ANALYSIS OF TRAUMA PATTERNS AND POST-TRAUMATIC TIME INTERVAL IN A LATE ROMANO-BRITISH AND SPANISH CONTEXT

ANALYSIS OF TRAUMA PATTERNS AND POST-TRAUMATIC TIME INTERVAL IN A LATE ROMANO-BRITISH AND SPANISH CONTEXT

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ABSTRACT

Fractures, one of the most common findings in paleopathology, can reveal information about behaviour and social identity in the past. A new methodology for assessing the healing stages of fractures has recently been proposed, which could allow for additional data to be gathered from the study of fractures. Trauma, post-traumatic time interval, and injury recidivism were studied in five late Roman (c. 3rd – 4th centuries AD) British and Spanish skeletal samples. The aims of this thesis are: 1) record fractures and their healing stage using new post-traumatic time interval estimation methods; 2) determine how trauma profiles vary in the Romano-British and Spanish samples; 3) employ biocultural and life course approaches in the analysis of the results to reveal information about the culture, social identities, and environmental circumstances in the two Roman provinces under study.

The remains of 214 adults from two Romano-British and three Romano-Spanish sites were examined for the presence of long bone and rib fractures. Fracture data was analyzed by age, sex, site, bone element, and fracture type to build a profile of trauma at each of the sites. In addition, cases of multiple injury were assessed using new post-traumatic time interval methods in order to discern cases of injury recidivism.

A total of 44 individuals were identified as having 89 fractures across all the skeletal samples. Sixteen individuals had multiple fractures, eight of which were determined to have fractures of different ages using methods for determining post-traumatic time interval. Males and females had similar rates of fractures and multiple injuries. Fractures peaked among economically active young and middle-aged adults. A number of differences between the Romano-British and Spanish sample were observed with regards to trauma patterns and fracture prevalence.

The results of this research contribute to our understandings of trauma profiles and injury recidivism in Roman populations, and provide the first comprehensive trauma study of a Romano-Spanish skeletal sample.

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LIST OF ABBREVIATIONS AND SYMBOLS

A – Adult

BAL - Baldock

CPR – Crude prevalence rate

CRA – Carissa Aurelia

F – Female

GLOS GAM – Gambier-Parry Lodge

GRGR – Colegio de La Presentacion

kV – Kilovolt

M – Male

MA – Middle Adult (35-49 years)

OA – Old Adult (50+ years)

OSC – Cerro San Cristobal

p – Significant at ≤ 0.05

P_{FET} – Fisher's exact test

TPR – True prevalence rate

χ^2 – Chi-square test

χ^2_{YATES} – Chi-square test with Yate's correction

YA – Young adult (18-34 years)

DECLARATION OF ACADEMIC ACHIEVEMENT

The research in this thesis was completed by Emma Jennings, under the supervision of Dr. Megan Brickley, and with additional guidance from committee member Dr. Tracy Prowse. Research questions and data collection forms were developed by the author in consultation with Dr. Brickley and Dr. Prowse. Age and sex estimation data was collected by Emma Jennings, L. Creighton Avery, and Sarah Timmins for the SSHRC funded project, 'Socio-Cultural Determinants of Community Wellbeing in the Western Roman Empire: Analysis and Interpretation of Vitamin D Status'. Macroscopic and radiographic fracture data collection and analysis was conducted by Emma Jennings. Permission to access the Baldock and Gambier-Parry Lodge skeletal collections and use of the radiographic equipment was obtained from Dr. Jo Buckberry of the University of Bradford, UK. Permission to access the three Spanish skeletal collections was granted by Dr. Sylvia A. Jiménez Brobeil at the University of Granada, Spain.

CHAPTER 1: INTRODUCTION

Human skeletal remains are a direct link to the past. Bones can provide us with information about an individual's environment, culture, and society. Human remains can also be examined at the population level, revealing epidemiological information about diseases or rates of trauma. Fractures are a common finding in paleopathology, and their study can reveal important information about an individual's behaviour, activities, and levels of risk exposure, as well as trends in fracture patterns at the population level, which may be culturally specific. Studies of trauma in paleopathology have long since moved past descriptive case studies and into systematic analyses of trauma patterns in skeletal samples. However, recent research has shown that additional information can be extracted from the study of trauma in paleopathology. For example, Ives et al. (2017) advocate recording a wider range of fracture features, such as eburnation, to aid in the identification of fractures occurring shortly before death. Brickley and Buckberry (2014) have called for greater inclusion of partial skeletal remains in paleopathological analyses, especially when recording conditions such as fractures, which do not need more complete remains for diagnosis. However, one of the greatest hurdles to the study of fractures remains the fact that it is difficult to ascertain when an older fracture may have occurred, making studies of phenomena such as multiple injury and injury recidivism difficult to undertake. A recent paper by De Boer et al. (2015) on post-traumatic time interval in archaeological dry bone may allow some progress to be made in this area. Fracture features, visible macroscopically and radiographically, can be matched to broad time intervals, which will allow further distinction to be made between the ages of healing fractures than the current categories of unhealed, healing, and healed. The ability to further distinguish between the chronology of fractures (i.e., when they occurred and how long they have healed) could open up several new avenues of research, including the study of injury recidivism and multiple trauma, which has only somewhat cursorily been studied in paleopathology.

The research in this thesis examines trauma in five skeletal samples from small, rural settlements in Britain and Spain that date to the Late Roman period (roughly the mid third century AD to the fifth century AD). At the height of its power, the Roman Empire covered a vast swath of Europe, as well as parts of Africa and Asia. However, the cultures and environments of the Roman provinces were not homogenous. Studies of fracture patterns from sites across the Roman Empire offer an opportunity to investigate the diversity among societies of this time period. There exists a wealth of information on trauma and overall health at a number of Romano-British sites (e.g., Lewis, 2010; Redfern, 2008; Redfern and DeWitte, 2011b), but there have been few studies that compare trauma levels across the Roman Empire to measure to what extent trauma patterns found at British sites were unique to the Romano-British province. Studies of Roman Spain in paleopathology in particular have been limited.

The skeletal samples recorded in this thesis come from Baldock, UK, Gambier-Parry Lodge, UK, and Granada, Spain. The remains of 214 individuals over the age of 18 were analyzed. Fractures were analyzed both macroscopically and radiographically, with information such as fracture type, mechanism of injury, and bone displacement recorded according to standardized criteria (Buikstra and Ubelaker, 1994; Lovell, 1997; Lovell, 2008). The stage of fracture healing was recorded according to the post-traumatic time interval for archaeological dry bone developed by De Boer et al. (2015). This method allows for a more precise time estimate to be provided for a healing fracture using macroscopic and radiographic analysis. Rates of trauma and multiple injuries are analyzed by age, sex, and settlement type, and placed in the context of current historical, paleopathological, and clinical understandings of trauma.

This thesis has three primary linked aims: 1) to identify fractures and their stage of healing using new post-traumatic time interval estimation methods for archaeological dry bone in individuals from five sites across two Roman provinces, providing the first trauma data set from Roman Spain and adding to data on injury recidivism in paleopathology; 2) to determine how rates of trauma vary by age, sex, and settlement in the two Roman provinces; 3) to use biocultural and life course approaches to discuss how the results of this study reveal information about the culture, social identities, and environmental circumstances across the two Roman provinces under study.

This thesis contains six chapters in total, including this introduction. Chapter two explores the kinds of information that can be gathered through studying trauma in the archaeological record, with particular focus on issues surrounding the timing of injuries, and injury recidivism. The chapter also briefly discusses the biocultural and life course approaches, theoretical frameworks common in bioarchaeology, that will be drawn upon in this thesis. Chapter three covers materials and methods, providing information on the archaeological skeletons used and methods used to estimate age and sex, as well as the ways in which fractures were recorded and analyzed. Chapter four presents the results of this study and their statistical significance, examining the impact of age, sex, settlement type, and multiple injuries. Chapter five discusses the significance of key results and places them in the context of modern clinical trauma data and our understanding of ancient Roman society. Finally, chapter six presents the conclusions of this study and provides a discussion on areas that would benefit from further research.

CHAPTER 2: BACKGROUND

2.1 Introduction

This chapter begins with a discussion of the mechanics of fracture repair, as an understanding of bone physiology and response to trauma is a necessary prerequisite in order to fully appreciate the macroscopic and radiographic features of fractures seen in paleopathology and which aid in the diagnosis and interpretation of fractures. The discussion then moves to fracture dating and post-traumatic time interval, a new methodology which determines the chronology of fracture occurrence, that has yet to be fully explored in paleopathology, but which promises to open up our ability to explore aspects of medical care for traumatic injury, child abuse, the life course, and injury recidivism. Fracture dating is the preferred term in the clinical literature, but emerging forensic and paleopathological work on deceased individuals has adopted the term, post-traumatic time interval. The third section touches upon injury recidivism, and how work in this area can be moved forward with the use of post-traumatic time interval analysis. The final section briefly discusses the theoretical frameworks that will be used in this thesis, the biocultural and life course approaches.

It is important to note that this thesis concerns itself exclusively with traumatic fractures. The term ‘trauma’ can be applied to a range of injury types and there are a range of possible causes of fractures other than trauma, such as infection, disease, and nutritional deficiency (Judd and Redfern, 2012). Pathological fractures will not be considered in this thesis.

2.2 The Mechanics of Fracture Repair

Bone is a dynamic tissue that remodels throughout an individual's lifetime. It is unique in that its healing process is more so one of regeneration, resembling embryonic bone development, than solely reparative (Tosounidis et al., 2009). The end result of the repair process, provided it is able to occur unhindered, is a remodelled bone that resembles its original form. Fractures are breaks (often complete, but sometimes incomplete) in the bone caused when external stresses exceed the bone's ability to flex. When such a trauma occurs, a repair process is initiated. The most common type of bone healing is secondary bone healing, in which spontaneous healing occurs at the fracture site in the absence of apposed fixation at the fracture site (Einhorn, 2005; Sfeir et al., 2005; Tosounidis et al., 2009). The fracture repair process has long been well understood, thanks to numerous histological animal studies. As early as the 18th century, John Hunter described the cascade of morphological processes involved in the fracture repair of tubular bones (Chapman, 1992):

1) hematoma formation
2) inflammatory response (or tissue metaplasia)
3) soft callus formation
4) ossification and hard callus formation
5) remodelling

This sequence is sometimes shortened into three phases:

1) inflammatory (which encompasses haematoma formation and inflammatory response)

2) reparative (soft and hard callus formation)

3) Remodelling.

Four types of tissue are involved in fracture repair: cortical bone, periosteum, external soft tissue, and bone marrow (Einhorn, 2005).

The inflammatory phase begins immediately after the initial trauma, peaks in the first 48 hours, and is typically resolved after one week (Sfeir et al., 2005). Immediately after the bone breaks there is bleeding from the blood vessels in the bone and the surrounding soft tissue, which begins to clot and form a haematoma between the fractured ends. Local blood vessels dilate and swelling prevents the fracture from moving. Plasma and white blood cells accumulate at the fracture site. Without adequate blood supply, the bone at the two fractured ends dies and is cleared away by macrophages, such as osteoclasts, along with other debris. The haematoma vascularizes and becomes fibrous, further stabilizing the fracture, resulting in a granular tissue containing collagen fibres, cartilage, and new blood vessels (Sfeir et al., 2005; Tosounidis et al., 2009; Mirhadi et al., 2013). The reparative phase begins in the first few days and lasts for several weeks (Sfeir et al., 2005). In this phase, a callus is formed and made up of connective tissue, blood vessels, cartilage, osteoid and woven bone. The torn periosteum stimulates osteoblasts that begin to mineralize the callus beginning in the periosteum and working towards the fracture ends. Mineralization continues until the callus is composed of woven bone and connects the two fracture ends. In the remodelling phase, woven bone is replaced by mature, lamellar bone. Excess callus is resorbed and the bone is remodelled to restore its original structure.

If there are complications in the healing process, delayed union or non-union may result. Non-union occurs when the two fracture ends fail to unite. In the clinical literature, non-union in long bones is believed to occur in 5-10% of fractures (Brighton et al., 1995). A number of different factors can affect the healing process, such as the type of bone involved, fracture type and severity of injury, mobility at the fracture site, the distance between the fracture ends, and disruption in the blood supply, as well as patient specific factors, such as age, nutrition, disease, and infection (Mirhadi et al., 2013).

2.3 Post-traumatic Time Interval

In paleopathology and forensics, fractures have traditionally been placed into three categories: antemortem, occurring before death; perimortem, around the time of death; postmortem, occurring after death. The use of these categories and the definitions of these terms have been debated, particularly the term *perimortem* (Bunch, 2014), but are still widely employed (i.e. Blau, 2017). Whether a fracture appears to have associated evidence of healing, and the extent of that healing, largely determines which category it falls into (Ubelaker and Montaperto, 2013). However, describing a fracture simply as 'antemortem' is limiting as it says very little about the timing between the injury and the death of the individual.

Analysis of healing features to determine post-traumatic time interval could add a new dimension to the study of trauma in archaeological samples. This section will examine the origins of fracture dating in the clinical literature and trace its evolution through forensic anthropology into its potential applications in paleopathology.

Consideration of the current limitations of this area of research will also be provided.

2.3.1 Fracture Dating in the Clinical Literature

Clinicians have been diagnosing fractures with the use of radiography for just over 110 years (Spiegel, 1995). However, the use of radiographic features of fracture healing to date fractures is a much more recent science. In the clinical context, there are three ways to assess the healing stages of fractures (Bilo et al., 2010):

1) fractures are painful and limit movement, which may provide anamnestic information about when the fracture occurred
2) changes that can be seen radiographically which allow dating
3) histopathological changes can be seen which allow dating

The need to determine a timetable for fractures in clinical cases of child abuse has prompted most of the existing work on the post-traumatic time interval dating of fractures. Fractures are the second most common injury in cases of child abuse (Loder and Feinberg, 2008). In most cases of abuse, the child is under three years of age and unable to provide any anamnestic information or context, making radiographic dating imperative (Leventhal et al., 2008; Worlock et al., 1986). O'Connor and Cohen (1987) provided the first comprehensive review of radiographic fracture dating in cases of child abuse. However, the timing of radiographic features was based solely on the authors' expertise and not comprehensive research. A further review was provided by Chapman (1992) who created stages of radiological features based upon the extensive body of existing knowledge on the histological phases of fracture healing. Subsequent studies have continued to base radiological stages of healing upon histological literature. Islam et al. (1999) conducted the first study of radiographic changes during bone healing, with the aim of creating a timetable. They examined 205 radial and ulna fractures in children aged one to 17 years. Their timetable considered eight features divided into five histologic stages, each with a minimum and maximum healing time, as well as peaks for each feature. The study found that density at the fracture margin, the appearance of new periosteal bone formation, and a fracture callus density equal to or greater than that in the cortex were the most reliable features in radiographic fracture dating (Islam et al., 1999). They concluded that an injury less than five to seven days old would not show any radiologic features. Between fourteen days to three weeks, a periosteal reaction would begin to be seen, with sclerosis developing between three and eleven weeks. Finally, periosteal new bone would begin to be incorporated into the underlying cortex six weeks after injury.

Prosser et al. (2004) conducted the first systematic review of the radiographic literature, attempting to synthesize previous findings into one comprehensive timetable. However, they found only three primary research papers that met their inclusion criteria: Islam et al. (1999), Yeo and Reed (1994), and Cumming (1979). Yeo and Reed (1994) looked at stages of callus formation in femoral fractures, while Cumming (1979) assessed a very small sample of newborns with long bone fractures at birth for the first appearance of mineralization at the fracture site. Prosser et al. (2004) found that while this area of study suffered from a lack of standardization of terms as well as methodology, there was some agreement on the timing of several features: an early (or soft) callus was consistently seen between seven days and three weeks, while a hard callus and early remodelling were seen at around eight weeks after injury. These authors called for larger scale studies to confirm previous findings, as well as to provide standardized criteria and definitions for radiologic features of fracture dating.

The next primary research paper in the field was not conducted until a study by Halliday et al. (2011) of 31 infants, aged 14 days to 44 months, with long bone fractures. Six radiographic features used in previous studies were assessed, but the authors concluded that only subperiosteal new bone formation could be reliably assessed. This was largely due to the fact that the radiographers assessing the data did not have a clear idea of the definitions or features of hard and soft calluses, as issues surrounding standardization still had not been resolved. The continued lack of standardization, combined with the small handful of primary research papers led some researchers to believe that the dating of injuries should be abandoned in favour of determining age-difference; simply, whether a fracture was recent versus healing (Adamsbaum et al., 2010).

The attempt to create a radiographic timetable for fracture dating was picked up again by Prosser et al. (2011), who conducted the largest study of fracture healing to date. The study examined 228 radiographs of long bone fractures in 63 children under five years of age. Six features found in previous studies were assessed and, most importantly, defined by the authors, allowing for some standardization in classification and comparison. The study found broad similarities in the timing of features with previous studies, and recommended that features be grouped into three phases: Acute (less than one week); Recent (eight to thirty-five days); Old (greater than thirty-six days). Another two large studies were conducted following Prosser et al.'s (2011) revitalization of the subject. Sanchez et al. (2013) provided the first and only study of fracture dating in ribs, which looked at 23 fractures in patients under 12 months. The study did not follow radiographic feature categories set out by Prosser et al. (2011), but did find similarities in fracture healing timing in callus formation and fracture line stages, concluding that rib fractures follow similar healing patterns as immobilized long bones.

Finally, the most recent clinical study in fracture dating looked at healing patterns in non-immobilized clavicular birth fractures (Walters et al., 2014). This large study looked at 131 fractures, but only assessed the timing of subperiosteal new bone formation and callus formation. However, the authors found that the timing for these features were in line with previous studies. Table 2.1 shows the timing of various radiological features of fracture dating found in each of the primary research papers, as well as major reviews, conducted on fracture dating to date in the clinical literature.

Table 2.1
Timing of Major Radiological Features of Fracture Healing as Proposed in Radiological Papers on Fracture Dating.

		Radiology Textbook and Reviews		Primary Scientific Studies						
Radiological Stage	Radiological Feature	O'Connor & Cohen (1987)	Chapman (1992)	Cumming (1979)	Yeo & Reed (1994)	Islam et al. (1999)	Halliday et al. (2011)	Prosser et al. (2011)	Sanchez et al. (2013)	Walters et al. (2014)
Induction/ Inflammation	Soft tissue swelling							1-2 d (1-31 d)		
	Resolution of soft tissues	4-10 d (2-21 d)					(>10 d)			
	Fracture gap widening					4-6 wk (2-8 wk)				
Soft callus	Sclerosis of margin					4-6 wk (2-11 wk)				
	Periosteal reaction	10-14 d (4-21 d)	7-14 d (4-14 d)	9-10 d (7-11 d)	1.6 wk (1-3 wk)	4-7 wk (>2 wk)	10-14 d (>4 d)	15-35 d (5-96 d)	1-3 wk	8 d (7-10 d)
	Loss of fracture line definition	14-21 d (10-21 d)					12-77 d			
	Soft/Early callus	14-21 d (10-21 d)	(10-14 d)			4-7 wk (>2 wk)	(>8 d)	22-35 d (12-66 d)	3-5 wk	13 d (9-15 d)
Hard callus	Hard callus	21-42 d (14-90 d)				13 wk (>4 wk)	20-106 d	> 22 d (19-96 d)	5-9 wk	
	Bridging		17-21+ d		2.6 wk (1.5-3.7 wk)	13 wk (>3 wk)		> 36 d (19-300 d)		
	Periosteal reaction incorporation					14 wk (>7 wk)				
Remodelling	Remodelling	1 yr (3 mo-2 yrs)	(3 mo – 2 yrs)		8 wk (5-11 wk)	9 wk (>4 wk)		> 36 d (45-421 d)	10-11 wk – 1 yr	

The peak dates of radiological features are shown. Ranges of healing times are shown in brackets. d = days, wk = weeks

The clinical studies on radiographic fracture dating suffer from several limitations. Primarily, there are a variety of terms used to describe radiographic features and stages of fracture healing, and a lack of clear definitions of terms, which makes it difficult to ascertain whether studies are in agreement (Halliday et al., 2011). There are also still many unknowns with regards to what effect factors such as fracture location, fracture type, severity, mechanism of injury, age of patient, and immobilization may have on the timing of fracture healing (Prosser et al., 2004; Offiah et al., 2009; Halliday et al., 2011; van Rijn and Sieswerda-Hoogendoorn, 2012; Pickett, 2015). All studies in the clinical literature have been conducted on long bones and ribs, as there is some evidence that fractures of the skull, spine, and metaphysis (in children) heal differently (Offiah et al., 2009). Despite some gaps in knowledge, all clinical studies are in agreement that fractures do heal according to a set pattern, which can be seen radiographically. Many studies agree broadly on the timing of certain key features (see Table 1).

2.3.2 Fracture Dating in Forensic Anthropology

Investigations of fracture dating have recently been taken up by the field of forensic anthropology, which has sought to refine aspects of the clinical studies and make them applicable to forensic cases. Ubelaker and Montaperto (2011) considered the effect that differences in bone structure may have on healing in different areas of the skeleton and even within a single bone. Malone et al. (2011) set out to answer two of the largest unknowns in fracture dating; the influence of age and fracture location. The authors confirmed the observation that infants and young children do heal at a faster rate than adults and older children, spending less time in the earliest stage of fracture healing, prior to new bone and callus formation. They also found that forearm fractures heal faster than lower limb fractures, with callus formation specifically taking longer in lower limb fractures. Malone et al. (2011) proposed their own fracture dating timetable that was broad enough to encompass differences in age and fracture location (Table 2.2).

The most recent research in this field has focused on the application of different imaging methods to further refine the fracture repair timeline. A study by Baron et al. (2016) revealed new information about the earliest stages of the fracture repair process using quantitative MR imaging. Their study was based on an adult sample with known dates of injury, helping to further elaborate the fracture healing timeline in adults. The majority of the forensic studies on fracture dating have been on living individuals, but some studies are beginning to look at this process in the deceased. It is acknowledged that the assessment of post-traumatic time interval may be complicated by issues of preservation obscuring or destroying healing features and negatively impacting radiological imaging (Aalders et al., 2017). However, the International Society of Forensic Radiology and Imaging has highlighted post-traumatic time interval in deceased individuals as an area where further study should be encouraged, promising future developments in this field (Aalders et al., 2017).

Table 2.2
Timing of Major Radiological Features in Fracture Dating, Accounting for Differences in Age and Fracture Location, as described in Malone et al. (2011).

Stage	Peak Healing Time	Range in Healing Time
Stage 1 – No healing: sharp fracture lines	3.3 days	0-14 days
Stage 2 – Granulation: beginning of resorption along fracture line, "fluffy" callus formation, blurring of fracture line	21 days	4-50 days
Stage 3 – Callus: mature callus formation bulging over site and radiopaque, fracture line visible but blurring	38.4 days	15-75 days
Stage 4 – Bridging: fracture gap connected across <50% of fracture site, blurring of fracture line	43.9 days	24-93 days
Stage 5 – Clinical Union: fracture line significantly blurred, fracture line >50% connected, callus minimal	65.2 days	24-156 days
Stage 6 – Completion: No evidence of fracture line, callus minimal or not present	313.3 days	42-750 days

Peak healing times as well as the full range of healing time since injury for key radiological stages of fracture healing are shown. This chart takes into account the impact of age and fracture location on healing time.

2.3.3 Post-traumatic Time Interval in Archaeological Dry Bone and its Applications in Paleopathology

Maat was the first to tackle post-traumatic time interval in paleopathology in a 2008 paper. This was prompted by investigations by the International Criminal Tribunal of Former Yugoslavia, which had reports of intentionally inflicted bone fractures prior to prisoner executions during the conflicts in the Balkans in the 1990s. The investigation hinged on the passage of time between an injury and the death of the victim. After an extensive literature review of clinical and forensic cases, as well as anatomical and pathological textbooks, Maat (2008) created a timetable of features that could be seen macroscopically, radiographically, and histologically, and established the maximum and minimum times required for a particular healing stage to be reached. Maat and Huls

(2010) later added to this table with further work on histological features of fracture healing in both fresh bone, as well as dry, archaeological bone. Their work demonstrated the potential for a fracture healing timetable, as can be found in the clinical literature, to be applied to archaeological dry bone. The most recent research to use Maat's (2008) post-traumatic time interval was a study by De Boer et al. (2015). This study assessed all aspects of Maat's (2008) constructed timetable and applied it to archaeological dry bone. They found that the majority of the features were still visible and had high inter-observer agreement, and concluded with a call for more studies to be done to improve the reliability of this method (DeBoer et al., 2015). The application of post-traumatic time interval to dry bone has opened this field of research up to paleopathologists.

As this method is fairly new, very few studies in paleopathology have applied it in any significant way to research in the discipline. Flohr et al. (2015) referenced one of the features in the De Boer et al. (2015) timetable to determine whether a flint arrowhead found embedded in the humerus of a Bronze Age individual was antemortem or perimortem, while Brickley et al. (2016) used De Boer et al.'s (2015) descriptions of periosteal new bone formation associated with fracture healing to determine whether this feature was associated with trauma or scurvy in a sample of 18th century prisoners in Old Quebec, Canada. The most extensive use of the post-traumatic time interval to date is by Assis and Keenleyside (2016), who employed the histological features of the time interval as part of a larger assessment of the potential usefulness of histological analysis in paleopathology. The study had success in using post-traumatic time interval to ascertain healing status using histology, but it was small in size and limited to six bone samples

(Assis and Keenleyside, 2016). Aside from the Assis and Keenleyside (2016) study, no study has utilized post-traumatic time interval as a meaningful part of its methodology, leaving this an area of research with underutilized potential. De Boer et al. (2015) pointed to the limitations of broadly categorizing fractures as antemortem or healing as this provides no estimation of the length of time between the moment of trauma and death. A more detailed temporal specification of antemortem fractures could open the doors to interpret underexplored aspects of trauma in paleopathology and bioarchaeology.

2.4 Injury Recidivism

Injury, or trauma, recidivism has long been discussed in the clinical literature, but has had limited applications in paleopathological and bioarchaeological studies, partly due to the difficulty in assessing whether fractures occurred in one-single episode, or whether the fractures constitute multiple repeat injuries. Injury recidivism is a clinical term that describes a subset of patients who have a history of repeatedly presenting at trauma centres with recurring patterns of injuries. Research in the clinical literature characterizes the type of individual most likely to present with repeat injuries, and the role that socioeconomic factors have on injury recidivism. One of the first studies on injury recidivism was conducted in a large urban trauma centre in inner city Detroit, and showed that drug use, unemployment, poverty, and crime had an overwhelming impact on repeat vulnerability to trauma (Sims et al., 1989). Sims et al. (1989: 940) found injury recidivism to be so prevalent that they characterized modern trauma as a "chronic, recurrent disease". Another large study at an urban trauma centre revealed that sharp force trauma was more commonly found in patients with repeat trauma, and that the mean interval between injuries was 7.9 months (Smith et al., 1992). In those individuals with repeat trauma who succumbed to their injuries, the mean interval between their first trauma and death was 18.8 months.

Numerous clinical studies have profiled the injury recidivist as young, male, belonging to an ethnic minority, and economically disadvantaged (Alghnam et al., 2016; Chong et al., 2015; Goins et al., 1992; Kaufman et al., 1998; Reiner et al., 1990; Smith et al., 1992). Rates of injury recidivism in urban trauma centres have varied widely from 1% to 52% (Hedges et al., 1995; Sims et al., 1989; Toschlog et al., 2007). The majority of these studies have been done in urban centres in the United States, but there have been a few large studies in Canada (Caufeild et al., 2004), Sweden (Röding et al., 2016), New Zealand (Dowd et al., 1996), and rural Israel (Sayfan & Berlin, 1997). Caufeild et al. (2004) found that the profile for the injury recidivist in Toronto was similar to urban centres in the United States, with recidivists more likely to be from the inner city, male, homeless, and suffering from chronic medical conditions and substance abuse. Röding et al. (2016) also found young males to be at high risk of injury recidivism, but their results also showed a high risk for injury recidivism in elderly women. The Swedish study did not examine the causes of injury recidivism, but did find that injury recidivists were at a higher risk for moderate to severe trauma (Röding et al., 2016). Interestingly, the study in New Zealand found no demographic patterns associated with injury recidivism (Dowd et al., 1996). In rural Israel, Sayfan and Berlin (1997) identified injury recidivism in 30% of individuals presenting with trauma, most of whom were young and male, but found that socioeconomic factors only played a small role.

The few studies that contradict the standard injury recidivist profile have been conducted in rural areas. The first study of rural injury recidivism was performed at an emergency department in West Virginia (Williams et al., 2007). The authors found that the injury recidivism rate was high at 24%, and like urban centres, injury recidivists tended to be young and of low socioeconomic status; however, no sex-based differences were found. Another investigation in rural Nevada found that the injury recidivism rate was much lower than in urban centres (3.4%), and that the rural injury recidivist tended to be older, white, and female (Toschlog et al., 2007). This led the authors to conclude that rural injury recidivism was a different phenomenon from that found in urban centres. However, poverty and substance abuse were still significantly associated with repeat injury. Based on these studies, it is clear that profiles for injury recidivists in large urban communities are fairly uniform, with socioeconomic factors playing a large role. In rural areas, the picture is less clear, and more culturally contingent.

The clinical work on injury recidivism provides considerable comparative data for the enterprising bioarchaeologist looking to draw cultural and socioeconomic conclusions from trauma in an ancient population. Judd (2002a) was the first bioarchaeologist to examine ancient injury recidivism. Her large-scale study of two archaeological skeletal samples, one urban and one rural, from the Kerma period of ancient Nubia, found that most of the injury recidivists were males under the age of 35, similar to urban profiles developed in the clinical literature (Judd, 2002a). Furthermore, there was little difference in violence or accident-related injuries among the urban and rural groups. Nevertheless, a high rate of non-lethal trauma was identified in the sample. Judd's (2002a) seminal study demonstrates the wealth of information that can be gathered through studies of injury recidivism.

Since Judd's (2002a) study of ancient Nubians, injury recidivism has been incorporated into relatively few bioarchaeology papers, with the exception of a study by Redfern et al. (2017) exploring the relationship between multiple injury and poor general health. This is undoubtedly due to problems in clarifying the timing of traumatic injuries. The research on the ancient Nubian samples demonstrated that injury recidivism had the potential to yield interesting insights about ancient groups, but it did not fully overcome the problem of post-traumatic time interval. An individual with multiple fractures could still have sustained them all in one episode, and not as the result of injury recidivism; a concern that researchers attempting to apply injury recidivism to other study samples have repeated (e.g. Spencer, 2012; Gilmour et al., 2015). In fact, Glencross (2011: 494) described the problem of healed fractures giving no indication as to when an injury occurred as “an insurmountable methodological challenge”. However, this does not mean that further studies in ancient injury recidivism should not be attempted. Studies of injury recidivism have the potential to reveal important information about occupational activities, status, poor general health, and interpersonal violence, including understudied areas, such as infanticide (Mays and Eyers, 2011; Mays and Faerman, 2001), child injury (Timmins et al., 2017), domestic abuse (Redfern, 2015) and elder abuse (Gowland, 2016a; Gowland, 2016b). The research presented in this thesis attempts to overcome these methodological obstacles by utilizing a post-traumatic time interval table to parse out cases of true injury recidivism.

2.5 Theoretical Frameworks for Studying Fractures in Paleopathology and Bioarchaeology

Fractures are one of the most common findings in paleopathological and bioarchaeological studies and have the potential to yield surprising amounts of information about individuals and populations (White and Folkens, 2005). Early paleopathological research on trauma tended to be purely descriptive, but over time the discipline has adopted new theories and frameworks to answer big picture questions about the cultures it studies. Ortner (1991: 5) described the job of the paleopathologist as answering two questions: "*What is it?* and *What does it mean?*". This section will focus on two theoretical frameworks, the biocultural and life course approaches, that will be used in this thesis.

One of the main ways that researchers in recent years have sought to answer the question '*What does it mean?*' has been by taking a biocultural approach. The biocultural approach simply seeks to situate human biology in its social and cultural context, as both the biological and cultural are seen as interacting with each other to influence human behaviour and adaptation (Zuckerman and Armelagos, 2011). In the field of bioarchaeology, biocultural analysis is centred around the theory of embodiment; the idea that engaging in a society is performed through the physical body and that the social and cultural activities that an individual engages in can be etched onto their remains (Gowland, 2017). The primary way that bioarchaeological analysis can access lived experience through physical remains are through the categories of sex and gender, age, social status, and ethnicity, all of which form social identities and are interconnected with biology and behaviour (Gowland, 2017; Knudson and Stojanowski, 2008). An examination of trauma, disease, or diet, etc. through these categories can reveal a lot about the social fabric of a society, and comparisons between different settlement types or regions can illuminate local biologies unique to certain populations or time periods. Although there have been some critiques of the biocultural approach as reductive and deterministic (Segal and Yanagisako, 2005), this framework has been a mainstay of bioarchaeology since the 1950s, though its definition has evolved over time (Zuckerman and Armelagos, 2011). In this thesis, trauma will be discussed within the context of Romano-British and Spanish culture and history, and will draw on other paleopathological, archaeological, and classical historical studies, to provide explanations for the impact that gender roles, occupational activities, stress, and economic factors may have had on trauma patterns.

The life course approach has emerged as a key way of studying age in bioarchaeology. The life course approach acts as a framework for understanding how an individual's culturally-specific social identity and agency changes over their lifetime. Glencross (2011) has discussed the importance of life course approaches, but notes that this is an area of study that has been overlooked. She points to the potential of accumulated biological indicators, and fractures in particular, to get at behaviour and attitudes of past populations (Glencross, 2011). Fractures accumulate throughout an individual's life and can represent changing roles and ageing biologies. There have been few studies of trauma in Roman Britain that consider the life course. However, detailed consideration of the life course will be given to the samples under study in this thesis, particularly when considering fracture patterns across different age categories and how they may be interpreted through changing social identities related to age and ageing.

CHAPTER 3: MATERIALS AND METHODS

3.1 Introduction

This chapter details the sites from which skeletal material was analyzed for this thesis, as well as the methods and standards that were employed in data collection. Section 3.2 provides context for each of the five skeletal samples used. Section 3.3 details the age and sex estimation techniques used in data recording and how they were adapted to suit the requirements of this research. It also discusses how preservation was recorded and how individuals were selected for exclusion on the basis of age and poor preservation. Section 3.4 deals with the recording of fractures; how fractures were identified and determined to be antemortem, and the methods and standards used in recording fracture features in order to build up a thorough trauma profile. Finally, section 3.5 discusses the macroscopic and radiographic methods used to determine post-traumatic time interval.

3.2 Materials

This section discusses the historical and archaeological context of the five archaeological sites that were selected for analysis; two rural Romano-British sites (Figure 3.1), and three rural Romano-Spanish sites (Figure 3.2). The two British sites are Baldock and Gambier-Parry Lodge and the three Spanish sites are Carissa Aurelia, Cerro San Cristobal, and Colegio de La Presentacion de Granada. Permission was granted from the Bioarchaeology Research Centre at the University of Bradford, UK as well as the Anthropology Department at the University of Granada, Spain to examine these collections.

Fig. 3.1 Location of Baldock and Gambier-Parry Lodge in Britain**.**

Fig. 3.2 Location of the Carissa Aurelia, Colegio de La Presentacion and Cerro San Cristobal in Spain.

Adults (18+ years) in each of the collections who were greater than 25% complete (n=147) were analyzed (see Section 3.3 for a more detailed discussion of preservation and age and sex estimation). The age cut off of 18 years was selected because the clinical literature on injury recidivism deals exclusively with adults (our modern notion of adulthood encompasses individuals who are 18 years or older) (e.g., Alghnam et al., 2016; Gentilello et al., 1999; Goins et al., 1992; Greer and Williams, 1999; Röding et al., 2016). This age group was also selected because there is an ongoing debate in the clinical literature as to whether fractures in children heal at a faster rate than adults, thus impacting any analysis of post-traumatic time interval, which was tested exclusively on adult skeletal remains (Prosser et al., 2004). By age 18, all epiphyses have fused with the exception of a select few bones, such as the sternal end of the clavicle (Cardoso, 2008a; 2008b). The skeleton number, age estimation, sex estimation, as well as the presence and location of any fractures were recorded for all excluded individuals, along with the reason for their exclusion.

3.2.1 British Sites

Baldock

Baldock is a well-studied site and much is known about its history; the settlement was a Roman *oppidum* (a provincial town) established in the first century BC (Burleigh and Fitzpatrick-Matthews, 2010). A medium-sized, rural settlement, Baldock's economy was primarily agriculturally-based, complemented by a thriving market, and some minor industry (Burleigh et al., 2006). The town was likely not of great regional or administrative significance, but it was well connected to several larger centres and towns by a series of roads. At its peak in the second century AD, the town was spread over 48 ha, and composed of around 25 domestic buildings, temples, and a possible *mansio* (a rest-stop along a road used by officials while travelling) (Burleigh et al., 2006). It has been difficult to assess the size of the population living at Baldock, due in part to the site's dispersed nature (Burleigh et al., 2006). The site began to decline in size by the third and fourth centuries, and was completely abandoned by the sixth century AD. Modern Baldock is a small market town in the district of North Hertfordshire in the east of England.

The Roman site was discovered in 1925 by W. Percival Westell, the curator of Letchworth Museum. However, most of the excavation work was carried out between 1978 and 1994 under the direction of Gil Burleigh of Letchworth Museum and the North Hertfordshire Archaeological Society. These excavations revealed a Late Iron Age burial, processional way and mortuary house, in addition to several Roman burial sites housing around 1,900 human remains. The individuals examined in this project came from an area designated as the Upper Walls Common Cemetery, also known as the California Cemetery, which was excavated between 1980 and 1985. This cemetery dates to between 150 and 550 AD, however, the majority of the inhumations date to the fifth and sixth centuries AD (Burleigh and Fitzpatrick-Matthews, unpublished). This would place the cemetery in the Late Roman to post-Roman period. However, the excavators noted that the site continues to appear culturally Roman until the seventh century AD when Saxon artifacts first appear (Burleigh and Fitzpatrick-Matthews, unpublished). The Upper Walls Common Cemetery contains a total of 139 individuals. Little has been published on the human remains at the site, save for a few case studies by McKinley (McKinley, 1992; McKinley, 1993), who analyzed the human remains at the site along with Charlotte Roberts (unpublished).

Gambier-Parry Lodge

This collection, housed at the University of Bradford, was excavated in 1983 and led by T.W. Courtney and V. Jenkins. The excavation, which was spurred by the construction of an 11-acre housing development, uncovered a cemetery 325m x 35m in size (Garrod, 1984). The site had two periods of deposition, dating to the second and fourth centuries AD (Roberts, 1988). The cemetery site was 1.5km northwest of a large Roman settlement at Gloucester (Roberts, 1988). Ninety-four discrete burials were uncovered, and the minimum number of individuals, based on a count of the left proximal ulna, was estimated to be 78 (Cameron and Roberts, unpublished). Analysis of the human remains for the site report was undertaken by Alison Cameron and Charlotte Roberts.

The modern city of Gloucester is the location of a number of Roman sites. Perhaps the most prominent is the fortress at Kingsholm. Tacitus records that the twentieth legion was moved to Gloucester in 49 AD in order to quash Welsh tribes (Annals XII 32), and likely founded the fortress at Kingsholm. The fortress was located near the River Severn, which granted easy access into Wales and gave the Romans control of the river crossing (Simmonds et al., 2008). Sometime between the reigns of the Emperors Domitian (81-96 AD) and Nerva (96-98 AD), the Roman settlement at Gloucester became a *colonia*, a settlement for retired legionaries (Simmonds et al., 2008).

The city at Gloucester was small compared to other Romano-British sites and likely not of much regional importance, but it had many sprawling towns and farming communities in its hinterland to which it was well connected and with which it traded (Simmonds et al., 2008). The site at Gambier-Parry Lodge would have been one such town. At least one of the individuals buried at Gambier-Parry Lodge also shows a connection to the military presence in the area; one of the few tombstones uncovered in the area contained the name, L VALERIUS AURELIUS VET LEG XX, indicating that he was a member of the twentieth legion (Garrod, 1984). However, the full extent of this settlement's connection with the military fortress at Gloucester is unknown.

Unfortunately, there is no published site report on the excavation at Gambier-Parry Lodge. There are some excavation updates published in *Transactions of the Bristol and Gloucestershire Archaeological Society* (Atkin and Garrod, 1988; Garrod, 1983; Garrod, 1984) and *Glevenis: Gloucester and District Archaeological Research Group* (Garrod, 1986), as well as an unpublished analysis of the human remains by Alison Cameron and Charlotte Roberts. It is therefore difficult to ascertain the exact nature of the site and how it fits into the larger Roman presence in Gloucester.

3.2.2 Spanish Sites

Carissa Aurelia

The site of Carissa Aurelia is located between Granada and Cadiz, Spain. The site was first excavated in 1985 but excavation work continued into the 1990s under the direction of Jiménez Pérez and Perdigones Moreno. The cemetery sample used for this thesis comes from a smaller villa site associated with the larger necropolis.

Approximately 169 tombs, containing a mixture of cremated remains and inhumations, were uncovered at the site (Moreno et al., 1985; Moreno et al., 1986). These tombs date to the Roman period and several have associated marble funerary inscriptions. In addition to the necropolis, a reservoir, silos, and ceramic ovens have been identified at the site (Moreno et al., 1991). Carissa Aurelia is a multi-period site with archaeological features and lithics dating to the Neolithic (c. 9000-3300 BC) and the Copper Age (c. 3300-2100 BC) (Moreno et al., 1991). The Roman necropolis was in use from the first century AD to the fourth century AD (Ramirez, 1998). The South necropolis dates to between the first and third centuries AD and almost exclusively contains cremated human bone, while the North necropolis contains inhumations and dates to the Late Roman period between the mid-second century and fourth century AD (Ramirez, 1998).

Cerro San Cristobal

The site of Cerro San Cristobal, located in Granada, Spain, has been occupied more or less consistently since the Neolithic period. The site was first excavated between 1988 and 1989, with the Roman levels excavated later in 1991, by a team of archaeologists led by Eduardo Fresneda and Oliva Rodriguez. The dig was a salvage excavation in order to make way for a housing development. The site of Cerro San Cristobal represents a small settlement (around 0.6 ha), located in the fertile Granada Basin (Murillo-Barroso et al., 2015). The site contained the remains of 71 individuals in single pit or cist burials. As this is a multi-period site with finds from the Neolithic (c. 9000-3300 BC), Copper Age (c. 3300-2100 BC), and Bronze Age (c. 2250-1450 BC), dating for the Roman levels is uncertain. Analysis of some ceramics have been dated to as late as the sixth century AD, while other grave goods have been dated to the second century AD (Padilla et al., 1991; Jiminez, 2012). Other Roman finds at the site included a paved road, a possible bath-house, and pottery finds (Martín, 1993). Unfortunately, most of the Roman structures were destroyed by later Medieval construction.

Colegio de La Presentacion

The site of Colegio de La Presentacion is located within the modern-day city of Granada, Spain. Like the site of Carissa Aurelia and Cerro San Cristobal, it has evidence of occupation dating back to the Neolithic. At the level of the Roman occupation, a necropolis associated with a secondary settlement, believed to possibly have been a villa or a series of farms, was uncovered (Torres, 1994; Guerrero et al., 2009). The site dates to the second to fifth centuries AD (Vaquerizo Gil, 2008), and was excavated in 1994 to make way for a gymnasium and playground at the college. The excavation, led by Pablo Casado Millan, uncovered 21 individuals. Unfortunately, there is little further information available about the site or the excavation.

Both Cerro San Cristobal and Colegio de La Presentacion would have been located near the Roman city, *Florentia Iliberritana*, in the modern Albaicin district in the heart of the city of Granada. Carissa Aurelia was further afield, linked between Roman Granada and another Roman city in Cadiz. So far, there is little known about the make-up and extent of the Romano-Spanish city (Vaquerizo Gil, 2008). Granada had been occupied by native Iberian populations, and contained a fortified settlement known as *Ilturir*. During the first century BC, the city took on the Latin name *Iliberri*, and later, under Emperor Augustus, became a *municipium*, a municipality with the privileges of

Roman citizenship, named *Florentia Iliberritana* (Orfila-Pons, 2013). The city was sizable and featured a main square, forum, a legal basilica, curio, and temple to the imperial cult (Orfila-Pons, 2013). All three sites represent smaller, rural settlements, but they undoubtedly interacted and traded with *Florentia Iliberritana* and the wider Roman Empire.

3.3 Methods: Age and Sex Estimation

Multiple methods were employed to improve accuracy and to overcome issues surrounding differential preservation of features used in age and sex estimation techniques. The recording form used to determine age and sex in all individuals is presented in Appendix A. This recording form was created for a SSHRC project (Insight Grant, File number 435-2013-1006, ID# 169793) and used with the permission of the authors for this thesis.

3.3.1 Age at Death Estimation

This study exclusively examined fractures in individuals over the age of 18 at death. Analysis of epiphyseal fusion (Cardoso, 2008a; Cardoso, 2008b), in combination with dental development (Gustafson and Koch, 1974; Anderson et al., 1976), were used to identify individuals under the age of 18 years for exclusion. Analysis of dental wear (Brothwell, 1963), pubic symphyseal scoring (Brooks and Suchey, 1990; Suchey and Katz, 1989), and auricular surface scoring (Boldsen et al., 2002), were then applied to allocate individuals into the four broad categories used: Young Adult (18-35 years), Middle Adult (35-50 years), Old Adult (50+ years), and Adult (where an age bracket could not be determined) (adapted from Buikstra and Ubelaker, 1994). It is important to note that the Young Adult category in Buikstra and Ubelaker (1994) encompassed individuals aged 20 to 35. This age category has been expanded for the purposes of this project. The use of the above ageing techniques were dependent on an individual's completeness and preservation. Individuals who were poorly preserved (less than 25% complete) were excluded (see Section 3.3.3 for a more detailed discussion of preservation).

Multiple ageing methods were used to exclude individuals under the age of 18, leading to overlapping, and sometimes conflicting, age ranges. Where age ranges did conflict, preference was given to dental development if it was clear that dentition (excluding M3s) was still developing. Dental development is under tight genetic control, so this method of subadult age estimation is widely used (White and Folkens, 2005). The eruption of the third molar is more variable (Mincer et al., 1993). If all dentition had erupted except for the third molar, epiphyseal fusion was given preference as this method spans late adolescent to young adult age ranges.

3.3.1.1 Exclusionary Ageing Technique: Epiphyseal Fusion Ageing

The cessation of bone growth is one of the best age indicators for adolescents and young adults (Ubelaker, 1987; Ubelaker, 2005). Epiphyseal fusion occurs in a particular order, which varies across the skeleton, providing a range for age estimation. Many studies have previously examined timing of epiphyseal fusion, but the technique used in this study, developed by Cardoso (2008a; 2008b), has the advantage of using dry bone data, as well as providing an age range for each bone element, in order to better account for population variation and differences in sex and socioeconomic status. This method of epiphyseal fusion ageing was also creating using a European skeletal sample (from Portugal), making it particularly suited for this study. Each element is scored based on whether the epiphysis displays non-union, partial union, or complete union, and corresponding age ranges are provided based upon which stage the element displays (Cardoso, 2008a; 2008b).

3.3.1.2 Exclusionary Ageing Technique: Dental Development Ageing

The technique of dental development ageing, developed by Gustafson and Koch (1974), provides an age range for each individual tooth, both deciduous and adult, based on its stage of development, or whether it has mineralized, has a complete crown, has erupted, or has a complete root. These stages are represented by a score between one and four. The score for each individual tooth then corresponds to an age range. The data for M3s comes from Anderson et al. (1976). M3s typically erupt around age 18, but the timing can be variable, so only root completion was scored. Gustafson and Koch's (1974) method of dental development ageing was developed using a European sample, making it suitable for the samples used here.

3.3.1.3 Adult Ageing Technique: Dental Wear

The most common method for assessing dental wear is described in Brothwell (1963) (Brickley and McKinley, 2004). This method scores each of the mandibular and maxillary molars separately based on wear patterns, which range from "no wear" to "worn down to the roots" (Brothwell, 1963). Each of these wear patterns corresponds to one of four age categories: 17-25 years, 25-35 years, 33-45 years, and 45+ years. If an individual displays no dental wear on any of the molars, they can be assumed to be under the age of 18 years. This has been shown to be a very reliable indicator of age (e.g., Lovejoy, 1985; Drier, 1994; Mays, 2002), with Lovejoy (1985) even citing it as the best indicator of age at death in archaeological samples. This method is also particularly suited to earlier archaeological samples, as diets in these populations would have contained coarser foods than today. For these reasons, in the event of a discrepancy between adult ageing techniques, dental wear ageing was given priority.

3.3.1.4 Adult Ageing Technique: Pubic Symphysis Scoring

Pubic symphyseal scoring is one of the most accurate and widely used adult ageing techniques (Aykroyd et al., 1999; Buikstra and Ubelaker, 1994; Meindl et al., 1985). The pubic symphyses of the ox coxae undergo a progressive development and deterioration, which allows for age at death determinations. This method was first developed by Todd (1920), who broke the stages of the pubic symphysis into ten phases. Today, the most widely pubic symphysis scoring systems are those of Katz and Suchey (1986) and Brooks and Suchey (1990), which are based on a larger, multi-racial and multi-gender modern samples. These methods divide pubic symphyseal changes into six phases, and differentiate between male and female phases (Katz and Suchey, 1989; Brooks and Suchey, 1990).

In this study, only the left side was scored to allow for faster recording. In the event that the left pubic symphysis was missing or damaged, the right side was scored. The Suchey-Brooks scoring system has detailed descriptions, images, and casts for each of the six phases in the method. With the aid of this material, pubic symphyses were scored and placed into one of the six phases. If a pubic symphysis appeared to bridge two phases, a mean age was calculated to determine in which category the individual should be placed.

3.3.1.5 Adult Ageing Technique: Auricular Surface Scoring

The auricular surface can be difficult to score, but it has the advantage of likely being preserved in archaeological material, as well as being a reliable ageing technique for individuals over the age of 50 years (White and Folkens, 2005). This technique was first proposed by Lovejoy et al. (1985a; 1985b), who noticed age-related changes to the surface texture, porosity, and organization of the auricular surface in the Hamann-Todd collection. This project employed the auricular surface scoring technique proposed by Boldsen et al. (2002). A comprehensive review of this method determined that, while the technique is not as accurate as one would like, it has a high success rate in determining the age of young and very old individuals and can produce a fairly accurate age-at-death distribution for an archaeological sample (Milner and Boldsen, 2012). Few age estimation techniques are accurate in determining the age of much older individuals, making transition analysis particularly valuable in this area. This technique scores nine areas of the auricular surface for their characteristic features such as porosity, billowing, and texture. The Boldsen et al. (2002) technique has the advantage of permitting a minimum and maximum score for each of the nine areas, so the observer does not need to commit to a single score that may only partially describe the features visible on a particular individual. The left auricular surface was preferentially scored in this study, with the right only being scored in the event that the left was not present or was heavily damaged. The scores from each of the nine stages were inputted into ADBOU software (version 2.1.046) in order to calculate the final age estimation for each individual.

3.3.2 Sex Estimation

Sex estimation was achieved by scoring features of the cranium, mandible, and pelvis (after Buikstra and Ubelaker, 1994). Sex was estimated for all individuals determined to be over the age of 18, provided the necessary skeletal elements were present. The os coxa is viewed as the most reliable indicator of sex and is also less subject to population variation (Buikstra and Ubelaker, 1994); therefore, when discrepancies arose between sex estimation based on cranial elements versus pelvic elements, more weight was given to the estimated sex based on the pelvis. Elements of both the cranium and the pelvis tend to display more extreme sexual dimorphism than elsewhere on the skeleton. Males tend to have a more robust cranial morphology than females, who tend to appear more gracile and small. The os coxa has undergone selective pressure to accommodate the functional differences between males and females, namely parturition. These differences allow for fairly accurate sex estimation. For both the pelvic and cranial assessments, the left side was preferentially scored, with the right side only being scored if the left was not present or incomplete.

Using the methods set out in Buikstra and Ubelaker (1994), five features of the cranium are given a score between one and five. The features of the cranium that were assessed are as follows: nuchal crest, mastoid process, supraorbital margin, glabella, and mental eminence. These features were scored as either Female, Probable Female, Ambiguous, Probable Male, Male, corresponding with the scores one through five. Five features of the pelvis were also scored, using a numbered scale. The ventral arc, subpubic concavity, and ischiopubic ramus ridge were all scored on a scale of one to three as Female, Ambiguous, or Male. The greater sciatic notch was scored on a scale of one to five as either Female, Probable Female, Ambiguous, Probable Male, or Male. Finally, the preauricular sulcus was scored on a scale of zero to four, with no sulcus indicating male and a wide, deep sulcus indicating female.

In the final estimation of sex, an individual was classified as Female or Probably Female if the majority of the combined cranial and pelvic scores indicated a female. A similar assessment was made if an individual had a majority of scores indicating Male or Probable Male. An individual was classified as Ambiguous if they had an even split of male and female scores, or if the majority of the scores were ambiguous. Finally, the sex of an individual was classified as Undetermined if no cranial or pelvic features were observable.

3.3.3 Preservation

Individuals were assessed for both completeness and taphonomic changes. An accurate inventory of skeletal remains is key for many statistical analyses, as well an understanding of the skeletal material and its limitations. An understanding of taphonomic changes is also crucial, especially when examining fracture features, which have the potential to be distorted by taphonomic processes.

An overall preservation score for each individual was first tallied, following the standards outlined in Buikstra and Ubelaker (1994). If an individual was less than 25% complete, they were excluded from the study. This study only examined fractures in the long bones (including the clavicle) and the ribs, so completeness scores were adapted to place an emphasis on the presence of these bones. Individual elements were then scored on the following scale: 0-25%, 25-50%, 50-75%, 75-100%. This was applied to the whole bone for certain elements, such as the scapula, sternum, pelvis, and sacrum. Long bones were divided into multiple sections, with each given its own preservation score. These sections were divided, following Judd (2002b), as follows: proximal epiphysis, proximal 1/3rd, mid 1/3rd, distal 1/3rd, distal epiphysis. To allow for quick recording, ribs were assessed for presence based on the number of left and right proximal ends. For example, if twelve left and right proximal ends were present, the ribs would be classed as 100% complete. Finally, adult skeleton recording diagrams (Attachments 3a to 4b) from Buikstra and Ubelaker (1994) were used to mark the absence of areas of the skeleton. Bones not present were coloured in to visually display completeness of the whole skeleton.

Using the preservation data, a survival index was calculated for the long bones of each skeletal sample (Eq. 3.1) (after Judd, 2002b: 1258). A segment was included if it was greater than 75% complete. The same equation was also used to calculate the percentage of preserved ribs in each sample. The number of proximal ends of ribs observed was divided by the number of proximal ends expected to provide a preservation percentage. Preservation data for each of the skeletal samples is presented in Section 4.3.

Equation 3.1

$$\text{Survival index} = \frac{\text{number of segments observed}}{\text{number of segments expected}}$$

Taphonomic change was assessed according to McKinley's (2004) standards, published in Brickley and McKinley's (2004) Guidelines to the Standards for Recording Human Remains. Abrasion and erosion were given a score from 0 to 5+, with a grade of 0 indicating a bone with little taphonomic change to its surface morphology, and a grade of 5+ indicating extensive erosion and abrasion modifying the surface morphology of the bone. When abrasion and erosion were variable across the bone, different grades were specified for different parts of the bone. The McKinley (2004) system for recording erosion is adapted for human bone specifically and covers the cracking and flaking which occurs with weathering, in addition to root and fungal action and abrasion, often seen in bones from British sites, making it especially suited to the collections for this project. To complement this, any instances of the following were also recorded as present or absent: bleaching/discolouration, fissuring, animal gnawing, and cut marks. Unlike abrasion and erosion, there is no grading system standard for recording these taphonomic features. When evidence of any of the above were found, they were recorded as present, and their features, such as location on the bone, extent, and shape were made note of in the Preservation section of the recording form.

3.4 Methods: Fracture Recording

Both macroscopic and radiographic techniques were employed to identify fractures and their features. Discussion of the recording of post-traumatic time interval follows in Section 3.5. All macroscopic and radiographic evaluations were conducted by the author over a six-week period at the University of Bradford and the University of

Granada. The recording forms used to assess all rib and long bone fractures in adults in each of the collections under study can be found in Appendix B.

3.4.1 Antemortem, Perimortem, and Postmortem Classification

Every long bone and rib fracture in the British and Spanish collections was evaluated. Arguably, the most important first step in assessing fractures is to determine whether the fracture occurred prior to, around the time of, or after death. As this study deals with healing features of fractures and their implications for injury recidivism, fractures occurring after death were of no concern for the purposes of this project. Care was taken to ensure fractures were accurately identified as antemortem, perimortem, or postmortem. A fracture was classified as antemortem if it displayed any evidence of bone remodelling. However, there is a common assertion that bone only displays macroscopically visible evidence of remodelling at an average of 13 days after the fracture occurred (Sauer, 1998). The post-traumatic time interval method put forth by DeBoer et al. (2015) lists healing features that can be seen radiographically, and macroscopically from four to seven days after the injury took place. Therefore, to avoid the possibility of overlooking these early healing features, perimortem fractures were also evaluated.

It is important to note that there is an ongoing debate, especially within the field of forensic anthropology, surrounding the definition of the term “perimortem” (e.g., Bunch, 2014; Dirkmaat, 2012; Ubelaker, 2015). In clinical fields, the term perimortem refers to the time at or around death, and is associated with the manner of death. However, biological (or forensic) anthropologists often use the term to describe fractures in fresh or wet bone that show no signs of healing. This definition has been recognized as problematic due to the fact that the perimortem interval, during which time bone can still exhibit fresh fracture patterns, can extend for several months after death (Capella et al., 2014; Ubelaker and Adams, 1995; Wieberg and Wescott, 2008), and the fact that different areas of the body may exhibit fresh or dry fracture patterns based on differential decomposition (Symes et al., 2008). For the purposes of this study, the term perimortem has been operationalized as a fracture exhibiting fresh bone fracture characteristics, but with no evidence of healing. This definition is in keeping with the current concept of perimortem fractures put forth by the Scientific Working Group for Forensic Anthropology. If radiographs confirmed evidence of healing in perimortem fractures, according to the post-traumatic time interval methods used in this thesis, then the fracture was re-classified as an antemortem fracture.

3.4.2 Fracture Profile

When recording fractures, important information about the nature of the fracture was recorded. Numerous papers have advocated for the standardized recording of fracture features, such as displacement (e.g., length, apposition, rotation, and angulation), fracture typology (e.g., transverse, spiral, and comminuted), and mechanism of injury (e.g., direct or indirect trauma) (e.g., Buikstra and Ubelaker, 1994; Judd, 2002b; Lovell, 1997; Lovell, 2008; Ortner, 2003). Such thorough descriptions of fractures are needed in order to develop a clear picture of trauma patterns in the individual and the sample, and allowing wider inferences to be made about the sociocultural and environmental context of trauma (Lovell, 1997).

For rib fractures, the rib number, side, location, and union (e.g. non-union, complete union, partial union) were recorded. For long bones, the bone, side, and location were also recorded. In addition to this, the bone length, apposition, rotation, and angulation were also recorded, in cases where both fracture ends had united. The above characteristics are set out in Lovell's (1997) descriptive protocols for long bone fractures, with additional protocols for recording rib fractures taken from Brickley (2006). Length, apposition, rotation, and angulation are also assessed in clinical presentations of fractures. Length of a long bone was assessed using an osteometric board and compared to its counterpart, when present. It was recorded as normal, lengthened, or shortened. Apposition, the percentage of bony contact between two fracture ends, was recorded as a percentage, with 100% indicating no anteroposterior or mediolateral horizontal displacement between the distal fragment in relation to the proximal fragment. Rotation, or the turning of the distal fragment relative to the proximal fragment, was recorded as absent, internal rotation, or external rotation. Finally, angulation, the degree to which the distal end of the fragment has shifted in relation to the midline of the proximal end, was recorded as present or absent. Where angulation was present, it was measured in degrees with the use of a goniometer, with the direction of the displacement of the distal end of the fragment also being noted.

For both rib and long bone fractures, the type of fracture, along with its associated mechanism of injury was recorded. Possible fracture types that were recorded are as follows: penetrating, comminuted, crush, transverse, spiral, oblique, torus, greenstick, impacted, and avulsion. In the event that the fracture was very well-healed, so that the fracture line was not visible macroscopically or radiographically, the fracture type was recorded as ‘unable to assess’. The first four types of fractures are commonly recognized as caused by direct trauma. The latter six are caused by indirect trauma. However, comminuted fractures in a T or Y shape can also be caused by indirect trauma (Lovell, 2008). Where the type of fracture and its associated mechanism of injury were unclear, it was recorded as 'unable to assess'. An understanding of fracture type and mechanism of injury provide evidence of the individual's, as well as the population's, interactions with their environment and sociocultural context. An understanding of trauma patterns in the individual, and the sample as a whole, contributes to interpretations of trauma and injury recidivism in the Roman samples under study. Finally, an individual was classified as an injury recidivist if they had two or more fractures with different post-traumatic time intervals, using the criteria set out in DeBoer et al.’s (2015) time interval estimates.

Using the collected fracture data, fracture prevalence rates were calculated. Both crude prevalence rates (CPR), as well as true prevalence rates (TPR), were calculated in order to provide a more accurate assessment of fracture prevalence in the differentially preserved skeletal samples. Crude prevalence rates compared the total number of fractures in a sample by the total number of individuals in that sample (Eq. 3.2) (after Lovell, 2008). While true prevalence rates compared the total number of fractured elements by the number of bones with at least one segment greater than or equal to 75% complete (Eq. 3.3) (after Gilmour et al., 2015: 80; Judd, 2002b: 1258).

Equation 3.2

$$\text{CPR} = \frac{\text{total number of fractures observed}}{\text{total number of individuals}} \times 100$$

Equation 3.3

$$TPR = \frac{\text{total number of fractured elements observed}}{\text{total number of bones with 1 segment} \geq 75\%} \times 100$$

3.5 Post-traumatic Time Interval

One of the purposes of this project was to determine the usefulness of new post-traumatic time interval methods and their potential applications in understanding injury recidivism in rural ancient Roman populations. To achieve this, the radiographic features of fractures in the new post-traumatic time interval method were compared to conventional features of healing fractures widely published in paleopathology. Radiographic features were also assessed alongside macroscopic features to see whether there would be any differences between the two in the resulting estimated time intervals.

3.5.1 Macroscopic Assessment

Individuals with antemortem and perimortem fractures of the long bones or ribs were assessed according to two different post-traumatic time interval charts. The first was based on a culmination of works from both the forensic and paleopathological literature, published in Lovell (1997; 2008). The second was the newer post-traumatic time interval put forth by DeBoer et al. (2015). The macroscopic features that were assessed are listed in Table 3.1 and 3.2 respectively. It was noted whether the two methods agreed or differed as to the post-traumatic time interval of a fracture. In the case that the two methods produced different results, the extent to which they differed was also noted. Each of the features was marked as 'present', 'absent', or 'unable to assess'. In the case of multiple features being present, the estimated age of the fracture was taken from the feature with the oldest time interval. An estimated post-traumatic age was recorded for each fracture, based solely on the macroscopic features present.

Table 3.1
Time Interval of Fracture Healing Based on Histological and Radiological Studies. Dry bone macroscopic healing features and associated time intervals included, following Lovell (1997, 2008) – combined from Adams (1987); Adams and Hamblen (1992); Apley and Solomon (1993); Buckwalter et al. (2006); Paton (1984); and Schenk (2003).

Stage	Healing Features	Time Interval
Cellular proliferation	Osteoblasts form collar of osteoid around each fragment. Fracture is bridged, which is visible in dry bone, but not in radiographs.	48 hours to 3-4 weeks
Callus Formation	Osteoid begins to mineralize. A woven bone callus forms around the periosteal and endosteal surfaces. Visible in both dry bone and radiographs.	2-3 weeks to 8-9 weeks
Consolidation	Lamellar bone replaces woven bone in the fracture callus, resulting in a firmly united callus.	Variable – several weeks to months
Remodelling	Bone remodelled to original form. Often permanently marked by a surface contour defect or abnormal radiographic density.	1-9 years

Table 3.2
Macroscopic Healing Features and Associated Time Intervals, following DeBoer et al. (2015) – combined from Maat et al. (2008; 2010).

Healing Feature	Time Interval
First scattered bone tissue spiculae between lesion ends	After 4-7 days
Remodelling of the lesion margins	After 4-7 days
Start of periosteal osteogenesis separable from cortex	After 7 days
Periosteal osteogenesis at a distance from fracture site	After 7 days
Aggregation of spiculae into woven bone	After 12-20 days
Margin of the lesion appears more sclerotic	After 12-20 days
Fields of calcified cartilage at sites of callus formation	After 14 days
Clearly visible periosteal callus	After 15 days
Union bridging of the cortical bone discontinuity	After 21-28 days
Periosteal callus becomes firmly attached (inseparable) from the cortex	After 6 weeks
After inadequate mobilization: Pseudoarthrosis development	6-9 months
After adequate immobilization: Quiescent appearance indicating subsided healing	1-2 years

3.5.2 Radiographic Assessment

All radiographs were taken at the Biological Anthropology Research Centre at the University of Bradford in Bradford, U.K.. Radiographs were taken of all long bone and rib fractures from the Baldock and Gambier-Parry Lodge collections. Access to radiography was unavailable for the collections at the University of Granada, so fractures in those collections were only macroscopically evaluated.

A few of the fractures identified in the collections at the University of Bradford had previously been radiographed by Charlotte Roberts for the purposes of the unpublished paleopathological assessments of the collections. Digital copies of these radiographs were used, provided they were in good condition (the original radiographs were printed on film, and a few had been damaged), to avoid unnecessary repetition. The majority of the radiographs, however, were taken by the author during the course of the data collection. All radiographs were taken using a Faxitron (Series 43855B) at 80-90kV. All fractures were assessed for features described in DeBoer et al. (2015). These features are listed below in Table 3.3. As in the macroscopic assessment, each of the features was marked as 'present', 'absent', or 'unable to assess'. In the case of multiple features being present, the estimated age of the fracture was taken from the feature with the oldest time interval. An estimated post-traumatic age was recorded for each fracture based on its radiographic features.

Table 3.3
Radiographic Healing Features and Associated Time Intervals, following DeBoer et al. (2015) – combined from Maat et al. (2008; 2010).

Healing Feature	Time Interval
First scattered bone tissue spiculae between lesion ends	After 4-7 days
Absorption of the cortical bone adjacent to the lesion	After 4-7 days
Remodelling of the lesion margins	After 4-7 days
Start of endosteal and periosteal osteogenesis separable from cortex	After 7 days
Periosteal osteogenesis at a distance from fracture site	After 7 days
Clearly visible endosteal callus formation	After 10-12 days
Aggregation of spiculae into woven bone	After 12-20 days
Osteoporosis of the cortex	After 12 days
Margin of the lesion appears more sclerotic	After 12-20 days
Fields of calcified cartilage at sites of callus formation	After 14 days
Clearly visible periosteal callus	After 15 days
Endosteal callus becomes indistinguishable from the cancellous bone in the marrow cavity	After 17 days
Union bridging of the cortical bone discontinuity	After 21-28 days
Periosteal callus becomes firmly attached (inseparable) from the cortex	After 6 weeks
After inadequate mobilization: Pseudoarthrosis development	After 6-9 months
After adequate immobilization: Quiescent appearance indicating subsided healing	After 1-2 years

CHAPTER 4: RESULTS

4.1 Introduction

This chapter examines the results relating to fracture characteristics of three rural Roman skeletal samples; Baldock, UK, Gambier-Parry Lodge, UK, and Granada, Spain. The three sites that compose the Granada collection were collated into one as two of the sites, Colegio de La Presentacion and Cerro san Cristobal, were too small to be independently analyzed. Each of the Spanish sites had similar demographic compositions and similar fracture rates. This chapter begins with a breakdown of the demographics at each site by sex and age group. Preservation is then examined and a survival index is calculated for each site and further divided by age and sex. Fractures and multiple injury are examined and subdivided by age and sex. Post-traumatic time interval among individuals with multiple injury is assessed. Finally, trauma patterns (fracture elements and fracture type) are examined at each site.

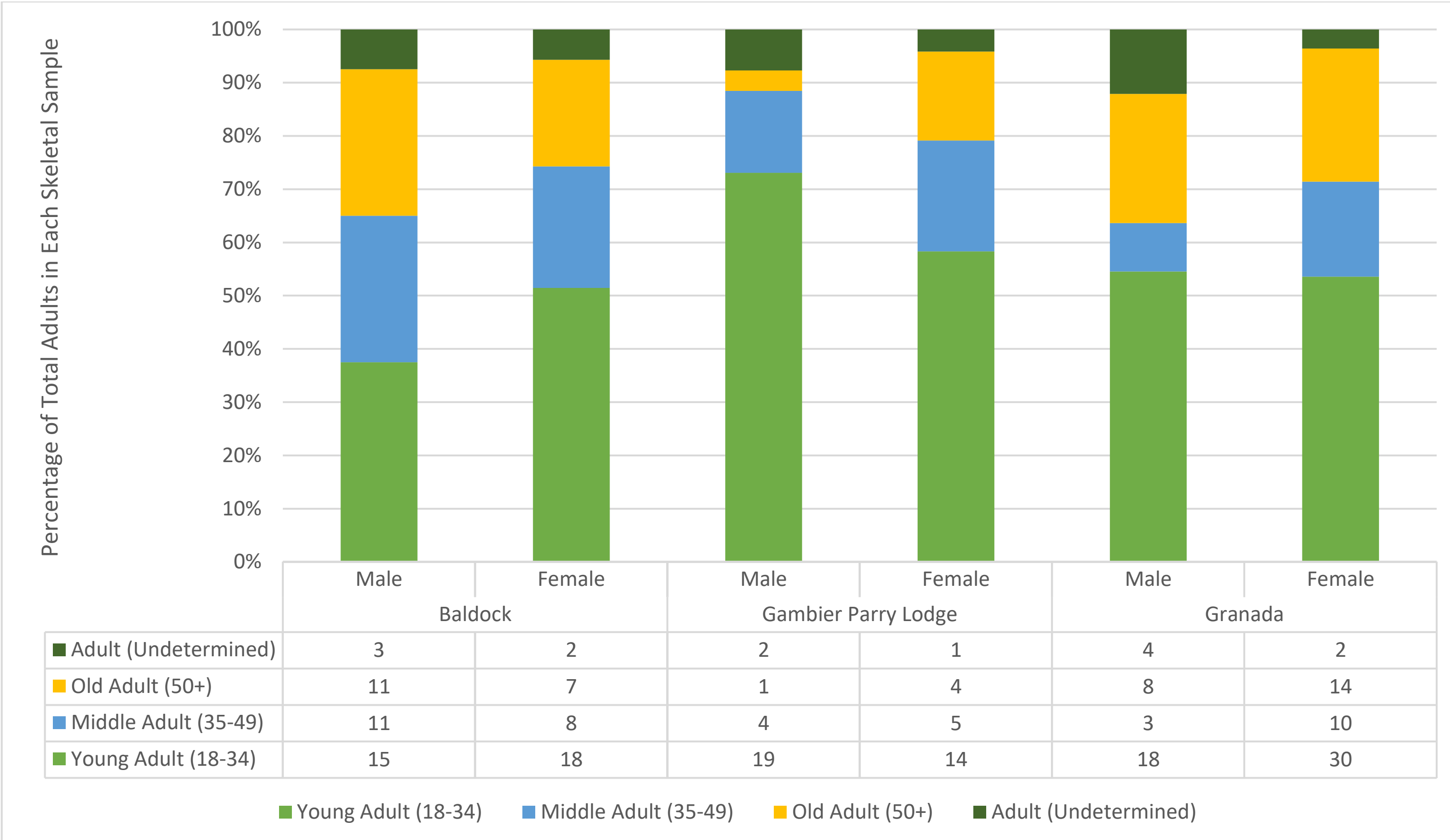
Differences in preservation, fractures and multiple injury by age, and fracture type were compared using statistical analysis. Chi-square tests (χ^2) were run to determine statistical significance. A result was considered statistically significant at $p \leq 0.05$. Where a sample size was small, a 2x2 Fisher Exact Test (P_{FET}) was performed instead. In cases where the degree of freedom was greater than 2, a Chi-square test with a Yates correction (χ^{2Yates}) was provided.

4.2 Sample Demographics

Fracture data from three collections were collected for this study. The total number of individuals under study across all three samples was 214. All three sites have a high proportion of young adults, while middle adults and old adults are both present in similar proportions. There is an almost even split between males and females across the two British sites, while at Roman Granada, almost two thirds of the skeletal sample are female. The demographics of each of the samples under study is presented in Table 4.1 below. Figure 4.1 also shows the age and sex breakdown in each skeletal sample graphically.

Table 4.1
Skeletal Sample Demographics by Age and Sex.

Sample		Male	Female	Combined
Baldock	Young Adult	15 (20.0%)	18 (24.0%)	33 (44.0%)
	Middle Adult	11 (14.7%)	8 (10.7%)	19 (25.3%)
	Old Adult	11 (14.7%)	7 (9.3%)	18 (24.0%)
	Adult	3 (4.0%)	2 (2.7%)	5 (6.7%)
	TOTAL	**40 (53.3%)**	**35 (46.7%)**	**75**
Gambier-Parry Lodge		Male	Female	Combined
	Young Adult	19 (38.0%)	14 (28.0%)	33 (66.0%)
	Middle Adult	4 (8.0%)	5 (10.0%)	9 (18.0%)
	Old Adult	1 (2.0%)	4 (8.0%)	5 (10.0%)
	Adult	2 (4.0%)	1 (2.0%)	3 (6.0%)
	TOTAL	**26 (52.0%)**	**24 (48.0%)**	**50**
Roman Granada (3 consolidated samples)		Male	Female	Combined
	Young Adult	18 (20.2%)	30 (33.7%)	48 (53.9%)
	Middle Adult	3 (3.4%)	10 (11.2%)	13 (14.6%)
	Old Adult	8 (9.0%)	14 (15.7%)	22 (24.7%)
	Adult	4 (4.5%)	2 (2.2%)	6 (6.7%)
	TOTAL	**33 (37.1%)**	**56 (62.9%)**	**89**
Combined		Male	Female	Combined
	Young Adult	52 (24.3%)	62 (29.0%)	114 (53.3%)
	Middle Adult	18 (8.4%)	23 (10.7%)	41 (19.2%)
	Old Adult	20 (9.3%)	25 (11.7%)	45 (21.0%)
	Adult	9 (4.2%)	5 (2.3%)	14 (6.5%)
	TOTAL	**99 (46.3%)**	**115 (53.7%)**	**214**



	Baldock Male	Baldock Female	Gambier Parry Lodge Male	Gambier Parry Lodge Female	Granada Male	Granada Female
Adult (Undetermined)	3	2	2	1	4	2
Old Adult (50+)	11	7	1	4	8	14
Middle Adult (35-49)	11	8	4	5	3	10
Young Adult (18-34)	15	18	19	14	18	30

Fig. 4.1. Age and Sex Distribution for Each Skeletal Sample. The Male category includes both Males and Probable Males. The Female category includes both Females and Probable Females. Raw numbers are provided in the table beneath the graph.

4.3 Preservation

A survival index was calculated for the long bones and ribs of each skeletal sample (See Section 3.3.3, Eq. 1). In addition to this, the percentage of preserved long bones was also broken down by age and sex for each skeletal sample. Chi-square tests were run to determine if the age and sex differences within each sample were statistically significant. Table 4.2 displays the preservation of long bones in each skeletal sample by age and sex. Table 4.3 shows the preservation of rib segments in each skeletal sample by age and sex.

4.3.1 Baldock

Baldock had the highest level of long bone preservation out of the three skeletal samples at 58%. Males were better preserved than females at this site. The difference in preservation between males and females is significant (χ^2=10.67, p-value= 0.001). When broken down by age, young adults had the highest level of preservation. Though the level of preservation was close across all categories except for the adult category, which was more poorly preserved. The difference in preservation between the age categories was significant (χ^2=55.84, p-value=0).

The rib preservation of the whole sample was 43.7% (787 proximal ends observed out of 1800 proximal ends expected). Males had slightly higher rib preservation than females, but this difference was not statistically significant (χ^2=1.32, p-value=0.25). Old adults had the highest level of rib preservation, followed by young adults, while adults had a very low level of rib preservation. The difference in rib preservation between age categories was statistically significant (χ^2=62.79, p-value=0).

4.3.2 Gambier-Parry Lodge

The number of long bone segments observed from this skeletal sample was 1812 out of 3500 expected segments. The long bone preservation percentage was 51.8% for the entire sample. Males were better preserved than females, and as with Baldock, the difference in preservation between males and females was statistically significant (χ^2=33.82, p-value=0). Unexpectedly, young adults had a similar level of preservation as old adults. As with the Baldock sample, adults had the poorest long bone preservation at 21.9% (46 long bone segments observed out of 210 expected). The difference in preservation between the age categories was significant (χ^2=33.28, p-value=0).

Gambier-Parry Lodge had the highest level of rib preservation at 44.5%. Males had a higher level of rib preservation than females though this difference was not significant. (χ^2=1.56, p-value=0.21). When rib preservation is analyzed by age categories, old adults had the highest level of rib preservation, while the other age categories had a more closely clustered levels of rib preservation. The difference in rib preservation between age categories was statistically significant (χ^2=10.2, p-value=0.02).

4.3.3 Roman Granada

Roman Granada had the lowest level of long bone preservation out of the three skeletal samples. The percentage of preserved long bone for this sample was 47.6%.

Males and females had similar levels of preservation at this site. Roman Granada is the only sample in which the difference in preservation between the sexes was not statistically significant (χ^2=0.86, p-value=0.35). Females were only slightly better preserved (6.2%) than males. Contrary to Baldock and Gambier-Parry Lodge, adults in this sample had the greatest level of preservation while old adults had the lowest level of preservation. Though the preservation was more evenly distributed across all age categories at this site, the difference in preservation between the age categories was statistically significant (χ^2=13.78, p-value=0.003).

Roman Granada had the lowest level of rib preservation. The rib preservation of this sample was 34.3%. Females had a higher level of rib preservation than males, and this difference was statistically significant (χ^2=5.34, p-value=0.02). Middle adults had the highest level of rib preservation in this skeletal sample while adults had the lowest. The difference in rib preservation between age categories was statistically significant (χ^2=20.03, p-value=0).

Table 4.2
Preservation of Long Bones by Age and Sex in Each Skeletal Sample. Number of segments observed by number of segments expected is shown. The percentage of preservation is shown in brackets.

Sample		Male	Female	Combined
Baldock	Young Adult	742/1050 (70.7%)	728/1260 (57.8%)	1470/2310 (63.6%)
	Middle Adult	429/770 (55.7%)	273/560 (48.8%)	702/1330 (52.8%)
	Old Adult	497/770 (64.5%)	277/490 (56.5%)	774/1260 (61.4%)
	Adult	68/210 (32.4%)	30/140 (21.4%)	98/350 (28.0%)
	TOTAL	**1736/2800 (62.0%)**	**1308/2450 (53.4%)**	**3044/5250 (58.0%)**
Gambier-Parry Lodge		Male	Female	Combined
	Young Adult	853/1330 (64.1%)	412/980 (42.0%)	1265/2310 (54.8%)
	Middle Adult	147/280 (52.5%)	162/350 (46.3%)	309/630 (49.0%)
	Old Adult	56/70 (80.0%)	136/280 (48.6%)	192/350 (54.9%)
	Adult	38/140 (27.1%)	8/70 (11.4%)	46/210 (21.9%)
	TOTAL	**1094/1820 (60.1%)**	**718/1680 (42.7%)**	**1812/3500 (51.8%)**
Roman Granada		Male	Female	Combined
	Young Adult	623/1260 (49.4%)	986/2100 (47.0%)	1609/3360 (47.9%)
	Middle Adult	80/210 (38.1%)	379/700 (54.1%)	459/910 (50.4%)
	Old Adult	222/560 (39.6%)	430/980 (43.9%)	652/1540 (42.3%)
	Adult	131/280 (46.8%)	114/140 (81.4%)	245/420 (58.3%)
	TOTAL	**1056/2310 (45.7%)**	**1909/3920 (48.7%)**	**2965/6230 (47.6%)**
Combined		Male	Female	Combined
	Young Adult	2218/3640 (60.9%)	2126/4340 (49.0%)	4344/7980 (54.4%)
	Middle Adult	656/1260 (52.1%)	814/1610 (50.6%)	1470/2870 (51.2%)
	Old Adult	775/1400 (55.4%)	843/1750 (48.2%)	1618/3150 (51.4%)
	Adult	237/630 (37.6%)	152/350 (43.4%)	389/980 (39.7%)
	TOTAL	**3886/6930 (56.1%)**	**3935/8050 (48.9%)**	**7821/14980 (52.2%)**

Table 4.3
Preservation of Ribs by Age and Sex in Each Skeletal Sample. Number of segments observed by number of segments expected is shown. The percentage of preservation is shown in brackets.

Baldock		Males	Females	Combined
	Young Adult	202/360 (56.1%)	193/432 (44.7%)	395/792 (49.9%)
	Middle Adult	98/264 (37.1%)	69/192 (35.9%)	167/456 (36.6%)
	Old Adult	139/264 (52.7%)	85/168 (50.6%)	224/432 (51.8%)
	Adult	0/72 (0.0%)	1/48 (2.1%)	1/120 (0.8%)
	TOTAL	**439/960 (45.7%)**	**348/840 (41.4%)**	**787/1800 (43.7%)**
Gambier-Parry Lodge		Males	Females	Combined
	Young Adult	213/456 (46.7%)	108/336 (32.1%)	321/792 (40.5%)
	Middle Adult	32/96 (33.3%)	70/120 (58.3%)	102/216 (47.2%)
	Old Adult	18/24 (75.0%)	61/96 (63.5%)	79/120 (65.8%)
	Adult	32/48 (66.6%)	0/24 (0.0%)	32/72 (44.4%)
	TOTAL	**295/624 (47.3%)**	**239/576 (41.5%)**	**534/1200 (44.5%)**
Roman Granada		Males	Females	Combined
	Young Adult	139/432 (32.2%)	200/720 (27.8%)	339/1152 (29.4%)
	Middle Adult	24/72 (33.3%)	116/240 (48.3%)	140/312 (44.9%)
	Old Adult	54/192 (28.1%)	162/336 (48.2%)	216/528 (40.9%)
	Adult	20/96 (20.8%)	18/48 (37.5%)	38/144 (26.4%)
	TOTAL	**237/792 (29.9%)**	**496/1344 (36.9%)**	**733/2136 (34.3%)**
Combined		Males	Females	Combined
	Young Adult	554/1248 (44.4%)	501/1488 (33.7%)	1055/2736 (38.6%)
	Middle Adult	154/432 (35.6%)	255/552 (46.2%)	409/984 (41.6%)
	Old Adult	211/480 (44.0%)	308/600 (51.3%)	519/1080 (48.1%)
	Adult	52/216 (24.1%)	19/120 (15.8%)	71/336 (21.1%)
	TOTAL	**971/2376 (40.9%)**	**1083/2760 (39.2%)**	**2054/5136 (40.0%)**

4.4 Fractures

A total of 89 long bone and rib fractures were identified in 44 individuals across the three skeletal samples. The crude prevalence rates (CPR) by age and sex for fractures from the three groups are summed up in Table 4.4 (See Section 3.4.2, Eq. 3.2, for the calculation of crude prevalence rate). Gambier-Parry Lodge had the highest crude prevalence rate for fractures, with fractures present in 30% of individuals assessed. The lowest CPR was 13.5% from the Spanish sites. CPR by skeletal sample is shown graphically in Figure 4.2.

Table 4.4
Crude Fracture Prevalence Rate by Age and Sex in Each Skeletal Sample. Number of fractures by number of individuals is shown. The percentage of individuals with a fracture is shown in brackets.

Sample		Male	Female	Combined
Baldock	Young Adult	5/15 (33.0%)	2/18 (11.0%)	7/33 (21.2%)
	Middle Adult	3/11 (27.0%)	2/8 (25.0%)	5/19 (26.3%)
	Old Adult	3/11 (27.0%)	2/7 (28.6%)	5/18 (27.8%)
	Adult	0/3 (0.0%)	0/2 (0.0%)	0/5 (0.0%)
	TOTAL	**11/40 (27.5%)**	**6/35 (17.1%)**	**17/75 (22.7%)**
Gambier-Parry Lodge		Male	Female	Combined
	Young Adult	8/19 (42.0%)	2/14 (14.0%)	10/33 (30.3%)
	Middle Adult	1/4 (25.0%)	2/5 (40.0%)	3/9 (33.3%)
	Old Adult	0/1 (0.0%)	2/4 (50.0%)	2/5 (40.0%)
	Adult	0/2 (0.0%)	0/1 (0.0%)	0/3 (0.0%)
	TOTAL	**9/26 (34.6%)**	**6/24 (25.0%)**	**15/50 (30.0%)**
Roman Granada		Male	Female	Combined
	Young Adult	4/18 (22.2%)	4/30 (13.3%)	8/48 (16.7%)
	Middle Adult	1/3 (33.3%)	0/10 (0.0%)	1/13 (7.7%)
	Old Adult	0/8 (0.0%)	2/14 (14.2%)	2/22 (9.1%)
	Adult	1/4 (25.0%)	0/2 (0.0%)	1/6 (16.7%)
	TOTAL	**6/33 (18.2%)**	**6/56 (10.7%)**	**12/89 (13.5%)**
Combined		Male	Female	Combined
	Young Adult	17/52 (32.7%)	8/62 (12.9%)	25/114 (21.9%)
	Middle Adult	5/18 (27.8%)	4/23 (17.4%)	9/41 (21.9%)
	Old Adult	3/20 (15.0%)	6/25 (24.0%)	9/45 (20.0%)
	Adult	1/9 (11.1%)	0/5 (0.0%)	1/14 (7.1%)
	TOTAL	**26/99 (26.3%)**	**18/115 (15.7%)**	**44/214 (20.6%)**

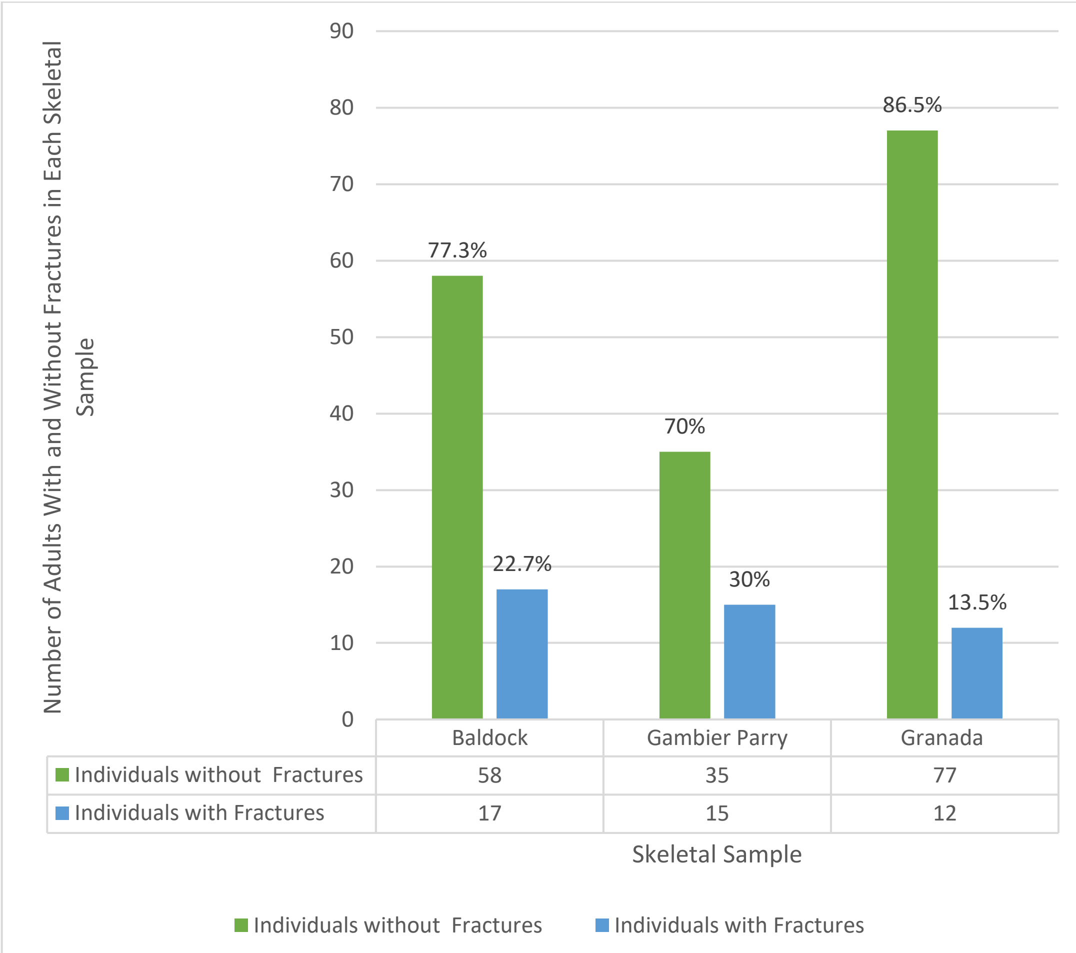


Fig. 4.2 Adults With and Without Fractures in Each Skeletal Sample. Crude prevalence rate is depicted as a percentage above each bar. Raw numbers are provided in the table beneath the graph.

4.4.1 Fractures by Sex

In each of the three skeletal samples, males had higher rates of fractures than females (Fig. 4.3). Within the Baldock sample, the difference between males and females was not statistically significant (χ^2 = 1.1423; p=0.28516). In the Gambier-Parry Lodge sample, the difference between the sexes was also not statistically significant (χ^2= 0.549; p=0.459). Finally, as at Baldock and Gambier-Parry Lodge, the difference was not statistically significant in the Spanish sample (χ^2=1.64, p-value=0.20).

The crude prevalence rate of fractures for males were higher than females across all the skeletal samples. Fracture rates among males compared to females were roughly 10% higher regardless of the skeletal samples. However, the differences between males and females were not statistically significant in each of the skeletal samples.

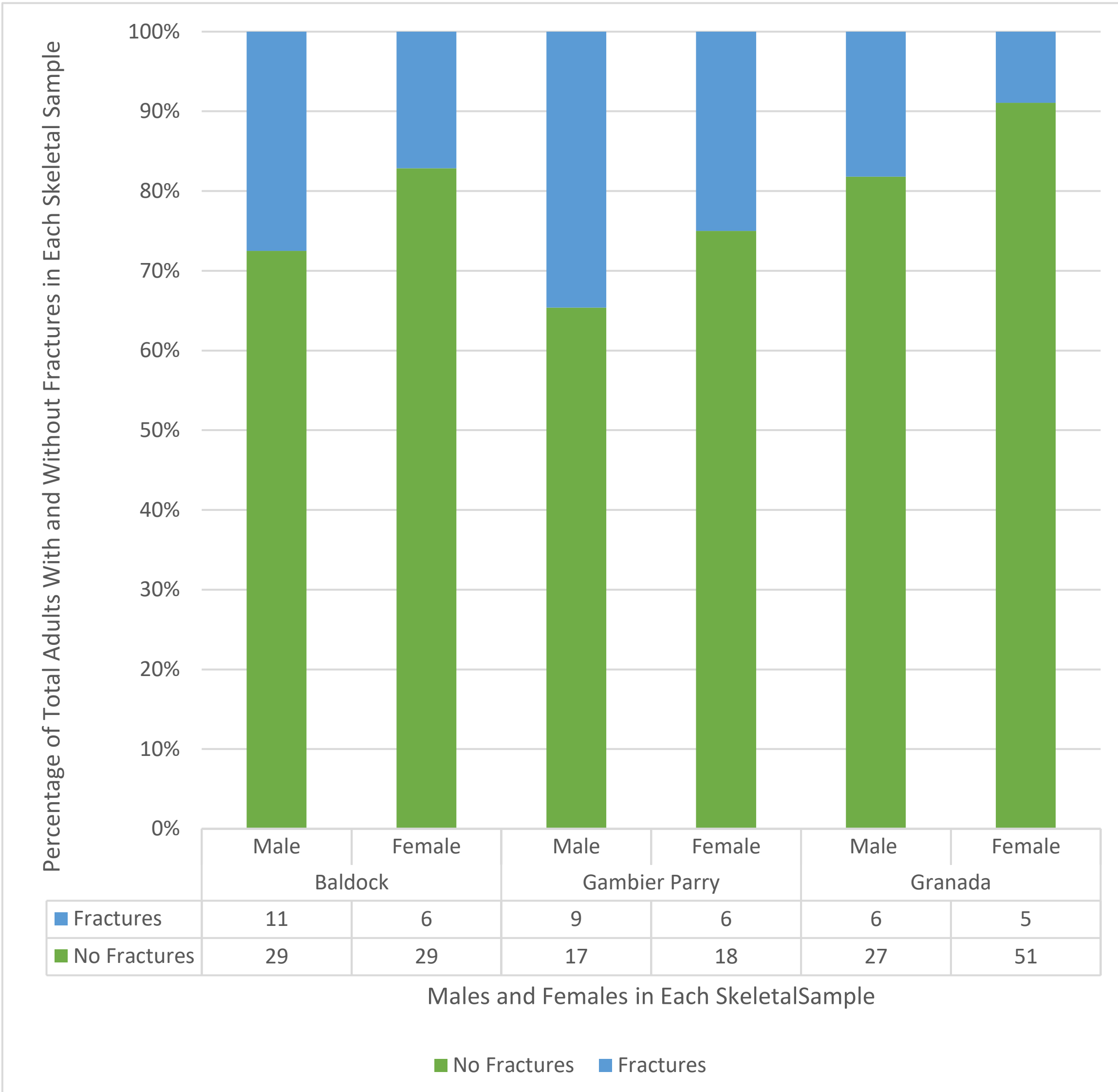


Fig. 4.3 Crude Fracture Prevalence Rates by Sex in Each Skeletal Sample. Raw numbers are provided in the table beneath the graph.

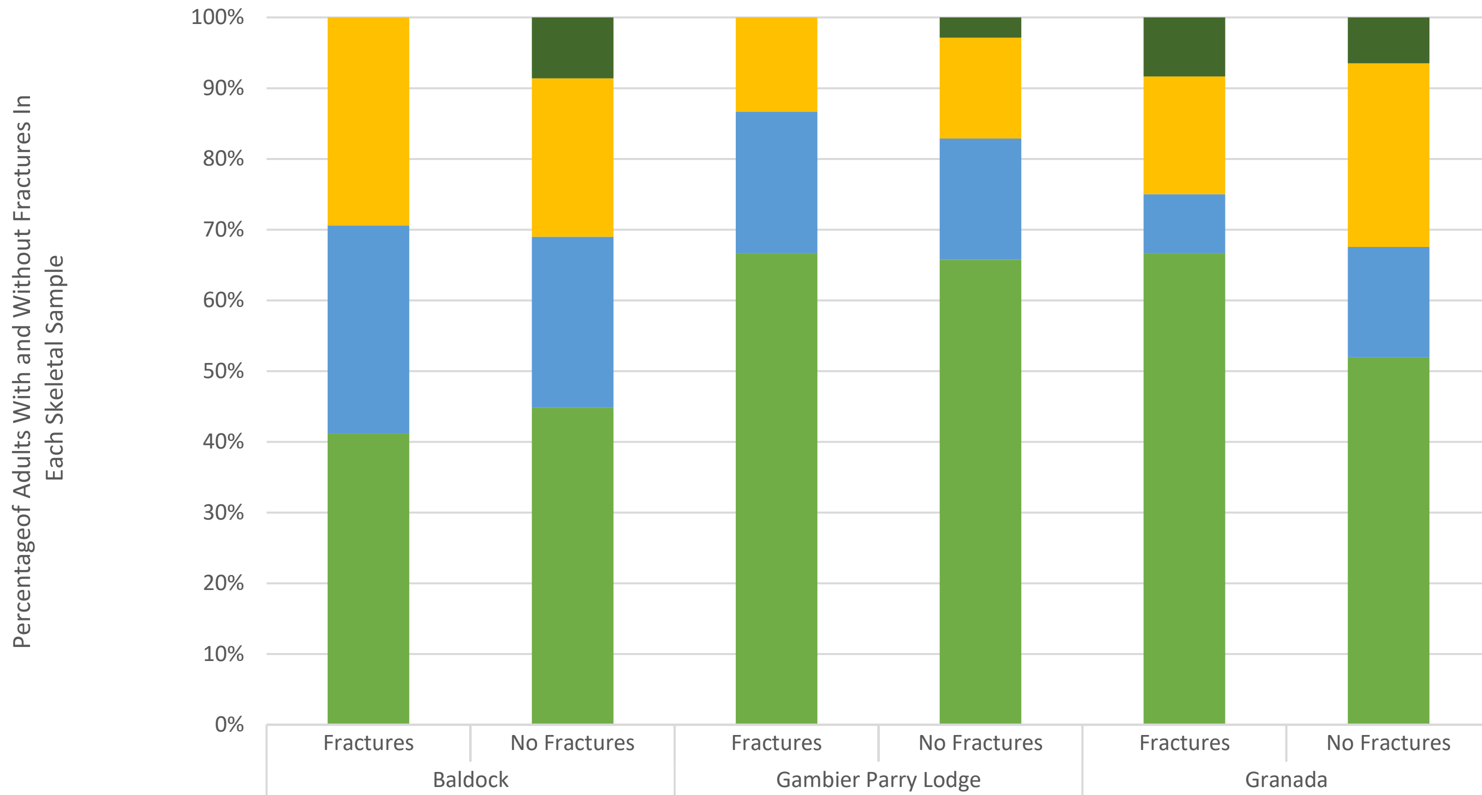
4.4.2 Fractures by Age

Both Baldock and Gambier-Parry Lodge had similar trends in fracture rates by age group; as expected, the prevalence of fractures increased with age at death. The Roman Granada sample had the highest fracture crude prevalence rate among both young adults and adults, followed by old adults, and finally, middle adults. Crude prevalence rates and raw counts for each of the skeletal samples by age are shown in Table 4.4 and Figure 4.4.

Old adults had the highest fracture prevalence among all the age categories at Baldock, while young adults had the lowest. There were no fractures among the adult category. The differences in fractures between age categories were not statistically significant (χ^2=0.33, p-value=0.85).

At Gambier-Parry Lodge, old adults also had the highest fracture CPR, while young adults had the lowest. There were no fractures among the adult category. The difference in fracture rates between age categories was not statistically significant (χ^2=0.20, p-value=0.91).

Finally, at Roman Granada, the same percentage of adults and young adults had fractures, while the lowest CPR was present in middle adults. The difference in fracture rates between age categories was not statistically significant (χ^2=1.21, p-value=0.75).



	Baldock: Fractures	Baldock: No Fractures	Gambier Parry Lodge: Fractures	Gambier Parry Lodge: No Fractures	Granada: Fractures	Granada: No Fractures
Adult (Undetermined)	0	5	0	1	1	5
Old Adult (50+)	5	13	2	5	2	20
Middle Adult (35-49)	5	14	3	6	1	12
Young Adult (18-34)	7	26	10	23	8	40

Young Adult (18-34) Middle Adult (35-49) Old Adult (50+) Adult (Undetermined)

Fig. 4.4 Crude Fracture Prevalence Rates by Age in Each Skeletal Sample. Raw numbers are provided in the table beneath the graph.

4.5 Multiple Injury

Gambier-Parry Lodge had the highest rate of multiple injuries as well as the highest rate of overall fractures. The crude prevalence rate of multiple injuries at Gambier-Parry Lodge is 14%, with seven individuals having multiple injuries. Baldock had the second highest rate of multiple injuries, with seven individuals with multiple trauma accounting for 10.7% of the sample. Roman Granada, along with its low fracture rate, also had a very low number of multiple injuries, with only 1 individual with multiple trauma and a crude prevalence rate of 1.1%. Table 4.5 shows the raw counts all the individuals from each of the three skeletal samples broken down by age, sex, and number of fractures.

Table 4.5
Crude Prevalence Rate for Multiple Fractures by Age and Sex in Each Skeletal Sample. Number of multiple fractures by number of individuals is shown. The percentage of individuals with multiple fractures is shown in brackets.

Sample		Male	Female	Combined
Baldock	Young Adult	2/15 (13.3%)	1/18 (5.6%)	3/33 (9.1%)
	Middle Adult	2/11 (18.2%)	1/8 (12.5%)	3/19 (15.8%)
	Old Adult	2/11 (18.2%)	0/7 (0.0%)	2/18 (11.1%)
	Adult	0/3 (0.0%)	0/2 (0.0%)	0/5 (0.0%)
	TOTAL	**6/40 (15.0%)**	**2/35 (5.7%)**	**8/75 (10.7%)**
Gambier-Parry Lodge		Male	Female	Combined
	Young Adult	3/19 (15.8%)	1/14 (7.1%)	4/33 (12.1%)
	Middle Adult	0/4 (0.0%)	2/5 (40.0%)	2/9 (22.2%)
	Old Adult	0/1 (0.0%)	1/4 (25.0%)	1/5 (20.0%)
	Adult	0/2 (0.0%)	0/1 (0.0%)	0/3 (0.0%)
	TOTAL	**3/26 (11.5%)**	**4/24 (16.7%)**	**7/50 (14.0%)**
Roman Granada		Male	Female	Combined
	Young Adult	0/18 (0.0%)	1/30 (3.3%)	1/48 (2.1%)
	Middle Adult	0/3 (0.0%)	0/10 (0.0%)	0/13 (0.0%)
	Old Adult	0/8 (0.0%)	0/14 (0.0%)	0/22 (0.0%)
	Adult	0/4 (0.0%)	0/2 (0.0%)	0/6 (0.0%)
	TOTAL	**0/33 (0.0%)**	**1/56 (1.8%)**	**1/89 (1.1%)**
Combined		Male	Female	Combined
	Young Adult	5/52 (9.6%)	3/62 (4.8%)	8/114 (7.0%)
	Middle Adult	2/18 (11.1%)	3/23 (13.0%)	5/41 (12.2%)
	Old Adult	2/20 (10.0%)	1/25 (4.0%)	3/45 (6.7%)
	Adult	0/9 (0.0%)	0/5 (0.0%)	0/14 (0.0%)
	TOTAL	**9/99 (9.1%)**	**7/115 (6.1%)**	**16/214 (7.5%)**

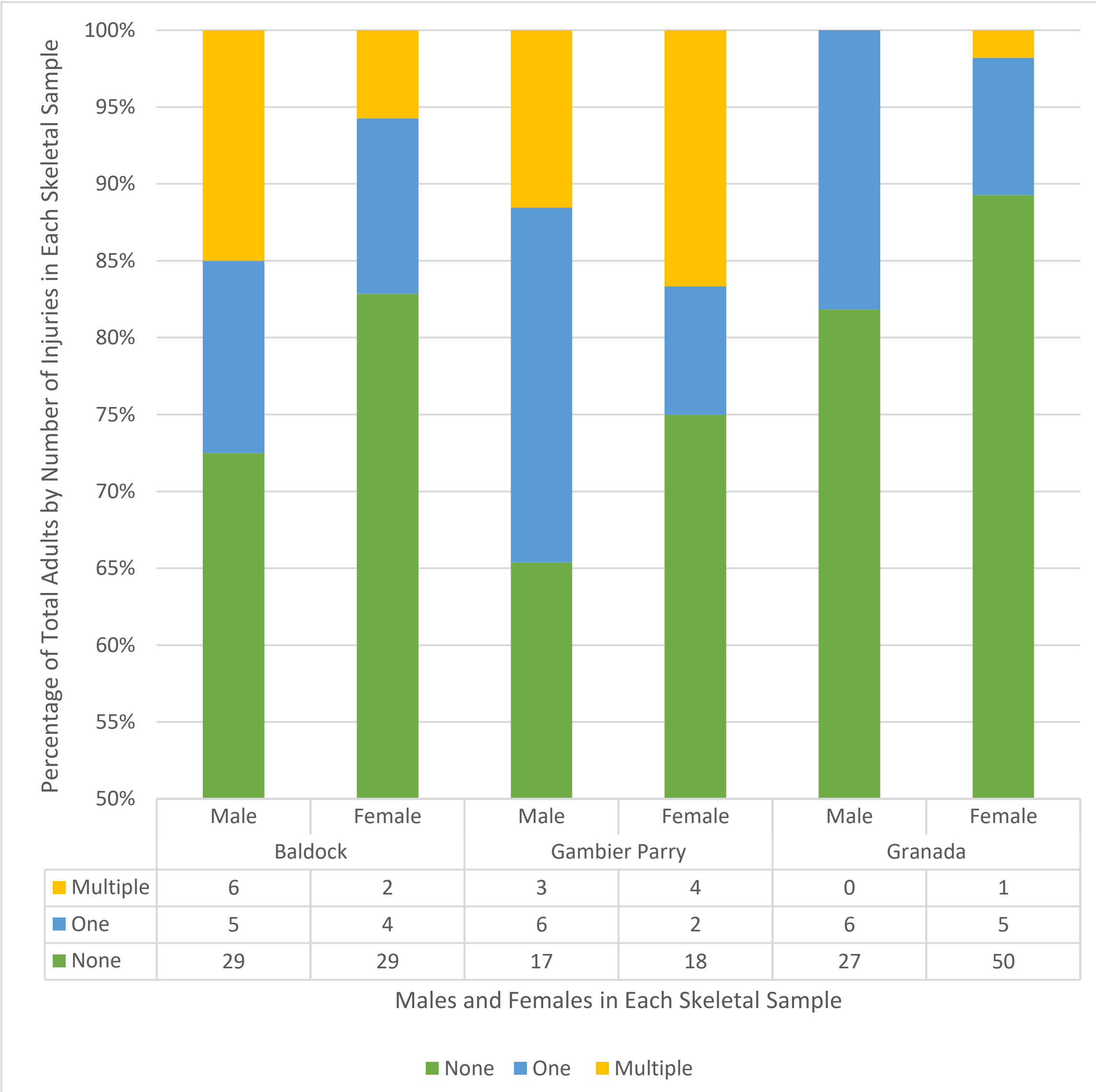
4.5.1 Multiple Injury by Sex

Although males in each sample had higher rates of fractures than females, when viewing multiple injury, females had higher rates of multiple injury than males at Gambier-Parry Lodge and Roman Granada. In fact, of individuals with fractures, females had double the rate of multiple injury than males. However, at Granada the number of individuals with multiple injury was very low and only consisted of one individual. Figure 4.5 shows the number of fractures by sex in each of the three skeletal samples.

Baldock was the only sample where males had higher levels of multiple injury than females. Six males had multiple fractures. This accounts for 54.5% of males with fractures and 15% of the total males in this sample. Of the females, only two individuals had multiple injuries, making up 33% of the females with fractures and 5.7% of the total female sample from Baldock. Differences between males and females with multiple injury were not statistically significant (P_{FET}=0.47).

At Gambier-Parry Lodge, four females had multiple fractures which accounts for 66% of the females with fractures and 16.7% of the total female sample from this site. 33% of males with fractures had multiple injuries, and multiple injuries made up 11.5% of the total male sample. Differences in multiple injury between males and females were not statistically significant (P_{FET}=0.7).

The sole individual with multiple injury at Roman Granada was female. Females with multiple injury made up 20% of the females with fractures and 1.8% of the total female sample at Roman Granada. This difference was too small to be statistically significant (P_{FET}=1).



	Baldock Male	Baldock Female	Gambier Parry Male	Gambier Parry Female	Granada Male	Granada Female
Multiple	6	2	3	4	0	1
One	5	4	6	2	6	5
None	29	29	17	18	27	50

Fig. 4.5 Multiple Injury by Sex in Each Skeletal Sample. Raw numbers are provided in the table beneath the graph.

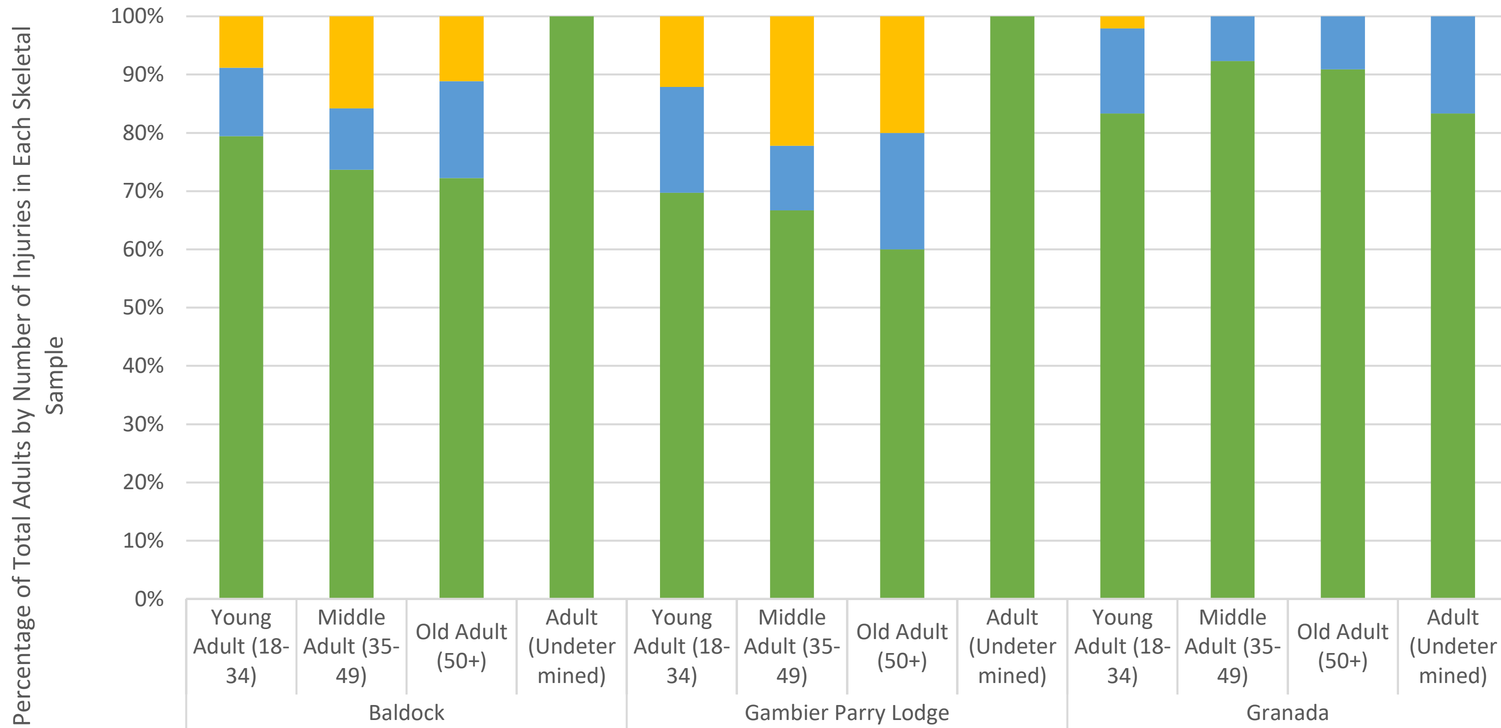
4.5.2 Multiple Injury by Age

Multiple injuries at Baldock and Gambier-Parry Lodge were highest among middle adults, followed by old adults, and lowest in young adults. This suggests that multiple injuries at these sites accumulate through young adulthood and into middle adulthood. At Roman Granada, the sole individual with multiple injury was a young adult. Figure 4.6 shows the number of fractures by age in each of the three skeletal samples.

At Baldock, multiple injuries among young adults accounted for 33% of this demographic and 42.9% of the female fractures. Among middle adults, the multiple fracture crude prevalence rate was 15.8% and the rate of multiple injury among middle adults with fractures was 60%. Finally, among old adults, the crude prevalence rate was 11.1% and the prevalence among the old adult fractures was 40%. The difference in multiple injury by age at Baldock was not statistically significant (χ^2_{YATES}=1.31, p-value=0.86).

At Gambier-Parry Lodge, four young adults had multiple fractures, making up 12.1% of this age category and 40% of all young adults with fractures. Two middle adults had multiple fractures or 22% of this group and 66.6% of all middle adults with fractures. Finally, a single old adult had multiple injuries, accounting for 20% of this age group and 50% of all old adults with fractures. The difference in fracture rates between age categories was not statistically significant (χ^2_{YATES} =0.31, p-value=0.99).

Finally, at Roman Granada, the single individual with multiple fractures was a young adult accounting for 1.9% of the total young adult sample and 12.5% of the young adult fractures.



	Baldock				Gambier Parry Lodge				Granada			
	Young Adult (18-34)	Middle Adult (35-49)	Old Adult (50+)	Adult (Undetermined)	Young Adult (18-34)	Middle Adult (35-49)	Old Adult (50+)	Adult (Undetermined)	Young Adult (18-34)	Middle Adult (35-49)	Old Adult (50+)	Adult (Undetermined)
Multiple	3	3	2	0	4	2	1	0	1	0	0	0
One	4	2	3	0	6	1	1	0	7	1	2	1
None	27	14	13	8	23	6	3	2	40	12	20	5

Fig 4.6 Crude Fracture Prevalence Rates for Multiple Injury by Age in Each Skeletal Sample. Raw fracture counts are provided in the table.

4.6 Post-traumatic Time Interval

An assessment of post-traumatic time interval was used to parse out cases of true injury recidivism as opposed to multiple injury that occurred in a single event. The majority of fractures in each sample were old and well-healed, therefore it was not possible to compare and assess whether they occurred in separate events. This was the case for the sole individual with multiple trauma at Roman Granada whose five fractures were all well-healed. Table 4.6 details the individuals determined to have multiple injuries with different post-traumatic time intervals across the three skeletal samples. The post-traumatic time interval determination for all individuals with fractures, single and multiple, can be found in Appendix C.

Individuals with fractures determined to be of different ages were found at both Baldock and Gambier-Parry Lodge. A total of eight individuals, four at each site were identified as having multiple injuries of different ages. This accounts for 50% of the individuals with multiple injury at Baldock and 57% of individuals with multiple injury at Gambier-Parry Lodge. At Baldock, three individuals with multiple injuries of different ages were males and one was female. At Gambier-Parry Lodge, there was an even split between males and females. At both sites, individuals with multiple injuries of different ages all belonged to either young adult (one at Baldock, three at Gambier-Parry Lodge) or middle adult (three at Baldock, one at Gambier-Parry Lodge) age groups. This indicates that injury recidivism at these sites occurred among younger, economically active individuals.

A fifth individual at Baldock may also have had multiple injuries of different ages. Of their 10 fractures, nine of which were well-healed, one rib appeared to have a recent fracture with a callus of woven bone. However, the fracture occurred on a small rib fragment, which was too small to clearly assess radiographically.

The three methods used to assess post-traumatic time interval all produced similar results. There were no cases of one method producing a time frame that did not overlap with the other methods. Given that half the individuals with multiple injury could be determined to have injuries of different ages, assessing post-traumatic interval may be useful in future studies of multiple injury and injury recidivism.

Table 4.6
Individuals Determined to Have Multiple Injuries with Different Post-traumatic Time Intervals Across the Three Skeletal Samples.

Individual	Bone	Stage	Post-traumatic time interval (Lovell 2008)	Post-traumatic time interval – Macroscopic (DeBoer et al. 2016)	Post-traumatic time interval – Radiographic (DeBoer et al. 2016)
BAL 1072 (YA, M)	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Rib	Antemortem	Callus Formation (3-9 weeks)	After 21-28 days	28 days to 6 weeks
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL 1374 (MA, F)	Right Rib	Antemortem	Callus Formation (3-9 weeks)	15-20 days	15-20 days
	Left Rib	Antemortem	Remodelling (several years)	6-9+ months (pseudoarthrosis)	6-9+ months (pseudoarthrosis)
	Unsided Rib	Antemortem	Cellular Proliferation (48 hours to 2-3 weeks)	7-12 days	7-12 days
BAL 1480 (MA, M)	Unsided Rib Fragment 1	Antemortem	Callus Formation (3-9 weeks)	After 21-28 days	28 days to 6 weeks
	Unsided Rib Fragment 2	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL F466 * (OA, M)	Left Tibia	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Fibula	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Tibia	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Fibula	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Unsided Rib Fragment	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years

	Unsided Rib Fragment	Antemortem	Callus Formation (3-9 weeks)	Around 6 weeks	Inconclusive
BAL F544 L1 (MA, M)	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Rib Fragment	Antemortem	Callus Formation (3-9 weeks)	6 weeks to 1 year	6 weeks to 1 year
GLOS GAM 525 (YA, M)	Left Radius	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Callus formation (2-3 weeks to 8-9 weeks)	Around 6 weeks	Around 6 weeks
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
GLOS GAM 545 (MA, F)	Right Humerus	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Consolidation (several weeks to months)	6 weeks – 1 year	6 weeks – 1 year
	Right Rib	Antemortem	Consolidation (several weeks to months)	Around 6 weeks	Around 6 weeks
GLOS GAM 553 (YA, F)	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Callus formation (2-3 weeks to 8-9 weeks)	Around 20-28 days	Around 20-28 days
GLOS GAM 570 (YA, M)	Left Rib	Antemortem	Cellular (24h to 3 weeks)	4-12 days	4-7 days
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years

BAL = Baldock, GLOS GAM = Gambier-Parry Lodge

YA = Young Adult, MA = Middle Adult, OA = Old Adult. M = Male, F = Female

* = Individual who may have injuries of different post-traumatic time intervals

4.7 Trauma Patterns

This section examines differences in fractured elements and fracture types to discern injury profiles for each site. Information provided by fractured elements and fracture type can include whether fractures were caused by direct, high energy impacts or indirect, low energy impacts and may have been accidental or a result of interpersonal violence.

4.7.1 Fracture Elements

Ribs were the most frequently fractured element among both males and females across all three samples. The crude prevalence rate for rib fractures were as follows: 37.3% Baldock; 46% Gambier-Parry Lodge; 9% Granada. Fibulae were the second most frequently injured element at Baldock and Gambier-Parry Lodge. At these two sites, lower limb bones were more frequently injured than upper limb bones (lower limb Baldock CPR=10.6%, Gambier-Parry Lodge CPR=12%; upper limb Baldock CPR=6.7%, Gambier-Parry Lodge CPR=6%). At Roman Granada, the reverse was true with more individuals having upper limb fractures (CPR=6.7%) than lower limb fractures (CPR=1.6%).

However, when true prevalence rate (TPR) is considered, fibulae were the most commonly fractured element at both of the British sites (see Section 3.4.2, Eq. 3.3, for the calculation of true prevalence rate). This is true for both males and females. At Granada, the upper limb bones were the most frequently fractured element, but this differed between males and females, with males fracturing the clavicle most often, while females most commonly had fractured ulnas. The true prevalence rates of each bone element by sex and age are displayed in Tables 4.7 and 4.8.

Table 4.7
Bone Element True Prevalence Rates by Sex in Each Skeletal Sample.

Sample		Male	Female	Combined
Baldock	Clavicle	2/53 (3.8%)	1/45 (2.2%)	3/98 (3.1%)
	Humerus	0/59 (0.0%)	0/41 (0.0%)	0/100 (0.0%)
	Ulna	0/60 (0.0%)	0/44 (0.0%)	0/104 (0.0%)
	Radius	1/57 (1.75%)	1/52 (1.9%)	2/109 (1.8%)
	Femur	0/68 (0.0%)	0/55 (0.0%)	0/123 (0.0%)
	Tibia	3/69 (4.3%)	0/53 (0.0%)	3/122 (2.5%)
	Fibula	4/63 (6.3%)	1/42 (2.4%)	5/105 (4.8%)
	Ribs	22/439 (5.0%)	6/348 (1.7%)	28/787 (3.6%)
	TOTAL	**32/868 (3.7%)**	**9/680 (1.3%)**	**41/1548 (2.6%)**
Gambier-Parry Lodge		Male	Female	Combined
	Clavicle	0/31 (0.0%)	1/26 (3.8%)	1/57 (1.8%)
	Humerus	0/40 (0.0%)	1/30 (3.3%)	1/70 (1.4%)
	Ulna	0/36 (0.0%)	0/29 (0.0%)	0/65 (0.0%)
	Radius	1/38 (2.6%)	0/30 (0.0%)	1/68 (1.5%)
	Femur	0/40 (0.0%)	1/34 (2.9%)	1/74 (1.4%)
	Tibia	1/31 (3.2%)	0/26 (0.0%)	1/57 (1.8%)
	Fibula	3/36 (8.3%)	1/19 (5.3%)	4/55 (7.3%)
	Ribs	10/295 (3.4%)	12/239 (5.0%)	22/534 (4.1%)
	TOTAL	**15/547 (2.7%)**	**16/433 (3.7%)**	**31/980 (3.2%)**
Roman Granada		Male	Female	Combined
	Clavicle	2/47 (4.3%)	0/82 (0.0%)	2/129 (1.6%)
	Humerus	0/55 (0.0%)	0/108 (0.0%)	0/163 (0.0%)
	Ulna	0/50 (0.0%)	3/93 (3.2%)	3/143 (2.1%)
	Radius	1/51 (2.0%)	0/90 (0.0%)	1/141 (0.7%)
	Femur	0/56 (0.0%)	0/101 (0.0%)	0/157 (0.0%)
	Tibia	0/45 (0.0%)	0/87 (0.0%)	0/132 (0.0%)
	Fibula	1/35 (2.9%)	0/71 (0.0%)	1/106 (0.9%)
	Ribs	2/237 (0.8%)	7/496 (1.4%)	9/733 (1.2%)
	TOTAL	**6/576 (1.0%)**	**10/1128 (0.9%)**	**16/1704 (0.9%)**
Combined		Male	Female	Combined
	Clavicle	4/131 (3.1%)	2/153 (1.3%)	6/284 (2.1%)
	Humerus	0/154 (0.0%)	1/179 (0.6%)	1/333 (0.3%)
	Ulna	0/146 (0.0%)	3/166 (1.8%)	3/312 (1.0%)
	Radius	3/146 (2.1%)	1/172 (0.6%)	4/318 (1.3%)
	Femur	0/164 (0.0%)	1/190 (0.5%)	1/354 (0.3%)
	Tibia	4/145 (2.8%)	0/166 (0.0%)	4/311 (1.3%)
	Fibula	8/134 (6.0%)	2/132 (1.5%)	10/266 (3.8%)
	Ribs	34/971 (3.5%)	25/1083 (2.3%)	59/2054 (2.9%)
	TOTAL	**53/1991 (2.7%)**	**35/2241 (1.6%)**	**88/4232 (2.1%)**

Table 4.8
Bone Element True Prevalence Rates by Age in Each Skeletal Sample.

Sample		Young Adult	Middle Adult	Old Adult	Adult
Baldock	Clavicle	2/48 (4.2%)	1/23 (4.3%)	0/26 (0.0%)	0/1 (0.0%)
	Humerus	0/54 (0.0%)	0/27 (0.0%)	0/28 (0.0%)	0/1 (0.0%)
	Ulna	0/46 (0.0%)	0/27 (0.0%)	0/29 (0.0%)	0/2 (0.0%)
	Radius	1/54 (1.9%)	0/26 (0.0%)	1/27 (3.7%)	0/2 (0.0%)
	Femur	0/55 (0.0%)	0/32 (0.0%)	0/31 (0.0%)	0/5 (0.0%)
	Tibia	0/57 (0.0%)	0/28 (0.0%)	3/31 (9.7%)	0/6 (0.0%)
	Fibula	0/44 (0.0%)	0/23 (0.0%)	5/31 (16.1%)	0/7 (0.0%)
	Ribs	12/395 (3.0%)	10/167 (6.0%)	6/224 (2.7%)	0/1 (0.0%)
	TOTAL	**15/753 (2.0%)**	**11/353 (3.1%)**	**15/427 (3.5%)**	**0/25 (0.0%)**
Gambier-Parry Lodge		Young Adult	Middle Adult	Old Adult	Adult
	Clavicle	0/37 (0.0%)	0/8 (0.0%)	1/9 (11.1%)	0/3 (0.0%)
	Humerus	0/46 (0.0%)	1/12 (8.3%)	0/9 (0.0%)	0/3 (0.0%)
	Ulna	0/43 (0.0%)	0/9 (0.0%)	0/10 (0.0%)	0/3 (0.0%)
	Radius	1/44 (2.3%)	0/10 (0.0%)	0/10 (0.0%)	0/4 (0.0%)
	Femur	0/52 (0.0%)	0/14 (0.0%)	1/6 (16.7%)	0/2 (0.0%)
	Tibia	1/41 (2.4%)	0/12 (0.0%)	0/3 (0.0%)	0/1 (0.0%)
	Fibula	4/40 (10.0%)	0/10 (0.0%)	0/3 (0.0%)	0/2 (0.0%)
	Ribs	11/321 (3.4%)	10/102 (9.8%)	1/79 (1.3%)	0/32 (0.0%)
	TOTAL	**17/634 (2.7%)**	**11/177 (6.2%)**	**3/129 (2.3%)**	**0/50 (0.0%)**
Roman Granada		Young Adult	Middle Adult	Old Adult	Adult
	Clavicle	0/69 (0.0%)	1/19 (5.3%)	0/32 (0.0%)	1/9 (11.0%)
	Humerus	0/93 (0.0%)	0/22 (0.0%)	0/38 (0.0%)	0/10 (0.0%)
	Ulna	2/79 (2.5%)	0/21 (0.0%)	1/33 (3.0%)	0/10 (0.0%)
	Radius	1/79 (1.3%)	0/20 (0.0%)	0/31 (0.0%)	0/11 (0.0%)
	Femur	0/89 (0.0%)	0/25 (0.0%)	0/32 (0.0%)	0/11 (0.0%)
	Tibia	0/74 (0.0%)	0/17 (0.0%)	0/31 (0.0%)	0/10 (0.0%)
	Fibula	1/56 (1.8%)	0/16 (0.0%)	0/24 (0.0%)	0/10 (0.0%)
	Ribs	8/339 (2.4%)	0/140 (0.0%)	1/213 (0.5%)	0/38 (0.0%)
	TOTAL	**12/878 (1.4%)**	**1/280 (0.4%)**	**2/437 (0.5%)**	**1/109 (0.9%)**
Combined		Young Adult	Middle Adult	Old Adult	Adult
	Clavicle	2/154 (1.3%)	2/50 (4.0%)	1/67 (1.5%)	1/13 (7.7%)
	Humerus	0/193 (0.0%)	1/61 (1.6%)	0/75 (0.0%)	0/14 (0.0%)
	Ulna	2/168 (1.2%)	0/57 (0.0%)	1/72 (1.4%)	0/15 (0.0%)
	Radius	3/177 (1.7%)	0/56 (0.0%)	1/68 (1.5%)	0/17 (0.0%)
	Femur	0/196 (0.0%)	0/71 (0.0%)	1/69 (1.4%)	0/18 (0.0%)
	Tibia	1/172 (0.6%)	0/57 (0.0%)	3/65 (4.6%)	0/17 (0.0%)
	Fibula	5/140 (3.6%)	0/49 (0.0%)	5/58 (8.6%)	0/19 (0.0%)
	Ribs	31/1055 (2.9%)	20/409 (4.9%)	8/519 (1.5%)	0/71 (0.0%)
	TOTAL	**44/2255 (2.0%)**	**23/810 (2.8%)**	**20/993 (2.0%)**	**1/184 (0.5%)**

4.7.2 Fracture Type and Injury Mechanism

At Baldock and Gambier-Parry Lodge, oblique and transverse fractures were the most common fracture types. At Baldock, oblique fractures accounted for all but one of the fractures among females. The additional fracture was a greenstick fibula fracture. Among males, around third of their fractures were caused by transverse, direct forces, followed by oblique and then spiral fractures. Males at Baldock were more likely to experience high-energy fractures (transverse and spiral fractures) than females (P_{FET}=0.005). All but one of the high-energy fractures also occurred in individuals with multiple injuries. However, there was no significant difference between individuals with high and low-energy fractures and multiple injury (P_{FET}=0.056).

At Gambier-Parry Lodge, high-energy, transverse fractures accounted for just under half of all fracture types. Direct, transverse fractures made up over half of the fractures among males and just under a third of fractures among females, while oblique fractures accounted for exactly half of all female fractures but only 7.5% of male fractures. The difference between high-energy and low-energy fractures was not quite significant between males and females (P_{FET}=0.076). High-energy fractures made up 43.5% of the multiple fractures and 62.5% of single fractures, but this difference was also not significant (P_{FET}=0.43).

A detailed analysis of fracture type and injury mechanism could not be performed on individuals at Roman Granada, as most fractures were well healed and radiography was not available. However, some interesting trends in fracture type can still be discerned. Several isolated distal ulna fractures were found among the Roman Granada sample. These fractures occurred exclusively among females and accounted for 33% of the total fractures and 100% of long bone fractures found in this group. Two of the distal ulna fractures were caused by direct force, while the injury mechanism of the third could not be determined. Among males, three of the four long bone fractures could be associated with falls, as these fractures occurred in the clavicle and distal radius (Colles' fractures). The high number of Parry fractures among females, along with the multiple injuries present exclusively in a female in this sample suggest that females at Roman Granada may have experienced higher levels of interpersonal violence relative to males. This is further commented on in Section 5.2.3 of the Discussion chapter. A complete list of the fracture types and injury mechanisms for each individual with a fracture across all the skeletal samples is provided in Appendix D.

4.8 Summary

This study examined trauma at three Roman sites; an agricultural town in Britain (Baldock), a rural town with connections to a Roman military fort (Gambier-Parry Lodge), and three rural sites surrounding Granada (Roman Granada). Fractures were most prevalent at Gambier-Parry Lodge and least prevalent at Roman Granada. Across all three sites, males had higher fracture prevalence rates than females. Fractures were 10% higher among males, on average, when compared to females at all three sites. However, differences in fracture rates among males and females were not statistically significant. When fractures were examined by age group, old adults had the highest rates of fractures at Baldock and Gambier-Parry Lodge, but age differences were not found to be statistically significant and fractures tended to be evenly spread among all age groups. At Roman Granada, the reverse was true and young adults had more fractures than other age groups, but again, the difference was not significant.

When multiple injury was examined, Gambier-Parry Lodge also had the highest prevalence of multiple fractures, while Roman Granada also had the lowest. Interestingly, at Gambier-Parry Lodge and Roman Granada, females had higher rates of multiple injury than males, while at Baldock twice as many males as females had multiple injury. However, at Roman Granada, only one case of multiple injury was found. Differences in multiple injury by sex were not statistically significant. Middle adults had the highest rates of multiple injury at Baldock and Gambier-Parry Lodge, followed by old adults, and finally young adults, suggesting that multiple injuries at these sites accumulate through young adulthood and into middle adulthood.

Post-traumatic time interval was assessed for individuals with multiple injury in an attempt to parse out injuries that occurred in a single event from injuries that occurred in separate events and may indicate injury recidivism. Injuries of different ages were found in both the Baldock and Gambier-Parry Lodge samples. All of the individuals with fractures of different ages were young adults or middle adults, suggesting multiple episodes of injury occur in economically active groups at this site.

At all three sites, crude prevalence rates showed that ribs were the most frequently fractured element. This was followed by lower limb fractures (specifically fibula fractures) for both males and females at Baldock and Gambier-Parry Lodge. At Roman Granada, the reverse was true, as upper limb injuries were the second most commonly fractured region. When true prevalence rates were examined, at both of the British sites, the fibulae were the most commonly fractured elements among both males and females, while at Roman Granada, males most frequently fractured the clavicle, while females most frequently fractured the ulna.

When examining fracture type and injury mechanism, oblique and transverse fractures were the most common fracture types at Baldock and Gambier-Parry Lodge. Significantly more males than females experienced high-energy fractures at Baldock. Individuals with multiple injury also experienced higher rates of high-energy fractures, but the difference was not quite significant. At Gambier-Parry Lodge, high-energy fractures accounted for just under half of all fractures. Males also had higher rates of high-energy fractures than females, but this difference was not quite significant. Levels of high-energy fractures were similar among individuals with multiple injuries and single injuries, so differences between these groups were not significant.

Fracture type and injury mechanism could not be as closely analyzed at Roman Granada. However, there were multiple Parry fractures among females in these skeletal collections, while males had long bone injuries to the clavicle and radius that were more indicative of falls, suggesting higher levels of interpersonal violence toward females among this population.

CHAPTER 5: DISCUSSION

5.1 Introduction

This chapter situates the results of this study in the context of current clinical research, other paleopathological research, and our understanding of life in the Roman Empire from archaeological and historical sources. The first section deals with findings of the trauma patterns among the three sites by age and sex, as well as considering the evidence for interpersonal violence in these communities. The second section examines the evidence for injury recidivism, as well as multiple injuries more broadly. In the final section, differences in fracture prevalence and trauma patterns between the British and Spanish sites are considered in the context of current historical and archaeological narratives of daily life in these two regions of the Roman Empire.

5.2 Trauma Patterns

Overall, crude prevalence rates (CPR) for fractures at Baldock and Gambier-Parry Lodge are slightly elevated compared to other Romano-British sites. This may be due to the smaller size of these two samples and the exclusion of infants and adolescents in this study. However, the CPRs for Baldock and Gambier Parry-Lodge are still similar to those reported at both Cirencester and Poundbury (McWhirr, 1982; Molleson, 1993). No paleopathological trauma studies are available for comparison of Romano-Spanish fracture rates, so it is not possible to discern whether the very low prevalence of fractures is unique to Granada or whether it represents a larger trend in the Romano-Spanish health. However, this thesis presents the first Romano-Spanish fracture study for which future research can be compared.

5.2.1 Trauma by Age and Sex

Crude prevalence rates in trauma differed between the Romano-British and Spanish sites across the life span. Key to interpreting trauma in archaeological populations is an understanding of the fact that the fractures we study are accumulated over an individual's life span. Once a fracture is fully healed, there is no way of knowing when that fracture may have occurred. Thus, fractures in an individual could be representative of many different life stages and their associated social behaviours and responsibilities. Building off an approach to fractures originally put forth by Lovejoy and Heiple (1981), a life course approach to the study of trauma has been advocated as it can reveal insights into social agency, cultural age, and risk across the life span (Glencross, 2011).

Clinical studies provide a starting point from which to analyze trauma across the life course, as they reveal interesting associations between age, sex, and fracture prevalence. Research on fracture prevalence in England and Wales found that among males, fracture rates peak in adolescence and young adulthood, then plateau, before increasing again in the oldest age categories (75-84+) (Johansen et al., 1997; Pasco et al., 2015). In women, fracture prevalence rates show a slight peak in adolescence, but remain low until the fourth decade of life, when they increase exponentially, and overtake male fracture rates after age 50. This trend is found consistently in similar studies from developed countries (Fife and Barancik, 1985; Holloway et al., 2015; Kanis et al., 2004; Pasco et al., 2015; Sahlin, 1990).

When overall trauma across the life span is examined at the British sites, crude prevalence rates (CPR) increase from young adulthood to old age, suggesting a steady accumulation of fractures over the life course. This contrasts with Granada where there is a spike in fractures among young adults, followed by a drop-off in middle age, and a small increase in old age, suggesting that, while the overall fracture prevalence rate was low at Granada, individuals who did incur fractures tended to die young. When CPR is analyzed by both age and sex at all Spanish sites, among males there is a peak in fracture prevalence among young adults, followed by a dip in middle adulthood and a plateau into old age. This correlates well with the research in modern clinical studies. Among females at all three sites, there is a steady increase in fracture prevalence from young adulthood into old age. Sex-based differences in fracture prevalence are often attributed to higher activity levels (i.e. sports, physical work, violence) among young men and the increased risk for osteoporosis in post-menopausal women (Holloway et al., 2015; Johansen et al., 1997; Pasco et al., 2015). However, it appears that at these Roman sites, this predicted increase of osteoporotic-related fractures in post-menopausal women is absent. It is possible that females at these more rural sites might have partaken in agricultural labour, making them more physically active and less prone to osteoporotic fractures in old age. It is also possible that individuals did not survive to an age at which osteoporotic fractures could occur. However, in women such fractures should be seen after around 50 years, but fractures in the old adult age category do not reflect this.

Overall, males at each of the three sites had a higher CPR than females, a finding that is consistent with current research on trauma in the ancient world (Redfern et al., 2017). However, these differences were not statistically significant, and when examining TPR, females had slightly higher rates of fractures than males at Gambier-Parry Lodge. This suggests that males and females at these sites may have been engaging in similar activities or similar levels of risk.

5.2.2 Trauma by Bone Element

Fractures to the ribs and upper limb, mainly the clavicle and radius, were common among all sites. Fractures to the upper limb increased into middle adulthood, suggesting that falls remained common into adulthood, contrary to clinical findings (discussed below). Across all the sites, only two potential fragility fractures were identified (GLOS GAM 521 and GLOS GAM 545), lending further support to the hypothesis that osteoporotic fractures were rare in all groups. Finally, when calculating the most frequently fractured bone element by site, true prevalence rates show that the fibula was most frequently fractured among both males and females at both the British sites, while upper limb bones were most the most frequently fractured bone element at the Spanish sites.

Clinical studies demonstrate that fractures to certain bones are more likely to occur in different stages of the life span. Fractures to the distal forearm, the result of falling onto an outstretched hand, tend to be the most common type of fracture in childhood and adolescence and again in old age, and may even follow a seasonal variation, with peaks in the summer and winter (Reinberg et al., 2005; Thompson et al., 2004; Wareham et al., 2003). Falls in general are the most common cause of fractures among school-aged children, regardless of sex (Frick, 2014; Peclet et al., 1990). As such, the upper limbs are more commonly fractured than lower limbs, with the humerus and clavicle also being commonly fractured in childhood, with clavicle fractures staying at a relatively low prevalence rate across the rest of the lifespan (Frick, 2014; Pasco et al., 2015). In young adulthood, males are most likely to sustain a fracture of the forearm, fingers, hand, wrist, or face, often related to sports or fights, while young women tend to incur fractures of the wrist and forearm, relating to accidents (Holloway et al., 2015). Following a plateau of fracture prevalence among men and women in middle age, fracture rates increase again in old age, after 50 years in women and after 65 years in men (Thompson et al., 2004). In addition to hip and spine fractures often associated with osteoporosis, one study found that two-thirds of adults over the age of 50 also showed peaks in the prevalence of fractures to the ribs, pelvis, and humerus, while women showed additional increases in fractures of the distal forearm, femur, and patella (Pasco et al., 2015).

Rib fractures were consistently high across all the samples and often multiple ribs were fractured. This finding is not particularly surprising. Although the clinical literature reports rib fractures as most common in old age, these types of fractures are often found to be the most frequently fractured element in paleopathological studies (Brickley, 2006). Clavicular fractures were also found among all three groups. Fractures to the clavicle can be the result of a direct blow to the shoulder, but are most commonly caused by a fall onto the shoulder or outstretched hand (Lovell, 1997; Lovell, 2008). Contrary to the findings of clinical studies which show a decline in clavicular fractures after childhood, TPR in this research revealed that clavicular fractures tended to peak in middle to old adulthood (TPR = 4.0%) across the three sites. This would indicate that falls continued to be a common occurrence into adulthood. The humerus and femur were the least fractured elements in this study, which is also consistent with previous paleopathological studies (Bonsall, 2013; Judd and Roberts, 1999). These fractures, both from Gambier-Parry Lodge, occurred in a middle-aged female and an old adult female, respectively, and may represent fragility fractures associated with post-menopausal women, though this is difficult to determine as both were well-healed (Figure 5.1 and Figure 5.2). Impacted femoral neck fractures, such as the one in GLOS GAM 521, are rare before the age of 50 years (Raaymakers and Martin, 1991), but they can also be associated with traumatic accidents (Ives et al.,

Fig. 5.1 Possible Fragility Fracture from GLOS GAM 545. Well-healed fracture of the right humeral head resulting in shortening of the bone and flattening, porosity, and eburnation of the head.

Fig. 5.2 Possible Fragility Fracture from GLOS GAM 521. a) Impacted neck fracture of a left femur. b) Radiograph of the impacted femoral neck fracture shows the fracture line is no longer visible and the fracture is well-healed.

2017). Hip fractures are rarely reported in the archaeological record, likely due to the high mortality rate associated with such a fracture (Ives et al., 2017). As discussed previously, fractures of the distal radius can also be indicative of fragility fractures. However, when the prevalence rates for fractures of the radius at all three sites were examined by age category, they were found to occur in younger adults, likely resulting from accidents. Of the 214 adults in this study, only two possible fragility fractures (GLOS GAM 521 and GLOS GAM 545) could be identified (CPR = 0.93%). This could indicate good bone health at these sites, but it is also important to note that the low instance of fragility fractures could also be the result of individuals not surviving long enough into old age to incur osteoporotic fractures.

When examining the most frequently fractured element by site, the CPR data revealed that ribs were the most frequently injured element across all three skeletal samples. However, when true prevalence rate (TPR) is considered, fibula fractures were actually the most frequently injured element, in both males and females at the two Romano-British sites. This is contrary to modern populations where the upper limbs are the most frequently fractured. At Granada, the most commonly injured element among males was the clavicle and among females it was the ulna. High rates of fibula fractures are found across many Romano-British sites and it is often found to be the most fractured long bone in both sexes (Bonsall 2013; McWhirr et al., 1982). Isolated fibular fractures often occur due to a direct blow to the leg or ankle. A predominance of fractures of the lower extremities has been linked to agricultural labour, as well as falls from heights in previous paleopathological studies (Judd and Roberts, 1999; Minozzi et al., 2012). Further discussion of the cultural and historical context that could explain the difference in fracture pattern between the Romano-British and Romano-Spanish can be found in Section 5.4.

In summation, the trauma patterns at all three sites vary to some extent from modern clinical results, but many of the findings are consistent with similar paleopathological studies. Trauma to the lower, not the upper, extremities predominates at the two Romano-British sites, indicative of farm work and falls from heights. Across all three sites, fractures to the ribs were very common and evidence of falls was found to extend beyond childhood and young adulthood. Fragility fractures were rare, which may indicate good bone density, particularly among females, who are prone to high rates of osteoporotic fractures after menopause; however, this could also be due to individuals not living long enough into old age to sustain osteoporotic fractures.

5.2.3 Interpersonal Violence

There was little evidence of interpersonal violence in each of the skeletal samples. Cranial fractures, ulna (Parry) fractures, multiple rib fractures in various stages of healing, and multiple trauma have often been linked to interpersonal violence (Judd, 2002a). Cranial fractures were only present in two individuals in this study. BAL 1028, a young adult female, had three perimortem cranial fractures in addition to two healed rib fractures. GLOS GAM 510, a young adult male, had a healed mandibular fracture in addition to an isolated fibular fracture. No cranial fractures were noted in the sample from Granada, despite fair levels of preservation.

Ulnar fractures were entirely absent from the two Romano-British sites under study. However, three isolated distal ulnar fractures, which fit the etiology of Parry fractures, were identified in three females from Granada. Judd (2008) developed the following criteria for parry fractures:

1) no radial involvement
2) transverse fracture line
3) located below the midshaft
4) minor unalignment or horizonal apposition from the diaphysis

Each of the three ulna fractures meet these criteria, although it should be noted that the fracture type could not be ascertained with complete certainty as the fractures were healed and radiographs were unavailable for the Spanish sites. Fractures of the clavicle, humerus, and radius were absent in females at this site, suggesting that these fractures may not be associated with falls. Ulnar fractures are also not particularly common in skeletal samples (Lovell, 2008), but at Granada they were the most frequently fractured bone element among females (TPR – 3/93 = 3.2%). This sex-based difference raises questions of domestic violence. Fractures of the lower arm and ribs are common among domestic violence victims, as well as multiple injury and injury recidivism (Redfern, 2015). The TPR for rib fractures among females (TPR – 7/496 = 1.4%) at Granada were almost double that for males (TPR – 2/237 = 0.8%), and the only individual with multiple trauma was female. OSC 30, a young adult female, had four rib fractures, a distal ulna fracture, and a fracture of the lateral border of the scapula (Figure 5.3). Scapular fractures have also been identified as a possible marker of domestic violence and beatings in the bioarchaeological literature (Blondiaux et al., 2012; Redfern, 2015). However, fractures of the head, face, and neck are most diagnostic of intimate partner violence (Redfern, 2015). These types of fractures were entirely absent in the Granada samples. Fracture prevalence rates overall were very low at Granada, as were cases of multiple injury, so no definitive conclusions can be reached. A larger study with a greater sample size would have to be carried out to confirm whether gendered violence was prevalent at Roman Granada. Nevertheless, this study presents the first possible evidence of domestic violence in a Romano-Spanish context, as well as in the larger context of the whole ancient Roman Empire.

Fig. 5.3 Fractures Possibly Related to Gendered Violence from OSC 30. a) Healed Parry fracture of the left distal ulna. b) Two healed fractures of the left 8th rib. c) Healed fracture of the left 9th rib. OSC 30 also had a fracture to the left scapula and additional rib fractures.

Rib fractures can have multiple causes ranging from falls, violence, excessive coughing, and habitual hard labour. However, multiple rib fractures, in different locations and sides and in different stages of healing are taken to be indicators of violence (Hershkovitz et al., 1996; Judd, 2002a). Rib fractures were common across each all of the samples, which is to be expected as the ribs are often the most frequently injured element in archaeological populations. In the two Romano-British samples, it was common for individuals to have multiple rib fractures, with a few individuals from both Baldock and Gambier-Parry Lodge having as many as six rib fractures each. As the results of the post-traumatic time interval demonstrated, several individuals from Baldock (n=5) and Gambier-Parry Lodge (n=4) had rib fractures in multiple stages of healing. The true prevalence rate for rib fractures peaked in middle-aged adults for both groups (see Table 4.8), suggesting these fractures were accumulated during young adulthood and middle adulthood, and that individuals who lived into old age sustained fewer rib fractures in their youth. True prevalence rates by sex, reveal that at Gambier-Parry Lodge, the prevalence of rib fractures was more evenly distributed among males (TPR – 10/295 = 3.4%) and females (TPR – 12/239 = 5.0%), with females having only slightly higher prevalence of rib fractures. At Baldock, the majority of the rib fractures occurred in males (TPR – 22/439 = 5.0%, versus 6/348 = 1.7%).

Fracture type can be useful in determining the cause of rib fractures. Transverse rib fractures are often caused by a direct trauma to the chest, such as a blow or a fall, while oblique fractures are often indicative of crushing or bending (Lovell, 2008). At Baldock, the majority of transverse rib fractures occurred in males, while at Gambier-Parry Lodge, there was a more even distribution of transverse and oblique rib fractures among males and females. The high number of multiple rib fractures of different healing stages among younger males at Baldock may therefore be indicative of interpersonal violence at this site.

Fractures to the metacarpals are also cited as an indicator of violence, as such fractures often occur due to punching, and have been found to vary according to culturally-specific methods of fighting (Brickley and Smith, 2006; Lovell, 2008). There were only two cases of metacarpal fractures in the Baldock sample, one in a young adult female and the other in a young adult male. Neither of these individuals had any additional fractures. Gambier-Parry Lodge had three individuals with metacarpal fractures; a young adult male and an adult male, both without any additional fractures, and GLOS GAM 545, a middle adult female with three rib fractures and a fracture of the humerus. Given that these fractures are spread out across males and females and the majority occur in isolation in individuals without any additional fractures, they are more likely to be the result of accidents, rather than violence.

Determining violence in the archaeological record is an imprecise science, as multiple injury mechanisms can produce similar fractures. However, several factors indicate that most of the trauma observed at all three sites is accidental.

1) Trauma is more evenly distributed by sex and there is no significant difference between males and females. Males do have a higher fracture prevalence rate at all three sites, but these differences are not statistically significant, and could be more related to daily activity levels than interpersonal violence.
2) The most commonly fractured bone elements are the same in both males and females, with the exception of Granada where females most commonly fractured their ulna.
3) If trauma is accidental, there should be a correlation between years at risk and number of fractures in each age category (Lovejoy and Heiple, 1981). Trauma accumulates at a steady rate at each of the sites, though there is a slight elevation

in fracture prevalence among young adult males, indicating that individuals in this age category may have been engaged in higher levels of risk leading to a higher risk of death.

4) Several fractures were indicative of falls, as fractures to the clavicle and distal radius were found in all of the samples.

The number of multiple rib fractures among young males at Baldock, along with the numerous cases of multiple injury at both Romano-British sites may be suggestive of violence; however, most of the evidence points to low levels of interpersonal violence at all three sites. The picture that emerges of each of these communities is that of small, rural towns and villas where injury is accidental, and likely occupationally-related, accumulating across the life course and is evenly distributed among the sexes.

5.3 Injury Recidivism

Injury recidivism in the clinical literature is defined as the occurrence of chronic and recurrent trauma in certain patient populations (Sims et al., 1989). Injury recidivism has proven difficult to access in the context of paleopathology for several reasons. These limitations and difficulties are discussed in Judd (2002a) and Redfern et al. (2016), but both these studies demonstrate that such research can still produce interesting results and reveal a wealth of information about a society's activities, behaviours, and engagement in risk. The principal difficulty in studying injury recidivism paleopathologically is that there is no way of knowing whether multiple healed injuries occurred at the same time or whether they represent multiple trauma events. If fracture events in past populations are at all comparable to modern populations, mortality rates for fractures would have been low (Peclet et al., 1990), making it unlikely that an individual would have died within the one-year window in which stages of fracture healing are still evident. It is also important to consider that even multiple trauma events may not necessarily equate to injury recidivism; an individual is not considered an injury recidivist if they acquire a fracture in childhood and then again in old age. Such limitations must be borne in mind. In the context of this study, post-traumatic time interval was employed to partially overcome some of these limitations when dealing with multiple healing fractures.

This study attempted to identify cases of injury recidivism by employing newly developed methodologies in assessing post-traumatic time interval. Some of the limitations described above were evident, as most of the observed fractures were well healed. Fracture treatment is evident across the three sites, as barring two individuals, BAL F466 and GLOS GAM 507 (Figure 5.4 and Figure 5.5), all long bone fractures had healed with minimal deformity. However, cases of injury recidivism could be confirmed by the post-traumatic time interval assessment undertaken in this study. Five individuals from Baldock and four individuals from Gambier-Parry Lodge were determined to be injury recidivists. At Baldock, four of the five individuals were male, while at Gambier-Parry Lodge there was an even split between males and females. This represents only a small number of individuals in each sample, but it follows an overall trend in both groups, where more of the trauma at Baldock is among males, whereas trauma at Gambier-Parry Lodge is more evenly split between males and females. When these cases of injury

Fig. 5.4 Deformity of the Left and Right Tibia and Fibula from BAL F466. An injury recidivist, BAL F466 also had multiple rib fractures. a) Healed spiral fracture to the right tibia and fibula. Bayonet apposition of the tibia's fracture ends has led to shortening. Distal end of the tibia has rotated internally and has angled posteriorly and laterally. b) Healed spiral fracture to the left tibia and fibula. Bayonet apposition of the tibia's fracture ends has led to shortening. The distal end of the tibia has angled laterally and posteriorly.

recidivism are broken down by age, all but one occurs in young and middle-aged adults. This suggests that many individuals who suffered repeat trauma did not live to old age. The causes of repeat trauma in these two samples may be linked to social roles and responsibilities engaged in by these age groups that incurred high risk, such as

Fig. 5.5 Deformity in the Right Tibia and Fibula from GLOS GAM 507. This individual had no additional fractures. Healed, oblique fractures in the tibia and fibula both display bayonet apposition that likely led to the shortening of the right leg. As the distal ends of the fractures are not present, so it is not possible to assess whether rotation or angulation was also present.

occupational activities. In fact, clinical and cross-cultural studies reveal that economically active age groups (20-40 years) tend to accumulate multiple injuries (Judd, 2004).

Another key finding of this analysis is that all the fractures that were still healing one year before death were of the ribs (Figure 5.6). This finding could be due to the fact that ribs are one of the most frequently fractured regions or that rib fractures can have many medical complications (Sirmali et al., 2003) and are linked to higher mortality in the clinical literature (Brickley, 2006), as would appear to be the case in the archaeological individuals this study. It would also seem to lend evidence to the idea that fractures of the ribs at these two sites are linked to the activities and behaviours of the economically active age groups. Conversely, fractures of the clavicle, humerus, radius, and femur may be more the result of falls among children and old adults, as is seen in modern clinical studies. Again, these nine individuals may not represent the full extent of injury recidivists at these sites. There could be additional individuals with a history of recurring injury but who hadn't incurred a fracture in the last year of their life. It is still necessary then to look at all cases of multiple trauma when investigating injury recidivism in the archaeological record.

Fig. 5.6 Close-Up of Healing Rib Fractures. a) A fracture from BAL 1374, an injury recidivist, in the early stages of healing. New bone formation is visible but a fracture callus has not yet fully formed. This fracture also had eburnation along the fracture margin. b) A fracture in GLOS GAM 525, an injury recidivist, showing callus formation of woven bone around the fracture margin. c) A fracture from GLOS GAM 556 showing callus formation of woven bone around the fracture margin.

Estimates of the prevalence of injury recidivism vary widely in the clinical literature (Hedges et al., 1995; Sims et al., 1989; Toschlog et al., 2007) and very few comprehensive studies of injury recidivism have been undertaken in paleopathology. As this research utilizes a novel methodology and represents the first comprehensive study of injury recidivism in a Roman population, it is difficult to accurately contextualize the findings within the literature. The classical profile of an injury recidivist is that of a young adult male of low socioeconomic status. Typically, these individuals acquire their first injury at around 20 years and experience a second within the span of a few years (Goins et al., 1992). These injuries are often the result of violent altercations. Baldock appears to fit this pattern most closely; males accounted for most of the multiple injuries, though not significantly so, and these injuries accumulated in young adults and peaked in middle-aged adults. Though only individuals over the age of 18 were included in this study, notes were made on the number and location of any fractures in excluded individuals. There was also no evidence of fractures among individuals under the age of 18 years, suggesting first fractures must have occurred in the young adult age group.

However, there is not much evidence of interpersonal violence at this site. At Gambier-Parry Lodge, the prevalence of multiple injuries was highest (CPR – 7/50 = 14.0%). The age of first fracture likely also occurred among the young adult age group, as there was only a single case of a fracture in an individual under 18 years (n=22). However, contrary to the typical injury recidivist profile, slightly more females than males had multiple injuries at this site. As at Baldock, there is little evidence for interpersonal violence. Finally, at Granada, only one case of multiple injury was present, demonstrating that the prevalence of fractures and multiple injury were very low at this site.

The profile of a typical injury recidivist comes from studies in large, urban trauma centres in developed countries. There are only a few studies of injury recidivism in rural populations. However, these few studies reveal that injury recidivism in the context of rural settings may look quite different than that of urban centres. These few studies do not present a uniform profile (rural injury recidivism appears to be more community specific), but they do present some trends that differ from the urban profile. These studies have found that injury recidivism in a rural context is often more evenly distributed among the sexes, may more closely reflect population demographics, and is more linked to overexertion and drug use than violence (Sayfan and Berlin, 1997; Williams et al., 1996). The largest of these studies, examining all trauma patients in a rural emergency department over eight years, found that the rural injury recidivist was significantly older, more likely to be female, and was more likely linked with substance abuse (Toschlog et al., 2007). This profile may best suit the two Romano-British sites, and Gambier-Parry Lodge in particular, where multiple injury was more common in females, peaked in middle adulthood, and did not appear to be particularly associated with violence. Even in the case of Baldock, while males had higher crude prevalence and true prevalence rates of fractures, this difference was not statistically significant.

5.4 Roman Britain and Spain

In order to fully understand the implications of this study, it is necessary to employ a biocultural framework and place these populations within their historical and cultural contexts. Each of the three sites are smaller settlements. Baldock is a small, nucleated settlement, dating primarily to the late Roman and into the post-Roman period. Gambier-Parry Lodge is a small-town site, dating to the late Roman period, on the outskirts of a larger town at Gloucester. It also potentially had links to a nearby Roman military fort at Kingsholm. The fracture analysis calls the strength of these links into question as the injuries at this site are not skewed towards young adult males, and the patterning of fractures is more indicative of accidental or occupational injuries than violence. However, it is also possible that this view is reductive and the relationship between Gambier-Parry Lodge and Kingsholm was more complex. Finally, the Granada sites are small, villa sites and a small town associated with a villa. The dates for the sites at Granada range from the first century AD to the fourth century AD. These sites were on the outskirts of a Roman *municipium* at Granada, called *Florentinum Iliberitanum*. In addition to being homes for the elite, villas were also working farms and some also produced crafts and good, such as pottery. The individuals buried at villa sites are often slaves and labourers, rarely the elite themselves. However, one study of a villa site on the outskirts of Rome identified tomb inscriptions for a variety of occupations, such as merchants, soldiers, and artisans, in addition to slaves and farm hands (Cifarelli and Zaccagnini, 2001).

Little is known about the daily lives of the labouring poor, as the Classical writers and historians seem to have had little interest in recording their experiences. We instead have to gather some idea of the lived experiences of these individuals through subjects that were recorded, such as economic activity. Any analysis of these sites must consider the consequences of agricultural exploitation, as this is undoubtedly the work that most individuals would have engaged in throughout their lives.

5.4.1 Agriculture in Roman Britain and Spain

During the Roman period in Britain, the agricultural economy expanded rapidly (Dark and Dark, 1997). Cereals were the primary crop, and herds of pigs, cattle, and sheep were raised, along with horses and oxen. Soils at most sites throughout Britain were easily worked and could be exploited continuously. In addition to agriculture, most small towns also had some industry, often in pottery production as was the case at Baldock, but many items were acquired through trade in consumer goods (Fitzpatrick-Matthews and Burleigh, unpublished). Andalusia, the geographical region in which Granada is contained, was Roman Spain's agricultural centre, due to its highly fertile soils and diverse landscapes. Wheat, cereal, and olive trees were the primary focus of food production, and horses, cattle, sheep, goats, and pigs would also have been reared (Keay, 1988). The region was also rich in metals and contains the Guadalquivir river, one of the only navigable rivers in Spain, making it a major route of communication and trade. Roman villas were present in this region from the early days of the Roman occupation (c. first century BC), taking advantage of its natural wealth. Late Roman Spain saw an expansion of villa culture throughout the countryside just outside cities, allowing elite Roman citizens to avoid cramped, urban spaces, but still affording them the access to a range of goods and services that could be found within the cities (Kulikowski, 2004). This expansion is likely reflective of an increase in prosperity, as villas were no longer available solely to the excessively wealthy.

It is important to briefly touch upon the evidence for sex and agricultural labour in the Roman world, as it offers a useful explanation for the sex-based differences (or lack thereof) in fracture patterns found in this study. In Classical Greek and Roman societies, there was an embedded idea of a division of labour where women were relegated to the domestic sphere, whilst men engaged in labour and the public realm. Historians and Classicists now challenge how widely practiced this ideal was among the lower and labouring classes (Scheidel, 1995). A large section of Roman society would have lived at or near subsistence levels, which would have necessitated women working in the fields alongside men in rural, agricultural areas (Garnsey and Saller, 1987). At villa sites, such as the sites in Granada, wealthy Romans would have had a mix of labourers and slaves to work the land. Scheidel (1995) argues that women likely engaged in agricultural labour at these villas just as they did in feudal Medieval societies and in colonial slave-societies in the Americas. It can be assumed then that women in the rural samples under study were likely engaging in similar occupational activities as men for most of their adult lives, which may explain why there is no statistical significance in fracture rates between males and females at these sites. It can also be used to explain the similarities in fractures by bone element for the two Romano-British sites. Furthermore, in times of conflict, rural women would have taken on the bulk of men's tasks, including harder and riskier tasks that they typically would not have engaged in. If Gambier-Parry Lodge was closely associated with the nearby Roman fort, this could explain why women at Gambier-Parry Lodge had more multiple injuries and a higher true prevalence fracture rate than males.

Occupational injury rates among farmers are higher than most other occupations in modern, developed countries. Similarly, many paleopathological studies that compare urban and rural sites find higher levels of fractures in rural samples (Judd and Roberts, 1999; Judd, 2002a). Common causes of injury among agricultural workers are animal related, such as kicks to the ribs or shin, followed by falls (Gerberich et al., 1994; Stueland et al., 1991). One two-year study at a Wisconsin emergency department found that female farmers receive a consistent number of injuries over their working lives, while men experience an small increase in the number of injuries up until the age of 40 years, when injuries gradually decline (Stueland et al., 1991). This model fits with the findings of this study, in which females had a regularly increasing number of fractures, indicative of accumulated risk to a consistent rate of fracture across the life course, while males displayed a peak in young adulthood. Estimates of the share of female agricultural injuries vary widely, ranging from 25% to 45% (Brison and Pickett, 1992; Stueland et al., 1991), demonstrating that women in modern populations can account for a large share of agricultural injuries, which is consistent with the findings of this study.

Finally, when agricultural injuries are examined by anatomical location, some studies have shown that women tend to incur more injuries of the upper extremities, while men incur injuries of the lower extremities (Stueland et al., 1991). However, Stueland et al. (1997) have shown that in women who consider agricultural work to be their primary business, 42.5% have injury to the lower extremities and only 17.5% have injuries to the upper extremities. This study furthers the point that females at the two Romano-British sites were likely engaging in similar levels of agricultural work as males, exposing them to the same risks and injury patterns as their male counterparts. The relationship between sex, age, and agricultural labour as they relate to fracture prevalence and trauma patterns among the skeletal samples has been thoroughly discussed above. However, the question remains: given that both the British and Spanish sites were presumably engaging in similar agricultural activities, what accounts for the differences in fracture prevalence and injury recidivism between the sites in these two countries? To answer this question, it will be helpful to turn to a discussion of socioeconomic status, stress, and substance use in the context of the history and culture of Roman Spain and Britain.

5.4.2 Socioeconomic Status

Low socioeconomic status is known to be correlated with increased rates of fractures, injury recidivism, and poor health outcomes in both the clinical and paleopathological literature (i.e. Curtis et al., 2016; Redfern and DeWitte, 2011a; Redfern et al., 2017). Individuals at all three sites likely belonged to poor labouring classes of low socioeconomic status. At Baldock, a previous study found mixed results on the health outcomes of individuals buried with and without grave goods and the authors of the study believe that this small nucleated settlement had much social stratification (Griffin et al., 2011). At Gambier-Parry Lodge, few individuals were buried in a coffin and/or with grave goods, suggesting little social stratification at this site also (Roberts, unpublished). As discussed previously, individuals at the villa sites and associated small towns are likely slaves and freed labourers. These individuals would have existed alongside elite villa owners in highly socially stratified circumstances. However, these owners were unlikely to be buried at the villa, so social stratification would not be visible (unfortunately, a detailed site report does not exist for the Granada sites to confirm this). One may still expect that slaves, belonging to the lowest rung on the social ladder, might have been exposed to greater levels of risk through strenuous daily activities, therefore resulting in an increase in fracture prevalence when compared to the free, rural poor. This does not appear to be the case in this study, and such a processual approach neatly linking social status with poorer health outcomes has been critiqued (Grauer, 2012).

5.4.3 Stress

Stress, in the context of negative health outcomes in relation to social, environmental, and nutritional strain, can be studied according to many different metrics and has been applied to numerous populations in paleopathology. In this section, stress will be discussed in relation to colonization, political and social instability, and economic or financial instability. In Roman Britain, recent focus has been paid to the negative health impacts that Romanization and urbanization had on the native British population (Redfern, 2008). These include a decrease in stature, fewer individuals surviving to old age and increases in nutritional deficiencies. Indeed, there is evidence of poor health at both Baldock and Gambier-Parry Lodge. Cases of dental enamel hypoplasia, cribra orbitalia, and porotic hyperostosis were identified at both Baldock and Gambier-Parry Lodge, with Harris' lines also being identified at Gambier-Parry Lodge (Cameron and Roberts, unpublished; Roberts, unpublished). The site reports remark that the presence of stress indicators was low but this was when compared to more urban sites, such as Cirencester. As studies of this kind do not exist for Roman Spanish sites, it is not possible to compare whether stress indicators and poor health also increased after Roman conquest in Spanish populations. Although, studies in other parts of the world do indicate a link between colonialism and poor health, especially if violent strategies are employed (Buzon and Richman, 2007). Given this, similar negative health may also have occurred in Spain.

However, the relationship between the two provinces and Rome were dissimilar. Spain was conquered in 218 BC, long before the invasion of Britain in 43 AD. The entirety of Spain, and later neighbouring regions also, was conquered and the remained stable until the later end of the fifth century AD. Britain by contrast was invaded much later, and was never fully conquered, leaving the region open to raids by neighbouring Picts and Scots. It is possible that the Romano-Spanish civilization at Granada may have benefited from prolonged stability and closer integration with the Roman Empire. Additional studies would need to be carried out to confirm whether the Romano-Spanish population had better health outcomes than Roman Britons in other areas of their health, in addition to a low fracture rate.

In the context of Baldock and Gambier-Parry Lodge, consideration must also be given to the effect of Britain's withdrawal from the Roman Empire. One study of Baldock found that health measures (i.e., stature, dental caries, and enamel hypoplasia) worsened during the late Roman period, leading to the conclusion that the population may have been experiencing moderate inequality and worsening health around the time of the Roman exit from Britain (Griffin et al., 2011). This was a tumultuous time in British history. Archaeologically, in the second half of the fourth century AD there is a decline of elite culture (coins, mosaics, villas, luxury objects, etc.) in Britain and an increase in defensive walls around towns and settlements, both large and small (Cleary, 2003). Raids by Scots, Picts and Saxons accelerated throughout this period and into the fifth century. Rome withdrew from Britain in 410 AD, taking its military with it, as the State and market crumbled (Cleary, 2003). By 440 AD, the Saxons gained control over parts of

Britain, causing some segments of the population to flee amidst widespread destruction (Wood, 2003). There is no evidence of destruction or a large population contraction at Baldock or Gambier-Parry Lodge; however, the instability of Britain in the late fourth and fifth centuries must have had some impact on the lives, and perhaps even the health of the population, leaving individuals more vulnerable to traumatic injuries and other stresses than their Spanish counterparts.

Psychological stress may be just as important to physical health outcomes, but is difficult to assess in past populations. Modern studies have shown a link between agricultural injury and higher levels of stress, often resulting from financial burdens and other socioeconomic stressors, with some suggesting that stressed farmers are almost two times more likely to experience an injury than a non-stressed farm worker (Day et al., 2012; Geller et al., 1990; Thu et al., 1997). Accidents resulting in injury are more likely to occur in stressed agricultural labourers due to cognitive failures and an increase in risk-taking behaviour and overexertion, such as working longer hours or working late into the night. Farm owners seem to be particularly vulnerable to stress, with one study estimating that 35% of farm owners experience at least one injury per year, while among labourers this drops to 17% (Rasmussen et al., 2000; Zhou and Roseman, 1994). Stress levels are likely higher among farm owners than labourers, which may account for this difference. It could be that the higher levels of fractures at the Romano-British sites is reflective of the fact that they were more self sufficient and likely to face dire consequences if crops were not planted or harvested in time. Fractures can have high social and economic consequences, such as a loss of productivity while the injury heals, causing some individuals not to seek medical attention (Otmar et al., 2013; Pasco et al., 2005; Rasmussen et al., 2000). This may have been the case for BAL F466 and GLOS GAM 507, for whom no attempt seems to have been made to reduce their lower limb fractures. In addition to this, in the context of fourth century Britain, there was an ever-increasing burden of taxes, in form of money or goods, to the State, in order to support the military (Cleary, 2003). This burden primarily fell on poor labourers, who had to hand over surplus to feed the army and urban centres, undoubtedly causing increased stress and financial burden. This could lead to increasingly risky behaviour and overexertion, one of the main factors in injury recidivism (Williams et al., 1996). Whereas at villa sites, an administrative hierarchy was in place to manage the farm, as well as domestic activities, such as providing care, provisions and meals for the slaves and labourers (Roth, 2004). Slaves and workers on villas were therefore buffered to an extent from some of the stresses associated with subsistence farming, and may not have needed to engage in riskier behaviours and overexertion. This could provide one possible explanation for the lower levels of fractures and multiple injury at Granada than is seen in Roman Britain.

5.4.4 Alcohol Consumption

One final explanation for the difference in injury rates between the Spanish and British samples may relate to alcohol consumption. As discussed previously, one large study of rural injury recidivism found that rural injury recidivists tended to be older and female, and injuries tended to be related to substance abuse (Toschlog et al., 2007). Another study of agricultural injuries in Alabama found that females had a higher risk of injury than males, and that other factors indicative of injury risk include farm ownership, greater amount of time spent working, consumption of alcohol, and presence of a prior injury (Zhou and Roseman, 1994). Unfortunately, little systematic work has been done on differences in the consumption and abuse of alcohol throughout the Roman Empire. However, it is commonly known that wine was consumed. The site report for Baldock mentions the presence of amphorae that may have held wine, although it should be noted that amphora are not particularly rare finds in ancient contexts and were not used exclusively for wine storage (Burleigh and Fitzpatrick-Matthews, unpublished). One study does present an interesting hypothesis that may link Roman Britons and heavy alcohol consumption. Engs (1995) argues that traditional European drinking patterns may have their origins in ancient Rome. She notes a difference between southern and northern European drinking culture. Northern European cultures, including Britain, have stricter rules regarding drinking (i.e. age limits), but they also tend toward heavy drinking, mainly of malt beverages, as viticulture is uncommon in these regions; whereas in southern European cultures, rules around alcohol consumption are more relaxed, drunkenness is not socially acceptable, and viticulture is common. Engs (1995) found statistical significance between southern drinking patterns and southern former Roman provinces where Latin languages are spoken. A similarly significant relationship was found between northern drinking patterns and frontier (and non-) Roman provinces and Germanic language. The author supports these findings with a discussion on climate and beverage choice, backed up by archaeology, as well as observations from Tacitus, disparaging drunkenness on malt liquor among Germanic and Gallic tribes (Engs, 1995).

There is evidence that the Celtic Britons consumed beer and other malt beverages prior to the Roman invasion, and there is also evidence that this tradition continued under the Romans, as proven by inscriptions found at military sites that call for the production and rationing of beer (Nelson, 2005). Heavy drinking of beer also appears to have been common among the Celtic and Gaul peoples. Pliny the Elder writes:

> There is a particular intoxication too among western peoples... and intoxication is absent in no part of the world, since they drink such juices pure, not weakening it through dilution as with wine. But, Hercules, the earth seemed to produce cereals there. Oh wondrous ingenuity of vices! Such a manner of making even water intoxicating was invented! (Pliny *Natural History* 14.29.149, as cited by Nelson, 2005: 69)

Furthermore, poor Britons may have consumed beer over wine as it was substantially cheaper and as wine was linked to higher socioeconomic status (Nelson, 2005). The Romans, as the Greeks had before them, viewed beer as inferior to wine and a drink of barbarians, so wine was priced disproportionately higher than beer (Nelson, 2005). It is reasonable to assume that the poorer, rural Roman Britons may have continued to engage in a northern European drinking culture of drinking malt beverages to excess. Engs (1995) conclusions are broad generalizations, but they are compelling, and provide another angle that may help in part to explain the patterns and differences in injury at the three sites under study.

5.5 Summary

An understanding of the daily lives of the non-elite classes are not well understood, as the written and archaeological record have a bias toward the rich and influential. This is especially true of the rural poor who remain particularly inaccessible. Bioarchaeological studies provide a way to peel back the veil shrouding these communities, and a thorough understanding of peoples' lived experiences can emerge when these studies are contextualized by a life course and biocultural approach.

The results of this study indicate communities whose lives likely revolved heavily around agricultural labour and for whom accidental, not violent injury, was the norm. Women's work at Baldock and Gambier-Parry Lodge overlapped with that of the men, exposing them to similar risks and accumulating fractures over their life course, but possibly shielding them from poor bone density and osteoporosis. Comparisons with other paleopathological studies show that Baldock and Gambier-Parry Lodge fall in line with other Romano-British studies, as well as clinical literature on agricultural injuries. Conversely, individuals at the two British sites fit more rural models of injury recidivism and multiple injury than the urban profile that has been applied in other paleopathological studies. Unfortunately, no large Romano-Spanish paleopathological studies exist with which to compare the Granada sample. However, it is evident that injury in this sample was more infrequent and random.

The reason for the differences in trauma patterns between the Romano-British and Spanish samples is complex and not entirely clear. Several hypotheses for these differences have been proposed, namely socioeconomic differences, stress owing to Romanization, subsistence farming and specific historical events, and a difference in drinking culture. Ultimately, explanations for the trauma patterns and differences in injury at these sites are likely multifaceted and may include a combination of the above explanations.

CHAPTER 6: CONCLUSION

This aims of this thesis were to identify fractures and their stage of healing using new post-traumatic time interval estimation methods, determine how rates of trauma varied by age, sex, and settlement, and to discuss how the results of this study revealed information about the social, cultural, and environmental circumstances across the two Roman provinces under study. The current study also provided the first trauma data set from Roman Spain and added to data on injury recidivism in paleopathology.

Using new methods for determining post-traumatic time interval in archaeological human dry bone this study looked at multiple trauma and injury recidivism. Several individuals at the two Romano-British sites of Baldock and Gambier-Parry Lodge were determined to definitively have injuries of different ages. Such a distinction would not have been possible using previous methods of classifying fractures simply as postmortem, perimortem, and antemortem, or healing versus healed. The study of multiple injury at these sites revealed an injury recidivist profile that more closely matched modern, clinical studies of rural injury recidivists, than previous paleopathological studies which have all found injury recidivist profiles closer to modern, urban models (Judd, 2002a; Redfern et al., 2017). Multiple injury was almost entirely absent at the Spanish sites, with the exception of one young adult female.

Overall, fracture events were found to be low in the Roman communities investigated and in line with previous studies of Romano-British sites. Examining the fracture patterns with a life-course approach revealed that the bulk of the injuries likely occurred during young adulthood and middle age, suggesting that fractures were most common throughout the economically active period of adulthood. There were no significant differences between males and females, contrary to past studies, as women were likely engaging in similar activities as men, out of economic necessity. The picture of injury painted across the sites investigated is of accidental trauma, likely relating to occupational injury from farming and other agricultural activities.

Fractures typical of osteoporosis were rare at these sites, suggesting that old adults, and females in particular, may have benefitted from the physical activity required of farm workers. This contrasts a previous study that identified high levels of osteoporotic fractures among women at a Romano-British site (Mays, 2006). However, the low number of frailty fractures could also indicate that individuals at these sites were not surviving long enough to suffer from osteoporosis.

There were several differences between the Romano-British and Spanish skeletal samples that could be explored using a biocultural approach. Overall, trauma rates in Roman Spain were much lower than those found in Britain, possibly due to the fact that the cemeteries in Granada were associated with wealthy villa sites, while the two cemeteries in Britain were linked with poor, rural, small towns. It is also of interest to note that trauma patterns differed between the British and Spanish groups, with the former having a preponderance of fibula fractures, as has been found in other Romano-British and even medieval British trauma studies (Bonsall, 2013; McWhirr et al., 1982). In Granada, by contrast, upper limbs were the most frequently fractured. As fractures in the lower extremities have been linked to individuals whose primary business is agricultural (Stueland et al., 1997), the difference in rates of upper versus lower limb fractures may relate to differences in the level of engagement with agricultural activities between the British and Spanish samples.

The reasons for differences in trauma patterning and injury rates between the two Romano-British and three Romano-Spanish sites are multivariate and may relate to differences in economic security and stress, leading farm owners at the British sites to engage in riskier behaviour. Furthermore, the historical context of the late Roman period may also have played a role, as the British province experienced political and economic upheaval during the later half of the late Roman period, which overlaps with the period the two Romano-British cemeteries were in use. Differences in drinking culture may account for the higher levels of multiple injury and injury recidivism at the Romano-British sites.

This thesis is the first to employ post-traumatic time interval as a key part of its methodology, and found the time table to be a useful tool in distinguishing cases of injury recidivism. It is recommended that post-traumatic time interval assessments be used in future fracture data collection. Future studies could also investigate the use of post-traumatic time interval as a means of addressing the osteological paradox. Wood et al.'s (1992) seminal paper on the failure of paleopathology to address fundamental conceptual issues of demography is still often overlooked or inadequately addressed in the discipline (DeWitte and Stojanowski, 2015). The use of a post-traumatic time interval could be used to overcome some of these issues as it has the potential to provide a better understanding of how long fractures take to develop, and could aid our understanding of how risk and frailty change throughout fracture development and healing.

This thesis also contributes new research into trauma at Romano-Spanish sites, a region that has been understudied in paleopathology. By contrasting British and Spanish data, it is possible to ascertain trauma patterns that may be unique to the two cultures and those that are held in common between rural individuals in the two Late Roman provinces. However, further study of Romano-Spanish sites is required in order to reveal whether the trauma trends found in this study are true of other Romano-Spanish rural sites. Such further research could also strengthen the arguments presented here for these differences or reveal new insights, leading to a greater appreciation of the temporal and culture-specific activities and behaviours that individuals were engaging in across the Roman Empire. In addition, a thorough examination of the impacts of social status on trauma patterns and injury recidivism at these sites could provide further evidence for the role of socioeconomic status on injury recidivism.

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APPENDICES

Appendix A: Age and Sex Recording Form

This form was created by Dr. Megan Brickley and Dr. Tracy Prowse for a SSHRC project on vitamin D deficiency in the Roman Empire. Permission was given for this form to be used for this project.

Sex/Age Estimation Date: ______________________ Site - ______________________

Observer: ______________________ Sk # ______________________

Age Estimation – Juvenile

Dental Development (following Gustafson and Koch 1974)

Deciduous Dentition

Maxilla	Left	Right	Unsided 1	Unsided 2
m^2	-	-	-	-
m^1	-	-	-	-
c	-	-	-	-
i^2	-	-	-	-
i^1	-	-	-	-

Mandible	Left	Right	Unsided 1	Unsided 2
m_2	-	-	-	-
m_1	-	-	-	-
c	-	-	-	-
i_2	-	-	-	-
i_1	-	-	-	-

Permanent Dentition

Maxilla	Left	Right	Unsided 1	Unsided 2
M^2	-	-	-	-
M^1	-	-	-	-
PM^2	-	-	-	-
PM^1	-	-	-	-
C	-	-	-	-
I^2	-	-	-	-
I^1	-	-	-	-

Mandible	Left	Right	Unsided 1	Unsided 2
M^2	-	-	-	-
M^1	-	-	-	-
PM^2	-	-	-	-
PM^1	-	-	-	-
C	-	-	-	-
I^2	-	-	-	-
I^1	-	-	-	-

Scoring: - = could not be assessed; 1 = start of mineralization; 1.5 = past start of mineralization, but not yet at complete crown; 2 = complete crown; 2.5 = crown complete, but not certain if eruption has occurred; 3 = eruption in progress; 3.5 eruption complete (teeth are in occlusion), but not certain if root is fully formed; 4 = eruption and root complete

If M3s are present, record side & development here: Max ____ Max ____ Mand ____ Mand _____

Long Bone Length (in mm)

	Left	Right
Femur		
Tibia		
Fibula		
Humerus		
Radius		
Ulna		

Epiphyseal Fusion (following Cardoso 2008 a, b) - Fusion should be scored on **left** bone only. If left is not present right should be scored.

Femur: 1 - proximal epiphysis; 2 – greater trochanter; 3 – lesser trochanter; 4 – distal epiphysis
Tibia: 1 – proximal epiphysis; 2 – distal epiphysis
Humerus: 1 – proximal epiphysis; 2 – distal epiphysis; 3 – medial epicondyle
Radius: 1 – proximal epiphysis; 2 – distal epiphysis
Pelvis: 1 – iliac crest; 2 – ischial epiphysis
Clavicle: 1 – sternal epiphysis

	Side	Epiphysis 1	Epiphysis 2	Epiphysis 3	Epiphysis 4
Femur	-	-	-	-	-
Tibia	-	-	-		
Humerus	-	-	-	-	
Radius	-	-	-		
Pelvis	-	-	-		
Clavicle	-	-			
Other	-	-	-	-	-

Scoring: - = could not be assessed; 1 = non-union (epiphysis and diaphysis are completely separate); 2 = partial union; 3 – complete union (all visible aspects of epiphysis are united)

Notes:

Sex/Age Estimation Date: ______________________ Site - ______________________

Observer: ______________________ Sk # ______________________

Summary Information

Dental Dev. Age Estimate	Long Bone Length Age Estimate	Epiphyseal Fusion Age Estimate	Dental Wear Age Estimate (if applicable)
Notes:			

Dental Wear (modified from Brothwell 1965) – for older adolescents and adults (M1 must be erupted and in occlusion)

Maxilla		
	Left	**Right**
M3	-	-
M2	-	-
M1	-	-

Mandible		
	Left	**Right**
M3	-	-
M2	-	-
M1	-	-

Modified scoring: - = could not be assessed; score - 1-13 (refer to diagram)

Notes:

Sex/Age Estimation Date: ______________________ Site - ______________________

Observer: ______________________ Sk # ______________________

Sex Estimation – Adult

Will not be attempted for those <16 years old. For those 16+ years the features of the skull/mandible and pelvis set out in Buikstra and Ubelaker (1994) will be used.

Pelvis		
	Left	Right
Ventral Arc (1-3) *	-	-
Subpubic Concavity (1-3) *	-	-
Ischiopubic Ramus Ridge (1-3) *	-	-
Greater Sciatic Notch (1-5) *	-	-
Preauricular Sulcus (1-4) *	-	-
Estimated Sex	Undetermi	

Skull		
	Left	Right
Nuchal Crest (1-5) *	-	
Mastoid Process (1-5) *	-	-
Supraorbital Margin (1-5) *	-	-
Glabella (1-5) *	-	
Mental Eminence (1-5) *	-	
Estimated Sex	Undetermi	

Notes:

In all cases (skull and pelvis) the left should be preferentially scored. When the left side is absent, the right can be scored.
* after observations described in Buikstra & Ubelaker 1994 (pp. 16-21):
0-3 scale: - (blank) = not observable; 1 = female; 2 = ambiguous; 3 = male
0-4 scale: - (blank) = no sulcus; 1 = sulcus is wide (>0.5cm) and deep; 2 = sulcus is wide but shallow; 3 = sulcus is well defined but narrow; 4 = sulcus is a narrow (<0.5cm), shallow, and smooth-walled depression.
0-5 scale: - (blank) = not observable; 1 = female; 2 = probable female; 3 = ambiguous; 4 = probable male; 5 = male

Age Estimation - Adult

Pubic Symphysis Scoring System (following Brooks and Suchey 1990; Suchey and Katz 1986)

	Left	Right
Phase	-	-

Notes:

Scoring: - = could not be assessed; phases 1-6 (see Buikstra and Ubelaker, 1994: 23-24)

Sex/Age Estimation Date: ______________________ Site - ______________________

Observer: ______________________ Sk # ______________________

Auricular Surface Scoring System – Transition Analysis (following Boldsen et al. 2002:101-103) (can record multiple stages for a single feature)[1]

	Left		Right	
	Min	Max	Min	Max
Superior Topography (1-3)	-	-	-	-
Inferior Topography (1-3)	-	-	-	-
Superior Characteristics (1-5)	-	-	-	-
Apical Characteristics (1-5)	-	-	-	-
Inferior Characteristics (1-5)	-	-	-	-
Inferior Texture (1-3)	-	-	-	-
Superior* Exostoses (1-6)	-	-	-	-
Inferior* Exostoses (1-6)	-	-	-	-
Posterior Exostoses (1-3)	-	-	-	-

Notes:

[1]Record the left auricular surface. When the left is absent, the right can be recorded but do not mix the two sides.
Scoring: - = could not be assessed; see Boldsen et al. 2002
* Superior and Inferior Posterior Iliac Crest

Summary Information – Adult Age and Sex

Age[1]	
Sex[2]	

[1]Young adult (20-34), middle adult (35-49), old adult (50+)
[2]After Buikstra and Ubelaker (1994: 21): undetermined; female; probable female; ambiguous; probable male; male

Appendix B: Fracture Recording Form
This form was created by the author to expediently record relevant information on all long bone and rib fractures identified in adults in each of the collections included in this thesis.

Fracture Recording Form

Date ____________________

Collection ____________________

Individual ____________________

Estimated Age ____________________ Estimated Sex ____________________

Preservation ____________________
(Buikstra & Ubelaker)

Bone Preservation

Bone	*Abrasion/Erosion*	*Bleaching/Discolouration*	*Fissuring*	*Animal Gnawing*	*Cut marks*

(McKinley, 2004)

Notes:

Fracture Profile

Date ___________________

Collection/Individual ____________________________________

Ribs

Rib #	*Length*	*Side*	*Location*	*Alignment*	*Stage of Healing*

(Brickley, 2006)

Bone	*Fracture Type*	*Mechanism of Injury*

(Buikstra & Ubelaker, 1994; Lovell, 1997)

Notes:

Date ___________________

Collection/Individual ____

Long bones

Bone	*Side*	*Location*	*Length*	*Apposition*	*Rotation*	*Angulation*

(Lovell, 1997)

Bone	*Stage of Healing*	*Fracture Type*	*Mechanism of Injury*

(Buikstra & Ubelaker, 1994; Lovell, 1997)

Notes:

Antemortem, Perimortem, Postmortem

Date ____________________

Collection/Individual ____

Bone ________________

	Yes	No	Unable to assess
Bone remodelling (Ant)	___	___	___
Consistent colour (Pe)	___	___	___
Sharp/irregular edges (Pe)	___	___	___
Hinging (Pe)	___	___	___
Eburnation (Pe)	___	___	___
Hairline Fracture (Pe)	___	___	___
Colour difference (Po)	___	___	___
Angled, clean edges (Po)	___	___	___

Estimated category: _________

Post-traumatic Time Interval – Macroscopic

Date ________________

Collection/Individual ______________________________

Bone ____

Healing Feature	Present	Absent	Unable to Assess
Cellular proliferation (3 weeks)			
Callus formation (3-9 weeks)			
Consolidation (few weeks to months)			
Remodelling (6-9 years)			

(Lovell, 1997 & 2008 – after Adams, 1987; Adams & Hamblin, 1992; Apley & Solomon, 1993; Buchwalter et al., 2006; Paton, 1984; Schenk, 2003)

Estimated post-traumatic time interval:

Notes:

Date ________________

Collection/Individual ______________________________

Bone ____

Healing Feature	Present	Absent	Unable to assess
Remodelling of lesion margins			
Periosteal osteogenesis at distance from fracture site			
Aggregation of spiculae into woven bone			
Margin of lesion appears sclerotic			
Fields of calcified cartilage at sites of callus formation			
Clearly visible periosteal callus			
Periosteal callus becomes firmly attached (inseparable) to the cortex			
First scattered bone tissue spiculae between the lesion ends			
Union by bridging of the cortical bone discontinuity			
After inadequate immobilization: Pseudoarthrosis development			
After adequate immobilization: Quiescent appearance indicating subsided healing			

(De Boer et al., 2015)

Estimated post-traumatic time interval:

Post-traumatic Time Interval – Radiographic

Date ________________

Collection/Individual ______________________________

Bone ____

Healing Feature	Present	Absent	Unable to assess
Absorption of cortical bone adjacent to lesion			
Remodelling of lesion margins			
Start of endosteal and periosteal osteogenesis separable from cortex			
Periosteal osteogenesis at distance from fracture site			
Clearly visible endosteal callus formation			
Aggregation of spiculae into woven bone			
Osteoporosis of cortex			
Margin of lesion appears sclerotic			
Fields of calcified cartilage at sites of callus formation			
Clearly visible periosteal callus			
Endosteal callus becomes indistinguishable from the cancellous bone in the marrow cavity			
Periosteal callus becomes firmly attached (inseparable) to the cortex			
First scattered bone tissue spiculae between the lesion ends			
Union by bridging of the cortical bone discontinuity			
After inadequate immobilization: Pseudoarthrosis development			

After adequate immobilization: Quiescent appearance indicating subsided healing			

(De Boer et al., 2015)

Estimated post-traumatic time interval:

Notes:

Appendix C: Post-traumatic Time Interval

Post-traumatic time interval estimates for each individual with a fracture are listed. Baldock is listed first, followed by Gambier-Parry Lodge, and then Roman Granada. In the Individual column, BAL = Baldock, GLOS GAM = Gambier-Parry Lodge, CRA = Carissa Aurelia, OSC = Cerro San Cristobal, and GRGR = colegio de La Presentacion. CRA, OSC, and GRGR are site codes for the three sites that make up the Granada skeletal sample. YA = Young Adult, MA = Middle Adult, OA = Old Adult, and A = Adult. M = Male, F = Female.

Individual	Bone	Stage	Post-traumatic time interval (Lovell 2008)	Post-traumatic time interval – Macroscopic (DeBoer et al. 2016)	Post-traumatic time interval – Radiographic (DeBoer et al. 2016)
BAL 883 (MA, M)	Left Clavicle	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL 1028 (YA, F)	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL 1072 (YA, M)	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Rib	Antemortem	Callus Formation (3-9 weeks)	After 21-28 days	28 days to 6 weeks
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL 1111 (OA, F)	Left Fibula	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL 1191 (YA, M)	Left Radius	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL 1203 (YA, M)	Right Clavicle	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL 1372 (YA, M)	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years

BAL 1374 (MA, F)	Right Rib	Antemortem	Callus Formation (3-9 weeks)	15-20 days	15-20 days
	Left Rib	Antemortem	Remodelling (several years)	6-9+ months (pseudoarthrosis)	6-9+ months (pseudoarthrosis)
	Unsided Rib	Antemortem	Cellular Proliferation (48 hours to 2-3 weeks)	7-12 days	7-12 days
BAL 1391 (MA, F)	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL 1447 (YA, F)	Right Clavicle	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL 1480 (MA, M)	Unsided Rib Fragment 1	Antemortem	Callus Formation (3-9 weeks)	After 21-28 days	28 days to 6 weeks
	Unsided Rib Fragment 2	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL 1487 (OA, F)	Right Radius	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL 2225 (OA, M)	Right Fibula	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL F466 (OA, M)	Left Tibia	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Fibula	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Tibia	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Fibula	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Unsided Rib Fragment	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Unsided Rib Fragment	Antemortem	Callus Formation (3-9 weeks)	Around 6 weeks	Inconclusive
BAL F475 L2 (YA, M)	Unsided Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years

BAL F488 L2A (OA, M)	Left Tibia	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Fibula	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
BAL F544 L1 (MA, M)	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Rib Fragment	Antemortem	Callus Formation (3-9 weeks)	6 weeks to 1 year	6 weeks to 1 year

Individual	Bone	Stage	Post-traumatic time interval (Lovell 2008)	Post-traumatic time interval – Macroscopic (DeBoer et al. 2016)	Post-traumatic time interval – Radiographic (DeBoer et al. 2016)
GLOS GAM 507 (YA, M)	Right Tibia	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Fibula	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
GLOS GAM 510 (YA, M)	Right Fibula	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
GLOS GAM 511 (YA, M)	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
GLOS GAM 518 (YA, M)	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
GLOS GAM 521 (OA, F)	Left Femur	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Clavicle	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
GLOS GAM 525 (YA, M)	Left Radius	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Callus formation (2-3 weeks to 8-9 weeks)	Around 6 weeks	Around 6 weeks
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
GLOS GAM 545 (MA, F)	Right Humerus	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Consolidation (several weeks to months)	6 weeks – 1 year	6 weeks – 1 year
	Right Rib	Antemortem	Consolidation (several weeks to months)	Around 6 weeks	Around 6 weeks
GLOS GAM 553 (YA, F)	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Callus formation (2-3 weeks to 8-9 weeks)	Around 20-28 days	Around 20-28 days
GLOS GAM 556 (MA, M)	Unsided Rib	Antemortem	Callus formation (2-3	Around 6 weeks	Around 6 weeks

			weeks to 8-9 weeks)		
GLOS GAM 563 (YA, F)	Left Fibula	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
GLOS GAM 570 (YA, M)	Left Rib	Antemortem	Cellular (24h to 3 weeks)	4-12 days	4-7 days
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
GLOS GAM 571 (MA, F)	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Right Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
GLOS GAM 572 (YA, M)	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
GLOS GAM 577 (OA, F)	Left Rib	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years
GLOS GAM 583 (YA, M)	Left Fibula	Antemortem	Remodelling (several years)	1-2+ years	1-2+ years

Individual	Bone	Stage	Post-traumatic time interval (Lovell 2008)	Post-traumatic time interval – Macroscopic (DeBoer et al. 2016)
CRA 1B (YA, F)	Left Ulna	Antemortem	Cellular Proliferation (3-4 weeks)	20+ days
CRA 3B (A, M)	Right Clavicle	Antemortem	Remodelling (several years)	1-2+ years
CRA 53 (YA, F)	Right Rib	Antemortem	Remodelling (several years)	1-2+ years
CRA 88 (YA, M)	Left Fibula	Antemortem	Remodelling (several years)	1-2+ years
OSC 19B (YA, M)	Right Rib	Antemortem	Remodelling (several years)	1-2+ years
OSC 25A (YA, F)	Left Rib	Antemortem	Remodelling (several years)	1-2+ years
OSC 30 (YA, F)	Left Ulna	Antemortem	Remodelling (several years)	1-2+ years
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years
	Left Rib	Antemortem	Remodelling (several years)	1-2+ years
OSC 70 (OA, F)	Left Rib	Antemortem	Remodelling (several years)	1-2+ years
GRGR 6 (YA, M)	Left Radius	Antemortem	Remodelling (several years)	1-2+ years
GRGR 11 (MA, M)	Right Clavicle	Antemortem	Remodelling (several years)	1-2+ years
GRGR 22 (YA, M)	Left Rib	Antemortem	Remodelling (several years)	1-2+ years
GRGR 27 (OA, F)	Left Ulna	Antemortem	Remodelling (several years)	1-2+ years

Appendix D: Fracture Type and Injury Mechanism

Fracture type and injury mechanism for each individual with a fracture is listed. Information about bone and location is also provided. Baldock is listed first, followed by Gambier-Parry Lodge, and then Roman Granada. In cases where fracture type and mechanism of injury could not be determined, "---" has been inputted into the cell. In the Individual column, BAL = Baldock, GLOS GAM = Gambier-Parry Lodge, CRA = Carissa Aurelia, OSC = Cerro San Cristobal, and GRGR = colegio de La Presentacion. CRA, OSC, and GRGR are site codes for the three sites that make up the Granada skeletal sample. YA = Young Adult, MA = Middle Adult, OA = Old Adult, and A = Adult. M = Male, F = Female.

Individual	Bone	Location	Fracture Type	Mechanism of Injury
BAL 883 (MA, M)	Left Clavicle	Mid 1/3 Shaft	Oblique	Indirect
BAL 1028 (YA, F)	Left Rib	Shaft	---	---
	Left Rib	Shaft	Oblique	Indirect
BAL 1072 (YA, M)	Left Rib	Shaft	---	---
	Left Rib	Shaft	Oblique	Indirect
	Left Rib	Shaft	Oblique	Indirect
BAL 1111 (OA, F)	Left Fibula	Distal 1/3	Greenstick	Indirect
BAL 1191 (YA, M)	Left Radius	Distal 1/3	Oblique	Indirect
BAL 1203 (YA, M)	Right Clavicle	Proximal 1/3	Oblique	Indirect
BAL 1372 (YA, M)	Left Rib	Shaft	Oblique	Indirect
	Left Rib	Shaft	Oblique	Indirect
	Left Rib	Shaft	Transverse	Direct
	Left Rib	Shaft	---	---
	Left Rib	Shaft	---	---
	Right Rib	Shaft	---	---
BAL 1374 (MA, F)	Right Rib	Shaft	Oblique	Indirect
	Left Rib	Shaft	Oblique	Indirect
	Unsided Rib Fragment	Shaft	Oblique	Indirect
BAL 1391 (MA, F)	Right Rib	Shaft	Oblique	Indirect
BAL 1447 (YA, F)	Right Clavicle	Distal 1/3	Oblique	Indirect
BAL 1480 (MA, M)	Unsided Rib Fragment	Shaft	---	---
	Unsided Rib Fragment	Shaft	Transverse	Direct
BAL 1487 (OA, F)	Right Radius	Distal 1/3	Oblique	Indirect
BAL 2225 (OA, M)	Right Fibula	Mid 1/3 Shaft	Oblique	Indirect
	Left Tibia	Distal 1/3 Shaft	Spiral	Indirect

BAL F466 (OA, M)	Left Fibula	Proximal 1/3 Shaft	Spiral	Indirect
	Right Tibia	Distal 1/3 Shaft	Spiral	Indirect
	Right Fibula	Proximal 1/3 Shaft	Spiral	Indirect
	Right Rib	Shaft	Transverse	Direct
	Right Rib	Shaft	Transverse	Direct
	Right Rib	Shaft	Transverse	Direct
	Right Rib	Shaft	Transverse	Direct
	Unsided Rib Fragment	Shaft	---	---
	Unsided Rib Fragment	Shaft	---	---
BAL F475 L2 (YA, M)	Rib	Shaft	Transverse	Direct
BAL F488 L2A (OA, M)	Left Tibia	Mid 1/3 Shaft	Spiral	Indirect
	Left Fibula	Mid 1/3 Shaft	Spiral	Indirect
BAL F544 L1 (MA, M)	Right Rib	Shaft	Transverse	Direct
	Right Rib	Shaft	Transverse	Direct
	Right Rib	Shaft	Transverse	Direct
	Left Rib	Shaft	Transverse	Direct

Individuals	Bone	Location	Fracture Type	Injury Mechanism
GLOS GAM 507 (YA, M)	Right Tibia	Mid 1/3 Shaft	Oblique	Indirect
	Right Fibula	Mid 1/3 Shaft	Oblique	Indirect
GLOS GAM 510 (YA, M)	Right Fibula	Proximal 1/3	Transverse	Indirect
GLOS GAM 511 (YA, M)	Right Rib	Shaft	---	---
GLOS GAM 518 (YA, M)	Right Rib	Shaft	Transverse	Direct
GLOS GAM 521 (OA, F)	Left Femur	Proximal articular	Impacted	Indirect
	Right Clavicle	Proximal 1/3	Oblique	Indirect
GLOS GAM 525 (YA, M)	Left Radius	Distal 1/3	Transverse	Direct
	Right Rib	Angle	---	---
	Right Rib	Shaft	Transverse	Direct
	Right Rib	Shaft	Transverse	Direct
	Right Rib	Shaft	Transverse	Direct
GLOS GAM 545 (MA, F)	Right Humerus	Proximal 1/3	Impacted	Indirect
	Right Rib	Shaft	Oblique	Indirect
	Right Rib	Shaft	Transverse	Direct
	Right Rib	Shaft	Transverse	Direct
GLOS GAM 553 (YA, F)	Left Rib	Shaft	Transverse	Direct
	Right Rib	Shaft	Oblique	Indirect
GLOS GAM 556 (MA, M)	Unsided Rib	Shaft	Transverse	Direct
GLOS GAM 563 (YA, F)	Left Fibula	Distal 1/3	Oblique	Indirect
GLOS GAM 570 (YA, M)	Left Rib	Shaft	---	---
	Left Rib	Angle	Transverse	Direct
GLOS GAM 571 (MA, F)	Right Rib	Angle	Oblique	Indirect
	Right Rib	Angle	Oblique	Indirect
	Right Rib	Angle	Oblique	Indirect
	Right Rib	Shaft	---	---
	Left Rib	Angle	Transverse	Direct
	Left Rib	Angle	Transverse	Direct
GLOS GAM 572 (YA, M)	Left Rib	Shaft	Transverse	Direct
GLOS GAM 577 (OA, F)	Left Rib	Angle	Oblique	Indirect
GLOS GAM 583 (YA, M)	Left Fibula	Distal 1/3	Transverse	Direct

Individual	Bone	Location	Fracture Type	Injury Mechanism
CRA 1B (YA, F)	Left ulna	Distal 1/3	Transverse	Direct
CRA 3B (A, M)	Right Clavicle	Mid 1/3	Oblique	Indirect
CRA 53 (YA, F)	Right Rib	Shaft	---	---
CRA 88 (YA, M)	Left Fibula	Proximal 1//3	---	---
OSC 19B (YA, M)	Right Rib	Shaft	---	---
OSC 25A (YA, F)	Left Rib	Shaft	---	---
OSC 30 (YA, F)	Left Ulna	Distal 1/3	Transverse	Direct
	Left Rib	Shaft	---	---
	Left Rib	Shaft	---	---
	Left Rib	Shaft	---	---
	Left Rib	Shaft	---	---
OSC 70 (OA, F)	Left Rib	Angle	Oblique	Indirect
GRGR 6 (YA, M)	Left Radius	Distal 1/3	---	---
GRGR 11 (MA, M)	Right Clavicle	Distal 1/3	Oblique	Indirect
GRGR 22 (YA, M)	Left Rib	Shaft	---	---
GRGR 27 (OA, F)	Left Ulna	Distal 1/3	---	---