REHABILITATION IN THE CARDIAC SURGERY INTENSIVE CARE UNIT

EARLY MOBILIZATION AND IN-BED CYCLING WITH CRITICALLY ILL PATIENTS POST CARDIAC SURGERY

By ANASTASIA NADENE LYNN NEWMAN, H.B. KIN, MSc(PT), MSc

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AUTHOR: Anastasia Nadene Lynn Newman, H.B. Kin, MSc(PT), MSc (McMaster University)

SUPERVISOR: Dr. Patricia Solomon

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LAY ABSTRACT

Early exercise can help patients rehabilitate after a critical illness. No current research exists examining the role of in-bed cycling with patients who become critically ill after heart surgery (so called “off-track”). The thesis goals were: (1) to conduct a survey of Ontario ICU physiotherapists to understand their role treating off-track patients with a complicated post-operative recovery; (2) to determine if cycling is safe and feasible with sick patients after heart surgery in the intensive care unit (ICU); and (3) to interview staff in the Hamilton heart surgery ICU to understand their experiences with in-bed cycling. Ontario physiotherapists provide a multitude of interventions in the heart surgery ICU. Cycling was found to be safe and feasible with adequate physiotherapy staffing. Intensive care unit staff supported in-bed cycling but were concerned about choosing the right patients and how best to time its introduction. With limited evidence around physiotherapy in the heart surgery ICU, larger studies are needed.

ABSTRACT

Critical illness can be iatrogenic, arising from the lifesaving measures undertaken during admission to critical care. Early mobilization (EM) of patients receiving intensive care unit (ICU)-level care may reduce the possible iatrogenic effects of critical care following cardiac surgery. While evidence supports the safety and efficacy of physiotherapy in the medical-surgical ICU, few studies have included critically ill patients with complicated, prolonged post-operative recoveries despite the worldwide frequency of cardiac surgery. This has resulted in a lack of clinical practice guidelines or systematic reviews to help guide critical care physiotherapy practice in post-operative cardiac surgery. In-bed cycling is a modality to initiate EM. However, its safety and feasibility have yet to be established in the critically ill cardiac surgery population. There is also a paucity of qualitative research investigating clinicians' attitudes and beliefs about in-bed cycling as an acceptable rehabilitation modality.

Purposes:

(1) To describe current physiotherapy practice for critically ill adult patients requiring prolonged admissions to ICU post cardiac surgery in Ontario via an electronic, self-administered survey;

(2) To investigate the feasibility of in-bed cycling in a pilot study in a sample of critically ill cardiac surgery patients in Hamilton, Ontario;

(3) To explore primary frontline clinicians' experiences and impressions of their involvement with in-bed cycling in the cardiac surgical ICU via an interpretive description qualitative interview study.

With adequate physiotherapy staffing, in-bed cycling was found to be safe and feasible with few adverse events occurring during cycling. With an 80% response rate, our survey results suggest that Ontario critical care physiotherapists provide a variety of interventions ranging from chest physiotherapy to functional mobility. Clinicians supported the use of in-bed cycling. Concerns included how to identify appropriate patients and timing of the intervention. This thesis built upon the current critical care research by increasing the presence of the cardiac surgery population in the rehabilitation literature.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

6MWT: Six Minute Walk Test

2MWT: Two Minute Walk Test

ARDS: Acute respiratory distress syndrome

APACHE II: Acute Physiology and Chronic Health Evaluation II

bpm: Beats per minute

CABG: Coronary artery bypass graft

CAM-ICU: Confusion Assessment Method for the Intensive Care Unit

CCS: Canadian Cardiovascular Society

CERT: Consensus on Exercise Reporting Template

CHERRIES: Checklist for Reporting Results of Internet E-Surveys

CI: Confidence interval

CIHI: Canadian Institute for Health Information

CIM: Critical illness myopathy

CIP: Critical illness polyneuropathy

CONSORT: Consolidated Standards of Reporting Trials

COPD: Chronic obstructive pulmonary disease

COREQ: Consolidated Criteria for Reporting Qualitative Studies

CPG: Clinical practice guidelines

CRRT: Continuous renal replacement therapy

ECG: Electrocardiogram

ECMO: Extracorporeal membrane oxygenation

EMG: Electromyography

FIM: Functional Independence Measure

FSS-ICU: Functional Status Score for the intensive care unit

HiREB: Hamilton Integrated Research Ethics Board

IABP: Intra-aortic balloon pump

ICU: Intensive care unit

ICUAW: Intensive care unit acquired weakness

ID: Interpretive description

IGF-1: Insulin-like growth factor-1

INF: Interferon

IQR: Interquartile range

km: Kilometer

KT: Knowledge Translation

KTA: Knowledge to Action

m: Meters

MAP: Mean arterial pressure

MRC: Medical Research Council

n: Number

Nm: Newton-meters

Nkg:	Newton-kilogram
NYHA:	New York Health Association
PCI:	Percutaneous coronary intervention
PFIT:	Physical Function in Intensive Care Test
PICS:	Post intensive care syndrome
POD:	Post operative day
PVD:	Peripheral vascular disease
RASS:	Richmond Agitation-Sedation Scale
RCT:	Randomized controlled trial
RN:	Registered nurse
RPM:	Revolutions per minute
RT:	Respiratory therapist
SD:	Standard deviation
SF-36 :	Short Form 36
SOFA :	Sequential Organ Failure Assessment
TNF-α:	Tumor necrosis factor alpha

LIST OF SYMBOLS

%	Percent
=	Equals
<	Less than
>	Greater than
≤	Lesser than or equal to
≥	Greater than or equal to
±	Plus or minus
/	Per
α	Alpha

DECLARATION OF ACADEMIC ACHIEVEMENT

The following is a sandwich thesis that consists of three manuscripts (Chapters 2 through 4), each structured as required by the individual journals to which they were submitted. I, Anastasia Nadene Lynn Newman, contributed significantly to each of the included manuscripts. As such, I am the first author for all three included studies.

STUDENT CONTRIBUTIONS

Chapter 2: Survey of Physiotherapy Practice in Ontario Cardiac Surgery Intensive Care Units

I designed and developed the survey questions and created the online survey using the Lime Survey platform. I applied for and obtained ethics approval from the Hamilton Integrated Research Ethics Board (HiREB). I contacted each cardiac surgical site and identified the 35 physiotherapists who received an email invitation. I ensured that all participants who completed the survey received their $25 incentive at the end of the study period. I also conducted the data analysis and interpretation and wrote the subsequent manuscript.

Chapter 3: A Pilot Feasibility Study of In-Bed Cycling in Critically Ill Patients Post Cardiac Surgery

I designed, developed, and implemented the CardiO Cycle research protocol along with assistance from my supervisory committee. I applied for and obtained ethics approval from HiREB and successfully obtained funding from the Hamilton Health Sciences Foundation to support this research. I contributed to the design and modification of all forms used to collect patient data. During the 19-month enrollment period, I screened for eligible patients, implemented bedside cycling with all enrolled participants with assistance from my critical care physiotherapy colleagues, performed data collection, entered data into the REDCap database, conducted data analysis and interpretation, and prepared the manuscript for publication. Finally, I performed all study administration duties, such as yearly ethic renewals, staff training and education, and coordinating equipment maintenance through Restorative Therapies.

Chapter 4: The Experience of Cardiac Surgery Critical Care Clinicians with In-Bed Cycling in Adult Patients Undergoing Complex Cardiac Surgery

I applied for ethics approval from HiREB and submitted the yearly renewals. I developed the interview guide and conducted each of the nine semi-structured interviews. I performed content analysis, coded each of the transcripts, and identified themes and subthemes from the data. I also prepared the manuscript for publication.

CO-AUTHOR CONTRIBUTIONS

Chapter 2: Survey of Physiotherapy Practice in Ontario Cardiac Surgery Intensive Care Units

Michelle Kho, Jocelyn Harris, Alison Fox-Robichaud, and Patty Solomon contributed to the development and refinement of the survey. All co-authors contributed to data interpretation and provided feedback on the manuscript.

Chapter 3: A Pilot Feasibility Study of In-Bed Cycling in Critically Ill Patients Post Cardiac Surgery

Michelle Kho, Jocelyn Harris, Alison Fox-Robichaud, and Patty Solomon assisted with the study protocol development and revisions, data analysis and interpretation, and manuscript revisions. Ellen MacDonald assisted with protocol and case report form development and manuscript review. Nasim Zamir assisted with data analysis and interpretation and provided feedback on the manuscript.

Chapter 4: The Experience of Cardiac Surgery Critical Care Clinicians with In-Bed Cycling in Adult Patients Undergoing Complex Cardiac Surgery

Michelle Kho, Jocelyn Harris, Alison Fox-Robichaud, and Patty Solomon contributed to the development and modification of the study protocol, interview questionnaire, data analysis and interpretation, and gave feedback on the prepared manuscript. Patty Solomon also assisted with coding and thematic development.

Thesis Introduction

Critical illness is defined as a disease or condition where death is highly possible or imminent.[1] It arises as a result of the presenting injury or disease but may also be consequence of the intensive care unit (ICU) medical management.[1] It can affect a multitude of organ systems, including the cardiovascular, neurological, respiratory and integumentary systems.[2] Prior to the development of the ICU in the 1950s, the course of an acutely ill patient was one of physiological deterioration and eventual death.[1,3] Patients diagnosed with polio during the 1952 epidemic in Denmark had an initial mortality rate of 80%, which subsequently decreased to 25% upon the administration of positive pressure airway management and specialized acute care.[4,5] Since the inaugural ICU, advances in medical science and technology have led to more effective management of patients with critical illnesses.[3] While increased ICU survival rates can be attributed to significant modernization of medical interventions and technologies,[6] this improvement has led to an increase in the number of patients who are left with a plethora of post-ICU morbidities and impairments.[7-9]

Intensive care units are structured and specialized units that provide organ support, invasive monitoring, and close observation of patients admitted with life threatening illness or injuries. While the first variation of an ICU arose out of the poliomyelitis epidemic in Denmark in 1952, Florence Nightingale has been credited with the blueprint of critical care.[10] Prior to the Crimean War in the 1850s, patients of various levels of illness or injury were treated together in one area. Nightingale was the first to consider separating wounded British soldiers based on the severity of their condition, moving the sickest patients closer to the nursing station, effectively inventing the process of triage.[5] Her insistence on monitoring the sickest patients more closely and more frequently has become the mainstay of ICU care and is one of the most identifiable attributes of critical care provision.[5] Modern critical care encompasses advanced therapeutic, monitoring, and diagnostic technology with the objective of supporting organ function and improving patient outcomes.[11] While initially staffed by physicians and nurses, ICUs are now serviced by a diverse group of healthcare practitioners that seek to provide patients with holistic care. Critical care physiotherapists are integral team members that assist with the promotion and initiation of physical activity and functional mobility within the ICU setting.

The World Health Organization (WHO) defines rehabilitation as "a set of interventions needed when a person is experiencing or is likely to experience limitation in everyday functioning due to ageing or a health condition, including chronic diseases or disorders, injuries or traumas."[12] In the ICU, the role of physiotherapy is diverse and involves assessing, treating and managing both respiratory conditions and mobility issues with the goal of rehabilitating critically ill patients.[13] Critical care physiotherapists provide a variety of interventions with critically ill patients, including patient positioning, airway clearance techniques, suctioning, passive and active range of motion exercises, bed exercises, strength and balance exercises, and ambulation.[14] Over the past 15 to 20 years, there has been a surge in research evaluating the role and effectiveness of physiotherapy and rehabilitation in the ICU.[15,16] Early mobilization, defined as the application of different modes of physical activity, including range of motion, functional mobility and ambulation, as early as possible in the care of critically ill patients,[17] has been associated with fewer days mechanically ventilated,[18] improved rates of delirium,[18] higher Six Minute Walk Test (6MWT) scores upon hospital discharge,[18,19] improved strength and functional mobility,[18,20-22] and a lower likelihood of developing intensive care unit acquired weakness (ICUAW).[18] However, other research has found no difference between patients undergoing early physical rehabilitation versus standard care.[23-26] Further research is required to obtain more definitive results on the effects of early physical rehabilitation with critically ill patients, and in particular how best to structure and time the implementation of this rehabilitation in order to improve patient outcomes.[16]

In Canada, there is a trend towards an aging population, with octogenarians the fastest growing demographic in North America.[27] It is expected that the number of people over the age of 65 will increase from 4.2 million to 9.8 million between the years of 2005 and 2036.[28] Across North America, the population of octogenarians will likely double in number between 2000 and 2026 due to increased life expectancy and the increasing number of people entering this age group.[29] These numbers will have a significant impact on the healthcare system. As the majority of patients admitted to ICU are over the age of 65, the demand for critical care in the next several decades is expected to rise.[30] Approximately 54% of the patients admitted to a Canadian ICU in 2014 were over the age of 65.[31] Needham and colleagues project an 80% increase in the need for mechanical ventilation in 2026 as compared to 2000 based on the demographic trends across Canada.[29] In their 2016 executive summary of the use of critical care in Canada (excluding Quebec), the Canadian Institute for Health Information (CIHI) found a 12% increase in ICU admissions between 2007 and 2014.[31] This increase in the number of patients admitted to ICU, combined with both the advancing age of the population and improved critical care mortality rates, will lead to a rise in the number of ICU survivors who may develop prolonged functional impairments.[3]

Cardiac Surgery Demographics

Cardiac surgery, including coronary artery bypass graft (CABG), valve replacements or repair, aortic aneurysm repair and a combination of the above, is one of the most common surgical interventions performed worldwide, with the vast majority requiring post-operative ICU care.[32] More than 500,000 patients undergo cardiac surgery each year in the United States, with the majority of these surgeries occurring in patients over the age of 65.[33] Coronary artery bypass grafting and valve replacement surgeries were the second and third most commonly performed surgeries in Canada in 2016, outnumbered only by percutaneous coronary interventions (PCIs).[31] The last 10 to 15 years has seen a decrease in the overall number of CABG surgeries performed.[32] Mirroring the advancements in critical care management, this change in practice has been precipitated by the improvements in both medical technology and procedural skill at less invasive cardiac revascularization through the use of PCIs. As the number of PCIs performed each year increases, the patients qualifying for cardiac surgery tend to be older with complex co-morbid conditions.[34] With advancing age as an independent risk factor of the need for prolonged critical care admissions post cardiac surgery, the need for ICU-level care post cardiac surgery is expected to rise along with our aging population.[33]

In a 2006 Canadian prospective cohort study of 2754 patients, both advanced age and the number of significant co-morbidities, such as diabetes (683/2754, 24.8%), peripheral vascular disease (PVD) (283/2754, 10.3%), and chronic obstructive pulmonary disease (COPD) (496/2754, 18.0%), were found to be more common in patients undergoing cardiac surgery.[35] As the number of co-morbid conditions increases, so does the risk of post-operative morbidity and mortality.[35] Older patients often present with a large number of co-morbidities which can increase the risk of prolonged intubation and extended critical care admissions. Age itself has been found to be an independent risk factor of post-operative morbidity and mortality in patient undergoing cardiac surgery.[27]

The terms 'on track' or 'fast track' refer to interventions involving several components of care during cardiac anesthesia and the immediate postoperative period, all with the goal of early extubation after surgery.[36] Examples include limiting sedation use post-operatively and early initiation of weaning from the mechanical ventilator.[36] Patients with post-operative on-track cardiac surgery trajectories spend less time in ICU (≤ 48 hours) and have an overall reduced hospital length of stay (≤ 5 days).[36] The reported one-year mortality rate for on-track patients is approximately 2.1%.[33] Conversely, "off track" patients require prolonged stays in ICU and more invasive monitoring such as prolonged mechanical ventilation, dialysis, and intra-aortic balloon pump (IABP). It is these individuals with complicated post-operative courses who have an increased risk of poor long-term outcomes and for development of ICU-acquired impairments.[33] Patients with off-track post-operative recoveries have a reported one-year mortality rate of 33.2%.[33] These ICU-acquired impairments are discussed in detail below.

Intensive Care Unit Acquired Weakness

Admission to ICU often leads to prolonged periods of relative immobility. The effects of bed rest on critically ill patients have been well documented in the literature and include muscle atrophy, bone degradation, contractures, and a documented loss of muscle strength of one to three percent per day.[37,38] Medical procedures, mechanical ventilation, prolonged periods of immobility, and the use of critical care medications have contributed to many individuals experiencing significant neuromuscular weakness, functional impairments, and cognitive dysfunction.[39]

One significant complication resulting from prolonged ICU stay is ICUAW. An umbrella term that encompasses several distinct pathological entities, ICUAW is defined as generalized muscle weakness which develops during the course of an ICU admission and for which no other cause can be identified besides the acute illness or its treatment.[40] Initially described in the nineteenth century as the "loss of flesh and strength" in patients with life-threatening infections,[41,42] its identification as a leading cause of prolonged functional disability and increased mortality has only recently been accepted in the last few decades.[40,43] Subtypes of ICUAW include critical illness polyneuropathy (CIP), critical illness myopathy (CIM) and a combined critical illness polyneuromyopathy in which patients present with features of both CIP and CIM.[38,43,44] Due to the considerable overlap in the clinical presentations of CIP and CIM, it is difficult to determine their individual incidences.[45] It is estimated that between 25% to 75% of mechanically ventilated, critically ill patients will develop signs and symptoms of CIP or CIM.[45]

Critical Illness Polyneuropathy

Critical illness polyneuropathy is a distal sensory-motor axonopathy that affects both limb and respiratory muscles.[44] It leads to flaccid tetraparesis, a reduction or loss of deep tendon reflexes and a loss of sensation to light touch and pin prick.[40,44,46,47] It presents as preferential weakness in the distal versus proximal muscle groups and in the lower limbs versus the upper limbs.[40] Failure to wean from the mechanical ventilator is a key feature of this condition. As facial musculature involvement is often spared, facial grimacing during pain provocation testing without an associated withdrawal of the tested limb is highly suggestive of CIP.[46] Electrophysiological testing, the gold standard for diagnosing CIP, demonstrates a reduction in the amplitude of compound muscle action potentials and sensory nerve action potentials with normal or mildly reduced nerve conduction velocity.[44]

The pathogenesis of CIP remains incompletely understood. Histological evaluations note axonal degeneration as the main pathological finding.[42] While the exact cause of this axonal degeneration has yet to be elucidated, one suggested mechanism is the onset of microvascular changes within the endoneurium leading to vascular permeability and eventual penetration of toxic factors into nerve endings.[40,42] The resulting endoneural edema impairs energy delivery, leading to eventual axon death. Alterations in endoneural membrane depolarization due to voltage-gated sodium channel dysfunction has also been proposed as another cause of CIP.[44]

Critical Illness Myopathy

Critical illness myopathy results from a complex interaction of multiple processes that negatively affect muscle structure and function.[40] It is believed to arise from a combination of both muscle atrophy and impaired contractility with a noted preferential loss in myosin and myosin-related proteins relative to actin filaments.[44,48] It presents as flaccid, symmetrical atrophy of the limbs and neck flexors with proximal muscles more affected than distal.[42] Unlike CIP, sensation remains intact in CIM.[42]

Numerous pathological mechanisms have been proposed to explain the development of skeletal muscle weakness. Muscle atrophy in the critically ill results from a disparity between muscle proteolysis and proteins synthesis, where proteolysis rapidly overwhelms the muscle's synthesis capabilities.[48] In critically ill states, autophagy is upregulated, leading to increased muscle breakdown and resulting in an increase in circulating toxins that are typically removed during usual cellular hygiene.[48] Muscle mitochondria biogenesis is also impaired, resulting in ATP depletion, impairment in mechanosensing, cytopathic hypoxia, and the production of reactive oxygen species.[44,48]

Infiltration of adipose tissue and fibrous deposits is associated with impaired muscle mass recovery and function and may represent a dysfunctional repair process post tissue injury sustained during critical illness.[48] Histopathological studies have suggested that a hyperpolarized state develops with critical illness that leads to a reduction in the availability of sodium channels for action potential generation at resting membrane potential.[42,44] Chronic inflammatory states increase the production and circulation of free radicals.[44] Free radicals, including nitric oxide and reactive oxygen species, depress myofibrillar protein contractile function and interferes with myofilament interactions. Finally, in critically ill states, chronically elevated sympathetic nervous activity leads to excitation-contraction uncoupling through a lack of calcium sequestration within the sarcoplasmic reticulum and subsequent increased cytoplasmic content.[44]

Diaphragmatic Weakness

Associated with ICUAW but often overlooked is the development of diaphragmatic weakness (DW). Defined as a decrease in diaphragm strength after the initiation of mechanical ventilation or as a consequence of sepsis, it is associated with reduced pressure generating capacity and decreased diaphragm thickness.[49] Some studies suggest that DW is more common than ICUAW. In a 2013 six-month observational prospective cohort study, 85 mechanically ventilated patients underwent tracheal twitch pressure assessment after magnetic stimulation of the phrenic nerve within 24 hours of intubation.[50] Within 24 hours, 53% of patients had developed DW as evidenced by reduced phrenic nerve stimulation pressures. An additional 26% of the enrolled patients exhibited signs of DW within a week.[50] Similar to CIM and CIP, the pathophysiology of DW remains incompletely understood. Suggested pathophysiological mechanisms include: (1) oxidative stress caused by increased mitochondrial reactive oxygen species which results from an increase in cytokine production; (2) metabolic dysfunction due to a sudden decreased in diaphragm activity resulting in metabolic substrate oversupply and leading to subsequent mitochondrial overload; (3) altered proteostasis due to the upregulation of autophagy; and (4) increased production of cytokines such as IL-6 and TNF-α.[49]

Risk Factors for Developing Intensive Care Unit Acquired Weakness

Several risk factors have been consistently implicated in the development of ICUAW, including sepsis, systemic inflammatory response syndrome, and multiple organ failure.[40,51] In a 2018 systematic review with meta-analysis, the use of aminoglycosides, neuromuscular blocking agents, and the severity of illness were found to be associated with the development of ICUAW, reaching statistical significance ($p < 0.05$).[52] Other possible risk factors include hyperglycemia, duration of immobilization, use of corticosteroids, female sex, advanced age, hypotension, renal replacement therapy and premorbid functional status prior to ICU admission, though these still require verification through large scale studies.[40,43]

Intensive Care Unit Acquired Weakness and Cardiac Surgery

Despite the significant amount of research being conducted on ICUAW, there are limited reports of the impact of this condition on patients who develop a critical illness after cardiac surgery. Previous literature includes two case reports[53,54] and a prospective cohort study[55]. Both case reports presented patients who were relatively young (ages 40[53] and 50[54]) who developed ICUAW after a prolonged ICU admission with minimal premorbid conditions. While the case described by Alhan et al was admitted for an urgent repair of an acutely dissecting aorta[53], the case described by Baek et al underwent a scheduled double valve replacement[54]. Both patients required prolonged post-operative stays and post-ICU rehabilitation (12 weeks[53] and 64 days[54] respectively). There was near-complete recovery by both patients at hospital discharge. In the 1997 German prospective cohort study, seven of the 1511 patients who underwent cardiac surgery developed CIP.[55] Patients who developed CIP had significantly increased length of ICU stay (62 ± 3 versus 14 ± 8 days, $p < 0.01$), spent more time mechanically ventilated (50 ± 28 versus 7 ± 13 days, $p < 0.01$), and required greater use of inotropic medications (85.7% versus 35.1%, $p < 0.05$), continuous renal replacement therapy (85.7% versus 5.4%, $p < 0.01$) and corticosteroids (100% versus 10.8%, $p < 0.01$) as compared to those without a CIP diagnosis. The development of CIP was not associated with a specific cardiac surgery procedure nor with the length of time on cardiopulmonary bypass.[55] Similar to the case reports, pre-operative health status of the seven patients was not associated with CIP.

Patients post cardiac surgery are at risk of developing cardiogenic shock, a life-threatening condition that involves hypotension (≤ 90 mmHg) in the absence of hypovolemia and associated with cyanosis, cold extremities, changes in mental status, persistent oliguria, and congestive heart failure.[56,57] Approximately 6% of patients post cardiac surgery will develop cardiogenic shock.[58] Perioperative myocardial injury can occur from a variety of causes, including ischemia-reperfusion and physical trauma from manual cardiac manipulation during surgery.[58] These events, plus the risk of systemic inflammatory response from cardiopulmonary bypass, can result in persistently low cardiac output with eventual worsening cardiac function and subsequent end-organ damage from poor tissue perfusion.[58] This resultant multi-system organ failure increases the risk of prolonged ICU admissions and subsequent development of ICUAW. Overall, this places the off-track, critically ill population at risk of significant post-operative morbidity and mortality.[56,57]

Nearly 500,000 cardiac surgeries are performed yearly in the United States.[33] Hence, with a 3% risk of developing post-operative complications,[33] approximately 15,000 patients per year will be at risk of acquiring ICUAW and/or DW. As future research continues to investigate the root causes of ICUAW, these findings will help guide future rehabilitation strategies. Improved understanding of how rehabilitation impacts the physiology and long-term outcomes of critically ill patients is necessary so physiotherapists can time the initiation of and assess the effectiveness of tailored treatments and rehabilitation programs.

Prognosis of Intensive Care Unit Acquired Weakness

The long-term effects of critical illness have become a focus for critical care researchers.[9,59] Survivors of critical illness are often left with significant disabilities, including impairments in physical function, cognition and psychological wellbeing, termed Post-Intensive Care Syndrome (PICS).[60] This syndrome is defined as a new or worsening impairment in physical, cognitive, or mental health status arising after critical illness and persisting beyond discharge from the acute care setting.[60] Numerous studies have described the physical, cognitive, psychological and functional impairments experienced by survivors of critical care.[7,44,59,61] Common physical and psychological symptoms include generalized weakness, fatigue, decreased mobility, anxious or depressed mood, sleep disturbances, memory loss, and slow mental processing.[8,60]

In their seminal work with survivors of acute respiratory distress syndrome (ARDS) who required prolonged admissions to critical care, Herridge and colleagues identified significant functional impairments at both 1-year and 5-year follow-up assessments.[7,62] With an average age of 44 years, only 48% of patients had returned to work one year after hospital discharge.[62] Four years later, only 77% of study participants reported having returned to work.[7] The authors also found that distance walked, as measured by the 6MWT, was significantly reduced as compared to age- and sex-matched normative values at the 1-year (422m (277m – 510m)), 3-year (418m (311m – 474m)) and 5-year (436 (324m – 512m)) follow-up assessments.[7]

In a 2019 Greek prospective cohort study, Sidiras and colleagues enrolled 128 patients and hypothesized that patients diagnosed with ICUAW would have decreased functional ability and quality of life 6 months after hospital discharge.[63] Their sample included patients with cardiovascular diagnoses, though they did not specify if this included patients post cardiac surgery. Patients diagnosed with ICUAW were noted to spend significantly more time mechanically ventilated and had higher Acute Physiology and Chronic Health Evaluation (APACHE) II scores and Sequential Organ Failure Assessment (SOFA) scores versus their non-ICUAW counterparts. Muscle strength, as assessed by the MRC sum score, was also significantly reduced at ICU discharge (37 (29 – 44) versus 57 (54 – 60), $p < 0.001$), hospital discharge (53 (49 – 56) versus 59 (58 – 60), $p < 0.001$) and 3 months post hospital discharge (59 (57 – 60) versus 60 (59 – 60), $p = 0.01$) in those with an ICUAW diagnosis.[63] While there was no significant difference in muscle strength noted between the two groups at the 6 month assessment, functional ability, assessed by the Functional Independence Measure (FIM), was found to be significantly reduced at hospital discharge (65 (53 – 87) versus 111 (86 – 122), $p < 0.001$) and 3 months (116 (73 – 126) versus 126 (121 – 126), $p = 0.002$), and 6 months (116 (87

– 126) versus 126 (124 – 126), $p = 0.001$) post discharge in patients with ICUAW. In-hospital ($p = 0.001$) and 6-month post discharge ($p = 0.04$) mortality was also significantly higher in patients with ICUAW.[63] Using the Nottingham Health Profile, quality of life of those with ICUAW was significantly impacted at hospital discharge in all areas except sleep ($p < 0.05$) and remained significantly reduced in all domains at 6 months post hospital discharge ($p < 0.05$). The impact of ICUAW extends well beyond a patient's ICU stay and significantly impacts physical function, quality of life, and mortality. Identifying means of preventing or mitigating the development of ICUAW is a necessary and essential endeavour.

Hermans and colleagues conducted a prospective, propensity-matched cohort study with a 5-year follow-up to evaluate the long-term effects of short (< 8 days) versus prolonged (≥ 8 days) ICU admissions on mortality and morbidity in a population of medical-surgical patients, including those post cardiac surgery.[64] The authors hypothesized that prolonged critical care admissions would be associated with increased mortality and morbidity at follow-up. Primary outcomes included 5-year all-cause mortality and post-28-day 5-year mortality. Secondary outcomes were handgrip strength, 6MWT, and SF-36 Physical Function score. One-to-one propensity-score matching of short-stay and long-stay patients was performed for nutritional strategy, demographics, comorbidities, illness severity, and admission diagnosis. Prolonged ICU stays were significantly associated with worse outcomes. All-cause 5-year mortality was significantly higher in long-stay versus short-stay patients (48.2% (95% CI: 43.9% to 52.6%) versus 36.2% (95% CI: 32.4% to 40.0%), $p < 0.001$). Post 28-day mortality was also significantly higher in the long-stay group (40.8% (95% CI: 36.4% to 45.1%) versus 29.7% (95% CI: 26.0% to 33.5%), $p < 0.001$). Similarly, handgrip strength (83% (95% CI: 60% to 100%) versus 87% (95% CI: 73% to 103%), $p = 0.019$), 6MWT distance (85% (95% CI: 69% to 101%) versus 94% (95% CI: 75% to 105%), $p = 0.005$), and SF-36 Physical Function scores (65 (95% CI: 35 to 90) versus 75 (95% CI: 55 to 90), $p = 0.002$) were significantly lower in the long-stay group. Multivariable regression analysis identified benzodiazepine use, vasopressor administration, and opioid use as possible ICU exposure variables that could explain the increased 5-year morbidity in the long-stay patients.

Prolonged admissions to ICU appear to impact mortality and function well beyond ICU discharge. These results are important to consider for the critically ill cardiac surgery population. Many off-track patients will have extended critical care admissions, and many will require multiple vasopressor or inotropic hemodynamic support, leading to an increased risk of morbidity and mortality post ICU-discharge. Identifying strategies that can help mitigate these risks, including the impact of rehabilitation on physical function measures, is essential.

Early initiation of rehabilitation in the ICU is one means of attempting to mitigate the effects of ICUAW. It is important to understand the impact of early mobilization in the treatment of critically ill patients post cardiac surgery with ICUAW as a means of potentially preventing the long-term functional disabilities associated with prolonged ICU admissions.

Early Mobilization in the Intensive Care Unit

Early mobilization of patients receiving ICU-level care is one means of reducing the harmful effects of critical care.[18] In the last decade, research has supported the safety and efficacy of early mobilization of patients requiring intensive care, including improvements in muscle strength[19], functional status[18,30,39], ventilator-dependent days[18], ICU and hospital length of stay[39] and delirium days.[18,39,65] In a 2017 systematic review with meta-analysis of 14 randomized or controlled clinical trials of the effects of active mobilization and rehabilitation in ICU on mortality and function, the authors noted that ICU rehabilitation led to greater muscle strength at ICU discharge, greater probability of walking without assistance at hospital discharge and more days alive and out of hospital to day 180.[22] The authors note that due to the diversity of patient populations enrolled across these 14 studies and the lack of subgroup population analysis, it is unclear which populations may most benefit from the early initiation of rehabilitation in the ICU.[22] Only one of the included studies included a population of solely critically ill patients post cardiac surgery.[66]

There is little rehabilitation research to guide clinical practice in the cardiac surgery ICU. Considering the number of cardiac surgeries both in Canada and worldwide, there is a need to examine current bedside physiotherapy practice to understand how physiotherapists are implementing care with critically ill, off-track patients post cardiac surgery. There remains a lack of information about how early mobilization and other critical care physiotherapy interventions are being implemented at the bedside and the factors that facilitate or impede the initiation of physiotherapy with these complex patients.

Rationale and Overview of Thesis Chapters

The role of physiotherapy in patients post cardiac surgery is diverse and not well studied.[67-69] Although most often initiated post-operatively, physiotherapy for 'on track' patients has commonly involved the initiation of education, deep breathing exercises, ambulation, strengthening exercises, and stair assessment, with discharge home around post-operative day (POD) five.[67,70] Despite the growing body of evidence supporting the role of early mobilization of patients in the ICU, the role of physiotherapy interventions in 'off track' patients undergoing cardiac surgery has received little attention.[66,69,71] The overarching goal of this thesis was to add to the body of knowledge surrounding the role of physiotherapy with critically ill off-track patients undergoing cardiac surgery with prolonged post-operative recovery. A brief rationale for each study and an overview of the included manuscripts comprising the next three chapters of my thesis are presented below.

Chapter 2: Survey of Physiotherapy Practice in Ontario Cardiac Surgery Intensive Care Units

The objective of the first manuscript was to develop and administer an electronic survey to describe current physiotherapy practice for off-track, critically ill adult patients requiring prolonged critical care stays in ICU (> 3 days) post cardiac surgery in Ontario. Specific aims included the identification of (1) typical physiotherapy interventions, (2) barriers and facilitators to early mobilization practices, (3) outcome measures used by critical care physiotherapists in the cardiac surgical ICU, and (4) current physiotherapy practice with patients requiring specific medical devices (IABP, continuous renal replacement therapy (CRRT), extracorporeal membrane oxygenation (ECMO)).

Four previous surveys have assessed the role of physiotherapy in adult patients undergoing cardiac surgery.[67,72-74] All four surveys included physiotherapists providing care for patients undergoing routine cardiac surgery, with Tucker et al specifying that only senior physiotherapists were surveyed.[67,72-74] Three of the four studies utilized postal questionnaires to obtain information from the responding physiotherapists,[72-74] while Overend et al conducted their survey via telephone.[67] The number of hospital sites surveyed ranged from eight to 43. Of the four surveys, two were conducted in Sweden,[72,73] one in Australia/New Zealand[74] and one in Canada.[67] All four reported high response rates, ranging from 83% to 100%. While these surveys provided insights into the routine physiotherapy provided post "on track" cardiac surgery, it has been a decade since the last survey was conducted in 2011. The role of physiotherapy in the cardiac ICU was not addressed in any of these surveys.

To guide the development, testing, and administration of the survey, I utilized the steps outlined by Burns et al in 2008.[75] I used Lime Survey as the secure, web-based platform for the design and management of the survey. Thirty-five physiotherapists employed in the 11 cardiac surgery ICUs across Ontario, Canada were identified and offered enrollment. I obtained an overall response rate of 80%. Respondents acknowledged that critically ill patients received physiotherapy while admitted to the

ICU, with passive and active range of motion exercises, manual chest physiotherapy techniques and sitting at the edge of the bed the most commonly implemented therapies.

The most commonly identified barriers to the initiation of early mobilization in ICU included patient acuity and lack of equipment. Adequate nursing staff, physician support and an appropriate complement of physiotherapy staffing facilitated early mobilization. Outcome measure use was limited. Intra-aortic balloon pump and ECMO appeared to restrict physiotherapy practice. The results of this study identified implementation gaps between stated practice and clinical research in regard to the use of outcome measures and adjunct rehabilitation therapies. It will help to inform a future national survey to identify cardiac surgery critical care practice patterns across Canada. This manuscript was accepted for publication by Physiotherapy Canada in September 2020.

Chapter 3: CardiO Cycle: A Pilot Feasibility Study of In-Bed Cycling in Critically Ill Patients Post Cardiac Surgery.

The objective of the second manuscript was to develop and conduct a prospective feasibility study of in-bed cycling in a sample of mechanically ventilated, adult critically ill patients post cardiac surgery with prolonged admissions to critical care (≥ 3 days). The early initiation of physiotherapy in the ICU can take many forms. In-bed cycling is a rehabilitation modality that involves the utilization of a bedside cycle ergometer as a means of initiating early mobilization. This device allows patients to cycle passively, actively and a combination of passively and actively and can promote early exercise in patients who are unable to mobilize out of bed.[19,76] The value of its role in the off-track cardiac surgery population remains uncertain.

In a recently published systematic review with meta-analysis, the efficacy and safety of in-bed cycling in critically ill adult patients was evaluated.[77] Fourteen trials were included (12 randomized, 2 non-randomized) with a total of 926 critically ill patients enrolled across all studies. Adverse events were rare, occurring in 0.16% of cycling sessions (5 out of a total of 3,117). The authors noted no difference in physical function at hospital discharge, duration of mechanical ventilation, hospital length of stay, or quality of life at 6 months post hospital discharge between cycling and control groups.[77]

Previous studies have supported the safety of in-bed cycling in a medical-surgical population. Kho and colleagues prospectively identified patients admitted to a 16-bed medical ICU who received in-bed cycling as part of their physiotherapy and critical care rehabilitation and incorporated a retrospective chart review to obtain details of each cycling session.[76] One safety event occurred, the accidental removal of a radial arterial line. Similar results were found in a 2016 prospective safety and feasibility study wherein 33 critically ill, mechanically ventilated patients admitted to a 21-bed adult medical-surgical ICU received in-bed cycling during their critical care admission.[78] Based on an adverse event rate of 2%, it is suggested that in-bed cycling is a safe rehabilitation modality in the critically ill medical-surgical population.[78] Prior to the initiation of their currently on-going multi-center, multinational RCT of in-bed cycling, Kho et al conducted a pilot RCT to determine the feasibility of participant recruitment, intervention delivery, and patient retention.[79] Protocol fidelity was achieved in 78.8% of all cycling sessions.[79] A single adverse event (supraventricular tachycardia) was observed across all cycling opportunities. The authors concluded that a large-scale RCT to evaluate cycling effectiveness was both feasible and safe.[79]

The inclusion of critically ill patients post-cardiac surgery in previous in-bed cycling literature has been limited. In a 2009 Belgian RCT, standard physiotherapy plus 20 minutes of in-bed cycling was associated with greater improvements in 6MWT scores (196m vs. 143m, $p < 0.05$), SF-36 Physical Function scores (21 points vs. 15 points, $p < 0.01$) and quadriceps force (0.54Nkg vs. 0.17Nkg, $p < 0.01$) at hospital discharge than those in the control group.[19] Of the 90 patients included in this study, 39% of their sample had undergone cardiac surgery, which amounted to approximately 35 patients.[19] In 2018, Eggmann and colleagues conducted an RCT with a 6-month follow-up comparing early endurance (using a motor-assisted bed cycle ergometer) and resistance training combined with early mobilization to a control group receiving standard early mobilization alone.[24] Of the 115 patients enrolled in the study, 21 had recently undergone cardiac surgery. No significant differences in 6MWT distances or FIM scores were noted between the intervention and the control group. Unfortunately, no sub-group analysis was performed for the patients post cardiac surgery in either RCT.[19,24] The effectiveness of bedside cycle ergometry in fast-track patients post-cardiac surgery was evaluated by Trevisan et al in a pilot controlled clinical trial which compared 20-minutes of in-bed cycling beginning on the third postoperative day with usual care.[80] Cycle ergometry replaced walking and stair exercises performed by the usual care group. While both groups improved, there was a tendency for greater maximum distance walked on the 6MWT in the cycling group (312.2 ± 80.6 m versus 249.7 ± 61.4m, $p < 0.001$ for both groups).

Pilot and feasibility studies are routinely used as a means of assessing the logistics and practicalities of a future large-scale study.[81] They provide opportunities to evaluate study processes such as recruitment potential, clinical expertise with the proposed study protocol, suitability of eligibility criteria, and data collection strategies and workload.[82,83] Qualifying patients for CardiO Cycle who were previously ambulatory adults (≥ 18 years), and mechanically ventilated for ≥ 72 hours, were enrolled within 3 to 7 days post surgery. Over a 19-month period between August 28, 2017 and March 29, 2019, I screened 2074 patients admitted to ICU-West at the Hamilton General Hospital. Twenty-nine patients met my inclusion criteria, with 25 offered enrollment and 23 consenting (23/25, 92% consent rate). Four were unable to be enrolled due to the current maximum number of patients enrolled at the time of study qualification. Patients underwent a standardized 20-minute protocol of in-bed cycling using the RT300 Supine Cycle which permitted passive cycling, active cycling, or a combination of both with patients in a supine or semi-recumbent position.

All enrolled patients received routine physiotherapy in combination with in-bed cycling. Across a total of 136 patient-cycling sessions, only 3 adverse events occurred with a calculated incidence of 2.2 per 100 patient-cycling sessions (95% CI: 0.5, 6.4). Out of 169 eligible cycling days, cycling was delivered on 136 days for a cycling feasibility rate of 80.5%. In this small, single-center study in-bed cycling was found to be potentially feasible with critically ill patients post cardiac surgery with adequate staffing.

Effectiveness trials with larger sample sizes and more liberal inclusion criteria are warranted. I utilized the guidelines, as laid out by Thabane et al in 2010, when preparing the manuscript for submission.[82] This manuscript was published in Pilot and Feasibility Studies in January 2021.

Chapter 4: The Experiences of Cardiac Surgery Critical Care Clinicians with In-Bed Cycling in Adult Patients Undergoing Complex Cardiac Surgery

The objective of the third manuscript was to explore frontline clinicians' experiences of in-bed cycling in the cardiac surgical ICU as a method of early initiation of rehabilitation with critically ill patients post cardiac surgery using an interpretive description methodology. Specifically, we examined (1) whether this intervention was acceptable and (2) explored the perceived barriers and facilitators to its implementation.

Implementation of early rehabilitation as part of routine ICU care can be challenging despite evidence supporting its safety and feasibility.[84] In a 2016 literature review, 28 unique barriers to early mobilization were identified across 40 studies of varying methodologies, including prospective cohort studies, RCTs, and quality improvement studies.[85] Examples of barriers that impede the delivery of physiotherapy in the ICU included patient-specific issues, such as delirium, agitation, fatigue, pain and high severity of illness. Structural barriers, such as limited staff, limited equipment, and time constraints, were reported by 70% of the included studies while barriers related to ICU culture, such as lack of mobility culture and lack of staff knowledge and expertise, were reported in 60% of the papers.[85] Staffing limitations, inadequate staff training, limited equipment, and a lack of a mobility culture were noted barriers.

In a 2018 qualitative study, 40 healthcare professionals from the United States and Canada, including nurses, rehabilitation professionals, respiratory therapists, and physicians, were interviewed to identify perceived barriers and facilitators to early rehabilitation in their respective ICUs.[84] A strong working relationship with bedside critical care nurses was identified as a key facilitator by rehabilitation staff. Inadequate physiotherapy staffing and discord between physiotherapists and bedside nursing staff about patient appropriateness for early rehabilitation were acknowledged by physiotherapists as significant barriers to practice.[84] While this study incorporated a variety of clinical backgrounds and experience, novel modalities such as the in-bed cycle ergometer were not discussed in the semi-structured interviews, nor did the authors identify the specific patient populations and critical care locations that inspired the clinician responses.

Three qualitative studies examined the role of in-bed cycling in critical care.[86-88] Populations consisted of both adult[86,88] and pediatric[87] patients. Increased familiarity with the modality increased both caregiver and staff acceptance of the device.[87] In-bed cycling allowed patients to feel safe, to feel in control of and be an active contributor in their own recovery, and to remain hopefully about their recovery.[86] Commonly identified barriers of cycling implementation included lack of physiotherapy resources[87], patient safety concerns[86,87], low patient motivation or fatigue[87,88], and the opinion that early mobilization was not a priority[88]. Clinicians felt that in-bed cycling assisted with the physical recovery of their patients, did not increase patient pain or discomfort, and minimally affected their ability to access a patient.[88]

Interpretive description is defined as a non-categorical, inductive analytic research method of developing clinical understanding.[89-91] Developed by Thorne and colleagues as a response to the lack of clinically-based qualitative methodologies, ID acknowledges both the personal experience of disease and illness as well as the potential for applying these findings into clinical practice with similar patient populations.[89,91] The foundation of interpretive description is the smaller scale qualitative investigation of a clinical phenomenon of interest to the discipline for the purpose of capturing themes and patterns within subjective perceptions and generating an interpretive description capable of informing clinical understanding.[91]

Using purposive sampling, I interviewed 9 frontline health care providers from a variety of professional backgrounds who were involved with cycling critically ill patients post cardiac surgery (i.e., registered nurses, respiratory therapist, physiotherapists, intensivist, physician assistant, nurse educator). Overall, participants supported the use of in-bed cycling as a rehabilitation modality. Acceptability appeared to be influenced by (1) previous cycling experiences, both positive and negative; (2) identification of the "ideal" patient who would benefit from the intervention; and (3) determining the "right timing" to introduce in-bed cycling within a critically ill patient's recovery process. The importance of striving towards a common goal and feeling confident in the method were two facilitator subthemes that emerged from the interview data. Participants noted that staffing shortages, of both nursing and physiotherapy, could negatively impact the ability to offer cycling. The presence of several patients with high acuity within the same room was a potential limiting factor as nursing staff would be required to assist with providing care to the most critically ill patient. Misconceptions around which medical devices are compatible with cycling were also raised, with some participants believing that femoral catheters and continuous renal replacement therapy prohibited cycling. Participants also raised concerns that cycling was not functional in nature, contrasting the method with more conventional bedside exercises. Finally, logistical concerns, such as the size of the ergometer and the limited space within the ICU, were also acknowledged to be potential barriers to cycling implementation. These results highlight the complexities of introducing a novel rehabilitation modality into a critical care environment. Future studies are needed to elucidate which critically ill patients benefit most from the use of in-bed cycling, how best to time the introduction of this modality within a patient's recovery trajectory, and how to overcome identified barriers to implementation. This manuscript was accepted for publication by Disability and Rehabilitation in April 2021.

CHAPTER 2

Survey of Physiotherapy Practice in Ontario Cardiac Surgery Intensive Care Units

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Survey of Physiotherapy Practice in Ontario Cardiac Surgery Intensive Care Units

Anastasia N.L. Newman;[*†] Michelle E. Kho;[*‡] Jocelyn E. Harris;[*] Alison Fox-Robichaud;[†§] Patricia Solomon[*]

From the: *School of Rehabilitation Science; §Department of Medicine, Division of Critical Care, McMaster University; †Hamilton Health Sciences; ‡Physiotherapy Department, St. Joseph's Healthcare Hamilton, Hamilton, Ont.

Correspondence to: Anastasia Newman, School of Rehabilitation Science, McMaster University, 1400 Main Street West, Hamilton, ON L8S 1C7; newmanan@mcmaster.ca.

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Abstract

Purpose: This article describes current physiotherapy practice for critically ill adult patients requiring prolonged stays in critical care (> 3 d) after complicated cardiac surgery in Ontario.

Method: We distributed an electronic, self-administered 52-item survey to 35 critical care physiotherapists who treat adult cardiac surgery patients at 11 cardiac surgical sites. Pilot testing and clinical sensibility testing were conducted beforehand. Participants were sent four email reminders.

Results: The response rate was 80% (28/35). The median (inter-quartile range) reported number of cardiac surgeries performed per week was 30 (10), with a median number of 14.5 (4) cardiac surgery beds per site. Typical reported caseloads ranged from 6 to 10 patients per day per therapist, and 93% reported that they had initiated physiotherapy with patients once they were clinically stable in the intensive care unit. Of 28 treatments, range of motion exercises (27; 96.4%), airway clearance techniques (26; 92.9%), and sitting at the edge of the bed (25; 89.3%) were the most common. Intra-aortic balloon pump and extracorporeal membrane oxygenation appeared to limit physiotherapy practice. Use of outcome measures was limited.

Conclusions: Physiotherapists provide a variety of interventions with critically ill cardiac surgery patients. Further evaluation of the limited use of outcome measures in the cardiac surgical intensive care unit is warranted.

Introduction

Cardiac surgeries are commonly performed around the world, and the majority of patients require postoperative intensive care.[1] Advances in surgical and anesthetic techniques have reduced the mortality and morbidity of patients after cardiac surgery. In addition, improvements in medical technology and procedural skill at cardiac revascularization have expanded the role of non-invasive revascularization in restoring blood flow, thereby delaying the need for cardiac surgery until a more advanced age.[1] Consequently, patients who undergo cardiac surgery are generally older and have a greater number of comorbidities, a situation that leads to increased case complexity compared with a decade ago.[1,2]

This more complex and older patient demographic is associated with an increased risk of developing postoperative complications,[3] including requiring prolonged time on mechanical ventilation,[4,5] receiving critical care medications, and developing intensive care unit (ICU)–acquired weakness.[6-9] The term off-track is used to denote the approximately 3% of patients who will require an extended critical care stay after surgery (defined as > 3 d).[3,10]

In the past decade, an increasing number of studies have investigated the safety and effectiveness of physical rehabilitation strategies in the ICU, including early mobilization.[11,12] Early mobilization is defined as the early initiation and intensification of traditional modes of physiotherapy and physical activity once patients achieve medical stability.[12] However, information remains lacking on how early mobilization and other critical care physiotherapy interventions are being implemented at the bedside in the cardiac surgical ICU and the factors that facilitate or impede initiating physiotherapy with these patients. Considering the frequency of cardiac surgeries both in Canada and around the world, a better understanding is needed of the current role of physiotherapy in treating critically ill patients who have undergone cardiac surgery.

Four surveys have evaluated physiotherapy practice in the ICU with stable, uncomplicated post–cardiac surgery patients. In a 1996 postal survey carried out in Australia and New Zealand, the respondents preoperatively identified patients at risk of postoperative pulmonary complications and provided manual hyperinflation and suctioning to intubated patients on postoperative day (POD) 0.[13] The patients had performed deep breathing exercises and assisted cough and limb exercises after extubation.[13] In a 2010 Canadian telephone survey, Overend and colleagues found that the majority of cardiac surgery sites had initiated routine physiotherapy on POD 1 in the ICU and ambulation on POD 2.[14] A 2010 Swedish postal survey of physiotherapy-supervised mobilization reported that the majority of respondents had provided preoperative information to all patients undergoing non-emergency cardiac surgeries.[15] Sitting at the edge of the bed and chair transfers were initiated on POD 1, and 79% began ambulation in the patient's room on POD 2.[15] In a subsequent Swedish survey using the same respondent sample, 88% of the respondents had provided preoperative information on breathing exercises. The respondents had performed manual chest physiotherapy on POD 1 and instructed patients in both splinted coughing and hourly deep breathing.[16]

None of these studies examined the use of standardized outcome measures in the cardiac surgery ICU.

Although these surveys provide insights into routine physiotherapy delivered after uncomplicated cardiac surgery, the role of physiotherapy with critically ill, off-track patients requiring prolonged ICU stays has not been investigated. Given that the increasing age and medical complexity of patients qualifying for cardiac surgery increases the risk of postoperative complications, gaps in the literature made our survey necessary to determine physiotherapy practice, use of modalities, and implementation of outcome measures.

The impact of life-saving medical devices, such as the intra-aortic balloon pump (IABP) and extracorporeal membrane oxygenation (ECMO), on physiotherapy practice in the cardiac ICU is unknown. Determining the potential influences on physiotherapy care of off-track patients, including the barriers to and facilitators of best practices and the use of outcome measures, could help to identify strategies for advancing practice. The findings will serve as a baseline for understanding stated Ontario physiotherapy practice in off-track critically ill patients after cardiac surgery.

The overall purpose of this study was to describe current physiotherapy practice for treating adult patients who require prolonged critical care stays in the ICU (> 3 d) after complicated cardiac surgery in Ontario. Our specific aims were to identify (1) the typical physiotherapy interventions, (2) the barriers to and facilitators of early mobilization practices (in-bed exercises, bedside mobility, ambulation), (3) the outcome measures used by critical care physiotherapists in the cardiac surgical ICU, and (4) current physiotherapy practice with patients requiring specific medical devices, such as IABP, ECMO, and continuous renal replacement therapy (CRRT).

This study received ethics approval from the Hamilton Integrated Research Ethics Board (Project No. 5620).

Methods

Study design

We conducted a cross-sectional, self-administered electronic survey of physiotherapists who were providing care to critically ill patients who had cardiac surgery, required an extended stay in the ICU (> 3 d), and required advanced life support measures (e.g., vasopressive or inotropic medications, dialysis, prolonged mechanical ventilation or failed extubation).

Respondents

Using the Canadian Cardiovascular Critical Care Society website, we identified 11 hospitals that performed cardiac surgery in Ontario. To identify eligible respondents, we contacted each hospital's cardiac surgery ICU and obtained the names and email addresses of all the critical care physiotherapists. All the physiotherapists employed full time or part time in an Ontario adult cardiac surgery ICU were then invited to participate.

Survey development, format, and content

We developed a preliminary version of our survey guided by the literature and the clinical expertise of the lead author, ANLN.[17,18] This process generated 73 items. Three physiotherapists, each with more than 15 years of cardiac surgery ICU experience at the same surgical site, reduced the number of items by identifying those to be included using the binary responses yes and no. We then conducted pilot and clinical sensibility testing. Two cardiac ICU physiotherapists and a former ICU physiotherapy student completed the pilot electronic survey. After survey completion, they responded to a brief questionnaire about the survey's overall completeness, missing items, any redundancy in the questions, and the likelihood of the survey eliciting reliable information about cardiac critical care physiotherapy practice. The goal of the clinical sensibility questionnaire was to further reduce the number of items and evaluate the administrative ease, comprehensiveness, clarity, and face validity of the survey.[18,19] The final version of the survey consisted of 52 items and required approximately 15 minutes to complete. (The survey is reproduced in the online Appendix.)

Survey administration

We used LimeSurvey (Version 3.22; LimeSurvey GmbH, Hamburg, Germany) to administer the survey. Three weeks before the survey was distributed, each participant was sent an email outlining its purpose. The survey link was sent out on May 15, 2019, and the survey closed on June 19, 2019. Four weekly reminders were sent. Before beginning the survey, the respondents gave their informed consent by reading the electronic waiver and then checking a checkbox. Each respondent was assigned a unique identifier to prevent duplicate survey responses. After they had completed the survey, the participants received a $25 gift card.

Statistical analysis

Descriptive statistics – means, medians, inter-quartile ranges (IQRs), and frequency and percentage response distributions – were used to analyze the numeric data. The response rate was calculated by determining the proportion of completed surveys compared with the total number of surveys sent, presented as a percentage. We included responses from all respondents who had completed both the demographic section and at least one of the other seven sections. We used Stata 14.2 (StataCorp LLC, College Station, TX) to statistically analyze the data.

Results

Respondents' demographics

We identified 35 critical care physiotherapists across the 11 cardiac surgery centres. In total, 27 full surveys and 1 partially completed survey were received, for an overall response rate of 80.0%. Of the 28 respondents, 27 were women. The median (IQR) number of years of clinical experience in the cardiac surgery ICU was 12 (13.5). Further details are presented in Table 1.

Table 1 Respondents' Characteristics (*N* = 28)

Characteristic	***n* (%)***
Female	27 (96.4)
Born, y	
Before 1970	7 (25.0)
1970–1979	10 (35.7)
1980–1989	9 (32.1)
1990–1999	2 (7.1)
Physiotherapy degree	
Master's	16 (57.1)
Undergraduate	12 (42.9)
Country of education	
Canada	25 (89.3)
Other	3 (10.7)
Country/region of previous practice	
Canada only	22 (78.6)
United States	2 (7.1)
Australia/New Zealand	2 (7.1)
Europe	1 (3.6)
Asia	1 (3.6)
Cardiac surgery ICU physiotherapy experience, y, median (IQR)	12 (13.5)
Time between graduation and starting work in a cardiac ICU, y	
Immediately after graduation	7 (25.0)
<1	5 (17.9)
1–2	4 (14.3)
3–4	3 (10.7)
>4	9 (32.1)

Note: Percentages may not total 100 because of rounding.
* Unless otherwise indicated.
ICU = intensive care unit; IQR = inter-quartile range.

Site characteristics

The median (IQR) number of cardiac surgical beds per site was 14.5 (4), with a median full-time-equivalent (FTE) staffing of 1.25 (1.1). The median number of surgeries performed each week was 30 (10; range, min–max, 9–60). The majority of respondents (18; 64.3%) carried a caseload of 6–10 patients per day, and 24 (86.0%) indicated that all patients had been assessed by an ICU physiotherapist on POD 1. Additional site characteristics are presented in Table 2.

Table 2 Characteristics of the 11 Sites (*N* = 28)

Characteristic	***n* (%)***
No. of cardiac surgery beds, median (IQR)	14.5 (4.0)
FTE staffing, median (IQR)	1.25 (1.1)
No. of cardiac surgeries performed per wk, median (IQR)	30 (10)
Physiotherapy patient caseload per d	
1–5	2 (7.1)
6–10	18 (64.3)
11–15	6 (21.4)
> 15	2 (7.1)
Method of referral to physiotherapy†	
Physician referral	23 (82.1)
Screening by physiotherapist	13 (46.4)
Nursing request	5 (17.9)
Type of cardiac surgery performed‡	
CABG	28 (100.0)
Valve replacement or repair	28 (100.0)
CABG + valve	28 (100.0)
Transcatheter aortic valve implantation	28 (100.0)
Replace or repair ascending aorta	27 (96.4)
Bentall procedure	26 (92.9)
Minimally invasive valve replacement/repair	25 (89.3)
Replace/repair hemi-arch	24 (85.7)
Minimally invasive CABG	18 (64.3)
Ross (pulmonary autograft) procedure	16 (57.1)
Trauma	14 (50.0)
No. of critically ill patients (with ICU length of stay > 3 d), per wk	
1–2	7 (25.0)
3–4	12 (42.9)
5–6	7 (25.0)
Other	2 (7.1)

* Unless otherwise indicated.
† More than 1 method could be used.
‡ More than 1 type could be performed.
IQR = interquartile range; FTE = full-time equivalent; CABG = coronary artery bypass graft; ICU = intensive care unit.

Typical physiotherapy interventions used

Of the 28 respondents, 26 (93.0%) indicated that off-track patients had received physiotherapy interventions in the ICU. The presence of inotropic and vasopressor infusions did not impede initiating physiotherapy for 26 physiotherapists (93.0%). A typical physiotherapy treatment could include passive and active range of motion exercises (27; 96.4%), airway clearance techniques (26; 93.0%), sitting at the edge of the bed (25; 89.3%), suctioning (24; 85.7%), bed exercises (20; 71.4%), and ambulation (16; 57.1%). Half of the respondents (14) had performed chest physiotherapy techniques, including manual percussions, vibrations, and rib springing, and 15 (53.6%) had shared this role with professionals from other disciplines, such as respiratory therapists and registered nurses.

The respondents reported using several modalities, including tilt-table standing (10; 35.7%), in-bed cycle ergometry (8; 28.6%), arm ergometry (2; 7.1%), and neuromuscular electrical stimulation (1; 3.6%). These results are presented in Table 3.

Table 3 Typical Physiotherapy Interventions Used (*N* = 28)

Intervention	***n* (%)**
Component of typical physiotherapy treatment, % yes*	
Range of motion exercises	27 (96.4)
Airway clearance techniques	26 (92.9)
Sitting at edge of bed	25 (89.3)
Transfer to bedside chair	25 (89.3)
Suctioning	24 (85.7)
Pre-ambulation exercises	24 (85.7)
Bed mobility	23 (82.1)
Bed exercises	20 (71.4)
Ambulation	16 (57.1)
Typical length of physiotherapy intervention, min	

< 15	1 (3.6)
15–25	14 (50.0)
> 25	13 (46.4)
Use of adjunct therapy, % yes*	
Tilt-table standing	10 (35.7)
In-bed cycling	8 (28.6)
Arm ergometry	2 (7.1)
Neuromuscular electrical stimulation	1 (3.6)
Other	3 (10.7)
I do not routinely use adjunct therapies	14 (50.0)

* Respondents could select more than one.

Barriers and facilitators to early mobilization

A total of 22 respondents (78.6%) acknowledged that they had experienced barriers to their ability to implement early mobilization in the ICU. Patient acuity was the most common barrier (19/28; 67.9%), followed by lack of equipment (7/27; 25.0%).

Adequate nursing staff was the most frequently endorsed facilitator (25; 89.3%). A total of 21 respondents (75.0%) stated that physician support had contributed to an early mobilization culture in the ICU. Physiotherapy staffing levels (18; 64.3%), access to appropriate mobility equipment such as wheelchairs and gait aids (15; 53.6%), and coverage for vacation and sick days (12; 42.9%) were also important facilitators of early mobilization. Further information on the identified barriers and facilitators is presented in Table 4.

Table 4 Barriers to and Facilitators of Early Mobilization in the ICU (*N* = 28)

Barriers and Facilitators	*n* (%)*
Barriers	
Patients too medically unstable	19 (67.9)
Lack of equipment	7 (25.0)
Lack of physiotherapy staffing	6 (21.4)

Caseload numbers	6 (21.4)
No barriers	6 (21.4)
Site does not support early mobilization	3 (10.7)
Facilitators	
Sufficient nursing staff	25 (89.3)
Support of ICU colleagues	21 (75.0)
Appropriate physiotherapy staffing levels	18 (64.3)
Physical environment (i.e., space)	15 (53.6)
Access to proper equipment	15 (53.6)
Vacation or sick time coverage	12 (42.9)
Rehabilitation assistants in ICU	3 (10.7)

* Respondents could choose more than 1.
ICU = intensive care unit.

Use of outcome measures in the cardiac surgery intensive care unit

The use of outcome measures was limited: of the respondents, 13 (46.4%) reported that they did not routinely use outcome measures to assess changes in functional status. Manual muscle testing was reported most frequently (17; 60.7%). The FIM (3; 10.7%), the Functional Status Score for ICU (1; 3.6%), hand-grip dynamometry (1; 3.6%), and the 6-minute walk test (1; 3.6%) were used only minimally with this population.

Reported physiotherapy practice with patients requiring specific medical devices

Femoral arterial lines

Of 27 respondents, 11 (40.7%) reported mobilizing patients using a femoral arterial line in situ. Of these, 7 reported that this was a policy in their institution. Chest physiotherapy, suctioning, and quadrilateral range of motion exercises were conducted by all 11 therapists. In-bed mobility and sitting at the edge of the bed were reported by 10 (90.9%) of these 11 physiotherapists, followed by pre-ambulation exercises (e.g., sit to stand, marching in place; 7; 63.6%), bed-to-chair transfers (5; 45.5%), and ambulation (4; 36.4%).

Intra-aortic balloon pumps

Although 96.3% of the respondents (26/27) stated that their sites inserted IABPs peri-operatively to reduce afterload in patients experiencing cardiogenic shock, the presence of this device significantly restricted physiotherapy interventions. Only 4 respondents provided interventions to patients when an IABP was present, including chest physiotherapy, suctioning, range of motion exercises, and bed mobility. One respondent initiated sitting at the edge of the bed, but only among those patients with a non-femoral IABP.[20,21]

Mechanical ventilation

Of 27 respondents, 23 (85.2%) routinely treated patients who required mechanical ventilation, and of these, nearly all provided chest physiotherapy treatments (21; 91.3%), bed mobility (22; 95.7%), sitting at the edge of the bed (22; 95.7%), and pre-ambulation exercises (22; 95.7%). All respondents conducted both in-bed exercises and transfers to a bedside chair. Although these 23 respondents conducted ambulation less frequently (14; 60.9%), when it was initiated, they were assisted equally by respiratory therapists (19; 82.6%) and registered nurses (19; 82.6%).

Continuous renal replacement therapy

CRRT is a means of providing renal support for patients who are hemodynamically unstable using slow, continuous hemofiltration.[22] Of 27 respondents, 24 (88.9%) stated that their site had access to CRRT, and of these 24 physiotherapists, 18 (75.0%) reported routine treatments during continuous dialysis: chest physiotherapy (17; 94.4%), range of motion exercises (17; 94.4%), and suctioning (16; 88.9%) were those most frequently initiated. Although half of these respondents (9) initiated bedside sitting in patients undergoing CRRT, only 3 (16.7%) transferred patients to a bedside chair, and none routinely ambulated them.

Extracorporeal membrane oxygenation

ECMO provides cardiac and respiratory support using artificial gas exchange and perfusion to patients with severe cardiorespiratory failure.[23] Of 27 respondents, 12 (44.4%) stated that their site offered this intervention, but only 2 (16.7%) reported that they routinely provided care for these patients. Both of these physiotherapists reported using range of motion exercises, bed mobility, sitting at the edge of the bed, pre-ambulation exercises, and bed-to-chair transfers with patients using ECMO; 1 reported routinely ambulating these patients.

Discussion

This is the first survey carried out with critical care physiotherapists working in cardiac surgical ICUs in Ontario. Its strengths are the multiple stages of survey development, following guidelines previously established by Burns and colleagues,[18] and a high response rate of 80%.

To the best of our knowledge, this is the first survey on physiotherapy practice with critically ill, off-track patients who had complicated cardiac surgery in Ontario. Our research builds on four previous surveys[13-16] by reporting data on critically ill patients with prolonged stays in the ICU. The previous surveys focused solely on interventions provided to cardiac surgical patients who had routine, uncomplicated postoperative courses.

Our respondents indicated that 6–10 patients per day was the typical daily caseload; the average length of treatment for 50.0% of our respondent sample ranged from 15 to 25 minutes (range, min-max, 90–250 min/d depending on caseload). A recent survey noted that the median shift length for critical care physiotherapists was 7.5 hours (450 min).[24] Considering the additional time required for charting, reviewing relevant diagnostic tests such as chest X-rays, team meetings, and breaks, some physiotherapists may have limited capacity to treat every patient every day. However, the number of patients treated per day is likely influenced by other factors, including the number of physiotherapy staff in a unit as well as the number of off-track patients in the ICU at a given time who often require more treatment time. Predicting which patients would benefit most from physiotherapy in the cardiac surgery ICU would help prioritize care and ensure the efficient use of rehabilitation resources.[14,25] When acuity is high with multiple critically ill patients, strategies to improve caseload management, such as sick time and vacation time coverage, are warranted.

The use of rehabilitation modalities was limited. Just more than one-third of the respondents reported using tilt-table standing in their respective ICUs; in-bed cycle ergometry was the next most common modality at 28.5%. Previous studies have supported the safety and feasibility of tilt-table standing in medical–surgical and neurotrauma populations.[26,27] In-bed cycling has also been found to be safe and feasible,[28] with some studies enrolling critically ill cardiac surgery patients.[10,29] Using modalities can also be time consuming; thus, comparison of their effectiveness and the burden of implementing them is needed. Considering the medical complexity of patients undergoing cardiac surgery and the number of cardiac surgeries performed around the world, patients have a greater likelihood of developing postoperative complications than in previous decades. More research is recommended to determine which modalities are effective in improving the outcomes of the critically ill, off-track cardiac surgery population.

The use of outcome measures was limited in the complicated post–cardiac surgery population, a common issue in physiotherapy practice.[30] Previous surveys in the United States,[30] Australia,[31] and the United Kingdom[32] found that only 21.0%–48.0% of the respondents used standardized outcome measures in their daily practice. Without using appropriate outcome measures, the ability to quantitatively evaluate functional outcomes and the effectiveness of physiotherapy treatment is limited. This disconnect highlights an implementation gap between research findings and clinical practice.[33] The Functional

Status Score for the ICU and the Physical Function in ICU Test are two examples of ICU outcome measures that have been validated with critically ill populations.[34,35] It is important to identify the best ways to enhance the uptake of research in acute care, such as increasing the use of validated, standardized outcome measures so that the effectiveness of physiotherapy treatments can be studied.

The previous literature has suggested that mobility with patients using a femoral arterial line is safe and feasible,[36] yet it was infrequently performed by our respondents. In their 2013 prospective, observational study, Damluji and colleagues found no adverse events during 253 physiotherapy sessions in patients with a femoral catheter in situ.[36] Future research is needed to determine why in situ femoral lines impede mobility in the ICU.

Our respondents did not identify mechanical ventilation as a barrier to initiating physiotherapy. These results are similar to those of a 2016 Canadian survey in which 85.5% of the responding physiotherapists did not identify mechanical ventilation as a barrier to mobilization.[37] Observational studies are necessary to determine the fidelity of stated versus actual practice.

ECMO and IABP were identified as the two most common advanced life support devices that prohibited providing physiotherapy to the critically ill, off-track cardiac surgery population. Evidence on the safety and feasibility of physiotherapy with patients requiring afterload reduction using an IABP is limited.[20,38] In a single-centre prospective, observational safety and feasibility study, 20 patients with femoral cannulated IABP were transitioned from a tilt-table to standing before initiating ambulation without adverse events across 45 total sessions.[38] Several recent publications have suggested that bed exercises, bed-to-chair transfers, and ambulation can be safely and feasibly implemented in patients requiring ECMO, even in those with femoral cannulation.[39-42]

However, two of these four articles were single-person case studies,[41,42] and another was a retrospective cohort study,[39] all of which are prone to bias. Overall, the evidence supporting early mobilization of patients with IABP and ECMO is limited. Before any researcher makes practice recommendations, studies with larger sample sizes and higher methodological quality are necessary to help determine the safety, feasibility, and effectiveness of physiotherapy interventions with patients using these advanced life support devices.

Our research was not without limitations. First, we have presented our results in aggregate to maintain anonymity; however, this prevents us from comparing practice patterns among sites with differing cardiac surgery programme size, between tertiary care centres and peripheral hospitals, and among individual academic centres. This anonymity also prohibited us from identifying any discrepancies in the reporting of FTE and number of beds per site from respondents employed at the same site. Second, to decrease the burden on our respondents and increase the response rate, we used a limited number of open text-box response formats; however, the forced responses did not give the respondents an opportunity to elaborate and may not have captured the nuances of critical care physiotherapy practice.

Conclusion

This survey explored the stated practice patterns of Ontario critical care physiotherapists. Our respondents provided a range of functional exercises and airway clearance techniques. Barriers to early mobilization included patient acuity and lack of equipment. Adequate nursing and rehabilitation staff, along with physician support, were identified as key facilitators of early mobilization. The results of our study highlight the need to further evaluate the limited use of outcome measures in the cardiac surgical ICU and the safety and effectiveness of physiotherapy interventions with patients using advanced life support devices.

Key Messages

What is already known on this topic

In the past decade, patients undergoing cardiac surgery have been older with more comorbidities than those in previous decades. Previous surveys described physiotherapy practice with patients undergoing routine, uncomplicated cardiac surgery.

What this study adds

This survey describes the practice of critical care physiotherapists in cardiac surgery intensive care units (ICUs) in an Ontario context and provides baseline information for future reference. It also identifies the facilitators of, and barriers to, implementing early mobilization in the cardiac surgery ICU. This is the first survey to focus on the role of physiotherapy in treating critically ill, off-track patients who have undergone cardiac surgery. The results can help guide the development of future national surveys and observational studies of frontline physiotherapy practice.

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CHAPTER 3

CardiO Cycle: A Pilot Feasibility Study of In-Bed Cycling in Critically Ill Patients Post Cardiac Surgery

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CardiO Cycle: A pilot feasibility study of in-bed cycling in critically ill patients post cardiac surgery

Anastasia N. L. Newman[1, 2]*, Michelle E. Kho[1, 3], Jocelyn E. Harris[1], Nasim Zamir[4], Ellen McDonald[5], Alison Fox-Robichaud[2, 5], Patricia Solomon[1], for the Canadian Critical Care Trials Group

[1] School of Rehabilitation Science, McMaster University, Hamilton, Ontario, Canada

[2] Hamilton General Hospital, Hamilton, Ontario, Canada

[3] Physiotherapy Department, St. Joseph's Healthcare Hamilton, Hamilton, Ontario, Canada

[4] College of Medicine, University of Saskatchewan, Saskatoon, Saskatchewan, Canada

[5] Department of Medicine, Division of Critical Care, McMaster University, Hamilton, Ontario, Canada

* Corresponding author

Email: newmanan@mcmaster.ca (ANLN)

Abstract

Background

In-bed cycling is a novel modality for the initiation of early mobilization in the intensive care unit. No study has investigated its use in the critically ill, off-track post cardiac surgery population. Before conducting an effectiveness trial, feasibility data are needed. The aim of this study was to determine the feasibility of in-bed cycling in a population of off-track cardiac surgery patients.

Methods

We conducted a prospective feasibility study in a 16-bed adult cardiac surgery intensive care unit in Ontario, Canada. Previously ambulatory adults (≥ 18 years) who were mechanically ventilated for ≥ 72 hours were enrolled within 3 to 7 days post cardiac surgery. Twenty minutes of in-bed cycling was delivered by ICU physiotherapists 5 days/week. The primary outcome, feasibility, was the percent of patient-cycling sessions that occurred when cycling was appropriate. The secondary outcome was cycling safety, measured as cycling discontinuation due to predetermined adverse events.

Results

We screened 2074 patients, 29 met eligibility criteria, and 23 (92%) consented. Patients were male (78.26%) with a median [IQR] age of 76 [11] years, underwent isolated coronary bypass (39.1%), and had a median EuroScore II of 5.4 [7.8]. The mean (SD) time post-surgery to start of cycling was 5.9 (1.4) days. Patients were cycled on 80.5%

(136/169) of eligible days, with limited physiotherapy staffing accounting for 48.5% of the missed patient-cycling sessions. During 136 sessions of cycling, 3 adverse events occurred in 3 individual patients. The incidence of an adverse event was 2.2 per 100 patient-cycling sessions (95% CI: 0.50, 6.4).

Conclusions

In-bed cycling with critically ill cardiac surgery patients is feasible with adequate physiotherapy staffing and appears to be safe. Future studies are needed to determine the effectiveness of this intervention in a larger sample.

Trial Registration

This trial was registered with Clinicaltrials.gov (NCT02976415). Registered November 29, 2016. https://clinicaltrials.gov/ct2/show/NCT02976415

Keywords

Intensive Care Unit, Critical Care, Physiotherapy, Rehabilitation, Cardiac Surgery

Key Messages Regarding Feasibility

1) What uncertainties existed regarding the feasibility?

- It was not known whether it was feasible to enroll a population of critically ill, off-track patients post cardiac surgery, how easy it would be to identify potential patients and gain consent, and whether they would tolerate this rehabilitation modality

2) What are the key feasibility findings?

- It is feasible to enroll critically ill, off-track patients post cardiac surgery although stringent inclusion criteria limited our sample size

3) What are the implications of the feasibility findings for the design of the main study?

- Future studies involving critically ill, off-track patients post cardiac surgery should consider a broader, less strict inclusion criteria, including patients who are extubated, those who failed extubation, and those who were readmitted to the ICU from the rehabilitation ward

Background

The number of cardiac surgeries has decreased significantly over the past decade, precipitated primarily by improvements in the use of percutaneous coronary interventions (PCI). As a result of increasing PCI use, patients who qualify for cardiac surgery are older with more co-morbidities [1]. The development of a critical illness occurs in approximately 3% of this population [2]. These patients have prolonged requirements for ventilatory and hemodynamic support (so called off-track) and may have limited mobilization in the initial post-operative phase.

Early mobilization of patients receiving intensive care unit (ICU)-level care may reduce the iatrogenic effects of critical care [3, 4]. Early mobilization includes the application of various modes of physical activity, including range of motion exercises, functional mobility and ambulation [5]. In-bed cycling using a bedside cycle ergometer is a modality to initiate early mobilization in critically ill patients. The safety and feasibility of in-bed cycling in the non-cardiac surgical ICU population, when initiated within the first 4 days of ICU admission has been documented [6, 7]. Kho and colleagues initiated cycling within 3 days of ICU admission to 33 patients in a medical-surgical ICU and noted infrequent cycling termination and no device dislodgements [7]. Similarly, a single-center randomized controlled trial (RCT) of in-bed cycling plus standard physiotherapy treatment in mechanically-ventilated medical-surgical ICU patients was associated with a low safety occurrence rate of 4% [8]. Eggmann and colleagues' RCT of early endurance and resistance training using an in-bed cycle ergometer versus standard physiotherapy noted a 0.2% adverse event rate [9]. Both RCTs included patients post cardiac surgery in their samples [8, 9]. Unfortunately, no subgroup analyses were performed in either study. It is unknown if any of these safety events occurred in the post-cardiac surgery population.

The benefits of in-bed cycling in critically ill patients [6-8] are conflicting with more recent studies suggesting no difference to conventional therapy [9, 10]. The majority of studies include medical or general surgical populations; the cardiac surgery population has received comparatively less attention. It is typical for on-track patients to be extubated within 8 to 12 hours after surgery and transferred to the ward on post-operative day 1. These patients are able to partake in functional mobility shortly after surgery and will be discharged home between 3 and 5 days post-operatively. The critically ill (off-track) cardiac surgery patients experience longer ICU stays, often have significant hemodynamic issues, and may not tolerate exercise. Saphenous vein graft site integrity during cycling has yet to be evaluated and no previous studies enrolling patients post cardiac surgery have documented graft site integrity while cycling. The purposes of this study were to determine 1) the feasibility of conducting in-bed cycling in a cardiac surgery ICU, 2) the feasibility of meeting a priori enrollment targets, and 3) the safety of in-bed cycling with off-track cardiac surgery patients.

Methods

Between August 28, 2017 and March 29, 2019, we conducted a single-center pilot, prospective, feasibility study in a 16-bed adult cardiac surgery ICU in Hamilton, Ontario, Canada. Our study was approved by the Hamilton Integrated Research Ethics Board (project number 1999) and was registered with Clinicaltrials.gov (NCT02976415). Inclusion criteria were: (1) Cardiac surgery patients ≥ 18 years old, (2) ICU stay for > 3 but < 7 days [7, 11], (3) Mechanically ventilated for > 72 hours, and (4) Able to ambulate independently, with or without a gait aid, before hospital admission. We excluded patients who consistently met one or more of the following criteria during the first 7 days after surgery: (1) Uncomplicated post-operative course with expected discharge to ward within 24 to 72 hours (on-track), (2) New onset of uncontrolled atrial fibrillation with a rate > 130 beats/min (bpm), (3) Temporary pacemaker insertion (transvenous pacemaker) or external pacing with no underlying rhythm, (4) Previous lower extremity injury that prevents cycling, (5) Open or unstable saphenous vein graft incision sites, (6) Presence of an intra-aortic balloon pump (IABP) or femoral sheath, (7) Use of more than 4 inotropes or vasopressors. A research coordinator screened admissions to the cardiac ICU and obtained written informed consent from each patient or their next of kin.

Intervention

Cycling was performed using the RT300 Supine Cycle, a portable in-bed device which provides passive cycling, active cycling or a combination of both with the patient in a supine or semi-recumbent position [12]. Throughout a single treatment session, the RT300 assisted with passive cycling, allowing patients the option to cycle actively, or to rotate between active and passive cycling depending on their physical abilities at the time of cycling. The amount of active versus passive cycling performed during each cycling session was patient controlled. Patients were enrolled for a maximum of 28 days or until they were either able to ambulate or discharged from the unit.

Critical care physiotherapists delivered 20 minutes of in-bed cycling, Monday to Friday, to patients as part of their post-operative care. We chose 20 minutes for consistency with previous cycling research that included patients post-cardiac surgery [8, 9] and moderate-intensity aerobic exercise recommendations for patients with cardiovascular disease [13]. All physiotherapists had received a multi-day training session using the in-bed ergometer and had experience using the device. The session protocol included a 30 second warm-up at a rate of 5 revolutions per minute (RPM) followed by 19 minutes of cycling at a rate of 10 RPMs and a 30 second cool down at 5 RPMs. Resistance was set at 0.6 Newton-meters (Nm) and remained constant for all cycling sessions. Pedaling rate was patient-directed. Patients were monitored by the physiotherapist and the bedside nurse. Physiotherapists provided verbal support to each participant as a means of encouraging active participation. Cycling was performed once per day. Heart rate, oxygen saturation, blood pressure, pulmonary artery pressure (if available), and respiratory rate, were documented before cycling, at 5-minute intervals throughout the 20-minute session and immediately post-cycling. Routine physiotherapy, which included chest physiotherapy, passive and active range of motion, bed exercises, progressive mobility (dangling at edge of bed), transfer training to bedside chair, standing, and ambulation as appropriate, was delivered in addition to cycling. Cycling sessions and routine physiotherapy were performed in separate sessions for all enrolled participants. Table 1 outlines the daily cycling exemptions and cycling termination criteria that were utilized once a patient qualified and was enrolled in the study.

INSERT TABLE 1 HERE

We recorded the route of oxygen delivery, mechanical ventilation settings, presence of dialysis (hemodialysis or continuous renal replacement therapy (CRRT)), agitation and delirium as assessed by the Richmond Agitation-Sedation Scale (RASS) [14], Confusion Assessment Method for ICU (CAM-ICU) [15], as well as the use of specific critical care medications (i.e. vasopressors, inotropes, opiates, benzodiazepines, sedatives and anti-arrhythmics) during cycling sessions.

Primary and secondary outcomes

The primary outcome was feasibility. The feasibility outcomes were 1) The ability to implement in-bed cycling into daily physiotherapy practice at least 80 percent of the time that patients had no cycling exemptions (Table 1; eligible cycling opportunities) and 2) Enrollment of 30 patients or recruitment over the 19-month enrollment period, whichever was achieved first.

The main secondary outcome was cycling safety. We defined the following potential adverse events a priori: (1) Sustained hypertension for ≥ 2 minutes (systolic blood pressure greater than 160 mmHg (or out of range for what is typical for the patient)), (2) Sustained hypotension for ≥ 2 minutes (systolic blood pressure less than 90 mmHg (or out of range for what is typical for the patient)), (3) Cardiorespiratory arrest, (4) Oxygen desaturation less than 88% for ≥ 2 minutes, (5) Removal of any lines or tubes, (6) Cardiac arrhythmias (new onset of uncontrolled atrial fibrillation, bigeminy, trigeminy, junctional or heart block rhythm), (7) Saphenous vein graft incision site dehiscence confirmed by the ICU intensivist, and (8) Sustained increased agitation for ≥ 2 minutes (RASS score > +2) [14].

Other secondary outcomes included: consent rate, hospital all-cause mortality, ICU length of stay, 28-day mortality, EuroScore II, New York Heart Association Functional Classification scores, handgrip strength, Functional Status Score for the Intensive Care Unit (FSS-ICU), Two-Minute Walk Test (2MWT), Clinical Frailty Scale and the number of cycling sessions per patient.

Sample Size Estimation

As no previous safety and feasibility study has been conducted in the cardiac surgery population, we based our enrollment rates on a previous safety and feasibility study of in-bed cycling in a similar-sized medical-surgical ICU [7]. The likelihood of developing a critical illness post cardiac surgery is approximately 3% [2]. With average cardiac surgical case numbers of 1,850/year at the Hamilton General Hospital, we anticipated 4.6 potential patients per month (87 patients total). As this group of potential patients would also include those meeting our exclusion criteria (i.e. patients with a palliative trajectory and non-mechanically ventilated patients who require other critical care interventions), we sought to enroll 30 mechanically ventilated, off-track cardiac surgery patients or recruit for a period of 19-months, whichever came first. A sample size of 30 was deemed sufficient to provide insights into the pragmatisms of recruitment challenges, cycle delivery, and safety with this population.

Analysis

Descriptive statistics were used to analyze participant demographics (e.g., age, sex) and baseline data (e.g., surgery, EuroScore II, saphenous vein incision site). The feasibility outcome was the percent of cycling sessions that occurred compared to the number of eligible cycling opportunities. The safety outcome was the percentage of cycling sessions terminated prematurely due to the development of one of the 8 a priori adverse events. We calculated means and standard deviations (SD) and medians and interquartile ranges [IQR] for normally and non-normally distributed data respectfully. Incidence of adverse events was reported as number of events per 100 patient-cycling sessions with 95% confidence intervals (CI) [16]. Analysis was performed using SPSS (IBM Corporation, 2017).

Progression Criteria

Progression criteria are defined as criteria that inform the decision to progress from a pilot study to a larger definitive trial [17]. Meeting these criteria suggests that a large-scale randomized trial would be viable [17]. We were guided by the work of Avery et al. (2017) and employed a traffic light system for specifying our progression criteria [18]. Using this system, green ("Go") indicated that all criteria has been met and a future, larger scale randomized trial should proceed, yellow ("Amend") indicated that some changes should be made to the larger trial, and red ("Stop") indicated that the investigators should not move forward with a larger trial. For our enrollment feasibility, an enrollment of ≥ 50% of qualifying patients was selected [19]. Progression criteria for cycling feasibility on eligible cycling days of ≥ 70% was chosen [19].

Results

Enrollment Feasibility Results

We screened 2074 patients admitted to the ICU over the 19-month period from August 28, 2017 to March 29, 2019 (Figure 1). We sought to enroll 30 patients. Twenty-nine patients met our inclusion criteria, 25 were offered enrollment, and 23 consented (23/25, 92% consent rate, Figure 1). Four were not approached for consent due to the maximum capacity for physiotherapists to manage 2 concurrent patients at the time of study qualification. We fell short of our enrollment targets by 7 patients, achieving 76.7% of our recruitment goal. The majority of the 2045 patients who did not meet the inclusion criteria (1932/2045, 94.5%) were excluded from consideration due to their routine, uncomplicated post-operative course, and subsequent transfer from the ICU within 72 hours post-surgery. Table 2 describes baseline demographic and clinical characteristics.

The mean (SD) time from ICU admission post cardiac surgery to the initiation of cycling was 5.9 (1.4) days. Overall, our patients cycled a median [IQR] of 4 [2, 8] sessions which yielded 136 patient-cycling sessions and completed a mean (SD) of 113.7 (90.7) minutes of cycling per patient. Of the 136 patient-cycling sessions, 104 (76.5%) occurred while participants were mechanically ventilated via an endotracheal tube, 17 (12.5%) with a pulmonary artery catheter, and 14 (10.3%) during dialysis (8/136 CRRT (5.9%), 6/136 hemodialysis (4.4%)). Participants cycled during receipt of inotropes/vasopressors (35/136, 25.7%), benzodiazepines (22/136, 16.2%), and propofol (36/136, 26.5%). The median [IQR] RASS score pre-cycling was -1 [1.75]. The 28-day mortality rate was 34.8%.

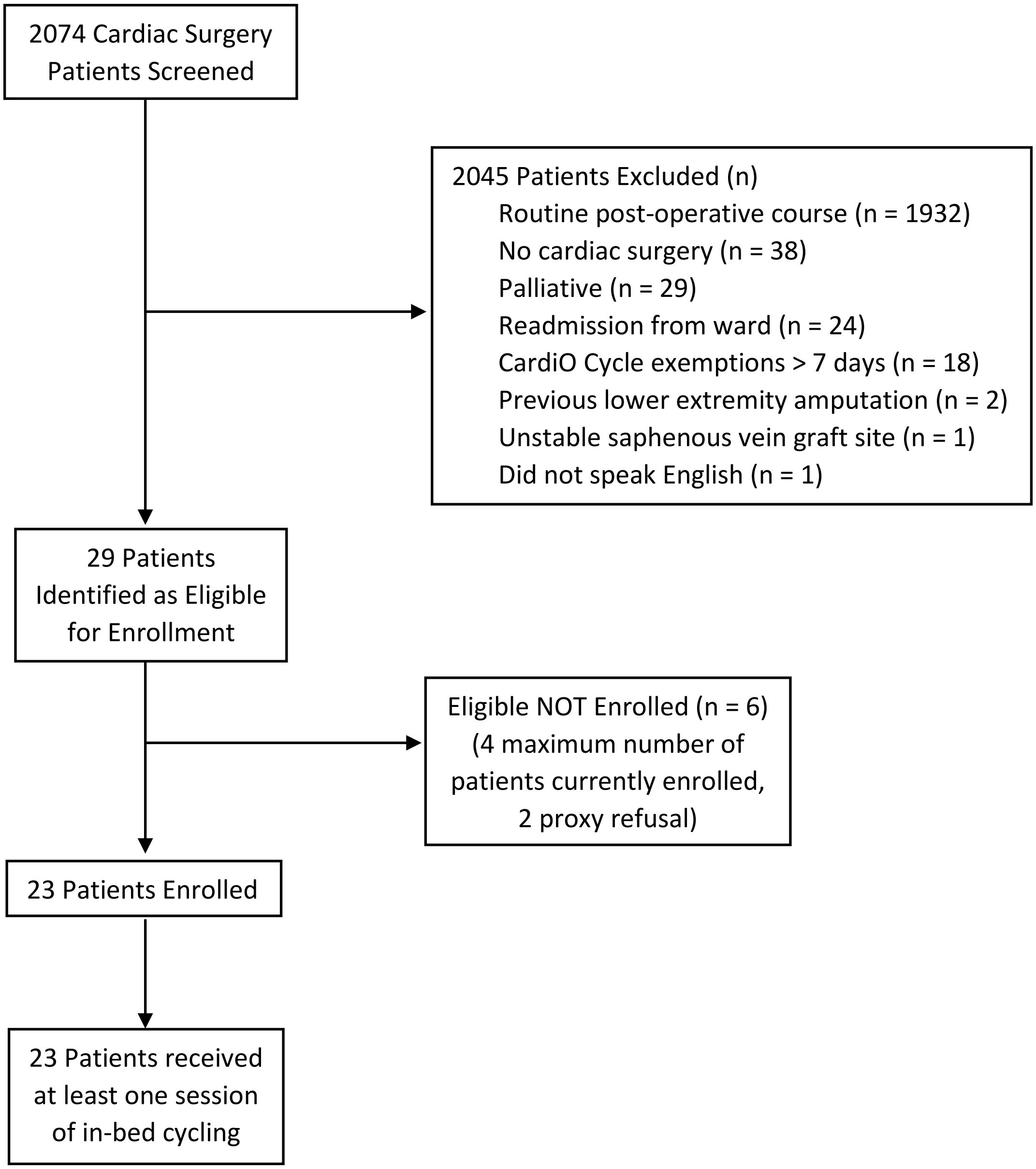

Figure 1: Patient flow diagram.

INSERT TABLE 2 HERE.

For patients enrolled in the study, 150 routine physiotherapy sessions were also conducted. These sessions occurred separately from cycling sessions. The most common routine interventions were airway clearance techniques, including manual percussions, vibrations and tracheal suctioning (131/150, 87.3%), followed by passive range of motion exercises (115/150, 76.7%) and sitting at the edge of the bed (83/150, 55.3%).

Outcome measure results are available in Additional File 1.

Cycling Feasibility Results

There were 169 eligible cycling days with cycling being delivered on 136 of those days (80.5%). Of the 33 days that cycling was not delivered, 16 (48.5%) were due to physiotherapy staffing shortages (e.g. uncovered sick and vacation days) and 6 (18.2%) occurred by participant discharge from ICU without advanced notification, preventing rescheduling of the cycling sessions (Table 3).

Cycling Safety Outcomes

Out of 136 patient-cycling sessions, 3 adverse events in 3 individual patients occurred with a calculated incidence of 2.2 per 100 patient-cycling sessions (95% CI: 0.50, 6.4). Two patients developed hypotension while cycling. One patient became agitated with a RASS of greater than +2. All 3 events lead to cycling termination with no further medical management required. Patients were able to cycle on subsequent days with no further events. The EuroScore II scores for these three patients were 1.58

(developed hypotension), 1.84 (developed agitation) and 3.71 (developed hypotension) respectively. These EuroScore II scores indicated low risk of post-operative mortality. We examined the saphenous vein graft incision sites before, during and after cycling. No wound dehiscence was noted during our study period as determined by the intensivist on staff.

During routine physiotherapy, 5 adverse events occurred in 5 individual patients (5/150, 3.3%): 3 oxygen desaturations to < 88% for > 2 minutes despite attempts to improve oxygenation and 2 developments of cardiac arrhythmias (controlled atrial fibrillation) from previous normal sinus rhythm. No further medical management beyond terminating the physiotherapy intervention was required.

In the 136 patient-cycling sessions, participants cycled a total of 164.6 kilometers (km) with the median [IQR] distance cycled per participant of 5.07 [7.28] km and per session was 1.23 [0] km. The proportion of active versus passive cycling during a single patient-cycling session varied based on each patient's status and available effort given at the time of cycling. Active cycling was noted in 45/136 patient-cycling sessions (33.1%). The minimum and maximum distances cycled during an individual session ranged from 0.49 km to 2.04 km. The maximum total cumulative distance cycled by a single patient was 19.51 km. The majority (123/136, 90.4%) of the patient-cycling sessions were completed to the full protocol with the median [IQR] length of each patient-cycling session being 20.0 [1.3] minutes. The shortest cycling session was 7.9 minutes. The median [IQR] time to set up and complete cycling was 34 [5.7] minutes.

Table 3: Reasons for missed cycling sessions

Reasons for Missed Cycling	**N (%)**
Staffing shortages	16 (48.5%)
Patient discharged from ICU	6 (18.2%)
Patient refusal	4 (12.1%)
Walking milestone achieved in ICU	4 (12.1%)
Daily CardiO Cycle exemption	2 (6.1%)
Bike incompatibility	1 (3.0%)
Total	**33**

Progression Criteria Results

For our enrollment feasibility, we enrolled 92% of our qualifying patients, which exceeded our target by 42%. Similarly, for our cycling feasibility, we were able to offer cycling on 80.5% of eligible cycling days, 10.5% above our target. This would correspond with the green traffic light colour, as per Avery et al. [18].

Discussion

Our study builds on the body of knowledge investigating the safety and feasibility of in-bed cycling with critically ill patients [6-9, 11, 20] and is the first to exclusively enroll off-track patients post complicated cardiac surgery. Our cycling protocol was safe, with only 3 adverse events occurring in 3 patients (incidence of 2.2 per 100 patient-cycling sessions), none of which required any further intervention other than cycling termination. This adverse events rate was similar to other ICU cycling studies (0.2 – 4%) [7, 8].

We obtained a high consent rate of 92% considering the acuity of our population. We screened 2074 patients, however due to our narrow inclusion criteria, only 29 patients qualified. While our inclusion criteria allowed us to include patients with high acuity, it limited the enrollment of other patients who may have benefited from early in-bed cycling, such as those who required reintubation within 48 hours of extubation, extubated patients who required prolonged hemodynamic support, and patients readmitted to ICU from the rehabilitation ward. While we exceeded our progression criteria with respect to recruitment of eligible patients, in consideration of future interventional trials in this population, the combination of our strict inclusion criteria and a high post-operative mortality rate would have limited the ability to assess the effectiveness of in-bed cycling on patients' post-operative strength and functional abilities as well as their long-term functional outcomes. Future effectiveness trials of in-bed cycling in this population should consider broader inclusion criteria to prevent the exclusion of patients who may benefit from the early initiation of this modality, to ensure enrollment targets are met, and to increase the likelihood of assessing long-term functional outcomes.

Feasibility was dependent upon adequate physiotherapy staffing. "Adequate" staffing for critical care physiotherapists is not defined in the literature. However, staffing limitations have been identified as a common structural barrier that can have a significant impact on patient care [21-26]. In a 2015 survey of American critical care physiotherapists, half of the 550 respondents identified insufficient staffing as a barrier to the provision of physiotherapy [21]. Both Needham et al [26] and Morris et al [23] have noted the financial benefits of consistent physiotherapy staffing to hospitals via reduced lengths of stay with adequate staffing.

All patients were cycled on the day of their study enrollment with the mean (SD) time to initiation of cycling from ICU admission of 5.9 (1.4) days. This is more conservative than previous cycling literature [7, 9]. Time to cycling initiation from ICU admission was a median [IQR] of 1.98 [1.45] days and 3 [2] days in Eggmann et al and Kho et al's studies respectively [7, 9]. In contrast, Burtin et al initiated cycling on average 14 days after ICU admission [8]. Given that patients required at least 72 hours of ICU admission before qualifying for study enrollment, cycling was performed within 3 days of study eligibility. Patients in our sample had a high median EuroScore II scores. Once patients were deemed medically stable, they were enrolled, and cycling was initiated. While the ideal timing to initiate early physical rehabilitation strategies with the critically ill is not known, it generally agreed upon that interventions should be delivered in the ICU [27]. Future randomized trials should consider the timing of exercise initiation as dictated by patient medical stability.

More than half our study patients (56.5%) had New York Heart Association Functional Classification scores greater than 3, signifying moderate to severe symptoms of congestive heart failure prior to surgery and 78.2% of our sample scored between Class I and II on the Canadian Cardiovascular Society Scores, indicating that symptoms of angina were present only during strenuous or moderate exertion. Over 80% of our sample were identified as either “Well” or “Managing Well” on the Clinical Frailty Scale [28, 29]. Despite the high operative risk, with a median EuroScore II of 5.4 [7.8], these patients were managing well at home and functionally independent prior to their cardiac surgery. Our mortality rate of 34% was similar to the 33.2% mortality rate in a 2018 population-based cohort study of long-term survival of post-cardiac surgery patients in Ontario [2]. Our sample spent a median of 13 [21] days in ICU and 76.5% of all cycling sessions were conducted while the patient was mechanically ventilated (104/136). In contrast, patients who spent less than two days in ICU had a one-year mortality rate of 2.1% [2]. These findings mirror the current trend of patients undergoing cardiac surgery who do not present as functionally compromised but who have multiple medical comorbidities which increases their operative risk [1, 2].

In comparison, patients identified as “on-track” post cardiac surgery tend to be younger in age, male, have intact left ventricle ejection fraction, no diagnosis of diabetes, and no previous history of either congestive heart failure or cardiac surgery [30]. The majority of these individuals will spend less than a day in ICU and will be discharged home within 5 days of surgery [2, 30]. As we continue to see an increase in the average age of the population undergoing cardiac surgery with underlying co-morbidities, this will impact the post-operative course for a large portion of patients with cardiovascular disease amenable to surgery. Identifying effective rehabilitation modalities to help mitigate the effects of prolonged critical care stays is essential and should be a focus of future physiotherapy research.

Our protocol of 20 minutes of in-bed cycling was consistent with previous cycling literature in which patients post cardiac surgery were enrolled [8, 9]. Eijvogels et al summarized the available evidence on the relationship between exercise volume and risk reductions in cardiovascular morbidity and mortality in patients identified as having cardiovascular disease, many who were post cardiac surgery [13]. Exercise volumes of 150 minutes/week, or 20 minutes/day, of moderate-intensity aerobic exercise were noted to reduce cardiovascular mortality. Considering patients were also receiving routine physiotherapy in addition to in-bed cycling, a 20-minute protocol met previously published recommendations and seemed a feasible length of time for both our patients and physiotherapists.

Admission to ICU is not benign. The strength and functional impairments acquired during extended stays may remain well beyond hospital discharge. Physiotherapy may mitigate the effects of prolonged critical care stays [3, 31, 32]. However, the literature has been divisive with respect to the role of rehabilitation in treating the manifestations of weakness acquired in the ICU and whether the intensity of these interventions is enough to promote muscle strength gains and concomitant improvements in functional abilities. Schweickert et al found that the initiation of early physiotherapy and occupational therapy in the ICU was associated with more patients achieving independent functional status at hospital discharge [3]. A 2018 systematic review of interventions to improve physical function of critically ill patients noted that early rehabilitation was associated with increased functional capacity, muscle strength, and improved walking distance at discharge [33]. In contrast, a recent RCT found no difference between the intervention group who received endurance training (with a cycle ergometer) and resistance training in combination with standard early mobilization as compared to the early mobilization group alone [9]. With the safety and feasibility documented, future research should focus on determining the effectiveness of this intervention in this population.

There are several presumed mechanisms on how muscles may respond to physical stress during the course of a critical illness, including the ability of mechanical signals to induce protein synthesis [34]. If muscles are able to respond to both passive stretch and mechanical stress with increased growth, the implementation of in-bed cycling can be justified as a means of mitigating the effects of prolonged critical care admissions. While only 33% of the cycling sessions in our study had periods of active cycling, the passive cycling may still contribute to promoting muscle strength gains by promoting muscle cell proliferation and growth [34]. This may justify the initiation of cycling while patients are intubated, sedated and unable to actively contribute to cycling. Future studies need to investigate how best to physically challenge critically ill patients with consideration of long-term functional follow-up. Patient strength and functional outcomes, assessed using an outcome measure such as the FSS-ICU [35], post prolonged critical care stays in the cardiac surgical ICU are lacking and should be considered as a means of informing clinicians on best practice for ICU rehabilitation.

In this study, we demonstrated that in-bed cycling was potentially feasible and safe to implement with off-track critically ill patients post cardiac surgery. Future studies can build upon this safety and feasibility evaluation and previous effectiveness studies to determine how best to challenge critically ill patients post cardiac surgery in an effort to moderate the effects of prolonged ICU stays.

Strength and Limitations

This study is novel in that it is the first study to investigate the feasibility and safety of in-bed cycling with a population of solely acutely critically ill, off-track cardiac surgery patients. We obtained a consent rate of 92% across our 19-month enrollment period. While our patients had high median pre-operative EuroScore II results, our findings suggest that in-bed cycling can be implemented with some of the most critically ill patients in the cardiac ICU.

Our study had limitations. We conducted a single-center study thus our results may not represent the broader critically ill cardiac surgery population. We did not meet our target sample size due to our strict inclusion criteria. Future studies should incorporate broader inclusion criteria and target subgroups of the critically ill post cardiac surgery population missed by our strict criteria.

Conclusions

In-bed cycling can be safely implemented in a population of off-track, critically ill patients post cardiac surgery and can be feasibly conducted by critical care physiotherapists with adequate staffing. The results of this single-center safety and feasibility study can be the basis for future studies evaluating the effectiveness of this intervention in this high-risk group. The low adverse event rate can provide confidence to broaden the inclusion criteria to include and enroll patients with or without mechanical ventilation who continue to require critical care interventions in future research.

List of Abbreviations

2MWT: Two-minute walk test

bpm: beats per minute

CABG: coronary artery bypass graft

CAM-ICU: Confusion Assessment Method – Intensive Care Unit

CCS: Canadian classification score

CI : Confidence interval

CRRT: Continuous renal replacement therapy

ECG: Electrocardiogram

FSS-ICU: Functional Status Score for the Intensive Care Unit

IABP: Intra-aortic balloon pump

ICU: Intensive care unit

IQR: Interquartile range

km: Kilometer

MAP: Mean arterial pressure

Nm: Newton-meter

NYHA: New York Health Association

PCI: Percutaneous coronary intervention

PFIT: Physical Function in Intensive Care Test

RASS: Richmond Agitation-Sedation Scale

RCT: Randomized controlled trial

RPM: Revolutions per minute

SD: Standard deviation

Declarations

Ethics Approval and Consent to Participate

This study was reviewed and approved by the Hamilton Integrated Research Ethics Board (Project Number 1999).

Consent for Publication

Not applicable.

Availability of Data and Materials

The datasets generated during the current study are available from the corresponding author on reasonable request.

Competing Interests

None

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Author's Contributions

ANLN, MEK, JEH, AFR, and PS assisted with designing the study. EM assisted with screening and obtaining consent from participants. ANLN performed the data collection. ANLN, MEK, NZ, AFR, and PS interpreted the data. ANLN wrote the manuscript with MEK, JEH, AFR and PS contributing to its review and extensive editing. All authors have reviewed the final manuscript and approved it for submission.

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Table 1: Daily Cycling Exemption and Cycling Termination Criteria

Daily Cycling Exemptions
Use of 4 or more inotropes or vasopressors
Any increased titration of inotropic medication in the past 2 hours
Active myocardial ischemia as confirmed by bedside 12-lead electrocardiogram (ECG)
Mean arterial pressure (MAP) < 60mmHg or > 110mmHg
Heart rate < 40bpm or > 140bpm within the past 2 hours
New onset of uncontrolled atrial fibrillation with a rate greater than 130 beats/min
Persistent $Sp0_2$ less than 88%, or out of what is typical for the patient, within the last 2 hours
Use of neuromuscular blockade within the past 4 hours
Severe agitation, as measured by the Richmond Agitation and Sedation Scale (score > 2)
Presence of an intra-aortic balloon pump or femoral sheath
Insertion of a temporary pacemaker (transvenous pacemaker) or those who are paced externally with no underlying rhythm
Unstable saphenous vein graft site(s)
Change in goals of care to palliation
Patient or proxy refusal
Team perception that cycling is not appropriate despite lack of listed exemption criteria
Cycling Termination Criteria

Sustained decrease in oxygen saturation of < 88% for > 2 minutes despite attempts to improve oxygenation (increasing FiO2, tracheal suctioning)
Patient or proxy refusal after 2 attempts at encouragement to continue
Unplanned extubation or decannulation
Dehiscence of saphenous vein graft incision site(s)
Sudden onset of severe agitation (Richmond Agitation and Sedation Scale (score > 2))
Concerns for new onset of cardiac ischemia as per continuous telemetry
Sudden onset of cardiac arrhythmias (including bradycardia < 40bpm, tachycardia > 140bpm, atrial fibrillation, right or left bundle branch block, sustained ventricular tachycardia, ventricular fibrillation, bigeminy, trigeminy)
Hypotension with a systolic blood pressure < 90mmHg
Accidental removal of any lines or tubes (i.e. chest tubes, Jackson-Pratt drain, arterial line)

Table 2: Participant Demographics and Baseline Information

Patient Demographics	**N = 23 Patients**
Age in years, median [IQR]	76 [11]
Males, n (%)	18 (78.3%)
Employment Status, n (%)	
- **Retired**	16 (69.6%)
- **Employed Full-Time**	2 (8.7%)

- **Employed Part-Time** - **Other/Unknown**	1 (4.3%) 4 (17.4%)
Surgical Procedure, n (%) - **Isolated coronary artery bypass graft (CABG)** - **Single Valve Repair/Replacement** - **Other***	 5 (21.7%) 2 (8.7%) 16 (69.6%)
History of Previous Cardiac Surgery, n (%)	6 (26.1%)
Pre-Operative New York Health Association (NYHA) Functional Classification - **NYHA I** - **NYHA II** - **NYHA II** - **NYHA IV**	 7 (30.4%) 3 (13%) 8 (34.8%) 5 (21.7%)
Pre-Operative Canadian Classification Score (CCS) - **CCS I** - **CCS II** - **CCS III** - **CCS IV**	 13 (56.5%) 5 (21.7%) 4 (17.4%) 1 (4.3%)
Pre-Operative Functional Independence Measure Scores, mean (SD)**	125.5 (1.5)
Pre-Operative Functional Status Score – ICU, mean (SD)	34.9 (0.3)
Pre-Operative Clinical Frailty Score	

- **Very Fit (1)**	1 (4.3%)
- **Well (2)**	9 (39.1%)
- **Managing Well (3)**	10 (43.5%)
- **Vulnerable (4)**	2 (8.7%)
- **Mildly Frail (5)**	1 (4.3%)
- **Moderately Frail (6)**	0 (0%)
- **Severely Frail (7)**	0 (0%)
- **Very Severely Frail (8)**	0 (0%)
- **Terminally Ill (9)**	0 (0%)
Pre-Operative EuroScore II, median [IQR]	5.4 [7.8]
Number of Days Mechanically Ventilated (Routine Physiotherapy)	98/150 (65.3%)
Number of Days Mechanically Ventilated (Cycling)	104/136 (76.5%)
ICU Length of Stay (days), median [IQR]	13 [21]
Hospital Length of Stay (days), median [IQR]	21 [29]
ICU Mortality, n (%)	8 (34.8%)
Hospital Mortality, n (%)	1 (4.3%)
Discharge Location of Surviving Participants from Hospital, n (%)	4 (28.6%)
- **Home**	4 (28.6%)
- **In-Patient Rehabilitation**	6 (42.9%)
- **Repatriation to Home Hospital**	

**** Other surgeries include CABG plus valve replacement/repair, Type A dissection repair, aortic root resection, double valve replacement/repair, Bentall's procedure**

*** Maximum FIM Score 126.0**

CHAPTER 4

The Experiences of Cardiac Surgery Critical Care Clinicians with In-Bed Cycling in Adult Patients Undergoing Complex Cardiac Surgery

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The Experiences of Cardiac Surgery Critical Care Clinicians with In-Bed Cycling in Adult Patients Undergoing Complex Cardiac Surgery

Author Information

Anastasia N. L. Newman[a,b], Michelle E. Kho[a,c], Jocelyn E. Harris[a], Alison Fox-Robichaud[b,d], Patricia Solomon[a]

[a] School of Rehabilitation Science, McMaster University, 1400 Main Street West, Hamilton, Ontario, Canada, L8S 1C7
[b] Hamilton Health Sciences, 237 Barton Street East, Hamilton, Ontario, Canada, L8L 2X2
[c] Physiotherapy Department, St. Joseph's Healthcare Hamilton, 50 Charlton Avenue East, Hamilton, Ontario, L8N 4A6
[d] Department of Medicine, Division of Critical Care, McMaster University, 1200 Main Street West, Hamilton, Ontario, Canada, L8N 3Z5

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Author Email Addresses
Anastasia Newman: newmanan@mcmaster.ca
Michelle Kho: khome@mcmaster.ca
Jocelyn Harris: jharris@mcmaster.ca
Alison Fox-Robichaud: afoxrob@mcmaster.ca
Patricia Solomon: solomon@mcmaster.ca

Corresponding Author
Anastasia Newman
School of Rehabilitation Science
1400 Main Street West
Hamilton, Ontario L8S 1C7
Primary Email: newmanan@mcmaster.ca

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Abstract

Purpose: In-bed cycling is a novel modality that permits the early initiation of rehabilitation in the intensive care unit. We explored clinicians' experiences and perceptions of in-bed cycling with critically ill cardiac surgery patients.

Materials and Methods: We used an interpretive description methodology. All critical care clinicians who had been present for at least 2 cycling sessions were eligible. Data were collected using semi-structured, audio-recorded, face-to-face interviews transcribed verbatim. Content analysis was used to identify themes.

Results: Nine clinicians were interviewed. Our sample was predominantly female (77.8%) with a median [IQR] age of 40 [21.5] years. Critical care experience ranged from < 5 years to ≥ 30 years. Acceptability was influenced by previous cycling experiences, identifying the "ideal" patient, and the timing of cycling within a patient's recovery. Facilitators included establishing team relationships and striving towards a common goal. Barriers included inadequate staffing, bike size, and the time to deliver cycling.

Conclusions: Clinicians supported the use of in-bed cycling. Concerns included appropriate patient selection and timing of the intervention. Teamwork was integral to successful cycling. Strategies to overcome the identified barriers may assist with successful cycling implementation in other critical care environments.

Keywords: Physiotherapy, cardiac surgery, critical care, rehabilitation, intensive care, early mobilization

Implications for Rehabilitation

- In-bed cycling is a relatively novel rehabilitation modality that can help initiate physical rehabilitation earlier in a patient's recovery and reduce the iatrogenic effects of prolonged admissions to an intensive care unit.
- Clinicians found in-bed cycling to be an acceptable intervention with a population of critically ill cardiac surgery patients.
- Teamwork and interprofessional communication are important considerations for successful uptake of a relatively new rehabilitation modality.
- Identified barriers to in-bed cycling can assist with developing strategies to encourage cycling uptake in similar critical care environments.

Introduction

Early mobilization of critically ill patients is one means of reducing the iatrogenic effects of prolonged admissions to an intensive care unit (ICU) [1-3]. There is consensus that early mobilization is an important aspect of critical care admissions [4-6]. While there has been some ambiguity in the recent literature about the effects of early mobilization as compared to conventional routine therapy with respect to functional outcomes [7], the safety and feasibility of the early initiation of rehabilitation in the ICU in a variety of populations is accepted [8, 9]. In-bed cycle ergometry is a relatively novel rehabilitation modality that allows critical care physiotherapists to initiate physical rehabilitation earlier in a patient's recovery [10, 11]. Recent literature suggests that bedside ergometry is both safe and feasible [10]. However, its effect on function remains undetermined. In a recently published systematic review with meta-analysis of 12 randomized trials and 2 non-randomized trials, cycling initiated in the ICU had no significant impact on physical function, duration of mechanical ventilation, quality of life, and mortality as compared to those not receiving cycling [12]. While in-bed cycle ergometry has the potential to increase mobility, improve muscle endurance, and maintain range of motion, the perceptions and experiences of bedside clinicians of this device have received limited attention [13, 14].

Health care environments are complex and dynamic entities with a variety of stakeholders who each bring their own perspectives and experiences. The introduction of a novel rehabilitation modality into a practice setting can be influenced by multiple factors, including the attitudes and perceptions of clinical staff and the specific attributes of the local context [15]. A 2016 narrative review identified 28 unique barriers that limit early rehabilitation in the ICU [16]. These barriers included patient-related (e.g., high severity of patient illness/patient medically unstable), structural (e.g., limited staff), ICU culture (e.g., lack of staff knowledge and expertise), and process-related (e.g., lack of planning/coordination) barriers [16]. Gaining an understanding of stakeholders' concerns and the nuances of the clinical environment can help identify potential barriers and develop strategies to facilitate acceptability of an intervention.

Three qualitative studies examined the role of in-bed cycle ergometry in critical care [13, 14, 17]. Zheng et al studied patient, caregiver and clinician impressions of in-bed cycling in a sample of critically-ill pediatric patients [14]. While families and clinicians were initially apprehensive about the introduction of the in-bed cycling in a child's critical care rehabilitation, they eventually became comfortable with its use in the most critically-ill patients [14]. In a 2018 descriptive-exploratory Swedish study, Ringdal and colleagues examined 28 patients' recollections and experiences of early mobilization, including 11 patients who underwent in-bed cycling, while admitted to one of two general ICUs [17]. Overall, participants endorsed the importance of active mobilization as an intervention for normalization after their critical illnesses. While most participants had positive experiences, some admitted to vivid delusions while cycling, symptoms of shortness of breath and feeling fatigued. In a 2020 observational process evaluation, in-bed cycling was found to be acceptable amongst a respondent group that included critical care clinicians, patients, and families in an Australian ICU, with respondents believing the modality assisted with patients' recoveries [13].

Cardiac surgery is one of the most common surgeries performed worldwide with most patients requiring admission to an ICU post-operatively [18]. There have been several qualitative studies investigating the experiences of patients undergoing routine cardiac surgery [19-25]. These studies have contributed to our understanding of the patient experience post cardiac surgery. However, there is limited research investigating the perceptions and experiences of the frontline clinicians who provide care to critically ill patients who require prolonged mechanical ventilation and hemodynamic support, referred to as "off-track" patients. In-bed cycling using a bedside ergometer has received increasing focus in the literature as a modality designed to initiate rehabilitation earlier in critical care [10, 11, 26]. As a newer modality employed in ICU, the experiences of clinicians assisting with cycling implementation has yet to be adequately studied.

Purpose

Our purpose was to explore primary frontline clinicians' experiences and impressions of their involvement with in-bed cycling in the cardiac surgical ICU as a method of early initiation of rehabilitation with the adult off-track, critically ill cardiac surgery population. Specifically, we examined (1) whether this intervention was acceptable and (2) explored the perceived barriers and facilitators to its implementation.

Materials and Methods

Study Design

We selected interpretive description (ID) as the qualitative methodological approach. Interpretive description is defined as a non-categorical, inductive analytic research method of developing clinical understanding [27-29]. Developed by Thorne and colleagues as a response to the lack of clinically based qualitative methodologies, ID acknowledges both the personal experience of disease and illness as well as the potential for applying these findings into clinical practice with similar patient populations [27, 29]. We defined acceptability as the willingness of cardiac surgery clinician(s) to use in-bed cycling as a rehabilitation modality with their critically ill patients.

This study received ethics approval from the Hamilton Integrated Research Ethics Board (Project Number 5994).

Cycle Ergometer

Cycling was performed using the RT300 Supine Cycle. This is a portable in-bed ergometer which allows patients the option to cycle passively, actively, or a combination of both while remaining in a supine position.

Participant Recruitment

All frontline critical care clinicians (nurses, physiotherapists, respiratory therapists, physicians, physician assistants, nurse educators) working in an adult cardiac surgical unit at a large teaching hospital in Hamilton, Canada, who met the inclusion criteria were eligible to participate. Our aim was to recruit 7 to 10 participants from 6 healthcare professional groups. Clinicians were offered enrollment if they (1) had been present for at least two, 20-minute in-bed cycling sessions while working in the cardiac surgery ICU at the Hamilton General Hospital and (2) provided direct patient care in ICU. Two cycling sessions was perceived to be sufficient to allow clinicians to develop familiarity with the bike and the intervention. Clinicians who met the inclusion criteria were identified by the primary author. Subsequently, a research coordinator contacted the eligible clinicians in-person to provide information about the study and obtain informed consent.

Sampling

We utilized purposeful, non-probability sampling to identify clinicians from a variety of professional backgrounds and practice experiences who provided care for critically ill, off-track adult patients who underwent in-bed cycling post cardiac surgery. Enrollment continued until saturation was obtained, defined as the absence of any new information revealed in subsequent interviews [30].

Data Collection

We conducted semi-structured, face-to-face interviews in a private room within the ICU with only the interviewer and participant present. The primary author who identifies as female, was a doctoral student and critical care physiotherapist with 13 years of experience working in the cardiac surgery ICU, conducted all interviews. The interview guide is available in Appendix 1. Open-ended questions and probes were used to facilitate discussion. We also collected participant demographic information. The primary investigator used field notes to document relevant contextual information and personal thoughts or feelings that arose during and after the interviews to promote reflexivity [31]. Each participant was interviewed on one occasion.

Analysis

Interviews were audio-recorded and transcribed verbatim. We used the QDA Miner Lite online software (version 2.0.7, Provalis Research, Montreal, Quebec) for data management. We utilized content analysis, as described by Hsieh and Shannon, to analyze the transcriptions [32]. Initially 2 authors (A.N.L.N. and P.S.) independently coded the transcripts from 4 interviews to develop the code book. This was an iterative process with the authors meeting periodically to review and revise the codes. The remaining transcripts were coded by one author (A.N.L.N.) with the second author (P.S.) periodically reviewing components of the transcripts. Authors reconciled inconsistencies that were identified through the review. Following the coding process, the authors met to review patterns and relationships in the codes and developed themes and subthemes. Field notes were reviewed and incorporated into the analysis. We did not incorporate member checking as this is controversial with some suggesting that as the results have been synthesized, decontextualized, and abstracted across individual participants, there is no reason for individuals to recognize themselves or their experiences [33-35].

Results

Nine frontline clinicians were recruited, and all agreed to be interviewed: 3 registered nurses, 2 physiotherapists, 1 respiratory therapist, 1 registered nurse educator, 1 physician assistant, and 1 physician. Our sample was predominantly female (n = 7, 77.8%) with a median [IQR] age of 40 [21.5] years. There range in years of cardiac surgery ICU clinical experience was from less than 5 years to over 30 years. Interviews lasted approximately 20 minutes.

Participants supported the use of in-bed cycling during a patient's critical care journey post complicated, off-track cardiac surgery. All identified benefits of early mobilization and the role in-bed cycling can play in initiating rehabilitation with critically ill patients. However, they also identified areas of concern with respect to the bike itself, the patient population and patient selection. The themes and subthemes are presented in Table 1 and representative quotes are provided in the text. While attempts were made to use quotes from all professions, due to small numbers the source of the quote is not identified to maintain confidentiality.

[Insert Table 1 here]

Acceptability of In-Bed Cycling

Acceptability of the intervention appeared to be influenced by: (1) Experiences with in-bed cycling and (2) Coordination of cycling within a patient's recovery journey.

Experiences with In-Bed Cycling

Previous experiences with in-bed cycling in the cardiac surgery ICU were important in determining the outlook participants had towards cycling with their critically ill patients. Prior interactions with the bike, both positive and negative, appeared to influence their perception of the device's acceptability.

Many participants found in-bed cycling acceptable and their comments reflected their positive experiences. Having a positive experience with in-bed cycling bolstered the credibility of the intervention for some. One stated that she enjoyed being involved with in bed cycling calling it "a really cool process" and that the "learning aspect" of a new intervention was an important motivating factor. Seeing a patient involved and progressing with in-bed cycling also helped to promote its use. One participant recalled that her patient enjoyed the fact that they could push with it, that it "wasn't a passive experience". A positive outlook about in-bed cycling provided confidence to "at least try" the intervention even in uncertain circumstances.

In contrast, several participants admitted to having a negative experience with in-bed cycling, tempering their opinions of acceptability. Participants expressed concern about unstable patients who could rapidly decline when cycling and were ambivalent about whether the bike could have any effect if the patients were "super sick". This participant spoke of the potential stress involved when cycling with unstable patients such as those requiring vasoactive medications for hemodynamic support or continuous renal replacement therapy (CRRT):

"There were times when the in-bed cycle sometimes either changed patients' blood pressures or heart rates to where it may have been more of a stressful situation for the health care team to now have to rebound and catch up with blood pressure and heart rates to get them back stabilized" (Participant 8, Less than 10 years of cardiac surgery ICU experience)

Coordination of Cycling within a Patient's Recovery Journey

Participants identified concerns around how best to time the implementation of cycling within the recovery process of a critically ill, off-track patient post cardiac surgery. Some felt patients were too sick or too unstable to undergo cycling, including those patients with femoral lines, vasoactive medications, and renal replacement therapy. Others postulated on what factors make up the "ideal" patient for this rehabilitation modality.

Participants identified a range of factors that contributed to an ideal cycling candidate. Most agreed that patients who required prolonged admissions (≥ 72 hours) to critical care post-cardiac surgery, and who could not partake actively in functional mobility, were appropriate for cycling consideration. However, the potential for post-operative complications impacted their personal perceptions of cycling acceptability. Some felt that patients who "were previously active [and who] get sick really fast" should receive cycling during their "sickest period". In contrast, others felt that the most appropriate patients are those who are "trending towards future transfer to the ward". "Ideal" patients included those who had been admitted to the ICU for greater than 24-hours, had the ability to actively participate, and required low doses of inotropic or vasoactive medications. Others felt that patients who were extubated but still requiring critical care interventions were often overlooked and would benefit from cycling more those who were mechanically ventilated and sedated, as noted by this participant:

"Maybe they are not necessarily [mechanically ventilated] anymore, or they are starting to wake on the [ventilator]. They are much more hemodynamically stable … and less critically ill but there are still barriers to doing full ambulation with them" (Participant 9, Less than 10 years of cardiac surgery ICU experience)

The concept of determining the "right timing" to introduce in-bed cycling was raised by the majority of participants. Participants highlighted that finding the balance between physical rehabilitation, critical care interventions, and "the exact time frame [in the recovery process]" to introduce cycling was an important consideration. For many, initiating cycling as a means of preventing a loss in muscle strength and physical function was essential. However, many worried that critical patients could not tolerate any physical rehabilitation during their acute post-operative phase. For example, patients requiring intra-aortic balloon pump for mechanical assistance with cardiac contraction or continuous renal replacement therapy for acute renal failure were deemed "too acute" for cycling by many participants. Others, however, worried that delaying rehabilitation could result in long term complications, such as reduced functional ability.

Some expressed concern about scheduling cycling around other medical procedures. Participants noted that cycling challenged the physical reserves of critically ill patients which could impact other medical interventions, such as weaning from mechanical ventilation.

"Sometimes coordinating [ventilator] weaning with cycling [could be challenging] because the two don't necessarily go that well [together]" (Participant 7, Less than 10 years of cardiac surgery ICU experience)

Facilitators to In-Bed Cycling

There were numerous facilitators perceived as integral to successful introduction of in-bed cycling into the cardiac surgery ICU. These factors were grouped into 2 subthemes: (1) Striving towards a common goal and (2) Feeling confident in the method.

Striving Towards a Common Goal

The importance of teamwork and interprofessional collaboration was unanimous. Participants from all disciplines noted that a strong working relationship within the cardiac surgical team was essential for successful cycling implementation. Having the "cohesiveness of everyone on board" promoted the introduction of this novel rehabilitation strategy within the ICU. Collaboration appeared to take on numerous forms, including nurses who described themselves as providing "moral support" and "monitoring" during cycling sessions. This participant identified the importance of a trusting relationship between practitioners:

"You need to collaborate with your physiotherapist. I think you need that relationship. So, you need to discuss whether [the patients] are physically able to do it, whether they have the reserve to do it, whether they are well enough to actually be able to do it." (Participant 3, Greater than 10 years of cardiac surgery ICU experience)

Nurses noted that mobilization was also within their scope of practice and an important part of their daily care regime. As one nurse noted, "it's [also] part of my job to mobilize my patients, so [in-bed cycling] was a form of mobilizing them." Another nurse described the wholistic, "full systems" approach to providing care for a critically ill patient, with the ultimate goal of mobilizing and increasing patients' levels of activity as a means of "teeing them up" in preparation for eventual transfer to the post-surgical rehabilitation ward.

Having a team member willing to advocate for the bike with other clinicians helped them move towards a common goal. These advocates demonstrated an eagerness to utilize the bike with their patients and assisted with promoting the intervention with their colleagues. One participant noted that cycling advocacy helped to "broaden [clinicians] perspective on the role and responsibility of physiotherapy" in the ICU. By encouraging cycling this individual felt that it "gave credit to something other than medical interventions in a patient's recovery". Another clinician noted that they "felt accomplished" that they advocated to have the device used with their patient, stating that they "really do think this is something my patient can benefit from".

Participants also highlighted the importance of the relationships with family of a critically ill patient. Building that relationship was seen as an important step and eased concerns about introducing an unfamiliar intervention with their loved one. One participant noted that having family at the bedside was an opportunity for them to see how they help their loved one:

"I think family should be at the bedside because I think it's important for them to see the kinds of innovations that we have and see that we are putting in all our effort to get their family member better" (Participant 2, Less than 10 years of cardiac surgery ICU experience)

Feeling Confident in the Method

Preparing critical care staff for the arrival of a novel rehabilitation modality was an important factor in building confidence in the intervention. Through an awareness of the modality and the theory behind its use, participants felt assured that cycling was being introduced with good intentions. Staff noted that education from physiotherapists and the nurse educator was helpful so they could be prepared and "know what to expect". This participant spoke of the importance of educational initiatives:

"Also, there was a good chunk of information sent out about it. I think education and even just sending out an email to [give] everybody a heads up, this is what we are doing right now. Because it is kind of scary to have somebody roll in with this medical device and you're like, what are you doing with that?" (Participant 2, Less than 10 years of cardiac surgery ICU experience)

As the in-bed cycling sessions were administered by the physiotherapists, their knowledge, expertise, and enthusiasm was important in promoting confidence amongst the team. One team member commented that having "very enthusiastic" physiotherapists that “know how to use it” made staff feel more receptive to the modality and encouraged its use.

The perception that in-bed cycling provided therapeutic benefits to critically ill patients was highlighted by participants. Seeing the bike as a means of encouraging early mobilization was found to be a positive experience. Participants stated that the bike offered an opportunity to initiate physical rehabilitation when patients were still too ill for typical functional mobility, such as sitting at the edge of the bed or transfer training. As one participant noted:

“There’s no reason why we can’t hook up this machine to someone who we can’t mobilize because of certain reasons, deconditioning or issues with them dropping their blood pressure when sitting up.” (Participant 2, Less than 10 years of cardiac surgery ICU experience)

The ability of the bike to provide both passive and active therapy was seen as a bridge towards increasing function. The modality was noted to compliment the role of physiotherapy by allowing the patient to progress from passive to active involvement in cycling. Participants felt that the initiation of cycling early in a patient’s recovery could reduce the iatrogenic effects of protracted ICU stays because the “percentage of muscle mass loss [per day] is substantial”.

Participants also felt that the bike offered other benefits beyond the early initiation of physical rehabilitation. Participants noted that the bike could play a role in preventing deep vein thromboses, provide pressure relief on dependent areas of the skin, promote feelings of well-being, and give patients "some sense of control over their own destiny within a hospitalization".

Barriers to In-Bed Cycling Implementation

Clinicians identified several barriers to successful implementation of in-bed cycling within the cardiac surgery ICU. These were organized into 2 subthemes (1) Staffing Priorities and Beliefs and (2) Logistical Realities.

Staffing Priorities and Beliefs

Participants identified that adequate staffing was an integral part of successfully conducting in-bed cycling. Both physiotherapy and nursing staffing shortages could negatively impact the ability to offer cycling to appropriate patients. High patient acuity could prevent the initiation of in-bed cycling as other nurses in the same room would be required to assist with providing care to the most critically ill patient. Unfilled vacation and sick time could result in larger than usual caseloads, limiting the human resources needed to provide cycling, as noted by this participant:

"…. if we don't have enough nurses or if the nurse-to-patient ratio is a little bit tighter than what we think it should be, there might not be enough hands to actually…to help the

physiotherapist with set-up, get that patient into the spot." (Participant 6, Greater than 10 years of cardiac surgery ICU experience)

When short staffed, setting up or delivering the intervention could be too time consuming without assistance and may result in insufficient time to conduct a session. Therapists noted that the ability of nursing staff to help with ergometer set up and take down was helpful with managing caseload or staffing restrictions "as it can be time consuming if you are doing all aspects of [cycling]".

Staff beliefs and attitudes surrounding types of medical appliances compatible with in-bed cycling could also impact whether cycling occurred. Several participants stated that cycling with femoral arterial lines or dialysis catheters could "complicate things" and was contraindicated.

In-bed cycling was also criticized for its inability to mimic functional mobility. Some staff stated they would prioritize functional tasks, such as bed exercises or sitting at the edge of the bed, over supine cycling when given the option. Some stated that in-bed cycling was appropriate for patients who were sedated and/or too unstable for out of bed mobility. However, once a patient became more alert and their status stabilized, it appeared that cycling was not their rehabilitation method of choice:

"…once [patients] are able to do progressive mobility that's more functional and the benefit of that, in my opinion, outweighs the benefit of cycle." (Participant 5, Great than 10 years cardiac surgery ICU experience)

Logistical Realities

Participants identified logistical concerns, such as lack of space in the ICU and the time-consuming nature of setting up and conducting cycling even with appropriate staffing levels, as possible barriers to successful initiation of cycling. The limited space in the cardiac surgery ICU and the proximity of patient beds within shared rooms was a common concern. When patients were critically ill and required multiple lifesaving medical devices, adding the bike further limited the available working space and "makes for a little bit of a crammed space". For many, an organized and controlled space was essential to ease concerns about their ability to respond efficiently to any unpredictable medical emergencies.

Aspects of the bike itself were considered barriers by some participants. Technical challenges with the tablet that is used to run the program and track patient progress, was raised by the ICU physiotherapists. Issues with the tablet connecting to the bike or "freezing mid-session" could be an added challenge. Its physical size was highlighted by nearly all participants, often described as "big" and "not exactly small and user friendly". Due to its imposing presence, nurses were concerned with their ability to properly respond to an emergency within the room as the bike could be cumbersome to work around.

The time to set up and conduct a cycling session was identified as an inhibiting factor when trying to manage a busy daily caseload. Physiotherapists noted that the added time it took to set-up the bike on top of conducting the session could prevent them from performing other treatments or seeing other patients on their caseload. As one physiotherapist noted:

"It's just too bad the amount of time [it takes to] set it up…even after you've done it many times, it's still at least 20 minutes cause of the fact of cleaning it every single cable and readjusting the [pedals]…So, the actual time that you wasted…so 45 minutes is my fastest one but it can range to almost 56 [minutes] if you have an interruption." (Participant 1, Greater than 10 years of cardiac surgery ICU experience)

Discussion

We believe this to be the first qualitative study to examine the perceptions and experiences of cardiac surgery critical care clinicians using in-bed cycling as a rehabilitation modality in a population of adult off-track patients post cardiac surgery. Overall, our group of interprofessional clinicians found in-bed cycling to be an acceptable intervention, which echoes previous qualitative work with clinicians who utilized in-bed cycling with critically ill pediatric patients [14]. Participants identified positive attributes of in-bed cycling that they believed could contribute to improved patient outcomes, including the opportunity for early initiation of rehabilitation and the ability for patients to actively control the amount of effort when cycling. Participants also raised several concerns related to identifying the best candidates for cycling and determining when to introduce cycling during a patient's critical care recovery.

Participants' willingness to utilize in-bed cycling was influenced by both their previous experiences with the bike as well as whether or not they felt it was being implemented at the "right" time and with the "ideal" patient. There was little agreement on the timing of the interventions with opinions ranging from early in a patient's illness to closer to ICU discharge. Establishing when cycling should be initiated with a critically ill patient post cardiac surgery is complex and will likely depend on a multitude of variables, including comorbid conditions, current acuity, medical devices in situ, and the number and amount of critical care medications required to maintain hemodynamic stability. Proper identification of appropriate patients likely involves input from the multi-disciplinary care team. Larger studies of this population could help shed light on when cycling should be initiated.

The World Health Organization defines the acceptability of an intervention as the extent to which that intervention is considered to be reasonable among those receiving, delivering or affected by the intervention [36]. We recognise that there might be some conceptual overlap between acceptability and facilitators. However, we believe that acceptability is important to study on its own as a means of gaining a deeper perspective about the motives behind participants willingness to cycle their patients. Perceived safety is a component of acceptability [37]. Four studies support the safety of in-bed cycling in various critically ill populations with the risk of adverse events ranging from 0.2 to 4 percent [10, 12, 26, 38]. While two of these included patients post cardiac surgery, no subgroup analyses were performed to determine if these adverse events disproportionately affected the cardiac surgery group [26, 38]. Increasing the understanding of cycling safety with bedside clinicians may be an effective strategy to improve acceptability of this intervention. With little evidence available regarding in-bed cycling with critically ill patients post cardiac surgery, it remains to be determined how best to identify patients who will benefit from the modality. Future quantitative studies should include larger sample sizes of critically ill patients within this population with varying post surgical illness severity to help clarify this important predictor of cycling acceptability.

Our participants identified barriers that could prohibit successful cycling implementation in a cardiac surgery ICU. While some of these, such as bike size and tablet nuances, are challenging to modify, participants noted that the number of acutely critically ill patients within a 4-bed ICU room was a significant factor in determining whether a patient could be cycled. One possible strategy to mitigate this concern could be to physically separate patients based on illness acuity to increase the chances that cycling could occur. While we acknowledge that moving patients within an ICU can be challenging from a team and time perspective, the potential benefits of increased mobility may outweigh the inconvenience. Similar to previous research evaluating cycling implementation in a pediatric ICU, staffing shortages directly influenced the ability to offer cycling [14, 39]. Staffing issues have been identified as a common structural barrier in other areas of physiotherapy practice [16, 40-43]. While we recognize the finite nature of healthcare resources in many areas around the world, innovative strategies to help overcome staffing shortages, such as the development of a mobility team within the unit, as well as coverage for vacation and sick time, are necessary while also considering the fiscal constraints and responsibilities of healthcare corporations [41].

Several participants perceived that femoral lines prohibit the initiation of in-bed cycling. This is a common misconception and previous literature has supported the safety of physiotherapy interventions in patients requiring femoral cannulation [44]. Three studies have reported successfully cycling patients with femoral catheters [10, 45, 46]. The authors noted no adverse events with these devices in situ, such as bleeding at the insertion sites or dislodgement of the catheter. Education of team members about the safety of cycling with respect to femoral cannulation is necessary to ensure all appropriate patient have equal access to rehabilitation.

Our results suggest that clinicians were concerned that in-bed cycling was not functional in nature, contrasting this method of rehabilitation with more typical exercises such as bedside sitting, standing and ambulation. While limited, there is evidence to suggest that cycling can improve certain functional outcomes in patients post cardiac surgery [26, 47]. Prolonged admissions to critical care often result in the development of weakness and functional impairments [3, 48]. Research continues to investigate the role of physical rehabilitation in the prevention or mitigation of ICU acquired weakness. There are currently several presumed mechanisms on how the muscles of critically ill patients may respond to physical stress, including the ability of mechanical signals, both active and passive, to induce muscle protein synthesis [49]. Using physiologic rationale and the current understanding of ICU acquired weakness, cycling could provide mechanical stimulation to muscle mitochondria and help reduce the development of severe losses in function and strength which are frequently seen in patients with prolonged critical are admissions. Future research is necessary to understand the functional contributions of cycling in this population and the long-term functional outcomes post ICU and hospital discharge.

Teamwork and interprofessional collaboration were identified as significant contributors to successful cycling initiation. In our study, the importance of collegiality and communication between team members was raised by all disciplines. It is known that optimal patient management requires the input of a variety of disciplines, especially in critical care [50-52]. Strategies to promote strong professional units are integral when conducting early physical rehabilitation or when introducing a novel modality into a complex and dynamic critical care environment [51, 52]. Based on our results, having an awareness of nursing breaks and patient daily routines to ensure cycling is offered during a convenient time, education sessions to increase clinician awareness and knowledge of the device, and listening to team member concerns and responding to them as appropriate could potentially help other cardiac surgical ICUs successfully introduce this modality.

These insights highlight that the introduction of a novel rehabilitation modality requires input from all team members and consideration of the specific attributes of the patient population in question. This study suggests that in-bed cycling can be implemented in a cardiac surgical critical care environment albeit with some considerations given to potential facilitators and barriers.

Strengths and Limitations

We believe this to be the first qualitative interview study examining the experiences of critical care clinicians using in-bed cycling as a rehabilitation modality in a cardiac surgery critical care environment. Strengths include recruitment of clinicians from a variety of backgrounds and years of experience. Field notes were taken by the primary author to promote self-reflection and the identification of any potential bias. Transferability was promoted through the documentation of contextual information and the use of rich, thick description.

Our study is not without limitations. Our sample size was small. The interviewer was employed in the cardiac surgery ICU and has a professional relationship with the participants. While the participants appeared to be candid and forthcoming about their perceptions it is possible that this relationship influenced their willingness to talk openly about their experiences.

Conclusions

The majority of clinicians from a variety of professional backgrounds found in-bed cycling to be an acceptable rehabilitation modality with an adult off-track, critically ill cardiac surgery population. This was a novel qualitative study that added to the previous literature by canvasing the experiences of cardiac critical care clinicians. Interprofessional teamwork facilitated successful implementation of cycling. Previous experiences with the device impacted practitioners' willingness to implement cycling with patients and many questioned how to best identify the right timing for cycling and the "ideal" patient who would benefit most from this modality. Knowledge of potential barriers and facilitator could help other cardiac surgical ICUs successfully introduce in-bed cycling.

Acknowledgments

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Table 1: Identified Themes and Subthemes

Themes	**Subthemes**
Acceptability	1. Experiences with in-bed cycling 2. Coordination of cycling within a patient's recovery journey
Facilitators	1. Striving towards a common goal 2. Feeling confident in the method
Barriers	1. Staffing priorities and beliefs 2. Logistical realities

Appendix 1: Interview Guide

1. Please tell me about your experiences with in-bed cycling while working in the intensive care unit.
2. How would you describe your role with in-bed cycling?
3. What would you like to see done differently with respect to in-bed cycling?
4. Do you feel that this intervention is an important part of a patient's recovery from complicated cardiac surgery?
    a. If yes or no, why or why not?
    b. Did you feel any sense of accomplishment after in-bed cycling?
5. Would you recommend in-bed cycling to other clinicians in your situation?
    a. Why or why not?
6. How does your involvement with in-bed cycling compliment your responsibilities as an PT/RN/RT/MD/Educator?
7. When your patient is appropriate for in-bed cycling, how important is it for you to have them cycle?
8. What barriers impede the initiation of in-bed cycling in the cardiac surgery ICU?
9. What facilitated the initiation of in-bed cycling in ICU-West?
10. Describe the ideal situation/patient for in-bed cycling.
11. Did you feel that ICU-West environment was supportive of in-bed cycling?

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Discussion

Early mobilization initiated in the ICU has been a focus of research over the past several decades and may offer remedial benefits to patients with residual functional impairments acquired in ICU.[9] Off-track, critically ill patients post cardiac surgery remain underrepresented in rehabilitation literature and particularly in research investigating the impacts of in-bed cycling on patient outcomes. This thesis has made novel contributions to the cardiac surgery critical care rehabilitation literature by addressing some of these gaps. I have added to the current knowledge base by (1) developing the first survey of cardiac critical care physiotherapists on a little studied patient population (Chapter 2), (2) providing further support for the feasibility of in-bed cycling, specifically with off-track, critically ill patients post cardiac surgery (Chapter 3), and (3) conducting the first known qualitative study focused on cardiac surgery critical care clinicians' perspectives of in-bed cycling (Chapter 4). These 3 studies were conducted independently but with the same goal of illuminating the important role physiotherapists play in the recovery of critically ill patients post cardiac surgery. Additionally, these studies provide a foundation for future cardiac surgery rehabilitation research. Throughout this final chapter, I explore the contributions of each of the 3 studies and reflect on the strengths and limitations of my thesis work.

Chapter 2: Survey of Physiotherapy Practice in Ontario Cardiac Surgery Intensive Care Units

To the best of my knowledge, this was the first survey to describe the critical care rehabilitation practice patterns of physiotherapists, and specifically within an Ontario context. This survey advances the field of critical care rehabilitation in several ways. First, it builds upon the 2010 survey of cardiac surgery practice in the province of Ontario. Second, it targeted therapists working directly with patients requiring prolonged admissions to critical care post complicated, off-track cardiac surgery. Third, with limited research in the form of CPGs and RCTs, these results allow physiotherapists working with similar populations to compare and contrast their standard practice with the stated practice patterns of Ontario therapists. Fourth, my study provides a methodological framework for a national survey of critical care physiotherapy practice within the subset of patients who develop a critical illness post-operatively. Finally, this survey highlights the need for future work on the limited use of outcome measures in cardiac surgery critical care.

Results found that nearly half of our respondents do not routinely use outcome measures in their clinical practice. This echoes the findings in previous physiotherapy literature.[92-95] Outcome measures provide information on intervention effectiveness, patient outcomes, and demonstrate the impact of therapy in an economically challenging health care climate.[95] Previous studies have identified barriers to the use of outcome measures, including time constraints, therapists' lack of knowledge of outcome measures' reliability and validity, and low organizational priority on their use.[95] Identifying the barriers to outcome measure use in cardiac surgery critical care is an important area for future research. Investigation via physiotherapist interviews and observational studies of their practice could help illuminate ways to encourage the use of validated outcome measures within cardiac surgery critical care.

My survey had numerous strengths. The survey was rigorously developed and went through pilot testing prior to initiation. I systematically identified all Ontario cardiac surgery critical care physiotherapists and obtained a high response rate of 80%. There was repeated follow-up for non-respondents with 4 weekly reminders. I utilized standardized reporting guidelines specific to electronic surveys, the Checklist for Reporting Results of Internet E-Surveys (CHERRIES), to guide manuscript development.[96]

The survey was not without its limitations. At several cardiac surgical sites, only one critical care physiotherapist was employed in the cardiac surgery ICU. In order to maintain anonymity for all respondents, I was unable to compare responses between individual sites. This limited my ability to identify differences in practice patterns between tertiary care centers and peripheral hospitals. There are only 35 cardiac surgery critical care physiotherapists working in Ontario. While we obtained a high response rate of 80%, it is possible that one or more surgical sites were not represented in the results as 7 respondents did not complete the survey. This could potentially limit the generalizability of the results.

Chapter 3: CardiO Cycle: A Pilot Feasibility Study of In-Bed Cycling in Critically Ill Patients Post Cardiac Surgery

The third chapter of my thesis, entitled CardiO Cycle, was a prospective pilot feasibility study of in-bed cycling with a population of off-track, critically ill patients post cardiac surgery. While the safety and feasibility of cycling has been reported in other medical-surgical populations,[76-78] no studies have evaluated the feasibility of enrolling solely critically ill, off-track patients post-cardiac surgery into a cycling study. I confirmed its feasibility with this population, with cycling being performed on 136 days out of a total of 169 eligible cycling days, for a feasibility rate of 80.5%. My study protocol was safe, with 3 adverse events occurring in 136 cycling sessions (incidence of 2.2 per 100 patient-cycling sessions).

Pilot studies are designed to test the feasibility of methods and procedures for later use on a large scale.[81,82] These are routinely used in a variety of clinical areas, and critical care is no exception. These help to ascertain the likelihood of success for large-scale studies by evaluating multiple aspects of trial methodology prior to initiation, including the following: (1) Process: assesses the feasibility of the steps that need to take place as part of the larger trial, including determining recruitment rates, retention rates, etc.; (2) Resources: evaluates the time and budgetary issues that could arise during the larger trial, such as the length of time needed to complete outcome measures or interventions; (3) Management: addresses the potential human and data collection problems at participating centres; and (4) Scientific: an assessment of treatment safety, determination of intervention dosing and response, and an estimation of treatment effect.[82] Previous pilot safety and feasibility studies of in-bed cycling have informed larger effectiveness trials and provided confirmation of future trial success.[78,79]

Early mobilization in the ICU is recommended for patients recovering from critical illnesses. While safety and feasibility of in bed cycling has been established in a medical-surgical population,[77] it has yet to be investigated in the critically ill cardiac surgery population. This population has unique characteristics including the tolerance of the saphenous vein graft sites and the risk of incision dehiscence to the repeated cycling motion and the frequency of vasopressors and inotrope medications necessitating this current study.

The CardiO Cycle pilot study identified several issues that could impact future efficacy trial success. First, while we did achieve our a priori feasibility goal of 80%, this was highly dependent upon adequate physiotherapy staffing levels. Rehabilitation trials in the ICU are highly dependent on the involvement of critical care physiotherapists to participate in research protocols.[97] CardiO Cycle was no exception. Therapist staffing gaps due to vacation and sick time impacted the ability to offer cycling to qualifying patients. Strategies such as hiring additional rehabilitation staffing or the development of a mobility team within the unit to overcome this limitation should be considered for future trials to increase the likelihood of successful intervention delivery. Second, CardiO Cycle fell short of the enrollment target of 30 patients. This was likely due to a combination of the specific inclusion criteria and the high post-operative mortality rate experienced by this population as demonstrated in a previous longitudinal cohort study.[33] Future effectiveness trials should reconsider the inclusion and exclusion criteria within this population. For example, the presence of mechanical ventilation may not need to be a criterion for delineating off-track status and may limit the inclusion of potentially appropriate patients. Sample size estimations should also factor in the mortality rate when planning subsequent trials.

Progression criteria inform the decision to progress from a pilot study to a larger definitive trial.[81,98] It is recommended that progression criteria be developed for pilot studies during the protocol stage and reported in resulting manuscripts.[81] In particular, the use of these criteria to determine enrollment feasibility is recommended as achieving pre-determined sample size is integral to trial success. Avery et al suggested a traffic light system to denote whether feasibility criteria have been adequately satisfied.[98] In their system, after a priori determination of feasibility specifics, authors would report if their results were green ("Go"), amber ("Amend"), or red ("Stop"). I included progression criteria within the CardiO Cycle manuscript as a means of improving the reporting of the results. My enrolment of 76.7% exceeded the 50% suggested by Avery et al, suggesting that it would be feasible to enroll patients in a larger effectiveness trial. The next phase in this program of research would be the initiation of a phase 2 single-centre pilot RCT to better assess the feasibility of patient enrollment and recruitment, the randomization process, participant retention, and intervention adherence. Based on the results of CardiO Cycle, modification of our inclusion criteria and implementing a system to ensure adequate physiotherapy coverage to ensure intervention fidelity would be important considerations for a next phase study.

CardiO Cycle had several strengths. The vast majority (90%) of participants in CardiO Cycle completed the full cycling protocol during each session and the manuscript clearly reports the treatment protocols for ease of implementation by other therapists and researchers.[16] The progression criteria results suggest that a future pilot single centre RCT is a feasible endeavour. Finally, I utilized the Consolidated Standards of Reporting Trials (CONSORT) extension to pilot trials statement when preparing the manuscript for publication.[99]

There were limitations to this work. CardiO Cycle's enrollment fell short of the targeted sample size of 30 by 7 participants. While the aim of the study was to determine the feasibility of in-bed cycling with an off-track, critically ill cardiac surgery population, the narrow inclusion criteria was likely a contributing factor. As a pilot study, these results have enrollment implications for future large-scale studies and more diverse inclusion criteria should be considered. While not the focus of the pilot study, the routine physiotherapy undertaken by our participants, such as the length of routine treatments and the type and frequency of the exercises performed, was not reported in detail, limiting its replication of the interventions in other clinical arenas.

Chapter 4: The Experiences of Cardiac Surgery Critical Care Clinicians with In-Bed Cycling in Adult Patients Undergoing Complex Cardiac Surgery

The final chapter of my thesis advanced our knowledge on how critical care clinicians experienced the use of a novel rehabilitation modality in the ICU. There is a lack of qualitative research exploring the perceptions of frontline healthcare professionals involved with early mobilization strategies in critical care. No studies have investigated the experiences of cardiac surgery critical care clinicians involved with early mobilization performed using an in-bed cycle ergometer. My study noted that clinicians from a variety of professional backgrounds found in-bed cycling to be an acceptable intervention to use in the cardiac surgery ICU, however this was influenced by previous cycling experiences (both positive and negative), the need to identify the "ideal" cycling candidate and knowing how to best time the intervention within a patient's critical care recovery process.

Qualitative research provides an opportunity to gain nuanced insights into the aspects of an intervention which influence its acceptability. Acceptability is a multi-faceted concept reflecting the extent to which people delivering or receiving a healthcare intervention consider it to be appropriate.[100,101] Acceptability can be influenced by factors inherent to the intervention or by previous experiences of clinicians which may temper their willingness to implement the therapy. Without the support of bedside healthcare professionals directly involved with the delivery of these interventions, it is less likely that it will be conducted as intended, reducing its effectiveness.[88,101] Understanding the factors that impact acceptability can lead to the development of targeted strategies designed to increase the uptake of the intervention at the bedside.[100]

Knowledge translation (KT) strategies can promote changes in clinical practice such as the uptake of a new intervention. Knowledge Translation is defined as the synthesis, exchange, and ethically-sound application of knowledge within a complex system of interactions among researchers and users.[102] The Knowledge to Action (KTA) cycle, proposed by Graham et al in 2006, informs the process of transferring research findings into practice.[103] This framework describes the interconnected and dynamic relationship between knowledge creation and the action cycle. The action cycle identifies different strategies for knowledge application, such as adapting knowledge to local context, assessing barriers to knowledge use, and selecting, tailoring and implementing interventions.[103] The findings from the qualitative study identify potential barriers to practice that could be addressed, such as room acuity and limited staffing, to promote uptake of in-bed cycling amongst cardiac surgical ICU staff.

This study advances the field of critical care physiotherapy in several ways. It was the first to consider the experiences of a multi-professional group of clinicians working in cardiac surgery critical care. I utilized interpretive description methods because of its clinical focus. While previously published qualitative work has been conducted with respect to the role of cycling in critical care,[86-88] clinicians working in an ICU exclusively with critically ill patients post cardiac surgery had yet to be interviewed. The results of this study can help guide future practice as the experiences of the participants provide insight into what aspects of cycling were accepted by frontline staff and which aspects were seen as barriers to implantation. Finally, while this study was novel and identifies the attributes of cycling that could impact successful implementation of cycling in cardiac surgery critical care, ideally future research is warranted that investigates the patient and family cycling experiences.

The qualitative study had a variety of strengths. I reported the findings using the Consolidated Criteria for Reporting Qualitative Studies (COREQ).[104] The qualitative study enrolled a variety of practitioners from diverse professional backgrounds and utilized a methodology specifically designed with a clinical focus. Detailed field notes were taken and incorporated into the analysis. I provided thick, rich descriptions of both the participant demographics, setting and the results, promoting transferability of the findings to other cardiac surgical ICUs.

This study was not without its limitations. As a critical care physiotherapist with 13 years experience working in the cardiac surgery ICU, I developed relationships with each of the interviewees for the qualitative study. Participants were encouraged to be honest about their in-bed cycling experiences, however there is a risk that our previous relationship could have influenced their responses. It is possible that some of the enrolled clinicians may not have felt comfortable sharing their negative experiences. While the results echoed previous literature, future qualitative interview studies should use an interviewer who does not have a professional relationship with the participants.

Future Directions

The amount of critical care research continues to grow each year, including research focusing on the role physiotherapy and rehabilitation with critically ill patients. While this manuscript thesis contributed new knowledge to the field, in particular with off-track patients post cardiac surgery, gaps in the literature remain. Building off the results of my provincial survey, a national survey of Canadian cardiac surgery critical care physiotherapy practice is necessary. This future survey could shed light on inter-provincial differences in practice and help tailor specific interventions to target practice changes (i.e., the use of outcome measures in critical care, the implementation of modalities). While in-bed cycling was found to be feasible with a low incidence of adverse events in a sample of 23 critically ill, off-track patients post cardiac surgery, the efficacy of the intervention requires further investigation. Beginning with a single-center pilot RCT and progressing to a multi-center RCT, the impact of in-bed cycling on physical function and long-term outcomes is needed. Lessons learned from this project can help future trials by encouraging more diverse inclusion criteria and the use of standardized reporting guidelines. Rehabilitation research often fails to report adequate detail of the evaluated interventions, such as frequency, intensity, and dosage of exercise.[16,105] This prevents the translation of research into practice. Similar to CONSORT, the CERT guidelines (Consensus on Exercise Reporting Template) were developed in 2016 as a means of encouraging accurate reporting of intervention protocols.[106] In a 2018 scoping review of 117 ICU physical rehabilitation studies, the authors noted that the median CERT scores across 87 planned intervention studies was 55.6% (44.7, 75.0).[16] This lack of transparent reporting limits the ability for bedside clinicians to accurately implement protocols with similar populations.[16] All future rehabilitation trials, regardless of the modality or therapy involved, should ensure accurate and detailed reporting of treatment protocols. Finally, future qualitative work is necessary to examine both patient and family experiences of in-bed cycling during a prolonged recovery in ICU post cardiac surgery. This future work will deepen the understanding of the important role physiotherapists play in the recovery of critically ill, off-track patients post cardiac surgery. It will also provide insight into efficacious interventions and strategies that will hopefully result in improved patient outcomes and patient satisfaction after prolonged cardiac surgery ICU admissions.

Conclusion

Critical illness is a modern dilemma, brought to life through advancements in medical science and technology. While early ICU care supported a “rest is best” theory, it is generally accepted that early mobilization leads to improved outcomes for critically ill patients.[9] With a rapidly growing body of evidence over the last several decades, early mobilization is becoming the ICU standard of care around the world. In-bed cycling is one method of initiating early mobilization that has the potential to challenge the effects of prolonged critical care admissions. Cardiac surgery remains one of the most common surgical procedures performed. The vast majority of patients will require an ICU stay post-operatively, with a minority of patients requiring an extended ICU admission due to the development of post-operative complications and critical illness.[33] These independent, yet interconnected, studies addressed gaps in the literature related to early rehabilitation with the off-track, critically ill cardiac surgery population. This thesis provided a summary of Ontario critical care physiotherapy practice, evaluated the feasibility of in-bed cycling post complicated cardiac surgery, and explored the experiences of frontline clinicians with in-bed cycling in the cardiac surgery ICU. This thesis provides a solid basis for future research into the effectiveness of in-bed cycling with cardiac surgery, a national survey of cardiac surgery critical care physiotherapy practice, and further qualitative evaluation of patient, family, and clinician experiences with cycling.

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