23	Normal
SCR 149		16	sand	16-17	M	-19.0	10.5	-10.2	3.58	5.33	
SCR 155		18	sand	35-40	F	-18.9	11.0	-11.6	3.33	5.16	
SCR 158		16	sand	40-45	M	-19.0	10.5	-10.7	3.07	3.72	
SCR 160		20	inhumation	40-50	F	-18.9	11.1		3.43	5.93	
SCR 172		20	sand	50+	M	-18.7	11.1	-13.6	3.39	9.66	Focalized
SCR 174		*	tomb 5E	30-40	M	-19.2	9.1	-11.1	3.34	10.16	
SCR 177		*	tomb 5E	50+	F	-18.4	12.3		3.16	9.04	Normal
SCR 178		19	sand	30-40	M	-18.7	11.1	-10.5	3.40	6.34	Amorphous
SCR 179		1	sarcophagus	50+	M	-18.2	11.2		3.27	4.99	
SCR 180		16	sand	20-25	M	-18.5	9.8	-11.3	3.43	6.12	
SCR 188		20	sand	20-30	M	-18.6	11.1	-9.9	3.34	5.31	
SCR 193		2	amphora	25-30	F	-19.1	9.8	-11.6	3.25	2.90	
SCR 200		12A	amphora	6-7	U	-19.2	10.7	-10.5	**3.70**	2.13	
SCR 208		18	sand	40+/-	F	-19.0	10.9		3.39	6.25	N/F
SCR 211		12A	sand	20+/-	M	-18.6	10.5	-11.5	3.26	9.35	Focalized
SCR 213		16	sand	20+/-	M	-18.5	10.8	-10.8	3.43	4.83	Focalized
SCR 220		*	tomb 2E	40-45	M	-18.6	12.0	-11.5	3.36	2.67	
SCR 237		1	amphora	14-15	U	-19.1	9.6		3.28	2.95	
SCR 239		20	inhumation	40-45	F		11.9	-10.3	3.28	4.09	
SCR 253		19	cappucina	40-50	M		12.1			0.42	Mineralized
SCR 258		16	sand	20-25	F	-18.8	10.4	-11.3	3.40	3.28	Focalized
SCR 265		19	cappucina	40-50	M	-18.8	13.0		3.34	12.26	N/M
SCR 280		18	semicappucina	40-50	M	-18.6	14.4	-12.3		5.86	Focalized
SCR 290		**15**	**cappucina**	**12-13**	**U**	**-19.3**	**11.0**	**-10.3**	**0.25**	**3.53**	
SCR 295		10	sand	40-50	F	-18.6		-10.7		2.70	
SCR 299		20	inhumation	40-50	F	-18.6	11.5		3.42	3.88	Focalized
SCR 309		1	amphora	10-11	U	-19.2	9.2	-10.4	3.58	2.97	

SCR #	Alt. SCR #	Zone	Burial Type	Age	Sex	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C_{ap}$ (‰)	C:N ratio	% Yield	Histology
SCR 310		14	pit	17-19	M	-18.6	9.9	-10.1	3.35		
SCR 315		14B	cappucina	8-9	U	-19.3	10.9	-10.8	3.26	2.09	
SCR 321		18	sand	30-35	F	-19.5	10.1	-10.6	3.42	3.37	
SCR 322		12A	cappucina	16-17	M	-18.7	11.7	-13.6	3.37	9.53	Normal
SCR 324		12A	cappucina	30-40	F	-18.7	10.9		3.35	2.57	
SCR 325		20	inhumation	20-25	M	-19.2	9.5	-9.8	3.38	4.48	
SCR 326		7C	semicappucina	35-40	F	-19.0	10.5		3.37	4.46	Amorphous
SCR 329		12A	cappucina	40-50	F	-19.1	10.9		3.43	2.10	
SCR 330		*	tomb 2E	20-30	F	-18.8	8.7		3.44	5.11	
SCR 331		12A	sand	30-35	M	-18.6	9.4	-10.9		3.80	
SCR 333		*	**tomb 5E**	**12-13**	**U**	**-19.8**	**9.3**	**-10.7**	**3.66**	**4.01**	
SCR 334		20	sand	30-35	F	-18.9			3.43	3.27	
SCR 336		13	cappucina	50+	F	-18.4		-12.6		0.01	Focalized
SCR 338		22	inhumation	50+	F	-19.3	8.8	-11.1	3.32	6.81	
SCR 341		*	*	40-50	M	-18.6	10.7	-11.0	3.37	5.51	
SCR 344		10	sand	30-35	M	-18.7	11.5		3.43	1.99	
SCR 354		10	sand	17-18	M	-19.1	11.5	-10.3	**3.72**	2.30	
SCR 360		10	amphora	17-19	M	-19.2		-10.4	**0.31**	3.07	
SCR 402		12A	inhumation	5-6	U	-18.8	11.3			2.42	
SCR 406		26	inhumation	18-20	F	-19.0	10.1	-9.5	**0.73**	2.63	
SCR 502		12A	cappucina	20+/-	M	-18.0	12.1	-12.3		4.21	Mineralized
SCR 519		15	cappucina	11-12	U	-19.7	10.0		3.39	1.64	
SCR 524		20	cappucina	50+/-	M		11.3	-12.6	3.42	1.46	
SCR 530		5	colombario	10-11	U	-19.1	10.7	-10.4	3.24	5.86	
SCR 538		12	sand	10-11	U	-19.2	10.9	-10.3	3.15	2.52	
SCR 557		*	colombario	12-13	U	-19.2	10.4	-10.6	**3.62**	5.16	
SCR A139	569	19	cappucina	25-30	M	-19.0	10.9			13.19	Normal
SCR A144	365	12	sparse scatter	20+/-	M	-18.9	10.5			7.62	F/A

SCR #	Alt. SCR #	Zone	Burial Type	Age	Sex	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C_{ap}$ (‰)	C:N ratio	% Yield	Histology
SCR A166	466	16	sand	40-50	F	-19.0	11.2	-12.1	3.40	3.05	
SCR A190	465	1	inhumation	20-30	M	-18.8	9.9		3.38	3.87	Focalized
SCR A202	410	19	sand	40+/-	M	-18.6	11.5	-10.6		10.79	Focalized
SCR A211	570	19	sand	20+/-	M	-18.6	9.5		3.46	5.73	Amorphous
SCR A222	418	19	sand	20+/-	M	-19.1	10.1		3.34	0.86	Focalized
SCR A236	449	19	sand	50+/-	M	-19.2	13.4			19.22	Normal
SCR A239	242	19	cappucina	30-40	U	-18.8	11.1		3.59	10.22	
SCR A247	454	19	sand	25-30	M	-18.8	10.6		3.40	7.23	Focalized
SCR A249	125	7C	semicappucina	25-30	M	-18.7	12.0		3.73	3.58	
SCR A306	558	5	colombario	20-21	F	-18.5	10.0			14.11	
SCR A326	448		tomb 2E	30-35	M	-18.4	12.4	-12.7		3.62	
SCR A329a	479		tomb 5E	30-40	F	-19.3	9.9		3.42	7.06	N/F
SCR A357	455	26	inhumation	30-40	M	-19.2	10.8		*	2.90	Focalized
SCR A360	151	20	inhumation	50+/-	M	-18.7	10.9		3.37	14.22	
SCR A362	371		tomb 5E	20-30	F	-19.1	7.5		3.50	12.24	
SCR A364/1						-18.6	11.7		3.38	9.51	Focalized
SCR A364/2						-18.5	12.1		3.40	12.01	Focalized
SCR A380	425		colombario	50+/-	M	-18.8	11.0		3.34	1.63	Focalized
SCR A412	405	9	inhumation	40-50	F	-19.0	11.6			3.56	Focalized
SCR A418	429	2	inhumation	20+/-	F	-19.0	11.3	-12.5		5.09	Focalized
SCR A422	122	99	inhumation	40-50	M	-18.5	9.6			4.22	Focalized
SCR A463	423	5	colombario	40-50	M	-18.6	11.2		3.43	5.02	Amorphous
SCR 1005/3	579		tomb 41	14-15	U	-18.7	9.4	-11.8		4.20	
SCR 1016/1			tomb	adult	U	-18.6	10.9			2.64	
SCR 1028/3			tomb	adult	U	-18.5	13.1			12.85	
SCR 1045	576		tomb 72	50+/-	M	-18.9		-12.6		10.15	Normal
SCR 1091	729		tomb 75	50+/-	M	-18.7	13.0			4.15	Focalized
SCR 1105/1			tomb	adult	U	-18.7	11.6			0.98	

SCR #	Alt. SCR #	Zone	Burial Type	Age	Sex	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C_{ap}$ (‰)	C:N ratio	% Yield	Histology
SCR 1112	591		tomb	20+/-	M	-18.6	10.6			3.67	Focalized
SCR 1133/3			tomb	adult	U	-18.9	11.1			1.32	
SCR 1139/1			tomb	adult	U	-19.0	10.3	-12.6		15.74	
SCR 1139/3			tomb	adult	U	-18.4	11.4			17.14	
SCR 1147/1			tomb	adult	U	-18.7	10.1	-13.8		13.30	
SCR 1175/4	741		tomb 7	5-6	U	-18.2	11.9	-10.4	3.40	5.33	
SCR 1210			tomb	adult	U	-17.8	7.8	-11.4		5.42	Focalized
SCR 1214/2			tomb 76	16-20	F	-19.2	10.6	-11.7		6.46	
SCR 1225			tomb 44	adult	U	-18.9	11.1	-12.0	3.73	8.74	
SCR 1230	719		tomb 85	45-50	M	-18.8	10.7			9.27	N/F/M

APPENDIX C –

CRYSTALLINITY INDICES

SCR #	Crystallinity Index	Burial Type
34	3.96	Cappucina
38	4.12	Inhumation
59	3.27	Soil
68	3.68	Cappucina
73	3.57	Cappucina
84	3.27	Soil
89	3.57	Soil
127	3.28	Inhumation
133	3.12	Tomb
138	3.28	Unknown
148	3.22	Cappucina
149	3.21	Soil
153	3.28	Soil
169	3.19	Soil
221	3.31	Cappucina
250	3.05	Soil
290	3.28	Cappucina
305	3.37	Amphora
306	2.85	Soil
310	3.22	Soil
331	3.36	Soil
343	3.07	Soil
352	3.20	Cappucina
360	3.31	Amphora
361	3.36	Cappucina
502	3.65	Cappucina

APPENDIX D –

ISOTOPIC DATA OF FAUNAL REMAINS FROM ISOLA SACRA

Sample #	Animal	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C_{ap}$ (‰)	% Yield
1	donkey	-21.2	3.6		7.62
2	cow	-20.3	6.0		4.21
3	horse	-19.8	7.7		3.10
4	pig	-20.1	4.5		2.36
5	pig	-20.5	4.0		2.97
6	dog	-19.3			0.54
7	sheep	-21.2			0.36
8	pig	-23.0			0.11
9	cow	-22.1	3.2		9.96
10	cow	-20.3	5.1		10.57
11	cow	-20.7	4.4		8.71
12	cow	-20.2	7.4	-9.8	5.66
13	dog	-19.2	9.2	-10.4	13.12
14	pig	-20.3	7.2	-11.4	14.51
15	goat	-20.6	5.8	-11.4	4.73
16	fox	-19.1	9.3		13.37
17	horse	-20.9	4.3	-10.3	6.10

APPENDIX E –

ANAS CEMETERY – ISOTOPIC DATA

ANAS #	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	% Yield
anas 4	-19.9	6.9	10.18
anas 5	-19.9	7.9	5.24
anas 15	-19.5	8.6	3.79
anas 25	-19.3	10.8	3.62
anas 31	-19.0	11.0	7.39
anas 34	-19.6	6.9	11.21
anas 54	-19.0	11.3	4.70
anas 77	-19.2	11.1	6.15
anas 79	-19.2	11.2	5.05
anas 83	-19.0	11.1	5.31
anas 84	-19.6	9.0	5.03
anas 85	-19.6	8.7	7.41
anas 87	-20.0	7.2	7.12
anas 93	-18.9	11.3	7.39

APPENDIX F –

ISOLA SACRA RIB DATA

SCR #	Zone	Burial Type	Age	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	C:N ratio	% Yield
SCR 001	14B	amphora	1.5-2	11.7	-19.1	3.49	1.32
SCR 003	14B	amphora	9-12 mo	15.1	-17.8	3.39	3.76
SCR 006	24	inhumation	3-4	11.0	-19.0	3.41	2.56
SCR 010	21	cassa	2-3	10.9	-19.3	3.65	3.54
SCR 014	**23**	**inhumation**	**2-2.5**	**83.5**	**-19.1**	*	**0.68**
SCR 023	24	inhumation	3-4	16.1	-18.8	3.56	8.65
SCR 026	24	inhumation	2-2.5	11.2	*	*	0.40
SCR 031	24	inhumation	4-5	8.7	-19.8	3.59	7.30
SCR 033	22	inhumation	1.5	14.5	-18.2	3.52	6.58
SCR 042	25	inhumation	3-4	10.8	-19.0	3.58	1.92
SCR 043	**25**	**amphora**	**3-4**	*	*	**10.88**	**3.20**
SCR 046	24	amphora	6-9 mo	14.7	-18.2	3.54	3.92
SCR 047	23A	amphora	2-6 mo	14.7	-18.2	3.45	6.14
SCR 061	19	sand	2-3	11.7	-19.2	3.57	5.45
SCR 062	14A	amphora	0-6 mo	15.2	-17.9	3.55	3.04
SCR 072	12A	inhumation	9-10	10.5	-19.1	3.48	3.14
SCR 101	21	sand	1.5-2	11.7	-19.0	3.60	4.73
SCR 108	14B	amphora	1.5-2	13.5	-18.8	3.63	1.10
SCR 109	20	sand	3-6 mo	13.7	-18.7	3.36	13.47
SCR 110	22	pit	1.5-2	14.9	-17.9	3.34	4.12
SCR 114	10	sand	12-13	11.2	-19.0	3.35	6.70
SCR 116	18	sand	17-20	*	-18.7	*	3.25
SCR 121	18	sand	14-15	10.3	*	*	4.17
SCR 139	10	amphora	1-1.5	13.9	-18.1	3.27	6.67
SCR 140	14A	amphora	9-12 mo	14.1	-18.2	3.29	4.85
SCR 141	20	amphora	1.5-2	12.5	-19.1	3.36	10.56
SCR 153	16	sand	2-3	11.8	-19.1	3.48	9.54
SCR 162	10	amphora	4-5	11.3	-18.9	3.28	15.90
SCR 167	16	sand	3-4	11.4	-18.9	3.42	3.41
SCR 168	14B	amphora	4-5	10.8	*	3.52	2.92
SCR 187	16	amphora	2-3	12.2	-18.9	3.47	8.48
SCR 222	10	amphora	6-12 mo	14.0	-18.2	3.41	9.77
SCR 235	12	cappucina	4-5	11.2	-19.0	3.21	8.16
SCR 248	12	amphora	1.5-2	11.5	-18.8	3.38	14.31
SCR 276	15	amphora	1.5-2	9.6	-19.8	3.42	7.24
SCR 278	12A	inhumation	2.5-3	11.4	-19.2	3.39	4.76
SCR 309	1	amphora	10-11	10.2	-18.8	3.53	4.82
SCR 310	14	pit	17-19	11.2	-18.9	*	1.17
SCR 313	18	sand	11-12	11.0	-18.7	3.32	14.04
SCR 315	14B	cappucina	8-9	11.2	-19.0	*	2.13
SCR 357	*	colombario	11-12	10.0	-19.2	3.40	11.13
SCR 359	10	amphora	1-1.5	13.8	-18.5	3.33	18.33
* Bold =	Deleted	from analysis					

SCR #	Zone	Burial Type	Age	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	C:N ratio	% Yield
SCR 400	25	inhumation	1-1.5	12.8	-18.4	*	7.11
SCR 402	12A	inhumation	5-6	11.8	-18.8	*	3.76
SCR 441	2E	tomb	1.5-2	13.3	-18.5	*	2.75
SCR 459	5E	tomb	9f-0	14.2	-17.9	*	16.75
SCR 491	7C	amphora	0-6 mo	15.4	-18.2	*	16.69
SCR 511	1	amphora	0-9 mo	14.4	-18.4	*	2.49
SCR 512	2E	tomb	15-16	15.4	-19.3	*	0.57
SCR 531	12A	amphora	6-7	*	-17.3	*	0.58
SCR 532	25	inhumation	6-12 mo	12.6	-18.7	*	0.80
SCR 542	1	inhumation	1-1.5	11.7	-18.9	*	7.46
SCR 564	4E	tomb	1.5-2	14.3	*	*	1.44

APPENDIX G –

TOTAL DENTAL SAMPLE: AGE, SEX, AND BURIAL TYPE

SCR #	Burial	Age	Sex
001	amphora	1.5-2	U
002	inhumation	7-8	U
005	inhumation	18-20	F
006	inhumation	3-4	U
007	cappucina	6-7	U
009	amphora	10-11	U
010	cassa	2-3	U
014	inhumation	2-2.5	U
015	cappucina	50+	F
016	pit	50+	F
018	amphora	25-30	F
019	inhumation	50+	F
023	inhumation	3-4	U
024	cappucina	11-12	U
025	amphora	6-7	U
026	inhumation	2-2.5	U
027	tomb	35-40	F
028	inhumation	50+	F
029	pit	14-15	U
030	cappucina	50+	M
031	inhumation	4-5	U
032	cappucina	18-20	F
035	sand	20-25	M
036	inhumation	20-21	M
037	sarcophagus	50+	M
038	inhumation	45-50	M
039	unknown	50+	F
040	sarcophagus	5-6	U
042	inhumation	3-4	U
043	amphora	3-4	U
044	inhumation	40-45	M
050	amphora	12-14	U
051	inhumation	7-8	U
052	pit	24-30	F
053	inhumation	50+	F
055	cappucina	40-45	F
058	inhumation	15-20	M
059	inhumation	35-40	F
060	inhumation	50+	F
061	sand	2-3	U

SCR #	Burial	Age	Sex
063	sand	1.5-2	U
065	semicappucina	1.5-2	U
066	sarcophagus	3-4	U
067	sand	45-50	F
068	cappucina	20-30	F
069	sarcophagus	30-40	F
072	inhumation	9-10	U
075	sand	20-30	M
076	cappucina	40-50	M
077	inhumation	30-35	M
078	cappucina	30-35	M
079	inhumation	40-50	F
080	semicappucina	12-15	U
081	tomb	3-4	U
084	sand	40-50	F
086	cappucina	20-25	M
088	sand	40+	M
090	inhumation	25-35	M
093	inhumation	3-4	U
094	amphora	4-5	U
095	inhumation	4-5	U
097	cappucina	40-50	M
098	cappucina	20-25	F
099	cappucina	40-50	M
100	sand	15-16	M
101	sand	1.5-2	U
102	amphora	1-1.5	U
103	amphora	8-9	U
104	sand	4-5	U
105	sand	40-50	F
106	cappucina	20-23	F
108	amphora	1.5	U
110	pit	1.5-2	U
111	sand	8-9	U
112	amphora	9-10	U
113	sand	45-50	F
115	sand	7-8	U
116	sand	17-20	M
118	inhumation	40-50	M
120	tomb	20-24	M

SCR #	Burial	Age	Sex
121	sand	14-15	U
124	cappucina	15-16	U
125	semicappucina	25-30	M
126	inhumation	16-18	M
127	inhumation	40+	M
129	cappucina	15-16	M
132	semicappucina	30-35	F
133	tomb	20-25	M
134	sand	50+	M
138	unknown	16-17	M
141	amphora	1.5-2	U
142	cappucina	30-35	M
143	cappucina	40-50	M
144	cappucina	25-30	M
145	cappucina	45-50	M
146	sand	11-12	U
147	inhumation	8-9	U
148	cappucina	40-50	F
149	sand	16-17	M
150	sand	40-50	F
151	inhumation	50+	M
153	sand	2-3	U
156	sarcophagus	50+	F
157	pit	19-20	F
158	sand	40-45	M
159	inhumation	40-50	F
160	inhumation	40-50	F
161	cappucina	30-40	F
162	amphora	4-5	U
163	sand	40-50	M
164	amphora	4-5	U
165	amphora	7-8	U
166	inhumation	12-13	U
167	sand	3-4	U
168	amphora	4-5	U
169	sand	20-30	F
170	unknown	40-50	M
171	cappucina	30-40	M
172	sand	50+	M
173	sand	40-44	F
174	tomb	30-40	M
175	amphora	8-9	U
176	inhumation	8-9	U
177	tomb	50+	F

SCR #	Burial	Age	Sex
178	sand	30-40	M
179	sarcophagus	50+	M
180	sand	20-25	M
181	coffin	40-44	M
182	tomb	6-7	U
183	sand	40-50	F
184	cappucina	50+	M
185	cappucina	40-50	F
186	tomb	50+	M
187	amphora	2-3	U
188	sand	20-30	M
189	colombario	40-45	M
190	cappucina	25-30	F
191	amphora	40-50	M
192	inhumation	40+	M
193	amphora	25-30	F
194	inhumation	40-45	F
196	unknown	20-25	M
197	amphora	20-30	F
199	unknown	35-40	F
200	amphora	6-7	U
201	cappucina	35-40	F
203	pit	18-20	F
204	cappucina	1.5-2	U
207	sand	20-25	M
208	sand	40+	F
209	sand	8-9	U
210	cappucina	50+	F
212	sand	20-30	M
215	sand	35-40	M
216	unknown	20-21	M
217	amphora	30-40	M
218	amphora	8-9	U
219	inhumation	17-19	M
220	tomb	40-45	M
221	cappucina	40-45	M
223	cappucina	35-40	F
224	tomb	20-25	M
225	amphora	8-9	U
226	cappucina	20-21	F
227	sarcophagus	50+	F
231	amphora	30-35	M
232	pit	40-50	M
233	sand	50+	F

SCR #	Burial	Age	Sex
234	sand	40-50	F
235	cappucina	4-5	U
236	inhumation	40+	M
237	amphora	14-15	U
263	unknown	20-24	F
264	sand	50+	M
265	cappucina	40-50	M
268	sand	15-16	F
269	tomb	35-40	F
270	tomb	3-4	U
271	cappucina	17-19	F
272	sand	30-35	F
273	sarcophagus	2-2.5	U
274	amphora	2.5-3	U
278	inhumation	2.5-3	U
279	semicappucina	9-10	U
280	cappucina	40-50	M
281	tomb	40-50	F
282	sand	30-40	M
283	inhumation	35-40	M
284	inhumation	20+	M
285	inhumation	50+	F
286	inhumation	30-40	M
287	cappucina	30-40	F
288	amphora	45-50	M
289	sand	45-50	F
290	cappucina	12-13	U
291	inhumation	45-50	F
292	semicappucina	30-40	F
295	sand	40-50	F
296	cappucina	30-35	F
297	sand	50+	M
298	sarcophagus	40-45	M
301	cappucina	30-40	M
302	cappucina	50+	M
303	cappucina	35-40	M
305	amphora	20-25	F
306	sand	20-25	F
307	cappucina	40-45	F
308	sand	50+	M
309	amphora	10-11	U
310	pit	17-19	M
312	semicappucina	35-40	F
314	sand	40-45	F

SCR #	Burial	Age	Sex
315	cappucina	8-9	U
317	inhumation	18-20	M
319	sand	18-20	M
320	inhumation	20-25	F
321	sand	30-35	F
322	cappucina	16-17	M
323	sand	50+	F
324	cappucina	30-40	F
325	inhumation	20-25	M
326	semicappucina	35-40	F
327	semicappucina	20-30	U
328	sand	11-12	U
329	cappucina	40-50	F
330	tomb	20-30	F
331	sand	30-35	M
332	cappucina	20-24	F
333	tomb	12-13	U
334	sand	30-35	F
335	cappucina	40-45	F
336	cappucina	50+	F
337	unknown	17-18	M
338	inhumation	50+	F
339	sand	45-50	M
340	inhumation	24-32	F
341	unknown	40-50	M
342	cappucina	40-50	M
343	inhumation	20-25	M
344	sand	30-35	M
347	sand	24-30	F
348	inhumation	40-50	M
351	unknown	15-20	U
352	semicappucina	35-40	F
354	sand	17-18	M
355	tomb	25-35	M
358	cappucina	30-35	F
360	amphora	17-19	M
361	cappucina	20-25	M
362	tomb	40-50	F
363	tomb	40-44	F
366	tomb	50+	M
368	colombario	17-19	M
369	tomb	30-40	M
371	tomb	20-30	F
376	inhumation	35-39	M

SCR #	Burial	Age	Sex
383	inhumation	40+	M
391	tomb	16-17	M
392	tomb	7-8	U
393	tomb	14-15	U
396	tomb	15-16	M
398	tomb	15-16	M
401	cappucina	40-45	F
402	inhumation	5-6	U
404	inhumation	20-25	M
406	inhumation	18-20	F
407	sand	50+	F
409	sand	30-40	F
410	sand	40+	M
411	cappucina	20-25	F
415	amphora	20-30	M
416	tomb	20-21	F
417	inhumation	40-45	F
419	amphora	40-50	F
420	pit	17-19	F
421	colombario	30-35	F
422	inhumation	45-50	F
423	amphora	40-50	M
425	colombario	50+	M
426	inhumation	25-30	F
429	inhumation	20+	F
433	tomb	30-35	F
434	cappucina	30-40	F
436	sarcophagus	50+	F
437	sand	50+	F
438	sand	50+	M
440	cappucina	50+	M
442	tomb	30-40	F
444	amphora	15-20	F
445	colombario	20-30	F
448	tomb	30-35	M
449	sand	50+	M
450	tomb	20-25	M
451	tomb	14-15	M
452	tomb	30-40	F
454	sand	25-30	M
455	inhumation	30-40	M
457	tomb	50+	M
462	inhumation	30-40	M
463	tomb	30-40	M

SCR #	Burial	Age	Sex
464	inhumation	25-30	M
465	inhumation	20-30	M
466	sand	40-50	F
467	cappucina	30-35	F
470	sarcophagus	24-30	F
474	inhumation	14-15	M
479	tomb	30-40	F
482	colombario	40-50	M
485	colombario	35+	M
494	colombario	50+	M
497	tomb	20+	F
501	tomb	30-40	F
507	tomb	24-30	F
509	tomb	20+	M
510	pit	30-40	F
512	tomb	15-16	M
517	colombario	14-15	F
519	cappucina	11-12	U
521	sarcophagus	20-21	M
522	sarcophagus	6-7	U
523	cappucina	5-6	U
526	tomb	30-40	M
530	colombario	10-11	U
531	amphora	6-7	U
534	sand	15-17	U
536	inhumation	4-5	U
537	cappucina	15-16	M
538	sand	10-11	U
539	colombario	11-12	U
540	inhumation	12-13	U
541	cappucina	3-4	U
557	colombario	12-13	U
558	colombario	20-21	F
562	cappucina	50+	M
563	cappucina	17-19	M
566	cappucina	50+	M
568	sand	25-30	F
576	tomb	50+	M
579	tomb	14-15	U
590	tomb	50+	M
605	tomb	16-18	U
609	tomb	16-18	U
677	tomb	17-20	F
678	tomb	50+	M

SCR #	Burial	Age	Sex
691	tomb	30-40	F
730	unknown	50+	M

APPENDIX H –

DENTAL DATA BY INDIVIDUAL TOOTH (AMTL, CALCULUS, ABSCESSES, CARIES, AND TOOTH WEAR)

POSTMORTEM LOSS, ANTEMORTEM LOSS, AND CONGENITAL ABSENCE

Tooth ID	Tooth		PM loss		AM loss		Congenital Absence
	Maxilla	Sockets (n)	(n)	%	(n)	%	(n)
1	right upper M3	147	18	12.24	13	8.84	12
2	right upper M2	214	7	3.27	19	8.88	0
3	right upper M1	242	13	5.37	22	9.09	0
4	right upper P2	216	38	17.59	10	4.63	0
5	right upper P1	218	35	16.06	9	4.13	0
6	right upper C	215	34	15.81	2	0.93	0
7	right upper I2	211	46	21.80	2	0.95	1
8	right upper I1	224	61	27.23	1	0.45	0
9	left upper I1	224	60	26.79	4	1.79	0
10	left upper I2	221	53	23.98	3	1.36	2
11	left upper C	220	38	17.27	3	1.36	0
12	left upper P1	217	43	19.82	9	4.15	0
13	left upper P2	209	35	16.75	13	6.22	0
14	left upper M1	237	9	3.80	26	10.97	0
15	left upper M2	208	7	3.37	18	8.65	0
16	left upper M3	156	21	13.46	23	14.74	11
	Mandible						
17	left lower M3	191	23	12.04	27	14.14	14
18	left lower M2	255	10	3.92	29	11.37	0
19	left lower M1	288	11	3.82	38	13.19	0
20	left lower P2	249	28	11.24	15	6.02	1
21	left lower P1	255	55	21.57	5	1.96	0
22	left lower C	266	40	15.04	3	1.13	0
23	left lower I2	269	60	22.30	8	2.97	0
24	left lower I1	264	73	27.65	24	9.09	1
25	right lower I1	270	77	28.52	17	6.30	0
26	right lower I2	273	68	24.91	9	3.30	0
27	right lower C	268	54	20.15	4	1.49	0
28	right lower P1	255	59	23.14	6	2.35	0
29	right lower P2	248	42	16.94	15	6.05	2
30	right lower M1	290	11	3.79	40	13.79	0
31	right lower M2	257	7	2.72	26	10.12	0
32	right lower M3	197	14	7.11	29	14.72	14
	Maxilla	3379	518	15.33	177	5.24	26
	Mandible	4095	632	15.43	295	7.20	32
	TOTAL	**7474**	**1150**	**15.39**	**472**	**6.32**	**58**

ABSCESSES

Tooth ID	Tooth	# Observable Sockets (n)	# of Abscesses (n)	Percent Abscess (%)
	Maxilla			
1	right upper M3	101	2	1.98
2	right upper M2	145	3	2.07
3	right upper M1	174	3	1.72
4	right upper P2	182	3	1.65
5	right upper P1	189	3	1.59
6	right upper C	180	0	0.00
7	right upper I2	181	1	0.55
8	right upper I1	165	2	1.21
9	left upper I1	166	6	3.61
10	left upper I2	171	2	1.17
11	left upper C	162	3	1.85
12	left upper P1	172	4	2.33
13	left upper P2	175	2	1.14
14	left upper M1	177	3	1.69
15	left upper M2	152	0	0.00
16	left upper M3	108	1	0.93
	Mandible			
17	left lower M3	168	0	0.00
18	left lower M2	224	1	0.45
19	left lower M1	251	4	1.59
20	left lower P2	222	0	0.00
21	left lower P1	233	1	0.43
22	left lower C	233	0	0.00
23	left lower I2	242	3	1.24
24	left lower I1	241	1	0.41
25	right lower I1	240	1	0.42
26	right lower I2	239	1	0.42
27	right lower C	226	0	0.00
28	right lower P1	232	1	0.43
29	right lower P2	226	2	0.88
30	right lower M1	254	3	1.18
31	right lower M2	226	0	0.00
32	right lower M3	167	0	0.00
	Maxilla	2600	38	1.46
	Mandible	3624	18	0.50
	TOTAL	**6224**	**56**	**0.90**

TOOTH WEAR

Tooth ID	Tooth Type	Teeth with Wear (n)	# Observable Teeth (n)	Cumulative Score	Average Tooth Wear
	Maxilla				
1	right upper M3	92	102	1038	10.18
2	right upper M2	170	175	2145	12.26
3	right upper M1	193	200	3007	15.04
4	right upper P2	142	160	489	3.07
5	right upper P1	139	166	446	2.69
6	right upper C	143	172	545	3.17
7	right upper I2	114	157	437	2.78
8	right upper I1	144	161	608	3.78
9	left upper I1	137	159	584	3.67
10	left upper I2	122	162	473	2.92
11	left upper C	145	172	531	3.09
12	left upper P1	130	155	425	2.74
13	left upper P2	139	154	462	3.00
14	left upper M1	182	189	2947	15.59
15	left upper M2	163	167	2184	13.08
16	left upper M3	74	94	943	10.03
	Mandible				
17	left lower M3	118	130	1512	11.63
18	left lower M2	201	206	2887	14.01
19	left lower M1	224	230	3885	16.89
20	left lower P2	187	198	616	3.11
21	left lower P1	153	186	471	2.53
22	left lower C	176	207	638	3.08
23	left lower I2	151	183	544	2.97
24	left lower I1	154	163	629	3.86
25	right lower I1	152	164	624	3.80
26	right lower I2	155	187	591	3.16
27	right lower C	175	199	633	3.18
28	right lower P1	156	180	470	2.61
29	right lower P2	179	189	569	3.01
30	right lower M1	220	226	3708	16.41
31	right lower M2	210	214	2960	13.83
32	right lower M3	129	142	1637	11.53
	Maxilla	2229	2545	17264	6.78
	Mandible	2740	3004	22374	7.45
	TOTAL	**4969**	**5549**	**39638**	**7.14**

CALCULUS

Tooth ID	Tooth Type	# Teeth with Calculus (n)	# Observable Teeth (n)	% Calculus
	Maxilla			
1	right upper M3	63	103	61.17
2	right upper M2	116	172	67.44
3	right upper M1	147	199	73.87
4	right upper P2	103	156	66.03
5	right upper P1	105	161	65.22
6	right upper C	117	169	69.23
7	right upper I2	95	155	61.29
8	right upper I1	96	153	62.75
9	left upper I1	89	153	58.17
10	left upper I2	93	158	58.86
11	left upper C	117	172	68.02
12	left upper P1	104	151	68.87
13	left upper P2	103	154	66.88
14	left upper M1	141	192	73.44
15	left upper M2	114	168	67.86
16	left upper M3	65	100	65.00
	Mandible			
17	left lower M3	101	132	76.52
18	left lower M2	150	201	74.63
19	left lower M1	165	233	70.82
20	left lower P2	145	194	74.74
21	left lower P1	144	180	80.00
22	left lower C	169	205	82.44
23	left lower I2	149	182	81.87
24	left lower I1	140	160	87.50
25	right lower I1	143	167	85.63
26	right lower I2	159	182	87.36
27	right lower C	160	193	82.90
28	right lower P1	141	176	80.11
29	right lower P2	136	185	73.51
30	right lower M1	169	229	73.80
31	right lower M2	160	214	74.77
32	right lower M3	105	146	71.92
	Maxilla	1668	2516	66.30
	Mandible	2336	2979	78.42
	TOTAL	**4004**	**5495**	**72.87**

CARIES

Tooth ID	Tooth	# Observable Teeth (n)	# Carious Teeth (n)	Percent Caries (%)
	Maxilla			
1	right upper M3	102	16	15.69
2	right upper M2	176	26	14.77
3	right upper M1	201	14	6.97
4	right upper P2	160	6	3.75
5	right upper P1	166	8	4.82
6	right upper C	171	5	2.92
7	right upper I2	160	3	1.88
8	right upper I1	159	4	2.52
9	left upper I1	155	2	1.29
10	left upper I2	160	3	1.88
11	left upper C	172	5	2.91
12	left upper P1	154	6	3.90
13	left upper P2	152	11	7.24
14	left upper M1	192	17	8.85
15	left upper M2	168	21	12.50
16	left upper M3	97	8	8.25
	Mandible			
17	left lower M3	133	13	9.77
18	left lower M2	201	21	10.45
19	left lower M1	231	18	7.79
20	left lower P2	199	6	3.02
21	left lower P1	184	2	1.09
22	left lower C	208	4	1.92
23	left lower I2	185	1	0.54
24	left lower I1	161	0	0.00
25	right lower I1	164	1	0.61
26	right lower I2	184	1	0.54
27	right lower C	195	2	1.03
28	right lower P1	179	0	0.00
29	right lower P2	187	10	5.35
30	right lower M1	234	23	9.83
31	right lower M2	216	26	12.04
32	right lower M3	143	14	9.79
	Maxilla	2545	155	6.09
	Mandible	3004	142	4.73
	TOTAL	**5549**	**297**	**5.35**

APPENDIX I –

CALCULUS DATA BY INDIVIDUAL (PERMANENT TEETH)

SCR #	# sides w/ calculus (n)	total # obs. Sides (n)	Calculus Score	Calculus Rate	Modified Calculus Rate
002	0	12	0.0	0.00	0.00
005	41	100	28.0	41.00	28.00
009	7	31	4.0	22.58	12.90
015	18	77	19.0	23.38	24.68
016	14	40	15.5	35.00	38.75
018	17	85	14.5	20.00	17.06
019	34	62	30.0	54.84	48.39
024	13	31	6.5	41.94	20.97
025	0	8	0.0	0.00	0.00
027	13	64	13.0	20.31	20.31
028	9	30	10.5	30.00	35.00
029	24	88	14.5	27.27	16.48
030	18	101	13.0	17.82	12.87
032	35	103	26.0	33.98	25.24
035	7	54	3.5	12.96	6.48
036	36	96	21.5	37.50	22.40
037	42	56	34.5	75.00	61.61
038	61	97	59.5	62.89	61.34
039	12	19	9.5	63.16	50.00
044	20	76	18.0	26.32	23.68
050	4	59	2.5	6.78	4.24
051	4	16	2.0	25.00	12.50
052	1	104	0.5	0.96	0.48
053	27	34	46.0	79.41	135.29
055	28	88	14.5	31.82	16.48
058	24	57	18.0	42.11	31.58
059	9	24	5.5	37.50	22.92
060	6	28	3.0	21.43	10.71
067	32	69	23.0	46.38	33.33
068	21	108	18.5	19.44	17.13
069	27	88	18.0	30.68	20.45
072	0	19	0.0	0.00	0.00
075	32	116	19.5	27.59	16.81
076	21	55	24.5	38.18	44.55
077	41	84	30.5	48.81	36.31
078	14	84	9.0	16.67	10.71
079	51	77	78.0	66.23	101.30
080	10	60	5.5	16.67	9.17
084	40	76	28.0	52.63	36.84
086	22	99	15.0	22.22	15.15
088	22	96	13.5	22.92	14.06
090	28	112	16.5	25.00	14.73
097	38	97	31.5	39.18	32.47

SCR #	# sides w/ calculus (n)	total # obs. Sides (n)	Calculus Score	Calculus Rate	Modified Calculus Rate
098	35	103	17.5	33.98	16.99
099	0	99	0.0	0.00	0.00
100	5	64	2.5	7.81	3.91
103	5	24	5.5	20.83	22.92
105	39	77	31.5	50.65	40.91
106	19	79	12.0	24.05	15.19
111	10	40	5.0	25.00	12.50
113	28	78	21.0	35.90	26.92
115	0	22	0.0	0.00	0.00
116	4	84	2.0	4.76	2.38
118	0	7	0.0	0.00	0.00
120	9	28	5.0	32.14	17.86
121	12	100	6.5	12.00	6.50
124	4	76	2.0	5.26	2.63
125	7	44	7.5	15.91	17.05
126	20	108	12.0	18.52	11.11
127	46	112	35.0	41.07	31.25
129	26	89	14.5	29.21	16.29
132	0	47	0.0	0.00	0.00
133	9	80	4.5	11.25	5.63
134	9	36	7.5	25.00	20.83
138	18	100	14.5	18.00	14.50
142	5	44	3.5	11.36	7.95
143	35	91	27.5	38.46	30.22
144	38	109	25.0	34.86	22.94
145	8	27	4.0	29.63	14.81
146	32	71	49.0	45.07	69.01
147	1	4	0.5	25.00	12.50
148	54	96	42.0	56.25	43.75
149	28	98	15.0	28.57	15.31
150	47	85	31.0	55.29	36.47
151	36	85	23.5	42.35	27.65
156	17	37	14.0	45.95	37.84
157	21	109	16.0	19.27	14.68
158	2	19	1.0	10.53	5.26
159	39	90	29.5	43.33	32.78
160	48	100	61.5	48.00	61.50
161	40	92	24.5	43.48	26.63
163	19	37	19.5	51.35	52.70
165	0	15	0.0	0.00	0.00
166	6	52	4.0	11.54	7.69
169	50	82	32.0	60.98	39.02
170	47	78	32.0	60.26	41.03

SCR #	# sides w/ calculus (n)	total # obs. Sides (n)	Calculus Score	Calculus Rate	Modified Calculus Rate
171	9	96	6.0	9.38	6.25
172	12	27	23.5	44.44	87.04
173	26	73	20.0	35.62	27.40
174	20	101	12.0	19.80	11.88
175	2	22	1.5	9.09	6.82
176	1	16	0.5	6.25	3.13
177	0	4	0.0	0.00	0.00
178	19	27	19.0	70.37	70.37
179	26	55	17.5	47.27	31.82
180	22	54	16.5	40.74	30.56
181	84	105	108.0	80.00	102.86
182	0	8	0.0	0.00	0.00
183	52	74	54.5	70.27	73.65
184	30	59	22.5	50.85	38.14
185	6	17	5.0	35.29	29.41
186	62	96	88.5	64.58	92.19
188	8	109	4.0	7.34	3.67
189	44	71	25.5	61.97	35.92
190	38	50	41.0	76.00	82.00
191	25	96	14.5	26.04	15.10
192	39	70	29.5	55.71	42.14
193	21	109	12.0	19.27	11.01
194	38	96	27.0	39.58	28.13
196	1	92	0.5	1.09	0.54
197	38	102	33.0	37.25	32.35
199	24	96	12.5	25.00	13.02
200	0	12	0.0	0.00	0.00
201	47	107	30.0	43.93	28.04
203	7	77	3.5	9.09	4.55
207	4	24	2.5	16.67	10.42
208	3	4	3.0	75.00	75.00
209	1	22	0.5	4.55	2.27
210	52	84	59.5	61.90	70.83
212	10	16	5.0	62.50	31.25
215	34	89	21.5	38.20	24.16
216	27	96	19.5	28.13	20.31
217	54	93	41.0	58.06	44.09
218	0	18	0.0	0.00	0.00
219	11	43	5.5	25.58	12.79
220	36	102	38.5	35.29	37.75
221	31	101	19.5	30.69	19.31
223	3	51	3.0	5.88	5.88
224	7	15	3.5	46.67	23.33

SCR #	# sides w/ calculus (n)	total # obs. Sides (n)	Calculus Score	Calculus Rate	Modified Calculus Rate
225	2	16	1.0	12.50	6.25
226	17	78	9.0	21.79	11.54
227	28	61	27.5	45.90	45.08
231	1	6	0.5	16.67	8.33
232	45	74	30.5	60.81	41.22
233	25	72	16.0	34.72	22.22
234	14	33	10.0	42.42	30.30
236	36	98	22.5	36.73	22.96
237	33	96	23.0	34.38	23.96
239	36	69	29.5	52.17	42.75
240	11	40	6.5	27.50	16.25
241	37	83	28.0	44.58	33.73
242	10	58	6.0	17.24	10.34
243	18	43	12.0	41.86	27.91
245	34	85	23.0	40.00	27.06
246	25	63	16.0	39.68	25.40
247	12	52	6.5	23.08	12.50
249	6	34	5.0	17.65	14.71
250	66	89	59.0	74.16	66.29
251	49	88	35.5	55.68	40.34
252	44	93	24.5	47.31	26.34
253	13	97	6.5	13.40	6.70
257	29	81	22.0	35.80	27.16
258	6	34	5.5	17.65	16.18
259	0	14	0.0	0.00	0.00
261	29	73	24.5	39.73	33.56
263	30	78	0.5	38.46	0.64
264	30	62	23.0	48.39	37.10
265	0	0	.	.	.
268	24	96	22.0	25.00	22.92
269	49	112	30.5	43.75	27.23
271	15	104	9.0	14.42	8.65
272	15	50	12.5	30.00	25.00
279	3	37	2.0	8.11	5.41
280	0	23	0.0	0.00	0.00
281	24	40	14.0	60.00	35.00
282	3	4	2.0	75.00	50.00
283	0	0	.	.	.
284	0	4	0.0	0.00	0.00
285	31	43	26.5	72.09	61.63
286	13	42	9.0	30.95	21.43
287	46	80	30.5	57.50	38.13
288	46	79	42.5	58.23	53.80

SCR #	# sides w/ calculus (n)	total # obs. Sides (n)	Calculus Score	Calculus Rate	Modified Calculus Rate
289	2	8	4.0	25.00	50.00
290	4	53	4.0	7.55	7.55
291	72	100	89.5	72.00	89.50
292	31	87	19.5	35.63	22.41
295	44	84	47.0	52.38	55.95
296	46	92	33.5	50.00	36.41
297	49	93	34.5	52.69	37.10
298	46	83	26.5	55.42	31.93
301	66	96	40.0	68.75	41.67
302	2	21	2.0	9.52	9.52
303	80	104	86.0	76.92	82.69
305	33	105	23.5	31.43	22.38
306	35	101	26.0	34.65	25.74
307	42	59	36.0	71.19	61.02
308	28	69	18.5	40.58	26.81
309	0	31	0.0	0.00	0.00
310	1	39	0.5	2.56	1.28
312	40	103	23.5	38.83	22.82
314	38	94	26.0	40.43	27.66
315	0	19	0.0	0.00	0.00
317	2	52	1.0	3.85	1.92
319	16	93	8.5	17.20	9.14
320	29	91	18.0	31.87	19.78
321	25	83	25.0	30.12	30.12
322	6	28	3.5	21.43	12.50
323	43	91	38.0	47.25	41.76
324	16	79	10.0	20.25	12.66
325	50	100	34.0	50.00	34.00
326	45	110	45.5	40.91	41.36
327	6	50	3.5	12.00	7.00
328	5	64	2.5	7.81	3.91
329	21	77	14.5	27.27	18.83
330	93	112	48.5	83.04	43.30
331	17	58	12.0	29.31	20.69
332	33	93	23.5	35.48	25.27
333	1	39	1.0	2.56	2.56
334	0	0	.	.	.
335	30	71	20.0	42.25	28.17
336	52	112	64.5	46.43	57.59
337	16	59	10.0	27.12	16.95
338	52	112	64.5	46.43	57.59
339	44	86	34.5	51.16	40.12
340	38	109	21.5	34.86	19.72

SCR #	# sides w/ calculus (n)	total # obs. Sides (n)	Calculus Score	Calculus Rate	Modified Calculus Rate
341	49	116	33.0	42.24	28.45
342	42	85	53.5	49.41	62.94
343	34	89	19.0	38.20	21.35
344	27	91	20.5	29.67	22.53
347	19	46	10.5	41.30	22.83
348	0	4	0.0	0.00	0.00
351	37	79	25.5	46.84	32.28
352	23	75	13.5	30.67	18.00
354	34	98	22.0	34.69	22.45
355	19	32	10.0	59.38	31.25
361	30	79	22.5	37.97	28.48
362	48	77	29.0	62.34	37.66
363	3	12	2.0	25.00	16.67
366	5	11	2.5	45.45	22.73
368	25	66	13.5	37.88	20.45
369	9	21	5.5	42.86	26.19
371	1	4	0.5	25.00	12.50
376	30	116	16.0	25.86	13.79
383	7	17	3.5	41.18	20.59
391	2	22	1.0	9.09	4.55
392	0	19	0.0	0.00	0.00
393	6	35	4.0	17.14	11.43
396	25	65	14.5	38.46	22.31
398	3	8	1.5	37.50	18.75
401	5	12	2.5	41.67	20.83
404	24	102	13.0	23.53	12.75
406	20	71	13.5	28.17	19.01
407	3	4	2.0	75.00	50.00
409	5	35	2.5	14.29	7.14
410	3	6	2.5	50.00	41.67
411	7	48	3.5	14.58	7.29
415	27	87	13.5	31.03	15.52
416	23	46	14.5	50.00	31.52
417	28	93	17.0	30.11	18.28
419	26	58	16.5	44.83	28.45
420	20	97	10.0	20.62	10.31
421	31	34	18.5	91.18	54.41
422	34	72	21.5	47.22	29.86
423	30	88	22.5	34.09	25.57
425	0	0	.	0.00	.
426	65	108	47.5	60.19	43.98
429	0	4	0.0	0.00	0.00
433	55	98	62.0	56.12	63.27

SCR #	# sides w/ calculus (n)	total # obs. Sides (n)	Calculus Score	Calculus Rate	Modified Calculus Rate
434	49	88	27.0	55.68	30.68
436	8	35	5.0	22.86	14.29
437	38	93	27.0	40.86	29.03
438	0	4	0.0	0.00	0.00
440	26	74	22.0	35.14	29.73
442	16	61	11.5	26.23	18.85
444	20	102	11.0	19.61	10.78
445	39	81	21.5	48.15	26.54
448	48	100	38.5	48.00	38.50
449	0	0	.	0.00	.
450	7	20	4.0	35.00	20.00
451	0	19	0.0	0.00	0.00
452	12	47	8.0	25.53	17.02
457	16	25	12.0	64.00	48.00
462	14	55	9.0	25.45	16.36
463	27	88	18.0	30.68	20.45
464	33	106	17.0	31.13	16.04
465	4	16	2.5	25.00	15.63
466	66	109	57.0	60.55	52.29
467	22	58	15.5	37.93	26.72
470	40	96	33.0	41.67	34.38
474	15	70	12.0	21.43	17.14
479	9	112	4.5	8.04	4.02
482	0	0	.	0.00	.
485	66	99	66.0	66.67	66.67
494	5	15	3.5	33.33	23.33
497	32	89	16.0	35.96	17.98
501	25	54	22.5	46.30	41.67
507	4	12	2.0	33.33	16.67
509	3	10	2.0	30.00	20.00
510	16	28	9.5	57.14	33.93
512	3	30	1.5	10.00	5.00
517	11	50	7.0	22.00	14.00
519	3	38	3.0	7.89	7.89
521	43	116	25.5	37.07	21.98
522	0	4	0.0	0.00	0.00
526	61	94	46.0	64.89	48.94
530	14	21	13.0	66.67	61.90
531	0	12	0.0	0.00	0.00
534	4	46	2.5	8.70	5.43
537	0	11	0.0	0.00	0.00
538	1	28	0.5	3.57	1.79
539	20	61	13.5	32.79	22.13

SCR #	# sides w/ calculus (n)	total # obs. Sides (n)	Calculus Score	Calculus Rate	Modified Calculus Rate
540	20	70	11.5	28.57	16.43
557	34	80	20.5	42.50	25.63
558	45	93	31.5	48.39	33.87
562	0	0	.	0.00	.
563	8	100	5.0	8.00	5.00
566	2	8	1.0	25.00	12.50
568	36	110	19.5	32.73	17.73
576	1	3	0.5	33.33	16.67
579	8	65	5.0	12.31	7.69
590	19	48	12.5	39.58	26.04
605	1	7	0.5	14.29	7.14
609	1	12	0.5	8.33	4.17
677	0	74	0.0	0.00	0.00
678	23	45	13.0	51.11	28.89
691	24	35	20.5	68.57	58.57
730	57	88	42.0	64.77	47.73

APPENDIX J –

ABSCESSES, CARIES RATE, AND DMI BY INDIVIDUAL (PERMANENT TEETH)

SCR #	Total Carious Teeth (n)	Total Obs. Teeth (n)	AMTL (n)	Caries Rate	DMI	# of Abscesses (n)
002	0	3	0	0.00	0.00	0
005	0	28	0	0.00	0.00	0
009	0	9	0	0.00	0.00	0
015	1	21	0	4.76	4.76	0
016	0	12	7	0.00	36.84	0
018	5	24	5	20.83	34.48	1
019	3	17	1	17.65	22.22	0
024	0	10	0	0.00	0.00	0
025	0	2	0	0.00	0.00	0
027	1	18	0	5.56	5.56	0
028	0	8	6	0.00	42.86	0
029	1	25	0	4.00	4.00	1
030	1	28	0	3.57	3.57	1
032	1	28	0	3.57	3.57	0
035	4	15	0	26.67	26.67	0
036	1	27	0	3.70	3.70	0
037	4	18	7	22.22	44.00	2
038	0	27	0	0.00	0.00	0
039	2	4	16	50.00	90.00	1
044	5	22	7	22.73	41.38	1
050	0	16	0	0.00	0.00	0
051	0	4	0	0.00	0.00	0
052	0	29	0	0.00	0.00	0
053	1	8	4	12.50	41.67	0
055	0	23	0	0.00	0.00	0
058	0	16	0	0.00	0.00	0
059	0	6	0	0.00	0.00	0
060	3	7	12	42.86	78.95	0
067	1	18	1	5.56	10.53	0
068	0	30	0	0.00	0.00	0
069	3	27	0	11.11	11.11	1
072	0	5	0	0.00	0.00	0
075	1	32	0	3.13	3.13	0
076	5	17	7	29.41	50.00	2
077	1	24	3	4.17	14.81	0
078	1	22	4	4.55	19.23	0
079	1	17	4	5.88	23.81	0
080	0	16	0	0.00	0.00	0
084	0	20	5	0.00	20.00	0
086	0	27	0	0.00	0.00	0
088	0	27	2	0.00	6.90	0
090	0	31	0	0.00	0.00	0
097	2	25	2	8.00	14.81	1

SCR #	Total Carious Teeth (n)	Total Obs. Teeth (n)	AMTL (n)	Caries Rate	DMI	# of Abscesses (n)
098	3	27	0	11.11	11.11	0
099	2	26	0	7.69	7.69	0
100	0	18	0	0.00	0.00	0
103	0	7	0	0.00	0.00	0
105	0	22	6	0.00	21.43	0
106	0	22	0	0.00	0.00	0
111	1	12	0	8.33	8.33	0
112	0	8	0	0.00	0.00	0
113	2	20	3	10.00	21.74	0
115	0	6	0	0.00	0.00	0
116	3	23	0	13.04	13.04	0
118	0	2	1	0.00	33.33	1
120	0	7	0	0.00	0.00	0
121	0	28	0	0.00	0.00	0
124	1	21	0	4.76	4.76	0
125	0	12	2	0.00	14.29	0
126	0	30	0	0.00	0.00	0
127	1	30	1	3.33	6.45	0
129	0	25	0	0.00	0.00	0
132	2	13	0	15.38	15.38	1
133	0	22	0	0.00	0.00	0
134	4	10	12	40.00	72.73	1
138	0	28	0	0.00	0.00	0
142	0	12	0	0.00	0.00	0
143	1	25	2	4.00	11.11	0
144	0	30	0	0.00	0.00	0
145	0	7	18	0.00	72.00	0
146	0	16	0	0.00	0.00	0
147	0	1	0	0.00	0.00	0
148	1	27	3	3.70	13.33	0
149	0	27	0	0.00	0.00	0
150	1	24	0	4.17	4.17	1
151	2	23	1	8.70	12.50	0
156	0	11	9	0.00	45.00	0
157	0	30	0	0.00	0.00	0
158	5	5	2	100.00	100.00	0
159	1	25	0	4.00	4.00	0
160	2	28	0	7.14	7.14	0
161	1	26	3	3.85	13.79	0
163	1	11	0	9.09	9.09	0
165	0	4	0	0.00	0.00	0
166	0	14	0	0.00	0.00	0

SCR #	Total Carious Teeth (n)	Total Obs. Teeth (n)	AMTL (n)	Caries Rate	DMI	# of Abscesses (n)
169	3	22	1	13.64	17.39	0
170	1	21	2	4.76	13.04	0
171	0	27	2	0.00	6.90	0
172	0	5	1	0.00	16.67	0
173	6	23	5	26.09	39.29	0
174	0	28	0	0.00	0.00	0
175	0	6	0	0.00	0.00	0
176	0	4	0	0.00	0.00	0
177	0	1	9	0.00	90.00	0
178	0	7	0	0.00	0.00	0
179	0	15	6	0.00	28.57	0
180	1	22	3	4.55	16.00	0
181	0	29	0	0.00	0.00	2
182	0	2	0	0.00	0.00	0
183	2	21	5	9.52	26.92	0
184	4	16	2	25.00	33.33	0
185	3	5	23	60.00	92.86	0
186	0	16	3	0.00	15.79	1
188	4	30	0	13.33	13.33	0
189	0	18	0	0.00	0.00	0
190	0	14	0	0.00	0.00	0
191	1	27	3	3.70	13.33	0
192	0	19	1	0.00	5.00	0
193	2	30	0	6.67	6.67	0
194	0	27	2	0.00	6.90	0
196	0	25	0	0.00	0.00	0
197	1	28	0	3.57	3.57	0
199	0	26	0	0.00	0.00	0
200	0	4	0	0.00	0.00	0
201	1	29	0	3.45	3.45	0
203	0	21	0	0.00	0.00	0
207	0	6	0	0.00	0.00	0
208	0	1	0	0.00	0.00	0
209	0	6	0	0.00	0.00	0
210	0	21	5	0.00	19.23	1
212	0	4	0	0.00	0.00	0
215	2	24	1	8.33	12.00	0
216	3	27	0	11.11	11.11	0
217	0	16	1	0.00	5.88	1
218	0	5	0	0.00	0.00	0
219	0	12	0	0.00	0.00	0
220	4	28	1	14.29	17.24	1

SCR #	Total Carious Teeth (n)	Total Obs. Teeth (n)	AMTL (n)	Caries Rate	DMI	# of Abscesses (n)
221	0	28	0	0.00	0.00	0
223	0	13	0	0.00	0.00	0
224	0	17	0	0.00	0.00	0
225	0	4	0	0.00	0.00	0
226	1	22	1	4.55	8.70	0
227	2	16	4	12.50	30.00	0
231	0	4	0	0.00	0.00	0
232	0	20	0	0.00	0.00	0
233	4	16	4	25.00	40.00	1
234	2	9	3	22.22	41.67	0
236	2	27	0	7.41	7.41	0
237	0	27	0	0.00	0.00	0
239	0	19	12	0.00	38.71	0
240	0	11	0	0.00	0.00	0
241	0	22	2	0.00	8.33	1
242	0	16	1	0.00	5.88	0
243	1	11	0	9.09	9.09	0
245	5	22	0	22.73	22.73	0
246	4	19	4	21.05	34.78	2
247	0	15	0	0.00	0.00	0
249	0	11	0	0.00	0.00	0
250	0	25	1	0.00	3.85	0
251	1	25	2	4.00	11.11	0
252	1	26	4	3.85	16.67	0
253	0	0	0	.	.	0
257	0	22	1	0.00	4.35	0
258	1	9	0	11.11	11.11	0
259	1	4	0	25.00	25.00	0
261	6	21	8	28.57	48.28	2
263	0	22	1	0.00	4.35	0
264	7	18	2	38.89	45.00	3
265	0	0	3	.	100.00	0
268	0	27	0	0.00	0.00	0
269	0	31	0	0.00	0.00	0
271	0	29	0	0.00	0.00	0
272	4	13	5	30.77	50.00	0
279	0	11	0	0.00	0.00	0
280	1	5	0	20.00	20.00	0
281	1	11	2	9.09	23.08	0
282	0	1	0	0.00	0.00	0
283	1	2	0	50.00	50.00	0
284	0	1	0	0.00	0.00	0

SCR #	Total Carious Teeth (n)	Total Obs. Teeth (n)	AMTL (n)	Caries Rate	DMI	# of Abscesses (n)
285	0	12	0	0.00	0.00	0
286	4	14	6	28.57	50.00	0
287	1	22	2	4.55	12.50	0
288	3	23	4	13.04	25.93	0
289	0	2	5	0.00	71.43	0
290	0	15	0	0.00	0.00	0
291	0	28	3	0.00	9.68	0
292	1	24	2	4.17	11.54	0
295	4	24	5	16.67	31.03	1
296	0	26	0	0.00	0.00	0
297	4	26	2	15.38	21.43	0
298	1	25	4	4.00	17.24	1
301	3	27	1	11.11	14.29	0
302	3	16	4	18.75	35.00	2
303	1	29	1	3.45	6.67	0
305	0	29	1	0.00	3.33	2
306	1	28	0	3.57	3.57	0
307	1	16	5	6.25	28.57	1
308	5	21	8	23.81	44.83	2
309	0	9	0	0.00	0.00	0
310	3	23	0	13.04	13.04	0
312	0	28	0	0.00	0.00	0
314	8	27	2	29.63	34.48	2
315	0	5	0	0.00	0.00	0
317	4	14	0	28.57	28.57	1
319	0	25	0	0.00	0.00	0
320	1	25	0	4.00	4.00	0
321	3	23	1	13.04	16.67	0
322	0	8	0	0.00	0.00	0
323	1	25	3	4.00	14.29	0
324	1	21	0	4.76	4.76	0
325	3	30	0	10.00	10.00	0
326	0	30	0	0.00	0.00	0
327	0	14	0	0.00	0.00	0
328	0	19	0	0.00	0.00	0
329	0	21	2	0.00	8.70	0
330	0	31	0	0.00	0.00	0
331	3	16	6	18.75	40.91	0
332	4	28	1	14.29	17.24	1
333	0	11	0	0.00	0.00	0
334	0	27	0	0.00	0.00	0
335	0	18	0	0.00	0.00	1

SCR #	Total Carious Teeth (n)	Total Obs. Teeth (n)	AMTL (n)	Caries Rate	DMI	# of Abscesses (n)
336	0	25	3	0.00	10.71	0
337	0	15	0	0.00	0.00	0
338	1	31	1	3.23	6.25	0
339	3	25	4	12.00	24.14	0
340	0	30	0	0.00	0.00	0
341	0	32	0	0.00	0.00	0
342	0	23	0	0.00	0.00	0
343	0	24	0	0.00	0.00	1
344	2	24	4	8.33	21.43	0
347	1	11	0	9.09	9.09	0
348	0	1	0	0.00	0.00	0
351	0	22	0	0.00	0.00	0
352	0	21	0	0.00	0.00	0
354	2	27	0	7.41	7.41	0
355	0	10	0	0.00	0.00	0
358	2	16	1	12.50	17.65	0
360	0	30	0	0.00	0.00	0
361	0	22	1	0.00	4.35	1
362	2	20	6	10.00	30.77	0
363	0	4	0	0.00	0.00	0
366	1	5	1	20.00	33.33	0
368	0	17	0	0.00	0.00	0
369	1	6	0	16.67	16.67	0
371	0	1	0	0.00	0.00	0
376	2	32	0	6.25	6.25	0
383	0	5	0	0.00	0.00	0
391	0	6	0	0.00	0.00	0
392	0	5	0	0.00	0.00	0
393	2	9	0	22.22	22.22	0
396	1	17	0	5.88	5.88	0
398	0	2	0	0.00	0.00	0
401	0	3	0	0.00	0.00	0
404	0	28	0	0.00	0.00	0
406	2	19	0	10.53	10.53	0
407	0	1	3	0.00	75.00	0
409	1	9	0	11.11	11.11	0
410	0	2	0	0.00	0.00	0
411	0	13	0	0.00	0.00	0
415	0	24	0	0.00	0.00	0
416	0	13	0	0.00	0.00	0
417	2	25	5	8.00	23.33	0
419	1	15	3	6.67	22.22	0

SCR #	Total Carious Teeth (n)	Total Obs. Teeth (n)	AMTL (n)	Caries Rate	DMI	# of Abscesses (n)
420	1	27	0	3.70	3.70	0
421	0	10	4	0.00	28.57	0
422	6	18	6	33.33	50.00	1
423	2	24	4	8.33	21.43	0
425	1	21	1	4.76	9.09	0
426	1	30	0	3.33	3.33	0
429	0	1	0	0.00	0.00	0
433	0	27	1	0.00	3.57	0
434	0	24	0	0.00	0.00	0
436	2	10	9	20.00	57.89	4
437	3	26	0	11.54	11.54	0
438	0	1	5	0.00	83.33	0
440	1	21	5	4.76	23.08	2
442	0	17	1	0.00	5.56	0
444	0	28	0	0.00	0.00	0
445	0	22	1	0.00	4.35	0
448	1	28	3	3.57	12.90	1
449	1	6	6	16.67	58.33	0
450	0	5	0	0.00	0.00	0
451	0	5	0	0.00	0.00	0
452	0	12	0	0.00	0.00	0
454	2	15	2	13.33	23.53	0
455	1	20	5	5.00	24.00	0
457	0	7	0	0.00	0.00	0
462	0	14	0	0.00	0.00	0
463	1	28	0	3.57	3.57	0
464	0	29	0	0.00	0.00	0
465	1	4	0	25.00	25.00	0
466	0	29	1	0.00	3.33	0
467	3	16	0	18.75	18.75	0
470	1	26	0	3.85	3.85	0
474	0	19	0	0.00	0.00	0
479	0	31	0	0.00	0.00	1
482	0	8	5	0.00	38.46	0
485	0	27	0	0.00	0.00	0
494	0	4	1	0.00	20.00	0
497	0	24	0	0.00	0.00	0
501	0	15	1	0.00	6.25	0
507	0	2	0	0.00	0.00	0
509	0	3	6	0.00	66.67	0
510	2	7	0	28.57	28.57	0
512	1	8	0	12.50	12.50	0

SCR #	Total Carious Teeth (n)	Total Obs. Teeth (n)	AMTL (n)	Caries Rate	DMI	# of Abscesses (n)
517	1	14	0	7.14	7.14	0
519	0	11	0	0.00	0.00	0
521	0	32	0	0.00	0.00	0
522	0	1	0	0.00	0.00	0
526	2	25	3	8.00	17.86	0
530	0	6	0	0.00	0.00	0
531	0	3	0	0.00	0.00	0
534	2	13	0	15.38	15.38	0
537	0	3	0	0.00	0.00	0
538	0	8	0	0.00	0.00	0
540	0	19	0	0.00	0.00	0
557	0	22	0	0.00	0.00	0
558	0	24	0	0.00	0.00	0
562	2	28	2	7.14	13.33	0
563	1	28	0	3.57	3.57	0
566	1	2	0	50.00	50.00	0
568	0	30	0	0.00	0.00	1
576	1	1	0	100.00	100.00	0
579	0	18	0	0.00	0.00	0
590	0	13	1	0.00	7.14	0
605	1	3	0	33.33	33.33	0
609	0	3	0	0.00	0.00	0
677	0	20	0	0.00	0.00	0
678	0	13	1	0.00	7.14	0
691	0	9	0	0.00	0.00	0
730	1	24	3	4.17	14.81	0

APPENDIX K –

TOOTH WEAR SCORES BY INDIVIDUAL AND TOOTH TYPE (PERMANENT TEETH)

SCR #	Molar Score	# of obs. Molars	Tooth Wear Molars	Premolar Score	# of obs. Premolars	Tooth Wear Premolars	Canine Score	# of obs. Canines	Tooth Wear Canines	Incisor Score	# of obs. Incisors	Tooth Wear Incisors
002	0	3	0.00	.	0	.	.	0	.	.	0	.
005	121	10	12.10	22	6	3.67	16	4	4.00	33	8	4.13
009	16	4	4.00	.	0	.	.	0	.	0	5	0.00
015	196	7	28.00	42	7	6.00	21	4	5.25	15	3	5.00
016	74	3	24.67	7	1	7.00	18	4	4.50	20	4	5.00
018	119	7	17.00	19	6	3.17	16	4	4.00	18	6	3.00
019	153	7	21.86	13	4	3.25	6	2	3.00	19	4	4.75
024	42	4	10.50	.	0	.	.	0	.	0	5	0.00
027	59	10	5.90	8	4	2.00	5	2	2.50	7	2	3.50
028	111	4	27.75	8	2	4.00	5	1	5.00	4	1	4.00
029	71	6	11.83	0	6	0.00	8	4	2.00	18	8	2.25
030	277	9	30.78	44	8	5.50	15	3	5.00	39	8	4.88
032	126	12	10.50	5	7	0.71	0	3	0.00	6	6	1.00
035	54	7	7.71	4	2	2.00	4	2	2.00	11	4	2.75
036	74	8	9.25	16	7	2.29	7	4	1.75	12	8	1.50
037	43	3	14.33	21	4	5.25	10	2	5.00	43	7	6.14
038	224	12	18.67	11	4	2.75	16	4	4.00	29	7	4.14
039	27	1	27.00	.	0	.	11	2	5.50	9	2	4.50
044	84	5	16.80	29	5	5.80	17	4	4.25	34	8	4.25
050	53	7	7.57	4	4	1.00	0	2	0.00	4	3	1.33
051	0	4	0.00	.	0	.	.	0	.	.	0	.
052	98	10	9.80	10	7	1.43	6	4	1.50	10	8	1.25
053	29	2	14.50	11	2	5.50	11	2	5.50	5	1	5.00
055	152	10	15.20	17	6	2.83	10	3	3.33	20	5	4.00
058	47	6	7.83	2	3	0.67	2	3	0.67	7	2	3.50
059	59	5	11.80	2	1	2.00	.	0	.	.	0	.
060	16	1	16.00	15	3	5.00	10	2	5.00	11	2	5.50

SCR #	Molar Score	# of obs. Molars	Tooth Wear Molars	Premolar Score	# of obs. Premolars	Tooth Wear Premolars	Canine Score	# of obs. Canines	Tooth Wear Canines	Incisor Score	# of obs. Incisors	Tooth Wear Incisors
067	136	8	17.00	24	7	3.43	8	2	4.00	5	1	5.00
068	116	11	10.55	18	7	2.57	10	4	2.50	23	8	2.88
069	151	9	16.78	9	5	1.80	10	4	2.50	27	8	3.38
072	20	3	6.67	.	0	.	.	0	.	0	1	0.00
075	144	12	12.00	8	8	1.00	12	4	3.00	23	8	2.88
076	35	4	8.75	23	5	4.60	11	2	5.50	25	4	6.25
077	100	6	16.67	20	6	3.33	15	4	3.75	39	8	4.88
078	70	8	8.75	13	6	2.17	19	4	4.75	14	4	3.50
079	108	6	18.00	27	6	4.50	16	4	4.00	9	3	3.00
080	67	7	9.57	0	5	0.00	0	1	0.00	9	3	3.00
084	152	7	21.71	22	6	3.67	27	4	6.75	24	4	6.00
086	135	12	11.25	12	6	2.00	13	4	3.25	18	5	3.60
088	144	9	16.00	16	6	2.67	12	4	3.00	31	8	3.88
090	144	12	12.00	20	7	2.86	6	3	2.00	20	8	2.50
097	176	10	17.60	25	6	4.17	18	4	4.50	31	7	4.43
098	53	10	5.30	2	6	0.33	4	4	1.00	0	6	0.00
099	147	12	12.25	22	6	3.67	12	4	3.00	19	5	3.80
100	100	8	12.50	2	2	1.00	0	2	0.00	6	6	1.00
103	20	2	10.00	.	0	.	.	0	.	4	4	1.00
105	162	8	20.25	8	3	2.67	13	4	3.25	26	7	3.71
106	85	8	10.63	5	5	1.00	4	3	1.33	0	6	0.00
111	34	4	8.50	.	0	.	.	0	.	0	8	0.00
112	19	4	4.75	.	0	.	.	0	.	0	4	0.00
113	183	7	26.14	21	5	4.20	14	3	4.67	34	7	4.86
115	22	4	5.50	.	0	.	.	0	.	0	2	0.00
116	120	9	13.33	19	6	3.17	7	2	3.50	20	6	3.33
118	.	0	.	3	1	3.00	4	1	4.00	.	0	.

SCR #	Molar Score	# of obs. Molars	Tooth Wear Molars	Premolar Score	# of obs. Premolars	Tooth Wear Premolars	Canine Score	# of obs. Canines	Tooth Wear Canines	Incisor Score	# of obs. Incisors	Tooth Wear Incisors
120	47	4	11.75	4	3	1.33	.	0	.	.	0	.
121	56	8	7.00	2	8	0.25	8	4	2.00	12	8	1.50
124	50	8	6.25	4	5	0.80	4	4	1.00	4	4	1.00
125	61	4	15.25	6	4	1.50	9	2	4.50	8	2	4.00
126	78	12	6.50	9	6	1.50	4	4	1.00	12	8	1.50
127	198	11	18.00	26	7	3.71	20	4	5.00	38	7	5.43
129	74	8	9.25	8	6	1.33	0	4	0.00	7	7	1.00
132	59	4	14.75	8	2	4.00	8	2	4.00	13	3	4.33
133	128	10	12.80	9	4	2.25	2	3	0.67	12	5	2.40
134	53	3	17.67	9	2	4.50	14	2	7.00	12	2	6.00
138	121	10	12.10	12	6	2.00	8	4	2.00	20	8	2.50
142	94	6	15.67	5	2	2.50	4	2	2.00	4	2	2.00
143	155	9	17.22	26	7	3.71	16	4	4.00	25	5	5.00
144	180	12	15.00	17	7	2.43	6	3	2.00	22	8	2.75
145	163	5	32.60	22	4	5.50	5	1	5.00	5	1	5.00
146	21	5	4.20	0	3	0.00	0	1	0.00	6	8	0.75
148	150	8	18.75	16	7	2.29	14	4	3.50	37	8	4.63
149	82	10	8.20	4	7	0.57	2	4	0.50	10	6	1.67
150	123	7	17.57	25	5	5.00	15	4	3.75	33	7	4.71
151	143	7	20.43	15	6	2.50	12	3	4.00	18	4	4.50
156	.	0	.	20	4	5.00	10	2	5.00	27	5	5.40
157	111	11	10.09	17	8	2.13	8	4	2.00	15	7	2.14
158	68	3	22.67	4	1	4.00	5	1	5.00	.	0	.
159	103	7	14.71	25	8	3.13	9	3	3.00	29	7	4.14
160	71	8	8.88	10	7	1.43	3	4	0.75	18	8	2.25
161	109	8	13.63	13	6	2.17	15	4	3.75	26	8	3.25
163	95	4	23.75	15	3	5.00	5	1	5.00	8	2	4.00

SCR #	Molar Score	# of obs. Molars	Tooth Wear Molars	Premolar Score	# of obs. Premolars	Tooth Wear Premolars	Canine Score	# of obs. Canines	Tooth Wear Canines	Incisor Score	# of obs. Incisors	Tooth Wear Incisors
165	19	3	6.33	.	0	.	.	0	.	0	1	0.00
166	49	5	9.80	11	5	2.20	2	1	2.00	3	3	1.00
169	69	6	11.50	15	7	2.14	13	4	3.25	16	6	2.67
170	166	9	18.44	26	6	4.33	12	3	4.00	15	3	5.00
171	119	10	11.90	18	7	2.57	13	4	3.25	34	8	4.25
172	88	3	29.33	5	1	5.00	5	1	5.00	.	0	.
173	62	4	15.50	13	5	2.60	12	4	3.00	22	8	2.75
174	132	10	13.20	18	7	2.57	16	4	4.00	20	7	2.86
175	33	4	8.25	.	0	.	.	0	.	0	2	0.00
176	17	4	4.25	.	0	.	.	0	.	.	0	.
177	.	0	.	.	0	.	6	1	6.00	.	0	.
178	103	6	17.17	.	0	.	5	1	5.00	.	0	.
179	174	7	24.86	14	3	4.67	19	4	4.75	5	1	5.00
180	60	6	10.00	24	6	4.00	10	3	3.33	31	7	4.43
181	194	11	17.64	22	7	3.14	15	3	5.00	46	8	5.75
182	0	2	0.00	.	0	.	.	0	.	.	0	.
183	83	6	13.83	14	5	2.80	10	4	2.50	15	6	2.50
184	181	7	25.86	17	4	4.25	11	2	5.50	19	3	6.33
185	16	2	8.00	.	0	.	11	2	5.50	6	1	6.00
186	179	10	17.90	34	7	4.86	20	3	6.67	34	5	6.80
188	116	12	9.67	17	7	2.43	11	4	2.75	23	7	3.29
189	181	11	16.45	24	6	4.00	.	0	.	4	1	4.00
190	42	4	10.50	8	4	2.00	4	2	2.00	8	2	4.00
191	127	8	15.88	30	7	4.29	20	4	5.00	45	8	5.63
192	154	6	25.67	35	6	5.83	15	3	5.00	19	3	6.33
193	117	12	9.75	14	7	2.00	6	4	1.50	15	7	2.14
194	117	8	14.63	17	7	2.43	15	4	3.75	26	8	3.25

SCR #	Molar Score	# of obs. Molars	Tooth Wear Molars	Premolar Score	# of obs. Premolars	Tooth Wear Premolars	Canine Score	# of obs. Canines	Tooth Wear Canines	Incisor Score	# of obs. Incisors	Tooth Wear Incisors
196	122	11	11.09	6	6	1.00	6	3	2.00	11	5	2.20
197	145	10	14.50	17	7	2.43	9	4	2.25	17	6	2.83
199	110	11	10.00	20	7	2.86	7	3	2.33	16	5	3.20
200	0	4	0.00	.	0	.	.	0	.	.	0	.
201	158	12	13.17	20	8	2.50	10	3	3.33	17	6	2.83
203	81	8	10.13	6	6	1.00	0	2	0.00	12	5	2.40
207	41	3	13.67	4	2	2.00	3	1	3.00	.	0	.
208	18	1	18.00	.	0	.	.	0	.	.	0	.
209	11	4	2.75	.	0	.	.	0	.	0	2	0.00
210	185	7	26.43	46	8	5.75	16	3	5.33	33	5	6.60
212	44	3	14.67	3	1	3.00	.	0	.	.	0	.
215	213	10	21.30	26	6	4.33	19	4	4.75	20	4	5.00
216	89	10	8.90	8	5	1.60	4	4	1.00	11	8	1.38
217	169	11	15.36	14	7	2.00	7	3	2.33	14	4	3.50
218	25	3	8.33	.	0	.	.	0	.	0	2	0.00
219	48	4	12.00	7	3	2.33	4	2	2.00	4	3	1.33
220	138	8	17.25	30	8	3.75	19	4	4.75	27	6	4.50
221	157	9	17.44	30	8	3.75	18	4	4.50	42	7	6.00
223	86	7	12.29	7	4	1.75	0	1	0.00	.	0	.
224	68	5	13.60	10	5	2.00	4	2	2.00	11	5	2.20
225	31	4	7.75	.	0	.	.	0	.	.	0	.
226	83	7	11.86	6	5	1.20	0	4	0.00	10	6	1.67
227	101	5	20.20	21	5	4.20	15	3	5.00	24	4	6.00
231	.	0	.	.	0	.	6	1	6.00	18	3	6.00
232	115	7	16.43	25	7	3.57	14	3	4.67	15	3	5.00
233	188	8	23.50	18	5	3.60	6	2	3.00	5	2	2.50
234	68	5	13.60	5	1	5.00	4	1	4.00	11	2	5.50

SCR #	Molar Score	# of obs. Molars	Tooth Wear Molars	Premolar Score	# of obs. Premolars	Tooth Wear Premolars	Canine Score	# of obs. Canines	Tooth Wear Canines	Incisor Score	# of obs. Incisors	Tooth Wear Incisors
236	161	10	16.10	23	6	3.83	18	4	4.50	32	6	5.33
237	75	8	9.38	4	7	0.57	4	4	1.00	16	8	2.00
239	78	7	11.14	16	5	3.20	11	2	5.50	33	5	6.60
240	34	4	8.50	.	0	.	.	0	.	0	7	0.00
241	177	8	22.13	28	8	3.50	16	3	5.33	13	2	6.50
242	126	9	14.00	13	5	2.60	4	2	2.00	.	0	.
243	14	2	7.00	6	5	1.20	0	1	0.00	8	4	2.00
245	154	12	12.83	10	7	1.43	5	2	2.50	.	0	.
246	46	3	15.33	16	4	4.00	18	3	6.00	47	8	5.88
247	37	4	9.25	0	3	0.00	.	0	.	8	8	1.00
249	41	4	10.25	.	0	.	.	0	.	2	6	0.33
250	167	8	20.88	30	6	5.00	24	4	6.00	42	7	6.00
251	93	6	15.50	15	7	2.14	16	4	4.00	28	8	3.50
252	141	8	17.63	23	7	3.29	17	3	5.67	44	8	5.50
253	.	0	.	.	0	.	.	0	.	.	0	.
257	124	8	15.50	19	7	2.71	11	3	3.67	14	4	3.50
258	49	6	8.17	0	1	0.00	2	1	2.00	4	1	4.00
259	26	2	13.00	.	0	.	.	0	.	4	2	2.00
261	266	8	33.25	30	5	6.00	12	2	6.00	35	5	7.00
263	83	8	10.38	8	4	2.00	11	4	2.75	24	6	4.00
264	182	6	30.33	14	2	7.00	11	2	5.50	20	4	5.00
265	.	0	.	.	0	.	.	0	.	.	0	.
268	65	8	8.13	6	7	0.86	0	4	0.00	6	8	0.75
269	161	11	14.64	16	7	2.29	14	4	3.50	28	8	3.50
271	85	10	8.50	8	7	1.14	4	4	1.00	24	8	3.00
272	89	6	14.83	15	4	3.75	.	0	.	5	2	2.50
279	38	4	9.50	.	0	.	.	0	.	4	7	0.57

SCR #	Molar Score	# of obs. Molars	Tooth Wear Molars	Premolar Score	# of obs. Premolars	Tooth Wear Premolars	Canine Score	# of obs. Canines	Tooth Wear Canines	Incisor Score	# of obs. Incisors	Tooth Wear Incisors
280	59	3	19.67	5	2	2.50	.	0	.	3	1	3.00
281	86	5	17.20	8	2	4.00	4	1	4.00	17	3	5.67
282	14	1	14.00	.	0	.	.	0	.	.	0	.
283	36	2	18.00	.	0	.	.	0	.	.	0	.
284	.	0	.	3	1	3.00	.	0	.	.	0	.
285	98	6	16.33	3	1	3.00	2	1	2.00	14	4	3.50
286	21	2	10.50	11	4	2.75	15	3	5.00	24	4	6.00
287	108	7	15.43	16	7	2.29	4	2	2.00	11	6	1.83
288	153	9	17.00	15	4	3.75	14	3	4.67	30	6	5.00
289	35	2	17.50	.	0	.	.	0	.	.	0	.
290	33	8	4.13	.	0	.	0	1	0.00	5	6	0.83
291	152	9	16.89	35	7	5.00	19	4	4.75	41	8	5.13
292	108	10	10.80	11	5	2.20	8	3	2.67	29	6	4.83
295	87	6	14.50	26	6	4.33	23	4	5.75	51	8	6.38
296	129	8	16.13	18	6	3.00	11	4	2.75	24	8	3.00
297	177	9	19.67	19	6	3.17	18	4	4.50	42	7	6.00
298	128	7	18.29	41	7	5.86	19	4	4.75	40	7	5.71
301	197	9	21.89	29	6	4.83	17	4	4.25	41	8	5.13
302	21	2	10.50	24	6	4.00	9	2	4.50	24	5	4.80
303	130	10	13.00	21	7	3.00	16	4	4.00	26	8	3.25
305	67	9	7.44	18	8	2.25	8	3	2.67	32	8	4.00
306	107	10	10.70	17	7	2.43	12	4	3.00	23	7	3.29
307	53	5	10.60	14	5	2.80	9	3	3.00	5	2	2.50
308	66	4	16.50	20	5	4.00	19	4	4.75	38	7	5.43
309	0	4	0.00	.	0	.	.	0	.	0	5	0.00
310	110	8	13.75	18	6	3.00	12	3	4.00	21	6	3.50
312	174	12	14.50	23	7	3.29	9	4	2.25	18	5	3.60

SCR #	Molar Score	# of obs. Molars	Tooth Wear Molars	Premolar Score	# of obs. Premolars	Tooth Wear Premolars	Canine Score	# of obs. Canines	Tooth Wear Canines	Incisor Score	# of obs. Incisors	Tooth Wear Incisors
314	114	7	16.29	19	7	2.71	6	3	2.00	26	7	3.71
315	26	4	6.50	.	0	.	.	0	.	0	1	0.00
317	70	8	8.75	5	2	2.50	4	2	2.00	2	1	2.00
319	85	7	12.14	17	7	2.43	5	3	1.67	20	8	2.50
320	90	9	10.00	4	7	0.57	4	4	1.00	8	5	1.60
321	90	7	12.86	12	6	2.00	0	1	0.00	36	8	4.50
322	14	2	7.00	4	2	2.00	12	4	3.00	.	0	.
323	263	9	29.22	40	7	5.71	22	4	5.50	30	5	6.00
324	126	8	15.75	21	8	2.63	4	1	4.00	19	4	4.75
325	139	10	13.90	20	8	2.50	14	4	3.50	16	8	2.00
326	185	12	15.42	29	8	3.63	11	4	2.75	33	6	5.50
327	18	4	4.50	4	4	1.00	6	2	3.00	11	4	2.75
328	27	3	9.00	0	4	0.00	0	4	0.00	6	8	0.75
329	135	7	19.29	35	7	5.00	21	4	5.25	15	3	5.00
330	135	12	11.25	13	7	1.86	12	4	3.00	27	8	3.38
331	50	5	10.00	12	4	3.00	2	2	1.00	18	4	4.50
332	76	9	8.44	2	7	0.29	0	3	0.00	14	8	1.75
333	26	5	5.20	0	1	0.00	.	0	.	0	5	0.00
334	104	9	11.56	19	7	2.71	18	4	4.50	32	7	4.57
335	178	12	14.83	16	5	3.20	3	1	3.00	.	0	.
336	115	5	23.00	35	8	4.38	9	4	2.25	27	6	4.50
337	85	8	10.63	6	6	1.00	0	1	0.00	.	0	.
338	222	11	20.18	42	8	5.25	24	4	6.00	44	8	5.50
339	108	7	15.43	22	7	3.14	8	4	2.00	19	6	3.17
340	137	11	12.45	22	8	2.75	12	3	4.00	30	8	3.75
341	290	12	24.17	36	8	4.50	20	4	5.00	40	8	5.00
342	218	10	21.80	23	6	3.83	10	2	5.00	26	5	5.20

SCR #	Molar Score	# of obs. Molars	Tooth Wear Molars	Premolar Score	# of obs. Premolars	Tooth Wear Premolars	Canine Score	# of obs. Canines	Tooth Wear Canines	Incisor Score	# of obs. Incisors	Tooth Wear Incisors
343	101	11	9.18	10	6	1.67	2	2	1.00	4	5	0.80
344	65	8	8.13	25	8	3.13	3	3	1.00	32	6	5.33
347	92	8	11.50	5	2	2.50	5	2	2.50	.	0	.
348	16	1	16.00	.	0	.	.	0	.	.	0	.
351	143	10	14.30	11	3	3.67	9	3	3.00	21	6	3.50
352	90	7	12.86	6	5	1.20	11	4	2.75	20	5	4.00
354	89	11	8.09	12	6	2.00	10	4	2.50	14	6	2.33
355	57	4	14.25	7	3	2.33	.	0	.	6	1	6.00
358	61	5	12.20	17	6	2.83	9	3	3.00	6	2	3.00
360	87	12	7.25	10	7	1.43	9	4	2.25	11	7	1.57
361	89	8	11.13	13	5	2.60	5	2	2.50	23	7	3.29
362	162	10	16.20	17	7	2.43	4	3	1.33	.	0	.
363	.	0	.	.	0	.	.	0	.	21	4	5.25
366	64	2	32.00	6	1	6.00	.	0	.	7	1	7.00
368	59	8	7.38	4	4	1.00	8	4	2.00	3	2	1.50
369	32	3	10.67	.	0	.	2	2	1.00	0	1	0.00
371	.	0	.	3	1	3.00	.	0	.	.	0	.
376	164	12	13.67	21	8	2.63	11	4	2.75	33	8	4.13
383	.	0	.	7	2	3.50	10	2	5.00	5	1	5.00
391	16	2	8.00	.	0	.	2	1	2.00	0	1	0.00
392	26	4	6.50	.	0	.	.	0	.	2	1	2.00
393	50	5	10.00	6	3	2.00	0	1	0.00	.	0	.
396	95	8	11.88	8	6	1.33	4	2	2.00	0	1	0.00
398	23	2	11.50	.	0	.	.	0	.	.	0	.
401	36	3	12.00	.	0	.	.	0	.	.	0	.
402	.	0	.	.	0	.	.	0	.	.	0	.
404	100	12	8.33	11	6	1.83	4	4	1.00	8	6	1.33

SCR #	Molar Score	# of obs. Molars	Tooth Wear Molars	Premolar Score	# of obs. Premolars	Tooth Wear Premolars	Canine Score	# of obs. Canines	Tooth Wear Canines	Incisor Score	# of obs. Incisors	Tooth Wear Incisors
406	67	8	8.38	12	6	2.00	7	3	2.33	6	2	3.00
407	.	0	.	7	1	7.00	.	0	.	.	0	.
409	86	6	14.33	9	3	3.00	5	1	5.00	.	0	.
410	.	0	.	.	0	.	5	1	5.00	5	1	5.00
411	43	6	7.17	6	3	2.00	0	1	0.00	2	3	0.67
415	119	10	11.90	10	5	2.00	10	4	2.50	13	5	2.60
416	26	3	8.67	8	4	2.00	4	2	2.00	18	4	4.50
417	214	11	19.45	22	7	3.14	7	3	2.33	19	4	4.75
419	229	8	28.63	19	5	3.80	9	2	4.50	.	0	.
420	73	8	9.13	8	8	1.00	4	4	1.00	20	7	2.86
421	27	2	13.50	8	3	2.67	6	2	3.00	14	4	3.50
422	127	6	21.17	29	5	5.80	15	3	5.00	28	5	5.60
423	174	8	21.75	39	8	4.88	10	2	5.00	35	6	5.83
425	201	9	22.33	29	6	4.83	14	3	4.67	16	3	5.33
426	146	11	13.27	19	7	2.71	10	4	2.50	29	8	3.63
429	6	1	6.00	.	0	.	.	0	.	.	0	.
433	126	10	12.60	16	7	2.29	14	4	3.50	21	6	3.50
434	117	8	14.63	16	8	2.00	9	3	3.00	20	5	4.00
436	72	3	24.00	18	3	6.00	12	2	6.00	3	1	3.00
437	221	10	22.10	24	5	4.80	21	4	5.25	38	7	5.43
438	15	1	15.00	.	0	.	.	0	.	.	0	.
440	77	4	19.25	39	7	5.57	19	4	4.75	26	6	4.33
442	60	5	12.00	8	5	1.60	4	3	1.33	8	4	2.00
444	100	11	9.09	12	7	1.71	0	3	0.00	13	7	1.86
445	119	10	11.90	13	5	2.60	2	2	1.00	0	5	0.00
448	87	9	9.67	23	7	3.29	19	4	4.75	30	8	3.75
449	102	3	34.00	6	1	6.00	12	2	6.00	.	0	.

SCR #	Molar Score	# of obs. Molars	Tooth Wear Molars	Premolar Score	# of obs. Premolars	Tooth Wear Premolars	Canine Score	# of obs. Canines	Tooth Wear Canines	Incisor Score	# of obs. Incisors	Tooth Wear Incisors
450	35	3	11.67	2	2	1.00	.	0	.	.	0	.
451	24	2	12.00	4	2	2.00	3	1	3.00	.	0	.
452	98	6	16.33	14	5	2.80	0	1	0.00	.	0	.
454	43	3	14.33	12	3	4.00	17	4	4.25	23	5	4.60
455	76	8	9.50	15	5	3.00	17	4	4.25	12	3	4.00
457	31	2	15.50	9	2	4.50	5	1	5.00	7	2	3.50
462	128	8	16.00	19	5	3.80	5	1	5.00	.	0	.
463	155	11	14.09	18	8	2.25	4	3	1.33	13	5	2.60
464	128	11	11.64	16	8	2.00	8	4	2.00	20	6	3.33
465	16	1	16.00	0	3	0.00	.	0	.	.	0	.
466	215	11	19.55	28	8	3.50	15	4	3.75	31	7	4.43
467	61	4	15.25	24	5	4.80	10	2	5.00	24	4	6.00
470	135	10	13.50	16	8	2.00	4	2	2.00	15	6	2.50
474	81	7	11.57	8	6	1.33	2	2	1.00	6	4	1.50
479	192	12	16.00	24	7	3.43	18	4	4.50	41	8	5.13
482	26	1	26.00	12	2	6.00	6	1	6.00	27	5	5.40
485	171	11	15.55	19	7	2.71	10	4	2.50	19	5	3.80
494	35	1	35.00	.	0	.	.	0	.	.	0	.
497	118	10	11.80	12	7	1.71	3	4	0.75	0	3	0.00
501	85	5	17.00	9	4	2.25	4	2	2.00	10	4	2.50
507	28	2	14.00	2	1	2.00	.	0	.	.	0	.
509	.	0	.	8	1	8.00	11	2	5.50	.	0	.
510	67	5	13.40	6	2	3.00	.	0	.	.	0	.
512	45	4	11.25	2	2	1.00	2	2	1.00	.	0	.
517	54	4	13.50	8	4	2.00	8	2	4.00	14	4	3.50
519	31	5	6.20	.	0	.	.	0	.	4	6	0.67
521	121	12	10.08	17	8	2.13	8	4	2.00	24	8	3.00

SCR #	Molar Score	# of obs. Molars	Tooth Wear Molars	Premolar Score	# of obs. Premolars	Tooth Wear Premolars	Canine Score	# of obs. Canines	Tooth Wear Canines	Incisor Score	# of obs. Incisors	Tooth Wear Incisors
522	0	1	0.00	.	0	.	.	0	.	.	0	.
526	155	10	15.50	22	6	3.67	6	3	2.00	18	7	2.57
530	27	3	9.00	.	0	.	.	0	.	0	3	0.00
531	0	3	0.00	.	0	.	.	0	.	.	0	.
534	41	5	8.20	4	5	0.80	0	1	0.00	3	1	3.00
537	20	2	10.00	.	0	.	0	1	0.00	.	0	.
538	35	4	8.75	.	0	.	.	0	.	0	4	0.00
539	51	7	7.29	.	0	.	0	4	0.00	4	7	0.57
540	78	8	9.75	8	5	1.60	2	3	0.67	0	3	0.00
557	43	6	7.17	0	8	0.00	0	3	0.00	6	5	1.20
558	97	8	12.13	4	5	0.80	7	4	1.75	16	6	2.67
562	192	8	24.00	42	8	5.25	20	4	5.00	40	8	5.00
563	110	8	13.75	16	8	2.00	9	4	2.25	21	8	2.63
566	19	1	19.00	6	1	6.00	.	0	.	.	0	.
568	134	12	11.17	23	8	2.88	10	3	3.33	24	7	3.43
576	.	0	.	.	0	.	.	0	.	3	1	3.00
579	48	6	8.00	6	5	1.20	4	2	2.00	15	5	3.00
590	98	5	19.60	17	4	4.25	17	4	4.25	.	0	.
605	22	1	22.00	3	1	3.00	2	1	2.00	.	0	.
609	39	3	13.00	.	0	.	.	0	.	.	0	.
677	77	8	9.63	10	6	1.67	6	3	2.00	0	2	0.00
678	120	4	30.00	23	4	5.75	10	2	5.00	17	3	5.67
691	68	5	13.60	7	3	2.33	2	1	2.00	.	0	.
730	189	8	23.63	36	8	4.50	16	4	4.00	28	5	5.60

APPENDIX L –

AMTL BY INDIVIDUAL (PERMANENT TEETH)

SCR #	Total Obs. Sockets (n)	# Teeth Lost (n)	AMTL (%)
002	10	0	0.00
005	31	0	0.00
007	4	0	0.00
009	17	0	0.00
015	23	0	0.00
016	23	7	30.43
018	32	5	15.63
019	18	1	5.56
024	18	0	0.00
027	31	0	0.00
028	16	6	37.50
029	32	0	0.00
030	29	0	0.00
031	6	0	0.00
032	30	0	0.00
035	17	0	0.00
036	27	0	0.00
037	28	7	25.00
038	31	0	0.00
039	24	16	66.67
044	31	7	22.58
050	19	0	0.00
051	8	0	0.00
052	30	0	0.00
053	16	4	25.00
055	24	0	0.00
058	16	0	0.00
059	14	0	0.00
060	26	13	50.00
067	29	1	3.45
068	32	0	0.00
069	29	0	0.00
072	5	0	0.00
075	32	0	0.00
076	28	7	25.00
077	30	3	10.00
078	32	4	12.50
079	27	4	14.81
080	28	0	0.00
084	29	5	17.24
086	32	0	0.00

SCR #	Total Obs. Sockets (n)	# Teeth Lost (n)	AMTL (%)
088	31	2	6.45
090	32	0	0.00
097	32	2	6.25
098	31	0	0.00
099	32	0	0.00
100	32	0	0.00
103	22	0	0.00
105	32	7	21.88
106	32	0	0.00
111	15	0	0.00
112	16	0	0.00
113	28	3	10.71
115	10	0	0.00
116	28	0	0.00
118	12	1	8.33
120	14	0	0.00
121	29	0	0.00
124	23	0	0.00
125	16	2	12.50
126	31	0	0.00
127	32	1	3.13
129	28	0	0.00
132	16	0	0.00
133	32	0	0.00
134	26	12	46.15
138	32	0	0.00
142	16	0	0.00
143	32	2	6.25
144	32	0	0.00
145	32	18	56.25
146	24	0	0.00
148	32	3	9.38
149	30	0	0.00
150	29	1	3.45
151	30	1	3.33
156	22	9	40.91
157	32	0	0.00
158	14	2	14.29
159	28	0	0.00
160	29	0	0.00
161	32	3	9.38

SCR #	Total Obs. Sockets (n)	# Teeth Lost (n)	AMTL (%)
163	17	0	0.00
165	6	0	0.00
166	15	0	0.00
169	29	1	3.45
170	27	2	7.41
171	32	2	6.25
172	15	1	6.67
173	31	5	16.13
174	31	0	0.00
175	9	0	0.00
176	12	0	0.00
177	16	9	56.25
178	8	0	0.00
179	31	6	19.35
180	28	3	10.71
181	32	0	0.00
182	2	0	0.00
183	30	5	16.67
184	30	2	6.67
185	31	23	74.19
186	32	3	9.38
188	32	0	0.00
189	30	0	0.00
190	14	0	0.00
191	32	3	9.38
192	28	1	3.57
193	31	0	0.00
194	32	2	6.25
196	28	0	0.00
197	32	0	0.00
199	31	0	0.00
200	6	0	0.00
201	32	0	0.00
203	27	0	0.00
207	6	0	0.00
208	1	0	0.00
209	12	0	0.00
210	32	5	15.63
212	8	0	0.00
215	31	1	3.23
216	29	0	0.00

SCR #	Total Obs. Sockets (n)	# Teeth Lost (n)	AMTL (%)
217	32	1	3.13
218	14	0	0.00
219	17	0	0.00
220	29	1	3.45
221	30	0	0.00
223	17	0	0.00
224	23	0	0.00
225	11	0	0.00
226	28	1	3.57
227	30	4	13.33
231	4	0	0.00
232	22	0	0.00
233	32	4	12.50
234	18	3	16.67
236	27	0	0.00
237	28	0	0.00
239	32	12	37.50
240	24	0	0.00
241	30	2	6.67
242	18	1	5.56
243	13	0	0.00
245	32	0	0.00
246	24	4	16.67
247	24	0	0.00
249	24	0	0.00
250	31	1	3.23
251	28	2	7.14
252	32	4	12.50
253	3	0	0.00
257	30	1	3.33
258	11	0	0.00
259	7	0	0.00
261	32	8	25.00
263	28	1	3.57
264	30	3	10.00
265	11	3	27.27
268	29	0	0.00
269	32	0	0.00
271	32	0	0.00
272	29	5	17.24
279	18	0	0.00

SCR #	Total Obs. Sockets (n)	# Teeth Lost (n)	AMTL (%)
280	6	0	0.00
281	22	2	9.09
282	1	0	0.00
283	2	0	0.00
284	4	0	0.00
285	16	0	0.00
286	25	6	24.00
287	31	2	6.45
288	32	4	12.50
289	14	5	35.71
290	23	0	0.00
291	32	3	9.38
292	27	2	7.41
295	32	5	15.63
296	29	0	0.00
297	32	2	6.25
298	32	4	12.50
301	32	1	3.13
302	22	4	18.18
303	31	1	3.23
305	31	1	3.23
306	32	0	0.00
307	32	5	15.63
308	30	8	26.67
309	12	0	0.00
310	28	0	0.00
312	32	0	0.00
314	32	2	6.25
315	9	0	0.00
317	24	0	0.00
319	29	0	0.00
320	32	0	0.00
321	29	1	3.45
322	8	0	0.00
323	32	3	9.38
324	24	0	0.00
325	32	1	3.13
326	30	0	0.00
327	14	0	0.00
328	23	0	0.00
329	29	2	6.90
330	32	0	0.00

SCR #	Total Obs. Sockets (n)	# Teeth Lost (n)	AMTL (%)
331	19	3	15.79
332	30	1	3.33
333	25	0	0.00
334	28	0	0.00
335	27	0	0.00
336	28	3	10.71
337	29	0	0.00
338	32	1	3.13
339	32	5	15.63
340	32	0	0.00
341	32	0	0.00
342	32	0	0.00
343	32	0	0.00
344	32	4	12.50
347	12	0	0.00
348	1	0	0.00
351	30	0	0.00
352	25	0	0.00
354	29	0	0.00
355	19	0	0.00
358	28	1	3.57
360	32	0	0.00
361	32	1	3.13
362	30	6	20.00
363	4	0	0.00
366	11	1	9.09
368	29	0	0.00
369	9	0	0.00
371	1	0	0.00
376	32	0	0.00
383	10	0	0.00
391	14	0	0.00
392	8	0	0.00
393	20	0	0.00
396	23	0	0.00
398	6	0	0.00
401	3	0	0.00
402	2	0	0.00
404	31	0	0.00
406	28	0	0.00
407	7	3	42.86
409	19	0	0.00

SCR #	Total Obs. Sockets (n)	# Teeth Lost (n)	AMTL (%)
410	2	0	0.00
411	16	0	0.00
415	26	0	0.00
416	13	0	0.00
417	31	5	16.13
419	32	3	9.38
420	29	0	0.00
421	19	4	21.05
422	32	6	18.75
423	29	4	13.79
425	26	1	3.85
426	32	0	0.00
429	1	0	0.00
433	31	1	3.23
434	29	0	0.00
436	32	9	28.13
437	27	0	0.00
438	16	5	31.25
440	28	5	17.86
442	25	1	4.00
444	32	0	0.00
445	31	1	3.23
448	32	3	9.38
449	16	6	37.50
450	5	0	0.00
451	5	0	0.00
452	29	0	0.00
454	23	2	8.70
455	29	5	17.24
457	9	0	0.00
462	22	0	0.00
463	32	0	0.00
464	32	0	0.00
465	10	0	0.00
466	32	1	3.13
467	17	0	0.00
470	28	0	0.00
474	23	0	0.00
479	32	0	0.00
482	16	5	31.25
485	32	0	0.00
494	10	1	10.00

SCR #	Total Obs. Sockets (n)	# Teeth Lost (n)	AMTL (%)
497	30	0	0.00
501	16	1	6.25
507	5	0	0.00
509	13	6	46.15
510	12	0	0.00
512	15	0	0.00
517	14	0	0.00
519	18	0	0.00
521	32	0	0.00
522	4	0	0.00
523	3	0	0.00
526	32	3	9.38
530	11	0	0.00
531	4	0	0.00
534	13	0	0.00
537	4	0	0.00
538	19	0	0.00
539	25	0	0.00
540	19	0	0.00
557	28	0	0.00
558	29	0	0.00
562	31	2	6.45
563	28	0	0.00
566	12	0	0.00
568	32	0	0.00
576	1	0	0.00
579	22	0	0.00
590	18	1	5.56
605	8	0	0.00
609	17	0	0.00
677	32	0	0.00
678	16	1	6.25
691	32	0	0.00
730	32	3	9.38

APPENDIX M –

DECIDUOUS DENTAL DATA (TOOTH WEAR, CARIES, AMTL, AND CALCULUS)

DECIDUOUS TOOTH WEAR BY INDIVIDUAL TOOTH

Tooth Type	# teeth w/ wear (n)	# observable teeth (n)	Cumulative Score	Average	S.E.
Maxilla					
R upper 2nd molar	39	51	379	7.43	0.74
R upper 1st molar	35	45	350	7.78	0.84
R upper canine	12	14	43	3.07	0.59
R upper 2nd incisor	5	10	18	1.80	0.88
R upper 1st incisor	7	8	27	3.38	0.92
L upper 1st incisor	8	9	30	3.33	0.82
L upper 2nd incisor	11	15	34	2.27	0.59
L upper canine	14	15	48	3.20	0.51
L upper 1st molar	34	41	330	8.05	0.85
L upper 2nd molar	36	47	355	7.55	0.85
Mandible					
L lower 2nd molar	50	59	587	9.95	0.92
L lower 1st molar	38	47	331	8.11	0.82
L lower canine	3	9	11	1.22	0.66
L lower 2nd incisor	14	23	39	1.70	0.33
L lower 1st incisor	12	13	39	3.00	0.36
R lower 1st incisor	13	15	40	2.67	0.36
R lower 2nd incisor	13	20	37	1.85	0.36
R lower canine	8	11	28	2.55	0.58
R lower 1st molar	44	52	433	8.33	0.73
R lower 2nd molar	53	61	582	9.54	0.77

SCR #	# AMTL. (n)	# carious teeth (n)	# obs. teeth (n)	Caries Rate	Tooth Scores	# obs. teeth	Tooth Wear Total	# sides w/ calculus (n)	# obs. sides (n)	Calc. Score	Calc. Rate	Modified Calc. Rate
SCR 001	0	0	5	0.00	5	5	1.00	0	15	0	0.00	0.00
SCR 002	0	0	6	0.00	78	6	13.00	0	24	0	0.00	0.00
SCR 006	0	0	10	0.00	75	10	7.50	0	36	0	0.00	0.00
SCR 007	0	0	13	0.00	65	13	5.00	0	47	0	0.00	0.00
SCR 009	0	0	10	0.00	95	10	9.50	6	19	3	31.58	15.79
SCR 010	0	0	10	0.00	36	10	3.60	0	36	0	0.00	0.00
SCR 014	0	0	12	0.00	28	12	2.33	0	43	0	0.00	0.00
SCR 023	0	0	18	0.00	86	18	4.78	5	54	3	9.26	5.56
SCR 024	0	0	3	0.00	44	3	14.67	4	12	2	33.33	16.67
SCR 025	0	0	4	0.00	121	14	8.64	0	15	0	0.00	0.00
SCR 026	0	0	6	0.00	0	6	0.00	0	24	0	0.00	0.00
SCR 031	0	4	14	28.57	116	14	8.29	0	49	0	0.00	0.00
SCR 040	0	0	4	0.00	48	4	12.00	0	16	0	0.00	0.00
SCR 042	0	0	7	0.00	19	7	2.71	0	27	0	0.00	0.00
SCR 043	0	0	12	0.00	52	12	4.33	1	44	0.5	2.27	1.14
SCR 051	0	1	7	14.29	52	7	7.43	7	27	4.5	25.93	16.67
SCR 061	0	0	8	0.00	17	8	2.13	0	32	0	0.00	0.00
SCR 063	0	0	7	0.00	14	7	2.00	0	25	0	0.00	0.00
SCR 065	0	0	6	0.00	0	6	0.00	0	21	0	0.00	0.00
SCR 066	0	1	11	9.09	38	11	3.45	1	41	0.5	2.44	1.22
SCR 072	0	0	4	0.00	40	4	10.00	1	16	0.5	6.25	3.13
SCR 081	0	0	3	0.00	15	3	5.00	0	12	0	0.00	0.00
SCR 093	0	0	6	0.00	47	7	6.71	0	27	0	0.00	0.00
SCR 094	0	0	11	0.00	57	11	5.18	0	41	0	0.00	0.00
SCR 095	0	0	10	0.00	86	10	8.60	3	38	1.5	7.89	3.95
SCR 101	0	0	11	0.00	17	11	1.55	0	38	0	0.00	0.00

SCR #	# AMTL (n)	# carious teeth (n)	# obs. teeth (n)	Caries Rate	Tooth Scores	# obs. teeth	Tooth Wear Total	# sides w/ calculus (n)	# obs. sides (n)	Calc. Score	Calc. Rate	Modified Calc. Rate
SCR 102	0	0	5	0.00	14	5	2.80	0	23	0	0.00	0.00
SCR 103	0	1	2	50.00	57	2	28.50	0	8	0	0.00	0.00
SCR 104	0	0	14	0.00	134	14	9.57	10	50	9	20.00	18.00
SCR 108	0	0	6	0.00	5	6	0.83	0	19	0	0.00	0.00
SCR 110	0	0	8	0.00	2	8	0.25	0	27	0	0.00	0.00
SCR 111	0	1	8	12.50	117	8	14.63	7	31	3.5	22.58	11.29
SCR 112	0	1	4	25.00	20	2	10.00	7	14	5	50.00	35.71
SCR 115	0	1	11	9.09	89	11	8.09	4	40	2.5	10.00	6.25
SCR 141	0	0	4	0.00	7	4	1.75	0	12	0	0.00	0.00
SCR 146	0	0	2	0.00	72	2	36.00	8	12	16	66.67	133.33
SCR 147	0	0	2	0.00	24	2	12.00	0	8	0	0.00	0.00
SCR 153	0	1	10	10.00	0	10	0.00	2	37	1	5.41	2.70
SCR 162	2	1	9	11.11	17	9	1.89	2	34	1	5.88	2.94
SCR 164	2	0	13	0.00	68	13	5.23	0	47	0	0.00	0.00
SCR 165	0	0	3	0.00	61	5	12.20	0	20	0	0.00	0.00
SCR 167	0	0	12	0.00	28	12	2.33	0	44	0	0.00	0.00
SCR 168	0	0	9	0.00	72	9	8.00	3	35	1.5	8.57	4.29
SCR 175	0	0	7	0.00	86	7	12.29	2	27	1	7.41	3.70
SCR 176	0	1	6	16.67	87	6	14.50	2	24	1	8.33	4.17
SCR 182	0	0	5	0.00	47	5	9.40	12	20	12	60.00	60.00
SCR 187	0	0	6	0.00	6	6	1.00	0	16	0	0.00	0.00
SCR 200	0	1	9	11.11	81	9	9.00	0	34	0	0.00	0.00
SCR 204	0	0	4	0.00	0	4	0.00	0	14	0	0.00	0.00
SCR 209	0	1	9	11.11	117	9	13.00	1	34	0.5	2.94	1.47
SCR 218	0	1	3	33.33	43	3	14.33	0	12	0	0.00	0.00
SCR 225	0	0	9	0.00	76	9	8.44	10	33	6	30.30	18.18

SCR #	# AMTL (n)	# carious teeth (n)	# obs. teeth (n)	Caries Rate	Tooth Scores	# obs. teeth	Tooth Wear Total	# sides w/ calculus (n)	# obs. sides (n)	Calc. Score	Calc. Rate	Modified Calc. Rate
SCR 235	0	0	9	0.00	66	9	7.33	1	34	0.5	2.94	1.47
SCR 240	0	1	4	25.00	38	4	9.50	10	15	8	66.67	53.33
SCR 244	0	0	6	0.00	48	6	8.00	2	24	1	8.33	4.17
SCR 247	0	0	2	0.00	28	2	14.00	4	8	3	50.00	37.50
SCR 248	0	0	6	0.00	5	6	0.83	0	22	0	0.00	0.00
SCR 249	0	1	4	25.00	66	4	16.50	0	16	0	0.00	0.00
SCR 259	0	0	4	0.00	64	4	16.00	0	16	0	0.00	0.00
SCR 270	0	0	1	0.00	6	1	6.00	1	4	0.5	25.00	12.50
SCR 273	0	0	1	0.00	5	1	5.00	0	4	0	0.00	0.00
SCR 274	0	0	10	0.00	24	10	2.40	1	38	0.5	2.63	1.32
SCR 278	0	0	12	0.00	28	12	2.33	0	43	0	0.00	0.00
SCR 279	0	1	5	20.00	52	5	10.40	0	11	0	0.00	0.00
SCR 309	0	0	3	0.00	55	3	18.33	2	12	1	16.67	8.33
SCR 315	0	0	7	0.00	97	7	13.86	0	27	0	0.00	0.00
SCR 328	0	0	4	0.00	61	4	15.25	0	16	0	0.00	0.00
SCR 392	0	1	1	100.00	2	1	2.00	0	53	0	0.00	0.00
SCR 402	0	0	15	0.00	83	15	5.53	3	20	3	15.00	15.00
SCR 519	0	1	5	20.00	86	5	17.20	1	32	0.5	3.13	1.56
SCR 522	0	0	8	0.00	69	8	8.63	20	37	18.5	54.05	50.00
SCR 523	0	0	10	0.00	51	10	5.10	6	12	4.5	50.00	37.50
SCR 530	0	0	3	0.00	57	3	19.00	0	27	0	0.00	0.00
SCR 531	0	0	5	0.00	57	7	8.14	0	44	0	0.00	0.00
SCR 536	0	0	12	0.00	38	12	3.17	0	20	0	0.00	0.00
SCR 538	0	1	5	20.00	39	3	13.00	1	8	1	12.50	12.50
SCR 539	0	0	2	0.00	26	2	13.00	0	44	0	0.00	0.00
SCR 541	0	0	12	0.00	59	12	4.92	0	4	0	0.00	0.00

APPENDIX N –

COMBINED ISOTOPE AND DENTAL DATA

SCR #	Age Category	Sex	Calculus Rate	Caries Rate	Tooth Wear Score	DMI	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ ap (‰)
SCR 002	5-15	U	0.00	0.00	0.00	0.00	-19.2	11.0	-10.1
SCR 005	15-30	F	41.00	0.00	6.86	0.00	.	9.2	-11.1
SCR 015	>45	F	23.38	4.76	13.05	4.76	-18.6	13.1	-13.9
SCR 018	15-30	F	20.00	20.83	7.48	34.48	-18.9	10.9	-11.3
SCR 027	30-45	F	20.31	5.56	4.39	5.56	-18.9	.	.
SCR 028	>45	F	30.00	0.00	16.00	42.86	-18.6	11.5	.
SCR 029	5-15	U	27.27	4.00	4.04	4.00	-18.8	.	-15.6
SCR 035	15-30	M	12.96	26.67	4.87	26.67	-18.8	8.6	-10.8
SCR 038	>45	M	62.89	0.00	10.37	0.00	-18.6	12.8	-14.1
SCR 079	>45	F	66.23	5.88	8.42	23.81	-18.5	11.4	.
SCR 090	30-45	M	25.00	0.00	6.33	0.00	-18.8	11.1	.
SCR 097	>45	M	39.18	8.00	9.26	14.81	-18.7	11.1	-10.3
SCR 098	15-30	F	33.98	11.11	2.27	11.11	-18.9	11.5	.
SCR 099	>45	M	0.00	7.69	7.41	7.69	-18.5	9.2	-10.6
SCR 1005/3	5-15	U	12.71	0.00	4.06	0.00	-18.7	9.4	-11.9
SCR 1045	>45	M	33.33	100.00	3.00	100.00	-18.9	.	-12.6
SCR 124	15-30	U	5.26	4.76	2.95	4.76	-18.9	9.7	.
SCR 127	30-45	M	41.07	3.33	9.72	6.45	-18.0	11.5	-12.0
SCR 142	30-45	M	11.36	0.00	8.92	0.00	-18.7	11.1	-10.1
SCR 145	>45	M	29.63	0.00	17.73	72.00	-18.5	8.9	-13.4
SCR 149	15-30	M	28.57	0.00	3.63	0.00	-19.0	10.5	-10.2
SCR 155	30-45	F	.	.	5.18	.	-18.9	11.0	-11.6
SCR 158	30-45	M	10.53	100.00	15.40	100.00	-19.0	10.5	-10.7
SCR 160	>45	F	48.00	7.14	3.78	7.14	-18.9	11.1	.
SCR 172	>45	M	44.44	0.00	19.60	16.67	-18.7	11.1	-13.6
SCR 174	30-45	M	19.80	0.00	6.64	0.00	-19.2	9.1	-11.1
SCR 177	>45	F	0.00	0.00	6.00	90.00	-18.4	12.3	.
SCR 178	30-45	M	70.37	0.00	15.43	0.00	-18.7	11.1	-10.5
SCR 179	>45	M	47.27	0.00	14.13	28.57	-18.2	11.2	.
SCR 180	15-30	M	40.74	4.55	5.68	16.00	-18.5	9.8	-11.3
SCR 188	15-30	M	7.34	13.33	5.57	13.33	-18.6	11.1	-9.9
SCR 193	15-30	F	19.27	6.67	5.07	6.67	-19.1	9.8	-11.6
SCR 200	5-15	U	0.00	0.00	0.00	0.00	-19.2	10.7	-10.5
SCR 208	30-45	F	75.00	0.00	18.00	0.00	-19.0	10.9	.
SCR 220	30-45	M	35.29	14.29	8.23	17.24	-18.6	12.0	-11.5
SCR 237	5-15	U	34.38	0.00	3.67	0.00	-19.1	9.6	.
SCR 239	30-45	F	52.17	0.00	7.26	38.71	.	11.9	-10.3
SCR 258	15-30	F	17.65	11.11	6.11	11.11	-18.8	10.4	-11.3
SCR 280	>45	M	0.00	20.00	11.17	20.00	-18.6	14.4	-12.3
SCR 295	>45	F	52.38	16.67	7.79	31.03	-18.6	.	-10.7
SCR 309	5-15	U	0.00	0.00	0.00	0.00	-19.2	9.2	-10.4
SCR 310	15-30	M	2.56	13.04	7.00	13.04	-18.6	9.9	-10.1

SCR #	Age Category	Sex	Calculus Rate	Caries Rate	Tooth Wear Score	DMI	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ ap (‰)
SCR 315	5-15	U	0.00	0.00	5.20	0.00	-19.3	10.9	-10.8
SCR 321	30-45	F	30.12	13.04	6.27	16.67	-19.5	10.1	-10.6
SCR 322	15-30	M	21.43	0.00	3.75	0.00	-18.7	11.7	-13.6
SCR 324	30-45	F	20.25	4.76	8.10	4.76	-18.7	10.9	.
SCR 325	15-30	M	50.00	10.00	6.30	10.00	-19.2	9.5	-9.8
SCR 326	30-45	F	40.91	0.00	8.60	0.00	-19.0	10.5	.
SCR 329	>45	F	27.27	0.00	9.81	8.70	-19.1	10.9	.
SCR 330	15-30	F	83.04	0.00	6.03	0.00	-18.8	8.7	.
SCR 331	30-45	M	29.31	18.75	5.47	40.91	-18.6	9.4	-10.9
SCR 334	30-45	F	.	0.00	6.41	0.00	-18.9	.	.
SCR 336	>45	F	46.43	0.00	8.09	10.71	-18.4	.	-12.6
SCR 338	>45	F	46.43	3.23	10.71	6.25	-19.3	8.8	-11.1
SCR 341	>45	M	42.24	0.00	12.06	0.00	-18.6	10.7	-11.0
SCR 344	30-45	M	29.67	8.33	5.00	21.43	-18.7	11.5	.
SCR 519	5-15	U	7.89	0.00	3.18	0.00	-19.7	10.0	.
SCR 524	>45	M	.	.	.	.	.	11.3	-12.6
SCR 530	5-15	U	66.67	0.00	4.50	0.00	-19.1	10.7	-10.4
SCR 538	5-15	U	3.57	0.00	4.38	0.00	-19.2	10.9	-10.3
SCR 557	5-15	U	42.50	0.00	2.23	0.00	-19.2	10.4	-10.6
SCR A166	>45	F	60.55	0.00	9.63	3.33	-19.0	11.2	-12.1
SCR A190	15-30	M	25.00	25.00	4.00	25.00	-18.8	9.9	.
SCR A202	30-45	M	50.00	0.00	5.00	0.00	-18.6	11.5	-10.6
SCR A236	>45	M	0.00	16.67	20.00	58.33	-19.2	13.4	.
SCR A239	30-45	U	17.24	0.00	8.94	5.88	-18.8	11.1	.
SCR A247	15-30	M	.	13.33	6.33	23.53	-18.8	10.6	.
SCR A306	15-30	F	48.39	0.00	5.39	0.00	-18.5	10.0	.
SCR A326	30-45	M	48.00	3.57	5.68	12.90	-18.4	12.4	-12.7
SCR A329a	30-45	F	8.04	0.00	8.87	0.00	-19.3	9.9	.
SCR A357	30-45	M	.	5.00	6.00	24.00	-19.2	10.8	.
SCR A360	>45	M	42.35	8.70	9.40	12.50	-18.7	10.9	.
SCR A362	15-30	F	25.00	0.00	3.00	0.00	-19.1	7.5	.
SCR A380	>45	M	0.00	4.76	12.38	9.09	-18.8	11.0	.
SCR A418	15-30	F	0.00	0.00	6.00	0.00	-19.0	11.3	-12.5
SCR A463	>45	M	34.09	8.33	10.75	21.43	-18.6	11.2	.