THE VALUE OF PROSTHETIC REHABILITATION FOR CURRENT AND POTENTIAL LOWER LIMB PROSTHESIS USERS

by

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ABSTRACT

TAAVY ALAINE MILLER. The value of prosthetic rehabilitation for current and potential lower limb prosthesis users. (Under the direction of DR. MELINDA FORTHOFER)

The goal of this dissertation is to inform clinicians, researchers and policy makers of the potential value of prosthesis intervention for individuals who experience a lower limb amputation. In addition, this dissertation supports the call for more studies of high methodological quality to provide evidence of the functional and economic value associated with prostheses intervention post lower limb amputation.

The second chapter (study 1) measured the time to prosthesis receipt for based on different demographic (e.g., amputation level and sex) and personal health factors (e.g., diabetes or vascular disease and age) using administrative claims data. Kaplan-Meir method and log-rank tests were used to examine overall time to prosthesis receipt following lower limb amputation surgery by amputation level (below-the-knee versus above-the-knee), sex, diabetes or vascular disease status, and region of care. Multivariable cox proportional hazard models were fit to assess the risk of prosthesis receipt after amputation. Patients without diabetes/vascular disease had a significantly longer time to prosthesis receipt than patients with diabetes/vascular disease, and those with a below-the-knee amputation had a higher risk of receiving a prosthesis earlier than those with above-the-knee amputations, after adjusting for covariates.

The third and fourth chapters (studies 2 and 3) investigated the cost and healthcare utilization of prosthesis receipt stratified by time from surgery up to 12 months post-amputation (strata post-amputation by month: 0-3, 4-6, 7-9, 10-12, or no prosthesis) using administrative claims data. The adjusted analysis was performed using general linear modeling with log transformed cost and logistic regression models were used to assess healthcare utilization measured by emergency department use. Healthcare costs and utilization were reduced for those who received a prosthesis earlier (i.e., between 0 to 3 months) compared to those who did not receive a prosthesis within 12 months of amputation surgery.

The fifth chapter (study 4) assessed the relationship between injurious falls and self-perceived functional mobility. Multivariable logistic regression was applied to a cross-sectional sample using clinical outcomes data. Patients with lower functional mobility scores had increased odds of experiencing an injurious fall as compared to those with higher functional mobility.

The results from these four studies add to the body of literature on the economic impact of a lower limb prosthesis for potential (new patients with lower limb amputation) and current prosthesis users. Implications of study findings support the need for further exploration of clinical and potentially modifiable personal health factors in relation to prosthesis receipt and use. Study findings underscore the economic benefit of early prosthesis provision in terms of cost and healthcare utilization by emergency department use and measured by adverse events such as injurious falls. For those who are currently using a prosthesis, maintaining and improving mobility may help to reduce the burden and risk of injurious falls.

Key Words: Lower limb amputation, prosthetic rehabilitation, economic value, prosthesis, healthcare utilization, emergency department use, injurious fall

DEDICATION

To my daughter, Camden Zoe DeBoever, you have taught me more about love, joy, and dedication than I could have anticipated. I am grateful to be your mother and hope to inspire you to always reach for your dreams.

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"They cannot see that we must lay one brick at a time, take one step at a time. A pebble cast into a pond causes ripples that spread in all directions. Each one of our thoughts, words and deeds is like that."

~ Dorothy Day (1897-1980), a journalist and activist who worked on the women's suffrage movement and many more efforts

A dissertation is not the result of a singular individual effort. It would not have been possible to accomplish this dissertation without the contribution of many others around me. I would like to take this opportunity to express my deepest appreciation and thanks to those who have made an impact on my journey.

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LIST OF ABBREVIATIONS

ADL	Activities of Daily Living
AIC	An information criterion
AKA	Above-the-knee amputation
AMP	Amputee Mobility Predictor
AUC	Area under the curve
BKA	Below-the-knee amputation
CART	Classification analysis regression tree
CI	Confidence Interval
CPT	Current procedural terminology
DME	Durable medical equipment
ED	Emergency Department
FRI	Fall-related injury
GLM	Generalized linear model
GoF	Goodness of Fit
HIPAA	Health Information Portability and Accountability Act
HR	Hazard ratio
IBM	International Business Machines
ICD	International classification of diseases
IRB	Institutional review board
IQR	Interquartile Range
KM	Kaplan-Meier
LLA	Lower limb amputation
MAAT	Mobility Analysis of AmpuTees
MFCL	Medicare Functional Classification Level
NHANES	National Health and Nutrition Evaluation Survey
OR	Odds ratio
PLUS-M	Prosthetic Limb Users Survey of Mobility
QoL	Quality of life
ROC	Relative Operating Characteristic
RWE	Real world evidence
STROBE	Strengthening the Reporting of Observed Studies in Epidemiology
US	United States
VHA	Veteran’s Health Administration

LIST OF DEFINITIONS

Above-knee amputation: A lower limb amputation between the hip joint and the knee joint, or transfemoral amputation

Below-the-knee amputation: A lower limb amputation distal to the knee joint, or a transtibial, partial foot, or Symes

Functional impairment: Physical difficulties often associated with a decline in mobility or balance, difficulty with physical performance in activities of daily living

Lower limb amputation: A surgical procedure of the lower limb that removes or augments whole or part of a lower limb due to injury or illness

Prosthesis; prosthetic device: Externally applied device, which includes the socket and other mechanical components (e.g., a knee or a foot) used to replace the whole or part of an absent or deficient limb segment

Prosthetist: A person and healthcare provider who, having completed an approved program of education and training, is authorized or certified by an appropriate authority to evaluate individuals for prosthetic needs, write care plans, as well as measure, fabricate, and fit prosthetic devices

CHAPTER 1: INTRODUCTION

1.1 Introduction

There has been a push for the use of clinician and patient reported outcomes in healthcare decision making for everyday clinical practice and policy decision-making [1,2]. This trend impacts the physical medicine and rehabilitation sector of health services. Currently, the field lacks evidence regarding the outcome factors related to delivery such as patient preferences, accessibility and timing of provision, and value of rehabilitation services for people with functional impairment or decreased mobility [3]. Without adequate evidence on the performance and effectiveness of physical medicine and rehabilitation treatment, scrutiny of services will continue by policymakers and payers, potentially resulting in reduced access to needed services [4]. This dissertation aims to address the dearth of evidence by evaluating the value of rehabilitation services within a population greatly affected by functional mobility impairment, those who experience amputation secondary to traumatic cause (e.g., car accident or farming injury) or non-traumatic cause of amputation (e.g., vascular disease or diabetes). Persons with an amputation require a multidisciplinary approach including services from rehabilitation medicine (physiatrists), surgeons, physical therapy, and prosthetics [3].

Beyond the direct implications on measuring patient outcomes among adults with major lower limb amputation (LLA), this examination of outcomes related to major lower extremity amputations has important implications for informing policy and driving clinical decision-making. The overarching goal of this dissertation is to determine the value of prosthetic rehabilitation services based on resource utilization and health outcomes. A key objective is to describe experiences of patients with lower limb amputation in the rehabilitation process and the effects on patient outcomes. The specific goals of the dissertation are to:

1. Describe and evaluate the factors that influence time from lower limb amputation surgery to receipt of a prosthesis.
2. Evaluate factors that influence total cost of care post-LLA and healthcare utilization defined by emergency department and the impact of prosthesis receipt.
3. Evaluate the relationship between functional mobility and injurious falls among adults who utilize lower limb prosthetic devices.

Rehabilitation services

Physical medicine and rehabilitation service is a broad category in healthcare targeting a wide population (children, adults, and older people) with a range of conditions impacting function and participation, including diverse interventions (rehabilitation medicine, orthopedic surgery, physical therapy, occupational therapy, prosthetics, orthotics, and assistive devices) and outcomes [5]. The primary goal of physical rehabilitation services is to address individual needs towards the reduction of symptoms and promote independence in daily activities or participation, which includes personal and environmental factors [4].

Rehabilitation is defined as “a problem-solving educational process aimed at reducing disability and handicap experienced by an individual as a result of disability or injury” and to improve function [4,6]. Clinical and policy decisions about appropriate and optimal rehabilitation interventions require evidence on resource allocation, costs and effectiveness [5]. Health systems often undervalue rehabilitation services due to rehabilitation services being under-funded, under-researched and under-provided in many contexts [4,5]. Lack of evidence and knowledge on patient outcomes due to physical rehabilitation services result in reduced access to appropriate services, which includes access to assistive devices and physical therapy [7,8].

Scope of the problem

A salient example population to study regarding functional impairment and the value of rehabilitation services (e.g., physical therapy and prosthetic provision) is those with major lower limb amputation (LLA). Major LLA refers to an amputation at or above the ankle joint [9]. A person's life dramatically changes permanently when a limb is amputated. Amputation surgery, regardless of cause, leads to functional changes resulting in varying levels of impairment.

There are approximately 1.6 million individuals living with limb loss in the US and that is expected to continue to increase [10] with projections by 2050 to be nearly 3.6 million Americans with limb loss [11]. Individuals are potential prosthetic users if they have congenital limb difference or lose a limb due to cancer, which contribute about 2.5% to the population [12]. Other causes of amputation are traumatic incidents such as from military combat, farming injuries, or car accidents, which contribute about 38-42% of the population [13]. However, the largest cause of amputation in the US is attributed to non-traumatic causes such as vascular disease or comorbid diabetes, approximately 60% of the population [12,13]. Due to the rise of chronic diseases, there has been an increase in vascular disease and comorbidities, such as diabetes [7]. There are almost 25.8 million people living with diabetes in the US, and this is predicted to grow potentially increasing the need for prosthetic rehabilitation [14].

Costs of rehabilitation services are approximately $158 billion US dollars [12]. Chronic conditions that may lead to functional impairment include diabetes, hypertension, cardiovascular disease, peripheral vascular disease and stroke. Multiple chronic conditions and the subsequent physiological mechanisms lead to difficulty performing activities of daily living (ADL) and maintaining personal independence. For example, people with diabetes who have a mid-tibia, often called below the knee, amputation also have a 26.6% significantly higher total impairment level as compared those who do not have an amputation [15].

However, there is scant information available to guide treatment choices for persons with physical impairment, specifically lower limb amputation. Treating chronic conditions as a whole has a cost to society at approximately more than $2 trillion US dollars annually [16]. To date, however, no study has quantitatively assessed the impact of a prosthetic rehabilitation using a commercial claims database and clinical outcomes database on patient outcomes in terms of fall-related injury, mobility, costs, and healthcare utilization after receipt of a prosthetic device.

1.2 Conceptual Framework

Health service utilization varies greatly based on health system characteristics, patient needs, and other social characteristics [48]. A widely accepted model that was developed to identify factors that contribute to healthcare utilization is the Behavioral model of health services use or also known as the Anderson Behavioral model of health services utilization [48–50]. The model, developed by Ronald Anderson in 1968, has been applied to numerous empirical studies over the years including in rehabilitation research [49]. It posits that the use of health services is determined by three sets of factors: predisposing factors, enabling factors, and need factors in addition to the environment, such as the health care system [50]. Predisposing factors include demographic characteristics and social structure elements. Enabling factors include family and community elements. Need factors include both perceived and actual health needs. The Andersen model of health services use will guide the selection of variables and to organize the presentation in this dissertation.

Generally, both theory and pragmatic reasoning guide variable selection. However, since the secondary data sources used in this thesis were not specifically designed for current application (i.e., administrative data is used for billing), this leads to some limitations in availability of information. Nevertheless, this study will include a wide range of individual factors and include contextual factors such as region of care or type of insurance. Adaptation of the Anderson model to individuals with lower limb amputation receiving rehabilitation services will move forward outcome studies and serve as the underpinning for this thesis to inform policy makers now and in the future.

1.3 Structure of Dissertation

Four studies comprise the main body of this dissertation. First this dissertation includes in chapter 1 a literature review that covers the background and significance. Chapter 1 also includes an overview of the methods and design including details about the two different databases that will be utilized to address the aims. The research questions are presented in detail, which are subsequently addressed in the main body of this dissertation. The first chapter is then followed by four chapters, each of which will present background, methodology, results, discussion and conclusion separately for the four empirical studies. The final chapter brings together the overall discussion and conclusions from each study, as well as discussion implications within the field of prosthetics and outlines future research.

1.4 Background & Significance

Prevalence of disability and mobility impairment

In the US, 22% of adults have some type of disability with mobility as the most common impairment, especially among older adults [17]. The population of adults with disabilities is too often overlooked, as found in a recent study of the Medical Expenditure Panel Survey in the US [18]. People with significant disabilities or mobility impairment represent at least 12% of the population or 38 million people in the US [17,19]. Functional impairment or decreased mobility is defined as having difficulty with performing physical ADLs such as, walking or climbing stairs or a condition that prevents full participation in work or the community [16,20].

Value of rehabilitation evidence

The concept of ‘value’ in healthcare is elusive [21]. Definitions of value vary based on perspective, societal or individual, and cultural perceptions [21,22]. The approach to place value and quantify treatment effects is more widely being applied with payers and policymakers asking for evidence [22,23]. The field of physical rehabilitation has perhaps fallen behind other services in the amount of value-based evidence [4,24].

Negative impact of no rehabilitation or prosthesis

Thirty-day mortality rates range from 9 to 17% after initial lower limb amputation surgery attributable to pre-surgery health status or surgery complications [25]. Mortality risk remains beyond the initial 30 days especially among adults who are not fit with a prosthesis within 6 to 12 months post-surgery (OR 2.6 95% CI: 1.16-6.25) [9]. Early mobility, independence with ADLs, and ambulation promote good physical health while reducing mortality risk [26]. About 30 to 60% of adults exclusively use a wheelchair after LLA, which significantly reduces quality of life, independence and functional capacity [27]. Yet, adults age 40 years and older, recently discharged from rehabilitation after a below-knee amputation have improved mobility compared to matched individuals with no rehabilitation services [28].

Aside from differences in patient acuity, a high post-operative mortality rate suggests that quality improvement programs need to address the prosthetic rehabilitation needs. For example, being mobile and physically active improves cardiovascular health, reduces the negative effects of diabetes and reduces depression or feelings of isolation [28]. Patient satisfaction and quality of life are associated with less time between amputation surgery and delivery of a prosthesis [29]. Furthermore, satisfaction and quality of life are correlated with mobility and patients with no prosthesis are unable to be as physically mobile [29]. Without prosthetic care individuals have increased risk of clinical complications including increases in healthcare utilization and spending [22]. Based on the current research, it is reasonable to propose that lack of rehabilitation intervention negatively influences mobility, satisfaction and quality of life. Further investigation is needed to establish why wearing a prosthetic device improves survival, adds value, and improves satisfaction and mobility.

Standards of care and rehabilitation guidelines post-amputation

The standards of care post-amputation are limited aside from the immediate surgical care protocols. Furthermore, of the limited guidelines published there is low physician adherence or awareness of the processes [30]. To date, there is no standard or regulated time from amputation surgery for when a lower limb prosthetic device should be provided or intervention initiated such as consult with a prosthetist [8]. Additionally, there is not any standard guideline to what type of device is appropriate based on patient presentation though teams globally are working on gaining professional consensus [30–32].

The recently published Mobility Analysis of AmpuTees (MAAT II) aims to assist in clinical decision-making by presenting standard outcome measures of mobility and demonstrates that the presence of comorbidities does not preclude an individual from prosthetic success [33]. Specific outcome measures are not standard of practice yet; however, the MAAT II study it is a start to standardize prosthetic decision-making. A greater understanding of what influences the time from amputation surgery to the provision of a lower limb prosthetic device will assist the interdisciplinary team in decision-making regarding exposure to physical therapy, region of care or other factors during the post-surgical recovery period. On average a patient receives a custom lower limb prosthesis between 8 to 20 weeks after surgery depending on individual acuity and healing process [34]. If a patient does not receive a custom prosthesis in 12 to 18 month, it is possible the individual is not a functional candidate for a prosthesis [22,35].

The provision and use of a prosthesis is a critical component of a person's rehabilitation after a lower limb amputation as it is associated with a person's ability to return to ADLs and reintegrate into social or work routines [22,36]. The timing from amputation surgery to initial device provision has several potential influences including the patient's age, income and rehabilitation setting [36]. Post-acute care typically occurs at home, an in-patient rehabilitation facility or skilled nursing facility, all which contribute to varying processes and therefore influence timing [36].

Mobility and falls

Approximately 29 million Americans fell in 2014, resulting in an estimated $31 billion in Medicare costs [37]. Fall-related injury and deaths have increasingly become a significant public health issue across the United States. Falls are a leading cause of injury among those 65 years or older with multiple risk factors including history of falls, increasing age, a variety of chronic health conditions, and functional impairment [38,39]. Approximately 33% of older adults fall at least once per year. Among adults that fall, 20 to 30% suffer an injury, which result in medical intervention through emergency departments or other healthcare providers [40–42]. Individuals with lower limb amputation (LLA) are at a higher risk of fall-related injury with more than half of individuals with LLA reporting a fall at least once per year [43,44].

A fall after an amputation can negatively affect the rehabilitation process and may even lead to an emergency department visit, hospitalization or admission to a long-term care facility further reducing quality of life and health outcomes [43]. A fall or fall-related injury results in pain, the need for medical treatment, increased fear of falling again, and self-induced isolation or activity reduction which lead to a reduced QoL [45]. Individuals with chronic diseases and disability consistently report having lower functional mobility and quality of life than people without chronic conditions [15,46]. Specifically, adults with LLA have unique characteristics such as prosthesis comfort and residual limb health, in addition to common risk factors that are associated with falls including mobility and balance concerns, walking distance, and social participation [47].

Decreased well-being, reduced mobility due to functional impairment, and an increased fear of falling are associated with having a lower limb amputation [44]. However, we are lacking a differentiation in the literature regarding the association between falls that result in an injury that requires medical attention and functional mobility among adults with amputations. A history of fall-related injury or hospitalization is strongly associated with future falls [39]. Functional mobility and its contribution to injurious falls among lower limb prosthesis users is often overlooked. Therefore, preventing and managing falls can effect healthcare costs and future healthcare spending.

Gaps in our knowledge

In spite of the growing number of potential prosthesis users, the increasing number of individuals with functional impairment, and of those who experience fall-related injuries in the US, research in the field of prosthetics is sparse. Nationally, we lack the outcomes research, cost analyses and clinical practice guidelines needed to minimize acute health care or emergency utilization, support patients' functional mobility, and reduce costs associated with less than optimal patient outcomes. The use of rehabilitation services and the provision of a prosthetic device are standard of care for patients after a major lower limb amputation [22]. Yet, the influence of service interventions on clinical outcomes, such as falls and functional mobility, are not well understood. There is a shortage of empirical outcomes research to demonstrate effectiveness and value of rehabilitation services for individuals with LLA.

Few articles have teased apart differences among unmet need and access to prosthetic rehabilitation services or value of services. Few studies have analyzed data on the time from surgery to the provision of a device and what factors influence or mediate that time. A shorter time may result in a more active and sustained recovery [3,29]. With more pressure from payers to efficiently and effectively provide prosthetic devices, evidence to demonstrate and describe the effect of prosthetic rehabilitation is crucial [3,22]. Further research needs to address these significant gaps in current knowledge. If rehabilitation and prosthetic services result in cost avoidance and improved quality of life this may influence administrative decision-making and improve coverage of these services for all people with functional impairment due to a major LLA [22]. This dissertation seeks to address these gaps in the literature.

1.5 Research Design & Methods

Data source I

The first two proposed studies will utilize data from the Watson/Marketscan database. The database contains de-identified records for commercial claims (billing data) representing 25 percent of all commercials claims nationwide. Specifically, this dataset includes all person's that have received a durable medical equipment (DME) and it includes inpatient and outpatient encounters. A range of data is available on each patient, including administrative codes (Current Procedural Terminology, International Classification of Diseases procedures, and diagnosis codes), pharmaceutical information, information on type of provider, region of care and costs from the payer perspective (total charges and total pay). Data includes information on patients from 2014 through 2016 and contains approximately 8,000 patients that have received some type of prosthesis according to DME codes.

Watson/Marketscan data preparation

The Watson/Marketscan data first was restricted to adults 18 to 64 years of age with continuous health coverage for the 3-year period (n=1100). Next, inclusion was based on amputation procedure; patients with initial surgical amputation procedures that occurred within the index period only were included (n=510). The index period was set between March 2014, allowing 3 months of data pre-index and 12 months of data post-surgery.

Data source II

A second database will be used to answer the final questions related to patient mobility and self-reported injurious falls. This database contains clinical outcomes data collected by a large, multi-site prosthetics provider with clinics in regions across the United States. De-identified data on approximately 19,600 individuals is available for analysis. Data collected include patient's date of amputation, reported quality of life and satisfaction, functional mobility scores, predicted Medicare functional classification activity level by practitioner, and patient demographics such as age and gender. This dataset is provided de-identified for research use.

Clinical outcomes data preparation

The clinical outcomes study is a retrospective cross-sectional analysis that contains data from a large, multi-site prosthetics provider with clinics in all regions across the United States. Inclusion criteria are unilateral lower limb amputation who have a prosthesis, and completion of the patient reported outcomes instrument. Falls are recorded from patients over a 6-month recall period. Data management and analysis will be conducted using SAS (Cary, NC) and R Studio.

1.6 Research Questions

Time to prosthesis receipt (Q1)

This question will be answered by applying a survival analysis, Kaplan Meir comparisons and Cox proportional hazards function, from time of amputation to prosthesis receipt. The primary outcome of interest is receipt of prosthesis, additional confounding variables include patient demographic information, region of care, and presence of comorbidities (i.e., diabetes mellitus II). Length of time between surgery (date of amputation surgery) and prosthesis delivery (service date that prosthesis is billed) will be and represented in number of days. Identifying factors, such as presence of diabetes or vascular disease, that may be associated with a shorter time from surgery to device, can address patient-level conditions, target modifiable risk factors and inform policy.

Cost and utilization (Q2- 2 parts)

The purpose of exploring cost is to develop a greater understanding of the impact of receiving a lower limb prosthesis, as well as the timing of such an event, on the total direct healthcare costs. Prior work suggests there are clinical benefits associated with early prosthesis receipt [9,26]. The resulting evidence could assist the interdisciplinary team in decision-making relative to time since amputation surgery, or other demographic factors during the recovery period. The objective was to assess the impact of a prosthesis and the timing of prosthesis receipt on total direct health care costs in the 12 months post-amputation period.

ED utilization can be considered a proxy measure for increased healthcare utilization, which is associated with increased economic burden[51]. Adverse events after a lower limb amputation (LLA) can negatively affect the rehabilitation process and may lead to emergency department (ED) visits. Receipt of a prosthesis or timing of prosthesis receipt may decrease or moderate the risk of increased ED utilization. Fractures and fall-related-injury (FRI) both can result in ED utilization and increased cost of care while negatively impacting health outcomes. The factors that influence ED use and total cost of care will be investigated using a Watson/Marketscan cohort. The primary outcomes of interest include ED utilization as a proxy for healthcare utilization and total cost of care post-amputation. The first part of this question, cost and LLA, will be treated using a log-normal regression. The second part, utilization, will use a logistic regression to explore the relationship and influential factors on ED use.

Functional mobility and injurious falls (Q3)

An observational research design will be implemented to explore the relationship between functional mobility and injurious falls. A clinical outcomes database will be accessed to extract the sample. First, the relationship between baseline functional mobility and report of previous falls will be established using a cross-sectional sample. Next a sub-sample will be analyzed that allows for longitudinal follow up with a minimum of 6 months between initial evaluation and follow up to assess functional mobility and the association with future injurious falls. To account for possible selection bias and attrition issues in the cohort sample, a differential loss to follow up analysis will be conducted to compare the cross-sectional sample to the cohort. The strengthening the report of observational studies in epidemiology (STROBE) guidelines will be followed.

The outcomes instrument, which is provided as a standard of care tool, contains a question on falls history. The question reads, "Have you had a fall in the previous 6 months that resulted in a hospital or physician visit?" Anchoring the recall to an outcome requiring a visit to a healthcare professional was viewed to mitigate recall bias [52]. Individuals who answered yes to this question are considered to be a "faller" otherwise they are a "non-faller" and designated to not have the outcome event. Individuals who did not have an answer for this question are assumed a non-faller. Fall-related injury that requires medical attention will be treated as a binomial event (i.e., 'yes'/ 'no').

Functional mobility was measured via the Prosthetic Limb Users' Survey of Mobility (PLUS-M) 12 question short-form [53]. The PLUS-M is a self-report mobility instrument administered to the patient and quantifies individual functional mobility resulting in a normalized T-score ranging from 21.8 to 71.4. Higher scores on the PLUS-M indicate greater mobility and a T-score of 50 represents the mean mobility as reported by the development sample [53]. For individuals with multiple mobility scores, the highest score is used as it is considered to represent their best possible mobility.

1.7 Human Subjects Protections

The Watson/Marketscan data is provided to researchers de-identified and under terms of privacy. Hanger Clinic, who owns the data and has an agreement for the use for this project, provided a portion of the data used for this dissertation. The institutional review board views the data as existing records and, thus, not human subjects research. Regardless of this determination, the data will be stored on a password-secured device. Access to the full datasets will only be available to Hanger Clinic.

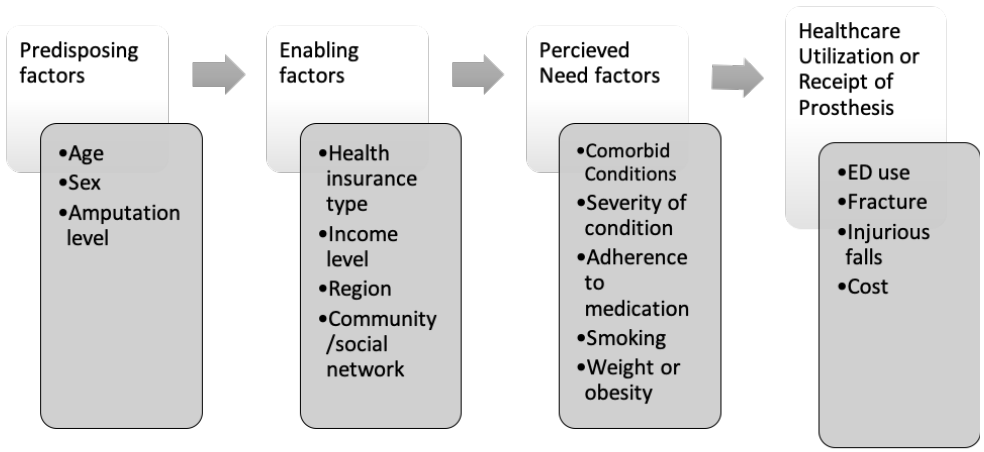
CHAPTER 1 TABLES

TABLE 1. 1: Summary of Research Questions & Methods

Question	Analytic approach	Outcome variable(s)	Independent variable(s)	Data source
1. What factors influence the time between amputation surgery and receipt of a prosthesis?	Survival analysis – Kaplan Meir and Cox proportional hazard	Receipt of lower limb prosthesis	Amputation level, patient age, sex, region of care, comorbidities	Watson/Marketscan administrative data
2. What factors influence utilization defined by emergency department use and costs after receipt of a device? [3 models; 2 manuscripts]	Log normal regression analysis	Cost, receipt of prosthesis, Fall/fracture, emergency department use	Patient age, sex, region of care, comorbidities, amputation level	Watson/Marketscan administrative data
3. What is the relationship between functional mobility and injurious falls among adults who utilize lower limb prosthetic devices?	Observational design: cross-sectional and longitudinal cohort	Fall-related injury results in medical intervention	Functional mobility level, patient age, sex, amputation level, cause of amputation, type of prosthesis, insurance type	Clinical outcomes data from national multi-site provider

CHAPTER 1 FIGURES

FIGURE 1. 1: Anderson behavioral model of health services utilization, applied to lower limb prosthetic rehabilitation



CHAPTER 2: FACTORS THAT INFLUENCE TIME TO PROSTHESIS RECEIPT AFTER LOWER LIMB AMPUTATION: A COX PROPORTIONAL HAZARD MODEL REGRESSION

2.1 Introduction

Lower limb prosthetic rehabilitation aims to optimize functional mobility, independence, health, and quality of life (QoL). However, there is a large amount of heterogeneity among those with amputation making rehabilitation complex; yet, a unifying challenge after lower limb amputation (LLA) is associated with mobility [1,2]. In order to overcome mobility or functional challenges, a prosthesis may facilitate restoration of mobility and independence in activities of daily living (ADL) [1,3]. Independence with ADLs, safety within one's environment, and participation in social and work-based events are key factors that enhance QoL [1,4]. Generally, being fit with a prosthesis within 12 months after a transtibial (below-knee) amputation and 18 months after a transfemoral (above-knee) amputation is considered acceptable, while longer times can negatively influence patient outcomes [4–6]. Additionally, early mobility, functional independence, and ambulation are associated with reduced healthcare utilization and economic burden while an increased risk of clinical complications is associated with no prosthesis [7]. In spite of these benefits, prosthetic devices are not always provided to potential prosthetic candidates during the initial 12 months post-amputation [1,4].

Individuals with LLA who do not receive a prosthesis have 2.6 times (95% CI 1.16-6.25) the odds of mortality compared with those who do receive a prosthesis [5]. After controlling for comorbidities, high 3-year morbidity and mortality rates remain after amputation [8]. Yet, evidence suggests that early mobility, independence with ADLs, and ambulation promotes good physical health while reducing mortality [9]. With improved prosthetic technology that is available today, it is reasonable to expect an improvement in patient outcomes, including reduced mortality and morbidity. Morbidity contributes to overall higher health care utilization due to falls and fractures for example [7]. Appropriate post-acute care and rehabilitation includes physical therapy and referral to a prosthetist, which may reduce waiting time for prosthesis provision [10,11] .

A shorter time between LLA surgery and prosthesis provision may result in a more active and sustained recovery [12,13]. Previous studies have confirmed the different effects, such as physiological, cardiovascular, mental, and social benefits, of prosthesis use on rehabilitation outcomes post LLA [14]. They were inconsistent, however, on describing characteristics that influence the time between LLA and receipt of a prosthesis. In particular, the literature discussing the factors that may contribute to an earlier prosthesis provision within this population is relatively sparse. Amputations that are the result of dysvascular conditions or attributed to diabetes are common and a few studies have found dysvascular conditions contribute to a lower likelihood of prosthesis receipt [6,9]. Understanding predisposing, enabling, or perceived need factors that influence time from surgery to prosthesis can give healthcare providers insight to targeted interventions and provide improved care to those in need of a prosthesis.

The studies of rehabilitation outcomes that included prosthetic rehabilitation service were rarely able to account for the time component in their analysis. To a certain extent, it is perhaps a data source limitation. Publicly accessible databases, such as survey data (e.g., NHANES) are cross-sectional and provide no obvious ability to conduct longitudinal analysis at the individual level. This is unfortunate as population-based datasets are a great resource for learning the characteristics associated with the outcomes that are more generalizable than the findings from restricted study settings (such as clinics, specific hospitals or systems, and nursing homes). Consideration of time to receipt of prosthesis has been instrumental to a number of researchers for identifying the rehabilitation outcomes and stratifying the individuals based on the associated factors [15].

Access to a prosthesis is through prosthetic prescriptions during outpatient prosthetic rehabilitation, which requires coordination across settings [15]. The provision and use of a prosthesis is a critical component of a person's rehabilitation after a lower limb amputation as it is associated with a person's ability to return to ADLs and reintegrate into social or work routines [7,16]. The timing from amputation surgery to initial device provision has several potential influences including the patient's age, cognitive ability, income, and rehabilitation setting [15,16]. However, there is no consensus on the factors that influence or predict provision of a prosthesis. By identifying factors that are associated with provision of a prosthetic device, it may be possible to have a better understanding of patient-level conditions (e.g., diabetes status or sex), target modifiable patient factors (e.g., mobility), standardize the prescription process, and better allocate resources in the future.

The goal of the current analysis was to evaluate the rate of prosthesis receipt and predictors among patients with LLA in a 12-month follow-up period. An analysis using a proportional hazard model calculates the risk of a future event, and in this study the event is prosthesis receipt. A survival analysis will be able to assess multiple factors, such as diabetes status and amputation level, that may influence the timing of prosthesis receipt among a diverse group of individuals who have an incident LLA. The current study uses administrative claims to describe a real-world pattern of LLA surgery to device provision among an insured population. We explore the opportunity of evaluating longitudinal health data from a national commercial claims database, which not only allows us to conduct the analysis at individual level, but also taking the time component into the statistical modeling.

Due to the nature of the current data, it was possible to determine the proportion of individuals receiving a prosthesis at any given point post-amputation. The first aim was to describe the average time to prosthesis receipt using real-world commercial claims data. The second aim was to assess the impact of patient demographic and health factors on the probability of prosthesis receipt within 12 months post-LLA. It was hypothesized the survival time (probability of prosthesis receipt) would be longer among those with concurrent diabetes/vascular disease compared to those without; that a more distal amputation level would reduce time with increased likelihood of device provision and as age increases the time with a reduced likelihood of device provision.

2.2 Methods

Study population & data source

This retrospective cohort analysis used the International Business Machines (IBM) Corporation Watson/Truven Health Analytics MarketScan (Watson) administrative database. The database contains de-identified records for commercial claims (billing data) representing approximately 25% of all commercials claims populated by payers in the United States (US). The Watson database includes adjudicated claims that are aggregated into one database including patient-level claims data from inpatient, outpatient, pharmacy, and enrollment history. The subset of that was extracted from the Watson database was limited to only claims on patients that received orthoses and prostheses from January 2014 through December 2016. The data were initially collected by a third party for administrative billing purposes of healthcare services, not for part of this study. Then the data is de-identified by IBM during the aggregation process and prior to release of the data for secondary analysis. Therefore, as this data are de-identified and complies with the Health Insurance Portability and Accountability Act, the subsequent analysis is not considered human subject research nor does it require approval from an institutional review board.

The final sample used for this analysis was limited to unique individuals 18 to 64 years of age who maintained continuous health coverage for the 3-year period (January 1, 2014 through December 31, 2016). Next, inclusion was based on amputation procedure (Appendix A); patients with initial lower limb surgical amputation procedures (first procedure claim = index date) and no subsequent amputation surgery within the study period were included. The index period was set between March 2014- December 2015, allowing 3 months of data pre-index and 12 months of data post-surgery for all individuals. The final sample includes all eligible patients based on the stated criteria, if individuals did not meet these criteria they were not in the final analytic sample.

Study variables

We considered two outcome measures. One of them was a binary measure indicating whether a prosthesis was received over a 12-month window post-LLA. Time to receipt of prosthesis (time-to-event) was calculated by determining the number of days from LLA surgery to the date the individual had a first claim for a lower limb prosthesis receipt. Prosthesis receipt was determined by presence of a lower limb prosthesis base code billed after LLA surgery (Appendix A). All types of prostheses were included and dichotomized, however, the specific kind of prosthesis was not extracted or used for analysis. Individuals who did not have a claim for a lower limb prosthesis during the 12-month follow-up period, were considered a censored observation. Specifically, time to censoring was defined as the number of days from amputation surgery to end of the study period or for those potentially waiting for a device by the end of 12 months post-surgery.

The time variable in the survival analysis was defined as the minimum of time to receipt of prosthesis or time to censorship. Time was measured in days. Age was treated as a continuous variable, years 18 to 64. Individuals were classified as either having diabetes mellitus type II or vascular disease (Appendix A) based on presence of diagnosis codes at baseline. Additional variables included in the model were sex (binary) and amputation level, which was determined by LLA surgical procedure. All covariates were treated with the assumption to persist throughout the study period.

Data analysis

Descriptive statistics to summarize the characteristics of the cohort were calculated with Chi-square or Student's T-test applied to discern group differences. The bivariate survivorship function [S(t)=Prob (time to prosthesis is longer than t)] and percentiles were estimated using the Kaplan-Meier product-limit survival distribution. Log-rank test was applied to determine if the survival function based on groups differed. Kaplan–Meier (KM) estimator for survival function facilitated the calculation of median days to prosthesis receipt and its 95% pointwise confidence interval (CI) in the study.

Survival function in this study was interpreted as the cumulative probability of receiving a prosthesis within 12 months. The final adjusted association between successful prosthesis receipt and the independent variables was quantified through multivariate analysis using a Cox proportional hazards model. The results were reported as hazard ratios (HR) and their 95% CI. Following KM analysis, variables identified with a p-value ≤0.10 were entered into the multivariate Cox regression model. To avoid potentially missing critical variables, a conservative significance level was selected similar to a previous study [6]. All data management and analyses were conducted using R studio version 1.1.423 (R Foundation for Statistical Computing, Vienna, Austria).

2.3 Results

Among the 510 adults who maintained continuous coverage, 86.9% received a prosthesis within 12 months (365 days) post-amputation surgery with an average time to prosthesis receipt of 130 days (Table 2.1). Of those who received a prosthesis, 352 had a BK amputation, whereas 91 had an AK amputation. In contrast, those who did not receive a prosthesis within 12 months were more evenly distributed, 33 with BK amputation and 34 with AK amputation. Overall, the sample consisted of individuals with an average age of 52 years, while 70% were male (Table 2.1).

Univariate analysis of prosthesis receipt that was carried out with KM models, stratified by patient characteristics, comparison of survival curves was assessed using the Log Rank Test. The median survival, or number of days to prosthesis receipt, with the 95% confidence intervals are presented with each KM curve stratified by specific patient characteristic. Diabetes/vascular status was significantly associated with time to prosthesis receipt, such that amputees with diabetes tended to receive their prostheses earlier than those without diabetes ($\chi^2 = 5.5$, $p = 0.02$). The median survival time to prosthesis receipt for those with diabetes or vascular disease was 113 (95% CI: 101-129) days compared to 124 (95% CI: 113-159) days for those without diabetes or vascular disease (Figure 2.2). Also, time to receipt of prosthesis was associated with amputation level (χ^2 = 27.5, p = <0.001) (Figure 2.1). The median survival time for an individual with a BK amputation to receive a prosthesis was 107 (95% CI: 102-119) days, compared to 168 (95% CI: 137-204) days for someone with an AK amputation (Figure 2.1). Region of care was not associated with time to prosthesis receipt (χ^2 = 0.9, p =0.8) and therefore, not included in the final adjusted model (Figure 2.3). Timing of prosthesis receipt was significantly different based on sex (χ^2 = 10.5, p =0.001), 141 (95% CI: 126-162) days for females compared to 106 (95% CI: 96-119) for males (Figure 2.4). Associations were considered statistically significant at p <0.05.

The Cox proportional hazard model is useful for examining the time dependent characteristics against the adjusted probability of prosthesis receipt. The adjusted probability of "surviving" or in our case, receiving a prosthesis post-LLA while controlling for covariates, was 200 days or fewer (Figure 2.5). The median number of days to receive a prosthesis for all individuals in the adjusted model was 137 days after LLA (Table 2.2). After 200 days, the probability of receiving a prosthesis reduces. Those with an amputation level of BKA have a hazard ratio (HR) or likelihood of prosthesis receipt within 12 months of 1.8 (95% CI: 1.42-2.26) (Table 2.3). Those who were male were more likely to receive a prosthesis compared to female (HR: 1.34, 95% CI: 1.08-1.65). Diabetes/vascular disease status marginally increased the hazard of prosthesis receipt (HR: 1.22, 95% CI: 1.02-1.49). Age did not have a statistically significant influence on timing of prosthesis receipt in this model (HR: 0.99, 95% CI: 0.98-1.00).

2.4 Discussion

In this retrospective cohort analysis, 443 individuals received a prosthesis within 12 months of LLA (79% BK and 21% AK). This statistic only includes patients who were continuously enrolled in the same commercial plan for the entire study period, therefore does not represent those who may have switched plans or died after LLA. In this real-world analysis of commercial claims data, the unadjusted median survival time between LLA surgery and prosthesis receipt is 107 days for BK amputation and 168 days for AK amputation with an overall adjusted median time of 137 days.

The hypothesis was partially confirmed with the finding that amputation level influenced timing of prosthesis receipt, age did not significantly influence timing of receipt, and while diabetes/vascular status influenced timing it was contrary to our expectation. Those without diabetes or vascular disease were not more likely to receive a prosthesis earlier, the results demonstrated the opposite. It was found that those with diabetes or vascular disease were 22% more likely to receive a prosthesis earlier potentially suggesting that there are underlying differences beyond diabetes or vascular disease. Perhaps, those who have an amputation not attributed to diabetes or vascular disease, are experiencing more complicated amputations secondary to trauma or Though as expected, individuals with a BK amputation had an 80% increased probability (HR: 1.8 95% CI: 1.42-2.26) to receive a prosthesis earlier than someone with an AK amputation within 12 months. This appears to be consistent with similar literature that reported those with BK amputation often have reduced mortality risk and have a higher functional status post-amputation [5,6,17].

However, previous work has also demonstrated that premorbid functional and ambulatory status is a greater predictor of successful prosthetic outcomes [18]. While this current study did not account for functional status due to the nature of the data, it is worth considering that premorbid function may be related to the type of amputation surgery, suggesting that the effect on amputation level seen in this analysis is influenced by more than the amputation level alone. Furthermore, the surgical decision for amputation level is often driven by illness or injury level, which may influence post-amputation prosthesis delivery timing that results in the 22% shorter time between LLA and prosthesis receipt in this current analysis.

This study reflects a prosthesis delivery rate higher than others, such as by Fletcher et al. (2001), yet it is difficult to compare due to their population being only geriatric patients (greater than 65) who all had a LLA due to vascular disease [19]. In contrast, the current finding of almost 87% receiving a prosthesis within 12 months of LLA surgery, comprises of younger individuals who maintain the same commercial plan for the study period. Our findings suggest that the current sample of individuals are potentially healthier.

There was an association with gender, which appears to be consistent with some literature in that females tend to have worse functional outcomes after LLA, which may contribute to the slightly longer time (approximately one month difference) for prosthesis receipt [20–22]. It is unclear based on our results if females have worse functional capabilities that lead to longer wait times to prosthesis receipt or perhaps the decreased functional outcomes are due to the increased time between LLA and prosthesis receipt. In literature from the other populations, there appears to be a sex-difference for women's health outcomes. For example, a recent study among stroke survivors, found women had worse functional outcomes than men more than 14 years post-stroke [23]. Another study found women had poorer perceived function post-total knee replacement [24]. In contrast, a study specifically evaluating factors that influenced prosthesis receipt, sex was not significantly associated with receipt [15]. In comparison, however, the Mundell study only evaluated individuals with AKA whereas our study includes individuals with both above and below-the-knee amputations. This may suggest functional status is contributing to the difference in timing of prosthesis receipt. Sex-differences appear to be multifactorial, however, there should be further investigation on sex-based disparities among those with LLA.

Previous research has suggested that chronic conditions, such as diabetes and vascular disease, are associated with increased likelihood of a LLA and those with diabetes have an increased risk of infection, falling and other complications that may delay prosthesis provision [25,26]. The current results suggest that the comorbid conditions of diabetes and/or vascular disease do not prevent prosthesis receipt as visually presented with the Kaplan-Meier curve (Figure 2.1, p=0.02). Additionally, as supported by previous work, diabetes or vascular disease alone do not prevent successful prosthesis use [27].

This study has several strengths, including that it has a relatively large sample size and it is based on a nationally representative sample of commercial claims. Also, this study focuses on a specific cohort continuously enrolled in the same insurance plan, a relatively younger adult population, which may prevent potential bias from the inclusion of older adults.

The primary limitations of this study are associated with administrative data, such as not knowing the exact cause of amputation, and therefore, this sample includes all-cause LLA. Another limitation due to the nature of the administrative data, it isn't possible to differentiate why it takes longer for an individual to receive a prosthesis. It is possible that a delayed fitting may be associated with other health complications, administrative (non-patient) issues, lack of social support or another unseen complication that contributes to adverse events thus increasing time from surgery to prosthesis receipt. For example, it has been suggested that lack of social support or marital status (being single) may negatively impact prosthetic rehabilitation [5,28]. Future studies could take these factors into account. A need persists to tease apart differences among unmet need and access to prosthetic rehabilitation services.

It is worth acknowledging the specific population we have analyzed in this study. We decided to include all-cause amputation with the intention to represent usual clinical practice among those who are commercially insured, who consequently tend to be younger. A disease-specific cohort among those commercially insured may not be the same as a cohort of those over 65 with different insurance options, such as Medicare or those of any age but who use the Veteran's Health Administration for prosthetic services. This sample population consists of all primary, major LLA cases from across the US who maintained continuous enrollment over a 3-year period. This group, therefore, may better reflect clinical practice across all regions of the US for those who maintain commercial (private) insurance plans and may provide more insight into this group. However, it is expected that a percentage of individuals may not receive a prosthesis due to not maintaining enrollment, who were therefore excluded from this analysis. Although, it is not clear if dropping one's insurance or switching enrollment to another commercial plan precipitates not getting a prosthesis or if issues with getting a prosthesis lead to changing insurance enrollment.

2.5 Conclusion

Despite the limitations in this study, our results are important because of their practical implications. This research expands the understanding of factors that influence the likelihood of receiving a prosthesis along with the timing of prosthesis receipt after LLA. The fact that all individuals remained enrolled in their insurance plan for the study period allows for a unique perspective evaluating a younger cohort who may reflect clinical practice for prosthetists. The delivery of an initial prosthesis may have significant impact on an individual's future recovery and rehabilitation performance especially among working-age adults as return to work is often an important goal. Among this sample of working age adults with commercial insurance, it appears that within 5 months or less at least half of the population receives a prosthesis while controlling for covariates, however disparities in timing and access to a prosthesis based on amputation level and sex should be addressed.

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CHAPTER 2 TABLES

TABLE 2. 1: Sample demographic characteristics and inferential statistics (chi-square test and t-test) stratified by receipt of prosthesis

Demographic Characteristics	Receipt of Prosthesis		
	yes	no	p-value
Total population, n(%)	443 (87)	67 (13)	
Amputation level n(%)			
Transtibial or below knee	352 (91.4)	33 (8.6)	<0.0001*
Transfemoral or above knee	91 (72.8)	34 (27.2)	
Gender, n(%)			
Male	315 (88.7)	40 (11.3)	0.06
Female	128 (82.6)	27 (17.4)	
Diabetes/Vascular Status n(%)			
Yes	290 (88.7)	37 (11.3)	0.1
No	153 (83.6)	30 (16.4)	
Region n(%)			
Northeast	54 (83.1)	11 (16.9)	0.26
North Central	112 (88.9)	14 (11.1)	
South	236 (90.8)	24 (9.2)	
West	50 (84.7)	9 (15.3)	
Age, mean (SD)	52.5 (9.4)	52.1 (10.1)	0.25
Days to prosthesis receipt, mean (SD)	130.1 (76.1)	-	-

TABLE 2. 2: Adjusted time to prosthesis receipt.

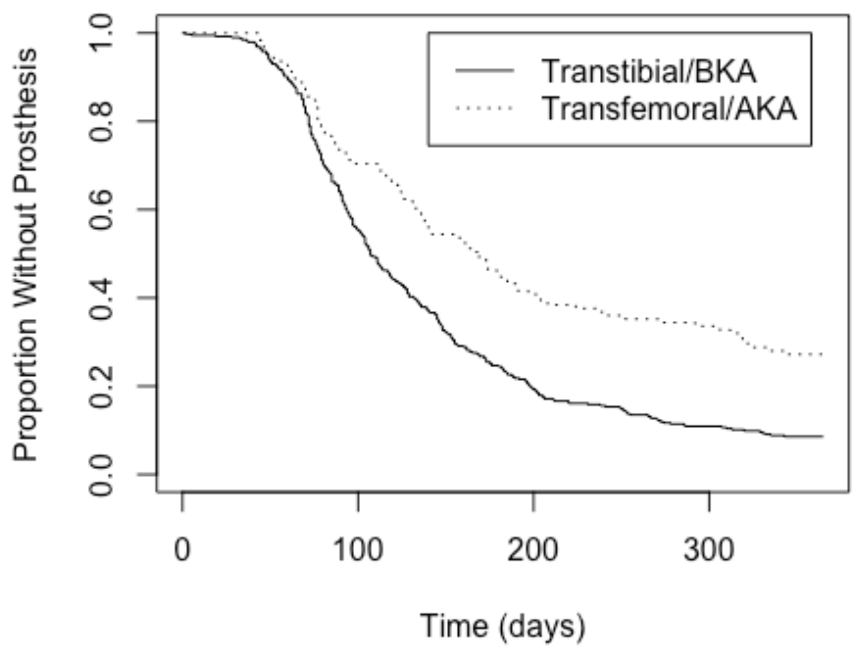
Inter Quartile Range (IQR)	Quantile (# of days)
25% Q1	84
50% Q2 (median)	137
75% Q3	334
Sample Mean	218

TABLE 2. 3: Cox proportional hazard ratio (HR) adjusted model results. A hazard ratio greater than 1 represents an increased likelihood of prosthesis receipt within 12 months post-amputation.

Characteristic	LLA surgery to receipt of prosthesis (n=510)		
	HR	95% CI	p-value
Amputation level*			
Transtibial or below knee	1.8	1.42-2.26	<0.001
Transfemoral or above knee	Ref		
Gender*			
Male	1.34	1.08-1.65	0.006
Female	Ref		
Diabetes/Vascular Status*			
Yes	1.22	1.02-1.49	0.04
No	Ref		
Age	0.99	0.98-1.00	0.7

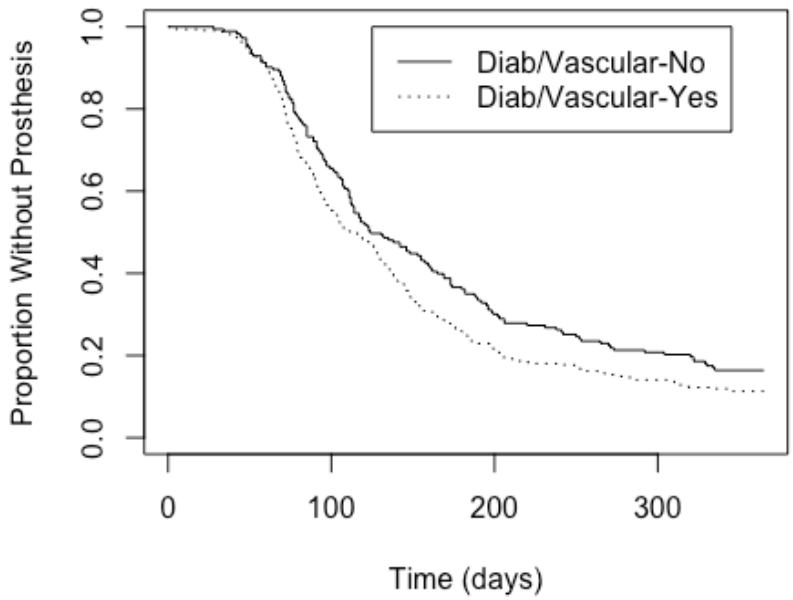
**Statistically significant at p<0.05.*

CHAPTER 2 FIGURES



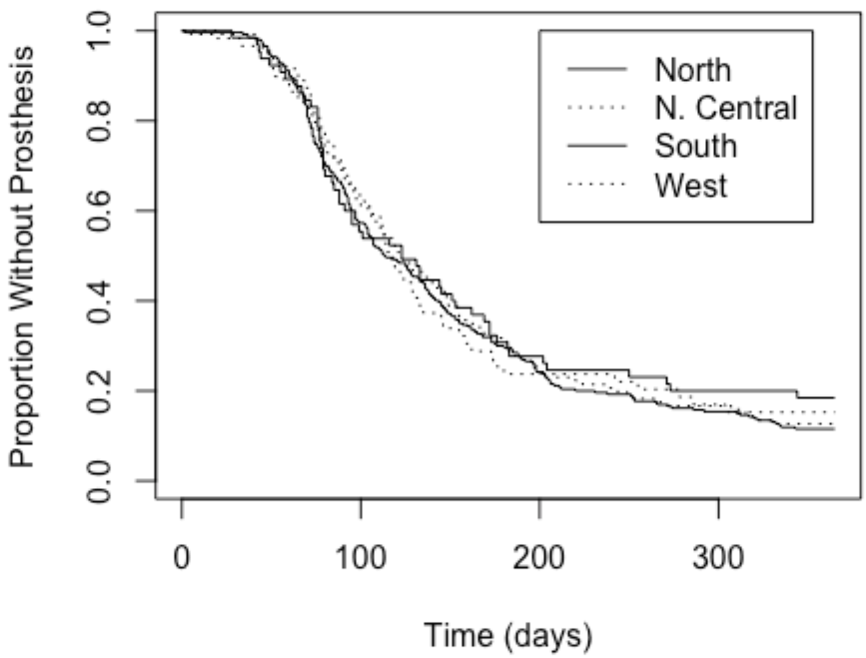
Group	Median days	95% CI
Below knee amputation (n=385)	107	102-119
Above knee amputation (n=125)	168	137-204
Log Rank = <0.001		

FIGURE 2. 1: Kaplan Meier analysis comparing amputation level, below-the-knee versus above-the-knee, time to prosthesis receipt



Group	Median days	95% CI
Diabetes/Vascular present	113	101-129
No Diabetes/Vascular present	124	113-159
Log Rank = 0.02		

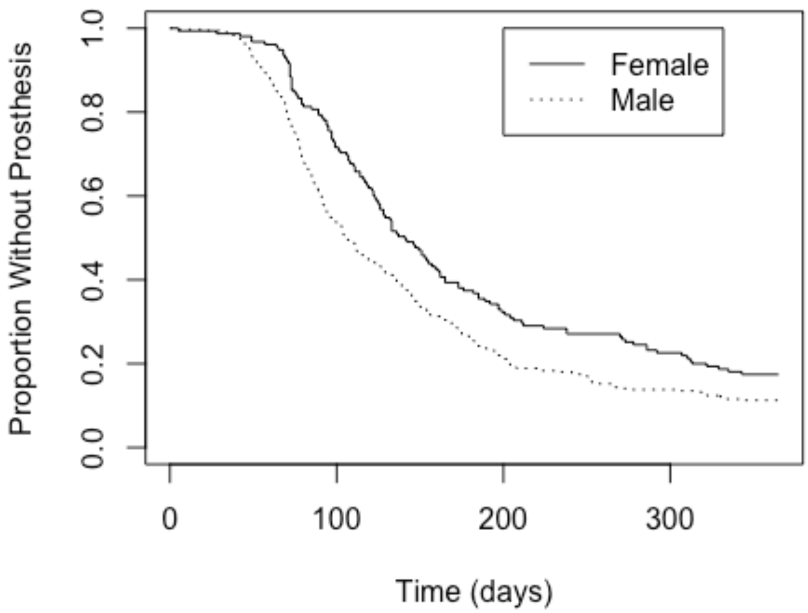
FIGURE 2. 2: Kaplan Meier analysis comparing diabetes/vascular status, those with versus those without, time to prosthesis receipt



Region	Median days	95% CI
North (n=65)	123	91-169
N. Central (n=126)	122	111-148
South (n=260)	114	104-136
West (n=59)	118	100-146

Log Rank = 0.8

FIGURE 2. 3: Kaplan Meier analysis comparing region of care, based on four different regions, time to prosthesis receipt. No significant difference between any groups.



Group	Median days	95% CI
Female (n=155)	141	126-162
Male (n=355)	106	96-119

Log Rank = 0.001

FIGURE 2. 4: Kaplan Meier analysis comparing sex, male versus female, and time to prosthesis receipt. Males (dotted line) receive a prosthesis significantly earlier than females.

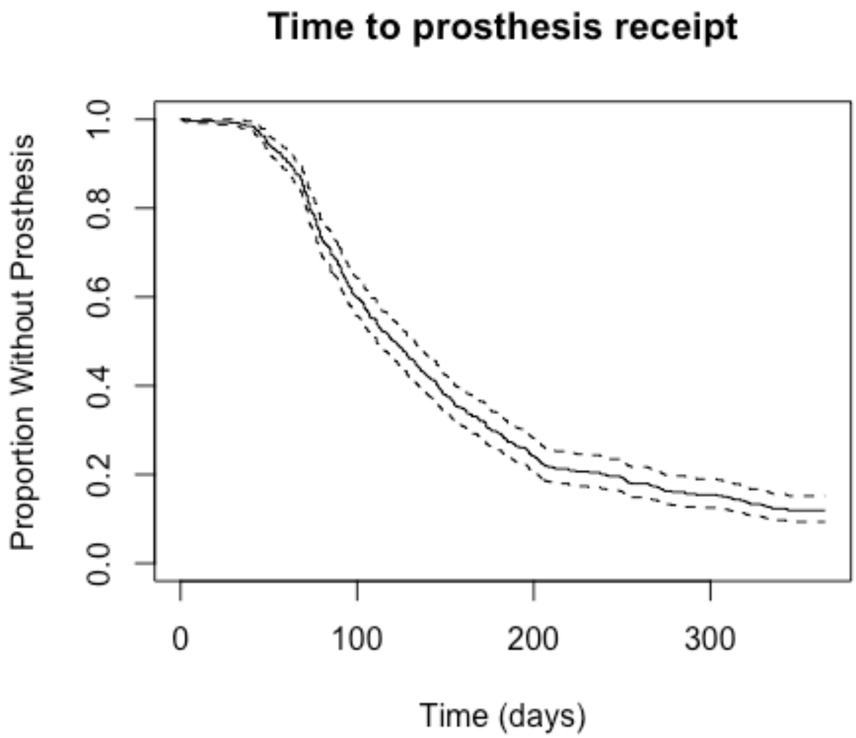


FIGURE 2. 5: Final adjusted Cox proportional hazard multivariate model, controlling for amputation level, diabetes/vascular status, sex, and age.

CHAPTER 3: IMPACT OF TIME TO RECEIPT OF PROSTHESIS ON TOTAL HEALTHCARE COSTS 12 MONTHS POST-AMPUTATION

3.1 Introduction

Over the past 30 years, healthcare costs have increased in the United States (US) as adults live and work longer with an increase in comorbidities [1,2]. Many discussions have occurred around the best way to address the increasing healthcare expenses with emphasis on those with chronic conditions or disability[2,3]. It is important to consider care structure, delivery of care, and costs of health services as healthcare procedures are advancing[3–5]. Based on current research of people aging, most want to remain independent and in their own home which often requires use of rehabilitation health services [6,7].

To maintain health and mobility, rehabilitation services are a critical part of healthcare. Rehabilitation health service is a broad category in healthcare, targeting a wide population (children, adults, and older people) with a range of conditions impacting function and participation, including diverse interventions (e.g., rehabilitation medicine, physical therapy, occupational therapy, prosthetics, orthotics, and assistive devices) and outcomes [3]. Clinical and policy decisions about appropriate and optimal rehabilitation interventions require evidence on resource allocation, costs and effectiveness [3]. Prosthetic rehabilitation is no exception. With increasing pressure from payers to provide health services more efficiently and effectively, evidence to demonstrate and describe the effect of prosthetic rehabilitation is crucial [8,9].

Lower limb amputation (LLA) is a major event that affects an individual's life both physically and mentally. However, a lower limb prosthesis can restore functional mobility and independence, which may reduce costs in other areas due to overall improved physical and mental health [10–12]. Furthermore, a shorter time from amputation to prosthesis delivery may result in a more active and sustained recovery [8].

The first 12 months post-amputation is critical as an individual requires rehabilitation to return to previous activities of daily living (ADL), to maintain independence, and to return to work. Among adults who are not fit with a prosthesis within 6 to 12 months post-surgery, mortality is a common endpoint to measure post-LLA and mortality risk remains high (OR 2.60 95% CI: 1.16-6.25) beyond the initial 30 days [13]. This includes concern of deconditioning which leads to poorer cardiovascular health, limb health, and lack of work or socialization. All of which are attributed to increased healthcare costs [14–17] that may be associated with the lack of a prosthesis. Limited data would suggest if a patient does not receive a custom prosthesis within 12 to 18 months, it is possible for the individual to decline to a health state so poor that they are considered unlikely to benefit from a prosthesis [9,18]. About 30 to 60% of adults exclusively use a wheelchair after LLA, which significantly reduces quality of life, independence and cardiovascular health[19]. Yet, adults who receive early rehabilitation after a transtibial amputation have improved mobility compared to matched individuals with no rehabilitation services and up to 80% lower hazard of death if they are a prosthesis user [18,20].

It has been recommended that on average, a patient receives a custom lower limb prosthesis between 8 to 20 weeks after surgery depending on individual acuity and healing process [21]. Any delay in prosthesis receipt can lead to difficulty with fitting a prosthesis as there is an associated decrease in limb health (e.g., contracture development or adhesions). Earlier receipt of a prosthesis improves mobility, independence with ADLs, and ambulation, all of which promote good physical health while reducing risk of contractures and mortality[22]. Early receipt of a prosthesis potentially reduces negative health effects and potentially may reduce overall resource utilization and direct costs. Therefore, there is clinical benefit to removing barriers to a patient's ability to be fitted with a prosthesis earlier in the process.

The purpose of this analysis was to develop a greater understanding of the impact of receiving a lower limb prosthesis, as well as the timing of such an event, on the total direct healthcare costs. The resulting evidence could assist the interdisciplinary team in decision-making relative to time since amputation surgery, or other demographic factors during the recovery period. A better understanding of timing in terms of economics of healthcare may also help with improved policy and practice for more cost-effective care. Prior work would suggest clinical benefits are associated with early prosthesis intervention[13,22,23]. Based on this prior work, the current study hypothesized that earlier prosthesis provision would provide economic benefits through reduced total direct healthcare costs among a cohort of commercially insured adults.

3.2 Methods

Study design & data source

This retrospective cohort study used data from the International Business Machines Corporation (IBM) Watson/Truven Health Analytics MarketScan Database (Watson) between January 2014 through December 2016. The Watson database is a large US private sector health claims database containing de-identified records representing approximately 25% of all commercial claims aggregated into one database with patient-level enrollment history, medical, and pharmacy commercials claims nationwide. The database is populated by approximately 350 payers. Specifically, this dataset includes individual level information on all durable medical equipment (DME), orthoses and prostheses, inpatient services, and outpatient services. The subset that was extracted was limited to only claims on patients that received orthoses and prostheses. Claims data within the database represent adjudicated claims (i.e., actual charges and dollars spent). The data initially was collected by a third party, not part of this study, for administrative billing purposes for healthcare services. Then the data is de-identified by IBM prior to release of the data for secondary analysis. Therefore, it was not possible to collect informed consent from subjects as individuals are unable to be identified. Moreover, as the data is maintained in a de-identified nature and complies with the Health Insurance Portability and Accountability Act, the subsequent analysis is not considered human subject research and therefore does not require approval from an institutional review board (IRB). This study conforms to all STROBE guidelines and reports the required information accordingly (see Supplementary Checklist).

The final subset that was extracted was limited to only claims on unique patients that maintained continuous enrollment in the same health plan from January 1, 2014 through December 31, 2016. The sample was restricted to adults 18 to 64 years of age. Next, inclusion was based on initial amputation procedure codes (first procedure claim = index date); only individuals with initial surgical amputation procedures that occurred within the given time while requiring a 3-month pre-surgery window to establish baseline pre-amputation costs and proxy acuity and 12-month post-surgery window for dependent variable calculation were included. To ensure initial amputation required no previous or subsequent amputation within the study period. Pre- and post-amputation time window lengths were chosen to maximize number of individuals with coverage during the months available for analysis. The final sample includes all eligible patients with data to cover the pre- and post-amputation windows, if individuals did not meet these criteria they were not in the final analytic sample for retrospective analysis.

Measures & analysis

All adjudicated payer costs for inpatient and outpatient procedures were summed across the 12 months post-amputation period for each individual. Prescription drug expenses were not included. Cost within the database was limited to the total amount paid by insurance and did not include charges, patient out-of-pocket costs, travel, or other indirect costs such as lost work. The dependent variable, total cost, was right skewed and subsequently log transformed for analysis. Individuals were classified into mutually exclusive groups for comparison into 3-month blocks based on length of time from surgery to device receipt within the 12 months post-amputation (Group A: 0-3 months, Group B: 4-6 months, Group C: 7-9 months, Group D: 10-12, and a final group that did not receive a prosthesis: Group X). Receipt of prosthesis, a binary variable, was determined based on presence of a lower limb prosthesis base code billed after LLA (Appendix A). All types of prostheses were included as captured by base code and dichotomized, yet specific type or kind of prosthesis was not extracted. Additional control variables entered into the model included age, gender, amputation level, diabetes/vascular status and 3-month pre-surgery baseline healthcare costs. Pre-surgery costs were treated as a continuous variable and thus similarly log-transformed. Diabetes/vascular disease status was determined by the presence of associated diagnosis codes in claims any time after enrollees' first admission with assumption the disease persisted throughout the study period (Appendix A).

Summary and descriptive statistics were calculated among the sample population across individual characteristics (Table 1). Chi-square tests of independence or Wilcoxon-Mann-Whitney U-tests were used to compare groups. All statistical analyses assumed two-tailed test of significance and alpha was set a priori at 0.05. Next, bivariate linear regression with lognormal distribution was used to model the relationship between independent variables and total cost. Each independent variable was also analyzed in a bivariate model to measure the unadjusted association. Lastly, generalized linear multivariate modeling was used to calculate estimates with a priori alpha values set at 0.05.

Generalized linear multivariate modeling with log link function was used to compare total healthcare cost based on timing of prosthesis receipt while adjusting for individual characteristics. All analyses and data management were conducted using SAS 9.4 (Cary, NC).

3.3 Results

Study population and baseline characteristics

There were 1100 individuals ages 18-64 with continuous enrollment through the 3-year window. After applying inclusion/exclusion criteria, 510 individuals with a first major LLA were available for analysis (Table 1). Among the sample of continually insured adults, 87% received a prosthesis within 12 months while 13% did not receive a prosthesis. Patients that received a prosthesis were more likely to have a transtibial amputation (352 is the total of transtibial patients who received a prosthesis), while it appears a similar proportion of transtibial and transfemoral patients did not receive a prosthesis. Among the 125 individuals with a transfemoral amputation, 34 did not receive a prosthesis within 12 months. Overall, 70% were male and the mean age was 52 years (SD: 9.4). Within the sample the proportion with diabetes or vascular disease was 327 (64%) individuals.

Influence of time in multivariate model

The generalized linear regression model of cost included age, sex, diabetes/vascular status, and baseline cost (pre-surgery) as covariates with length of time (Table 2). In this model age, gender and diabetes/vascular status turned out to be non-significant. Higher pre-surgery costs at baseline affect the total costs significantly by an increase of 0.125 ($p < 0.0001$) in log scale. The lowest total cost, while holding all other factors constant, occurred when an individual received a prosthesis in Group A (between 0 and 3 months). Receipt of a prosthesis in Group A post-LLA decreased total cost by 0.24 ($p=0.044$) in log scale when compared to not receiving a prosthesis within 12 months (Figure 1). Note that costs for Group A patients included the cost of a prosthesis while those for Group X patients did not.

3.4 Discussion

In a large representative population of commercially insured adults with LLA, earlier receipt of a prosthesis was associated with approximately 25% lower total direct healthcare costs compared with those who did not receive a prosthesis within 12 months of LLA surgery. Inverse log transform of group means reflected an average of approximately $99,409 in healthcare costs in the 12 months post-amputation for individuals in the earliest group compared to $125,459 when no prosthesis was delivered within 12 months. This demonstrates a potential cost saving with the intervention of a prosthesis earlier post-LLA. The finding that pre-surgical costs, which represent patient health spending, increase total post-amputation costs by 12.5%, supports that health acuity prior to surgery impacts overall total cost. However, it does not change the findings related to earlier prosthesis receipt on total healthcare expenditures. In other words, earlier receipt of a prosthesis is associated with reduced total healthcare expenditures while controlling for the level of spending per patient prior to surgery.

Our primary finding of financial benefits coinciding with earlier delivery of a prosthesis is in alignment with previous evidence regarding the clinical benefits of early fitting of a prosthesis [18,22,24]. Proposed clinical practice guidelines have suggested that intervention with a prosthesis early in the rehabilitation process is critical to individual physical health, improved quality care and promotes cost-effective patient management[25]. There is a likelihood of different healing rates among patients post-LLA. Yet, without appropriate prosthetic care, individuals have an increased risk of clinical complications, which may coincide with increases in healthcare utilization, such as acute hospitalizations and increased spending[9]. The study sample contained a proportion of individuals with diabetes or vascular disease that was greater than the percentage of individuals noted in previous work[26] yet falls within the reported LLA among persons with diabetes in a more recent systematic review, which ranged of 27% to 65% [27].

The potential value added by the receipt of a prosthesis is also highlighted with findings when comparing the individuals with no prosthesis to those who received their prosthesis from 4-6 months and 7-9 months post-amputation. While the average total healthcare costs in the 12 months post-amputation were similar for individuals receiving their prosthesis 4-6 months (~ $123k) or 7-9 months (~ $119k) compared to no-prosthesis (~ $125k), it should be noted the cost of a prosthesis was included in the healthcare costs for those that received a prosthesis. Thus, in light of recent work noting the positive relationship between prosthetic mobility and quality of life[28], there is considerable value in providing a prosthesis prior to 10 months post-amputation to afford patients the opportunity for improved quality of life. The notable increase in costs for individuals receiving a prosthesis after 10 months post-amputation should elicit individual level considerations for prosthetic rehabilitation.

Several studies have discussed the clinical benefits and advantages of prosthesis use, such as reduced falls, improved use and satisfaction of a prosthesis and overall higher quality of life[21,29,30]. This study excludes sources of other outcomes, such as mobility level or K-level. However, administrative data offer the opportunity to study utilization patterns and longitudinal health outcomes, such as date and timing of prosthesis receipt. It has also been documented that delayed fitting of a prosthesis or delayed rehabilitation can increase risk of complications such as re-amputation and result in lower functional status [22,24]. By measuring time to receipt of a prosthesis in groups anchored to LLA surgery, it was possible to objectively estimate the difference in cost associated with each group as time passed from LLA up to 12 months, which demonstrated a financial benefit of a prosthesis from a payer perspective. A limited amount of analyses have evaluated costs and utilization for prostheses. A recent study by Dobson et al. (2016) estimated cost and utilization anchored around receipt of prosthetic services as opposed to amputation surgery. Yet, the results of the Medicare analysis demonstrated that over a 12 month period, those who received a prosthesis had reduced total Medicare payments by a reduction in hospitalizations, physician visits, facility - based care, and a lower rate of emergency room admissions compared to controls who did not receive prosthetic services[9]. Overall our study includes a generally younger population with access to commercial insurance. While the findings demonstrate the potential value of early receipt of a prosthesis with associated decrease in healthcare costs, age is a risk factor with increased comorbidities[12,30]. Furthermore, in the US as adults reach the age of 65, they qualify for Medicare insurance.

Another estimation on total cost of care for adults with LLA was conducted by Jindeel and Narahara based on a cohort in California that included patients that experienced a LLA at an academic tertiary county hospital. They included patients with and without insurance, yet the study contained only descriptive information and did not present timing of prosthesis receipt within the cost estimate [31]. Rehabilitation is a complex process with many factors involved including variation in reasons that may contribute to the delay of a prosthesis, such as administrative delay. The evidence base on health economics of lower limb prosthetic rehabilitation is limited. The information deficits in this area have been discussed in recent articles, for example, in the RAND report on transfemoral economics and a literature review by Highsmith et al. on transtibial prosthesis economics [8,32]. More detailed information on timing of prosthesis receipt will continue to assist informing key stakeholders including physicians and payer sources on the benefits of early referral and delivery of a device anchored to a specific time, such as within 3 months post-LLA.

The main strength of the current study was the ability to analyze a large nationwide dataset with 12 months of follow-up post-LLA. Furthermore, this sample is representative of adults that have an LLA and who are continuously enrolled in a commercial health plan for at least 12 months post-amputation but does not represent all people with amputation in the US. Receipt of prosthesis as well as diabetes/vascular status with the corresponding costs could be directly assessed from these claims data without relying on self-reported information. This is advantageous as often there is poor or inaccurate recall on self-reported information such as when an individual received their prosthesis or on status of health conditions, which could lead to bias in the analysis.

However, there are also limitations to be considered in the current study. First, the costs represented individuals that had commercial insurance and did not include individuals with Medicare, Medicaid or the uninsured. Second, classification according to type of diabetes was not possible because a large amount of diagnoses were coded as unspecified. Also, cause of amputation was inferred to be due to diabetes or vascular disease based on presence of this diagnosis, therefore it is possible that some individuals with the diagnosis had a traumatic amputation. However, the proportion of individuals with diabetes or vascular disease in our cohort was similar to reported incidence rates among adults with LLA [26,27,33]. Third, there are limits to our ability to understand the factors associated with the timing of prosthesis receipt due to the nature of claims data, such as clinical or administrative decisions that may influence timing of prosthesis receipt.

Finally, not all direct medical costs were included that may represent additional healthcare resource use, such as expenditures related to prescription drugs, dentist related costs, or out-of-pocket spending. However, the inpatient, outpatient and emergency department settings are reflected in the current analysis. It is noted that a 3-month pre-amputation window could be longer to gather seasonal variations in healthcare use. Furthermore, given the magnitude of the group mean costs over a 12-month period, it seems unlikely that the results would be heavily swayed by prescription drug costs. Nevertheless, future work should consider prescription drug and out-of-pocket expenses. It is also pertinent to note that private insurance plans may vary and not cover all services equally. However, as costs of treatment for chronic conditions and healthcare in the US have continually increased over the past decades, several studies have reported the significance of access to rehabilitation services for restoration of mobility and independence post-amputation [12,29,30].

3.5 Conclusion

In conclusion, although the economic burden associated with healthcare for those with chronic health conditions and the aging population remains high, the clinical benefits of prosthetic rehabilitation services can actually serve to potentially reduce other non-prosthetic costs. The current findings suggest that age, sex, and diabetes/vascular status alone are not drivers of total healthcare costs in the 12 months post-amputation. As such, efforts to mitigate total healthcare costs likely will not do well when driven by such factors. Alternatively, earlier delivery of a prosthesis is associated with reduced overall direct healthcare costs. Not only are there physical, social and mental benefits to receiving a prosthesis, the current study notes there are also economic benefits[9,22,30]. The physical, social, and mental benefits may be responsible for the economic benefits, but future work is needed to explore this notion. Pre-surgical costs and health acuity result in increased healthcare costs, but there are benefits of earlier prosthesis receipt in reducing an individual's overall healthcare costs.

3.6 References

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CHAPTER 3 TABLES

TABLE 3. 1: Baseline characteristics of patients stratified by time from amputation to receipt of prosthesis within 12 months, or no prosthesis.

Group X: no prosthesis delineated by solid line, then to the right is Group A: 0-3 months post-amputation prosthesis receipt, Group B: 4-6 months post-amputation, Group C: 7-9 months post-amputation, Group D: 10-12 months post-amputation. Continuous variables presented as mean values ± standard error (mean ± SE).

Demographic Characteristics	Group X	Group A	Group B	Group C	Group D	Total	p-value
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	
Total population	67 (13.1)	174 (34.1)	186 (36.5)	58 (11.4)	25 (4.9)	443 (100)	-
Amputation level							
Transtibial or below knee	33 (6.5)	141 (27.6)	150 (29.4)	46 (9.0)	15 (2.9)	352 (75.4)	
Transfemoral or above knee	34 (6.6)	33 (6.5)	36 (7.1)	12 (2.4)	10 (2.0)	125 (24.6)	<0.0001*
Gender, n(%)							
Male	40 (7.7)	142 (27.8)	121 (23.7)	41 (8.1)	14 (2.7)	355 (70.0)	
Female	27 (5.2)	32 (6.2)	65 (12.7)	17 (3.2)	14 (2.7)	155 (30.0)	0.06
Diabetes/Vascular Status							
Yes	37(7.3)	123 (24.1)	120 (23.5)	33 (6.5)	14 (2.7)	327 (64.1)	
No	30(5.9)	51 (10.0)	66 (12.9)	25 (4.9)	11 (0.2)	183 (33.9)	0.11
Age, mean years (SE)	52.1(±0.69)	52.4 (±0.69)	52.4 (±0.68)	53.2(±1.20)	50.7(±2.45)	52.16(±0.42)	0.06
Post-index total cost, log scale (SE)	9.03(±0.19)	8.59 (±0.14)	8.79 (±0.11)	9.06(±0.18)	9.05(±0.37)	8.8(±0.19)	0.8

*indicates variable significant influence at 0.05

TABLE 3. 2: Multivariate linear regression results comparing total direct cost post-index on timing of prosthesis receipt while adjusting for covariates. Timing is stratified by groups.

Group A results demonstrate a significant influence on total direct cost associated with a decrease as seen with the negative estimate as opposed to Group D with an increase on total cost as seen with the positive estimate all compared to no prosthesis. The percent change represents the magnitude by ratio that the variable influences the outcome (total costs).

Variables	Estimate (% change)	Standard Error	p-value
Age	-0.0049 (-0.5%)	0.004	0.1997
Gender (female vs male)	-0.058 (-5.8%)	0.079	0.4639
Diabetes/vascular status (no vs yes)	-0.059 (-5.9%)	0.075	0.4339
Pre-surgery cost*	0.125 (12.5%)	0.019	<0.0001
Group A (vs Group X)*	-0.236 (-23.6%)	0.188	0.044
Group B (vs Group X)	-0.021 (-2.1%)	0.115	0.86
Group C (vs Group X)	-0.051 (-5.1%)	0.144	0.72
Group D (vs Group X)*	0.458 (45.8%)	0.089	0.015

*indicates variable significant influence at 0.05

CHAPTER 3 FIGURES

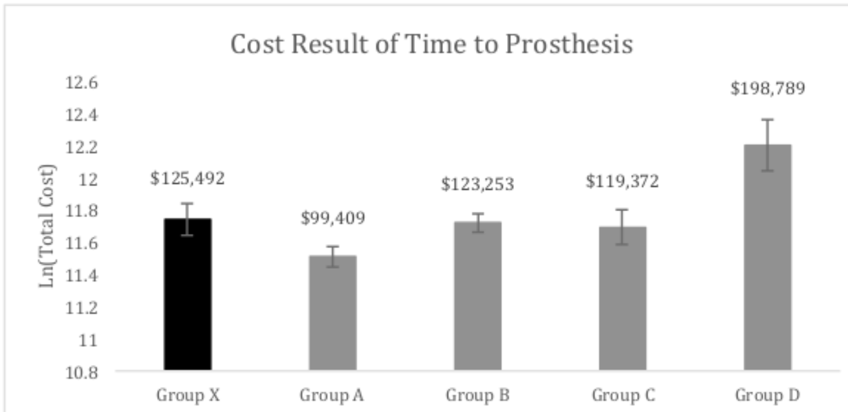

FIGURE 3. 1: Group comparisons of total healthcare costs revealed earlier receipt of a prosthesis coincided with reduced total healthcare costs.

Individuals receiving a prosthesis 4 – 9 months post-amputation had similar costs to those that never received a prosthesis despite inclusion of the costs of a prosthesis in their healthcare costs which is not part of the expenses incurred by individuals grouped in the no-prosthesis group. Group estimated marginal means shown with associated standard error. Inverse log-transformation values for means presented above bar for qualitative comparison. Group A: 0-3 months post-amputation prosthesis receipt, Group B: 4-6 months post-amputation, Group C: 7-9 months post-amputation, Group D: 10-12 months post-amputation, Group X: no prosthesis.

CHAPTER 4: THE ROLE OF EARLIER RECEIPT OF A LOWER LIMB PROSTHESIS ON EMERGENCY DEPARTMENT UTILIZATION

4.1 Introduction

The potentially preventable use of emergency departments (ED) accounts for $38 billion dollars of spending waste within the healthcare industry in the United States (US)[1]. Annually about 20% of adults in the US will visit the ED for acute care, which accounts for 141.4 million visits [1]. ED utilization can be considered a proxy measure for increased healthcare utilization, which is associated with increased economic burden[2]. Approximately 34% of total ED visits are comprised of individuals who have limitations in their activities of daily living (ADL)[3]. Additionally, those with functional limitations have nearly three times the odds of repeated visits among patients released from the ED [4]. Understanding the population subgroups who are utilizing emergency services frequently, and in what manner, may inform targeted interventions to eliminate the avoidable expenses associated with non-emergent care.

Lower limb amputation (LLA) is a life changing event, which requires an increased use of healthcare services encompassing the amputation surgery, immediate post-operative care, rehabilitation, fitting of a prosthesis, and follow-ups with other services post-discharge into the community. Previous studies report that a shorter time between amputation surgery and receipt of a prosthesis improves use of and satisfaction with the device [5,6]. There is also evidence that increased ED use is associated with a poor quality of life (QoL)[7]. However, there is no certainty about the influence of early prosthesis receipt on ED use and potentially preventable healthcare utilization. Early mobility along with functional independence and ambulation are associated with reduced unnecessary healthcare utilization while an increased risk of clinical complications is associated with no prosthesis [8]. It has been suggested among community dwelling adults that falls or fall-related injuries (FRIs) may be the result of functional limitation and poor physical activity[2,3].

Individuals with LLA are at a high risk of falls and FRI with more than half of individuals with LLA reporting a fall at least once per year [9,10]. A fall or FRI after an amputation can negatively affect the rehabilitation process and may lead to increased healthcare utilization such as an outpatient medical visit, an ED visit, hospitalization, or admission to a long-term care facility [9]. A fall/FRI also results in pain, the need for medical treatment, increased fear of falling again, and self-induced isolation or activity reduction which leads to a reduced QoL [11]. However, a percentage of emergency care or acute injuries incurred may be avoided with interventions such as access to a prosthesis. If prosthetic services result in cost avoidance by reducing preventable use of the ED, or improve function and prevent adverse events, then there is increased value placed on the associated health service such as receipt of a prosthesis [8,12,13].

Earlier receipt of a prosthesis, as compared to delayed receipt or not receiving a prosthesis within 12 months after amputation surgery, may decrease the risk of future adverse events or increased healthcare utilization, and thereby contribute to improved patient outcomes and the value of having a prosthesis fit after amputation. The purpose of the present study was to determine the role which timing of prosthesis receipt has in ED utilization and the association of fall/FRI with healthcare utilization measured by ED use among adults who recently had a LLA in the US. Two hypotheses were tested: 1) the receipt of a prosthesis and timing of intervention with a prosthesis reduces ED use and healthcare utilization, and 2) the receipt of a prosthesis and adverse events (i.e., fall or FRI) may be factors associated with increased healthcare utilization among adults with LLA.

4.2 Methods

Study design & data source

This was a retrospective observational cohort analysis using data extracted from the International Business Machines Corporation (IBM) Watson/Truven administrative (Watson) database. The database is populated annually from approximately 350 payers providing commercial (private insurance) claims (billing data) for their members. Data contains de-identified longitudinal, patient-level records. Included within the dataset are all fully adjudicated claims for approximately 230 million unique individual patients in the US. This included any orthotic/prosthetic services as well as all other inpatient and outpatient claims. The subset of individuals extracted was limited to either persons that received an amputation or orthotic/prosthetic services enrolled from January 1, 2014 through December 31, 2016. The original database as maintained by IBM Watson is de-identified in nature and complies with the Health Insurance Portability and Accountability Act (HIPAA). The subsequent analysis is not considered human subject research and therefore does not require an institutional review board (IRB) review or approval.

Participants

Enrollees in one of the commercial plans contained within the Watson database who were greater than or equal to 18 years or older with continuous health coverage for the 3-year period (n=1100) were eligible for the study. Next, inclusion was based on amputation procedure codes using the International Classification of Diseases (ICD) and Current Procedural Terminology (CPT) codes (ICD-9 and ICD-10 used due to time period crossing 2015) to identify all cases of LLA surgery. The index event was amputation surgery during 2014 through 2015 while allowing for 3 months of data pre-index to capture baseline characteristics and 12 months of data post-amputation surgery. Baseline characteristics include age, sex, amputation level, diabetes/vascular status. Only patients with initial surgical LLA procedures that occurred within the index period were included in the final sample (n=510; Figure 1). Time of prosthesis receipt was noted as the point where a prosthesis claim (i.e., base prosthesis L-code) appeared, which is the date of service the prosthesis was provided to the patient (Appendix A). Time was collapsed into mutually exclusive 3-month categories or groups and treated as a categorical variable. Individuals that received a prosthesis within the 12 months post-amputation were subsequently grouped based on time since amputation. Group time period breakdown was: 0-3 months post-amputation, 4-6 months post-amputation, 7-9 months post-amputation, and 10-12 months post-amputation. Individuals that did not receive a prosthesis within 12 months of their amputation were the final group, "no prosthesis".

Measures

The outcome variable, ED use, was defined as the presence of CPT codes billed for all-cause ED services (99281 – 99285) on any claim that occurred after the amputation date up to 12 months post-amputation. ED use was counted as a binary event, the first visit or event occurrence post-amputation was captured and counted based on procedure code. Fall/FRI was defined as the presence of diagnosis codes that met the criteria of fall (ICD-9 and ICD-10) in outpatient procedures that occurred after amputation date up to 12 months post-amputation (Appendix A). Fall/FRI was conceptualized as a proxy for functional limitation or reduced QoL for use in the second model as the fall required medical attention or healthcare utilization. Prosthesis receipt was determined by noting major lower limb prosthesis base codes billed after amputation surgery. Claims that included a prosthesis base code after amputation were flagged to have received a prosthesis and time elapsed post-amputation noted. The prosthesis date of service is the date the prosthesis was delivered to the patient irrespective of the date billed. Presence of diabetes or vascular disease were identified based on ICD-9 or ICD-10 in claims any time after enrollees' first admission with assumption the disease persisted throughout the study period (Appendix A). Amputation level was determined based on diagnosis code. Amputation level was collapsed into two categories: above-the-knee (AKA) and below-the-knee (BKA). For example, amputations through the tibia (i.e., transtibial) or distal to the knee were grouped as BKA. An amputation through-the-knee (knee disarticulation) and proximal, including at the level of the hip, were all grouped as AKA. Toe or partial-foot amputations were excluded. There were no hemipelvectomy or further proximal levels of amputation.

Analysis

Summary and descriptive statistics were calculated among the sample population based on receipt of prosthesis for population subgroups (Table 1). Chi-square tests of independence or Wilcoxon-Mann-Whitney U-tests were used to compare groups. Two-tailed tests of significance with alpha levels set a priori at 0.05 were implemented in all statistical analyses. Next, bivariate logistic regression was used to model the crude association between outpatient fall/FRI and all cause ED use. Each independent variable was also analyzed in a bivariate model to measure the unadjusted association. Lastly, multivariate logistic regression was used to calculate adjusted odds ratios (OR) and 95% confidence intervals (CI).

In the first model to address hypothesis 1, the influence of timing of prosthesis receipt on the likelihood of all-cause ED use was analyzed while controlling for age, sex, diabetes status, and amputation level. Time in 3-month based categories between amputation surgery and receipt of prosthesis were included as primary independent variable of interest (no prosthesis as referent category, 0-3 months, 4-6 months, 7-9 months and 10-12 months). Unadjusted OR and 95% CI were obtained using bivariate logistic regression to provide a crude association for each variable with ED use. A multivariate logistic regression was model conducted and then a post-hoc pairwise multiple comparisons was applied evaluate the difference between time categories (Table 3). Subsequently, the predicted cumulative incidence function was applied to determine the predicted probability of ED use versus age while stratifying by time to prosthesis receipt groups.

A second model to address hypothesis two, set the outcome of interest to ED use. Primary independent variables were fall/FRI and prosthesis receipt. Unadjusted OR and 95% CI were obtained using bivariate logistic regression to provide a crude association for each variable with ED use. Multivariate logistic regression was used to assess the fall/FRI association while adjusting for covariates, prosthesis receipt, and possible confounders, such as age, sex and amputation level (Table 4). To assess confounding effects, each potential confounder was entered into a bivariate model separately. If the variable changed the magnitude of the OR compared to the crude OR by at least 10% it was considered a confounder [14].

Model assumptions and fitting were assessed using standard techniques, such as, ROC curves. All analyses and data management were conducted using SAS 9.4 (Cary, NC).

4.3 Results

Descriptive statistics

Among the sample, 13% (67/510) did not receive a prosthesis within 12 months post-amputation surgery (Table 1). Of those that received a prosthesis, 131 individuals (30%) utilized the ED post-amputation as opposed to 26 individuals (39%) of patients with no prosthesis (Table 1). Most of the individuals had a transtibial (below knee) amputation (75%). Three hundred and twenty-seven individuals (64%) had diabetes or vascular disease. The average age was 52 years old (± 9.4 years) while the majority of patients were males (70%). A simple comparison of the percent of ED use based on timing of prosthesis receipt groups demonstrates an upward pattern of increased ED use the longer it takes to get a prosthesis or not receiving one within 12 months (Figure 2).

Model results

After assessment for confounding effects, none of the potential confounding variables influenced the odds ratios (OR) by 10% or more. However, the decision was made to retain and control for the potential confounding variables in the final models based on strong previous literature identifying these variables as strong risk factors associated with falls/FRIs[2,15].

Model 1: ED use and timing of prosthesis receipt

The first model evaluated the impact of timing of prosthesis receipt against ED use while controlling for sex, age, diabetes/vascular status, and amputation level. Individuals who receive a prosthesis early, between 0-3 months, after LLA were 48% (OR=0.52 95% CI: 0.28 – 0.97) less likely to use the ED compared to the referent group, those who did not receive a prosthesis during the 12 months post-amputation period (Table 3). The other time periods were not significantly associated with predicting ED use as compared to the referent group. The covariates including sex, amputation level, age, and diabetes/vascular status were not significantly associated with ED use (Table 3).

The predicted probability graph (Figure 3), demonstrates the difference in risk of ED use versus age stratified by time of prosthesis receipt groups. At age 60, there is approximately a 40% increased probability of an individual with no prosthesis (purple line in Figure 3) to use the ED as compared to a 60-year-old who receives their prosthesis between 0-3 months. The increased risk of ED utilization appears to be a consistent trend the longer time between LLA surgery and prosthesis receipt (Figure 3).

Model 2: Healthcare utilization/ED use and adverse events

The second model assessed the factors associated with ED use while controlling for prosthesis receipt. Individuals who experienced an adverse event, defined as any fall/FRI after amputation surgery, had 2.80 (95% C.I.: 1.32 – 6.54) times increased odds of using the ED within the follow-up period compared to those with no fall/FRI while adjusting for covariates (Table 4). The covariates in model 2 were not significantly associated with ED use (Table 4).

4.4 Discussion

Using claims data for commercially insured adults in the US, these findings substantiate that (a) adults with no lower limb prosthesis within 12 months of amputation surgery are almost twice as likely to use the ED as compared to those who receive a prosthesis within 3 months with the odds likely worsening with extended delays (Table 3), and (b) among those with LLA who experience a fall within 12 months of amputation surgery there is a 2.8 times increased odds of associated ED utilization (Table 4). This study included a representative sample population, similar to estimates presented in previous work with approximately 65% of lower limb amputee patients between 18 and 65 years of age to be male[16]. Moreover, our sample is reflective of those with LLA and commercial insurance that highlights the potential value of a prosthesis in terms of health care utilization defined by all-cause ED use at least once within 12 months post-amputation. Those who receive a prosthesis early are less likely to use the ED and this indirectly may improve QoL[7]. This study excludes determination of value in terms of return to work or as a measure of functional outcomes.

Our descriptive analysis suggests that with further time delay from surgery to receipt of prosthesis, the use of the ED increases as seen in the percent of ED use comparison (Figure 2). This is similar to our results presented in the multivariate analysis with model 1 revealing a pattern of a graded decline in odds ratios with comparisons between individuals without a prosthesis and those individuals that were further removed from amputation (i.e., 4 months up to 12 months post-LLA) (Table 3). This observation is consistent with the expression that the earlier a prosthesis can be provided, the greater protection against the potentially preventable excess healthcare utilization or ED use as seen visually in the predicted probability graph (Figure 3) and therefore increased value associated with having the prosthesis.

Early prosthesis intervention and healthcare utilization

As the findings from model 1 suggest, earlier receipt of a prosthesis decreases healthcare utilization as measured by ED use. Earlier intervention with physical rehabilitation and lower limb prostheses has been suggested to improve patient functional mobility and therefore reduce healthcare utilization due to adverse events reinforcing prosthetic value [17]. Pezzin et al (2004) conducted a survey, which included both patients with upper and lower limb amputations, and their findings suggested a shorter time between amputation and receipt of a prosthesis improved patients' reporting of satisfaction and increased use of devices. Furthermore, respondents from the survey reported an average time to receipt of prosthesis at 90 days. The reported shorter time from surgery to receipt of prosthesis and patients reporting improved function is consistent with the current study's findings that an earlier intervention may reduce healthcare utilization, such as ED visits, and reduce adverse events thus increasing the economic value of a prosthesis. It has been suggested in other studies that there is a protective effect, such as reduced mortality, of initial prosthesis fitting [18]. Mortality risk remains elevated among individuals with LLA beyond the initial 30 days especially among adults who are not fit with a prosthesis within 6 to 12 months post-surgery. [18] Individuals without a prosthesis will have more difficulty participating in physical therapy, mobility around the community, and have greater risk of fall or injury in the home. All of these factors can increase incidence of adverse events, which lead to ED utilization and increased strain on the health system.

The results of model 1 in this study did not indicate age, sex, and amputation level or diabetes/vascular disease status to be significant indicators for increased odds of ED use among people with LLA. The findings suggest that patient level factors such as age, sex and cause of amputation should not create exemptions for certain patients to realize the benefits of early prosthesis fittings with regards to reduction in ED use. These findings are consistent with previous evidence that found such factors were not necessarily restrictive to a patient's ability to achieve successful mobility with a prosthesis [18,19].

The provision and access to a prosthesis is a critical component of a person's rehabilitation after a LLA as it is associated with a person's ability to return to ADLs, safety, and reintegrate into social or work routines[5,8]. It has become more important to provide evidence of benefit for provision of a prosthesis in order to ensure patients have appropriate access to a prosthesis[8,20]. This study further substantiates the value of a prosthesis while highlighting specifically that earlier receipt of a prosthesis impacts health care utilization by reducing the associated risk of ED use. This study's results demonstrate that having a prosthesis earlier is protective against using the ED while controlling for age, sex, amputation level, and diabetes status.

Healthcare utilization associated with adverse events

The current findings from model 2 are consistent with recent literature suggesting that individuals having a LLA incur increased use of healthcare services due to adverse events such as falls and fractures [8,21]. Dobson et al. (2016) conducted a retrospective cohort study using Medicare beneficiaries, who were significantly older than our study group (sample mean age 73 years). They found the number of falls or fractures were comparable or higher among those with LLA compared to the control group. Importantly, it is worth noting the Dobson et al. study only included those subjects with LLA that had received a prosthesis within 12 months of amputation surgery. In contrast, the current study also included individuals without a prosthesis within 12 months of surgery for analysis.

Individuals that experienced a fall/FRI after discharge from amputation were almost 3 times more likely to use the ED in the current study. Falls are common among those with amputation, including injurious falls that result in need for medical treatment, which has been demonstrated in a previous study among community dwelling adults with LLA[22]. Adults with LLAs are often described as an at-risk population for increased healthcare utilization because of their increased association with chronic diseases and functional disability[22]. The study by Mundell et al.[23] notes an association between transfemoral amputees and cardiovascular events. However, it was found that no change in risk occurred for those with or without a prosthesis[23]. It is interesting to highlight that we found no effect of sex as a few studies have found women with limb loss have worse function or increased adverse events compared to men with limb loss[22,24,25]. Yet, the current study differed from previous studies in that this study utilized claims of those with commercial insurance as opposed to relying on self-report, which may have recall bias influencing the report of injurious falls. It is likely that other factors besides sex may be driving increased healthcare utilization within 12 months after LLA.

Limitations

This study has several strengths, in particular noting the relatively large sample size for this specific population. Additionally, findings are based on a nationally representative sample of commercial claims generalizable to the US adult population with LLA who have commercial (private) health insurance. However, there are limitations of this study. Due to the nature of administrative data, it is not possible to differentiate the reasons some individuals took longer to receive a prosthesis or not at all. It is possible that a delayed fitting or functional limitations that contribute to falls may be associated with other health complications, lack of social support, certain payer policy restrictions, or another unseen complication that contributes to increased healthcare utilization. Future studies should attempt to determine such factors using clinical databases or potentially registry data. However, understanding this should place greater emphasis on working to resolve issues seen to potentially delay provision of prosthetic rehabilitation so that patients are afforded the benefits of earlier receipt of their prosthesis.

The current study did not assess the events prior to ED use. Unfortunately, the nature of claims data makes it difficult to determine events that may have precipitated or caused increased healthcare utilization. This study did not assess potential difference in severity or frequency of ED use. Further exploration on the association of adverse events, falls/FRIs, and the subsequent acute care utilization with respect to frequency remains needed. Such work, as well as the current study, would be enhanced if possible, to ascertain the functional status of patients. There are other confounding variables that influence both timing of prosthesis receipt and that influences falls/FRIs, such as poor general health and functional mobility. The receipt of a prosthesis, as captured by date of service, does not guarantee use of the prosthesis. However, a strength of using claims data includes accurate reflection of dates, such as the date a prosthesis was received as opposed to relying on patient recall.

4.5 Conclusion

The current study findings have valuable implications for clinical care and potentially policy. Earlier receipt of a prosthesis is associated with reduced marginal odds of ED use. This is valuable in further consideration of the current study results showing a strong association between falls/FRIs and ED use, indicating a prosthesis plays an important role in individual mobility and potential to reduce preventable healthcare utilization. In light of previous work, which has noted the negative impact of ED utilization on QoL[7] and overall quality of care, it is concluded that if an individual is provided a prosthesis earlier in the rehabilitation process after LLA. There is increased value and opportunity to avoid preventable healthcare utilization and further reductions in QoL.

4.6 References

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CHAPTER 4 TABLES

TABLE 4. 1: Sample demographic characteristics and inferential statistics stratified by receipt of prosthesis.

Demographic Characteristics	**Receipt of Prosthesis**		
	yes	no	p-value
Total population, n(%)	443 (87)	67 (13)	
Emergency Department Utilization			
Yes	131(83.4)	26 (16.6)	0.13
No	312 (88.4)	41 (11.6)	
Fall after LLA			
Yes	396 (86.5)	62 (13.5)	0.43
No	47 (90.4)	5 (9.6)	
Amputation level			
Transtibial or below knee	352 (91.4)	33 (8.6)	<0.0001*
Transfemoral or above knee	91 (72.8)	34 (27.2)	
Sex, n(%)			
Male	315 (88.7)	40 (11.3)	0.06
Female	128 (82.6)	27 (17.4)	
Diabetes/Vascular Status			
Yes	290 (88.7)	37 (11.3)	0.10
No	153 (83.6)	30 (16.4)	
Age, mean (SD)	52.5 (9.4)	52.1 (10.1)	0.80

*Statistically significant at 0.05

TABLE 4. 2: Characteristics of patients based on time from amputation to receipt of prosthesis within 12 months, or no prosthesis.

Groups: No prosthesis, 0-3 months post-amputation prosthesis receipt, 4-6 months post, 7-9 months post, 10-12 months post-amputation time.

	No Prosthesis		**0-3 mon**		**4-6 mon**		**7-9 mon**		**10-12 mon**		**Total**	
Demographic Characteristics	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Total population, n (%)	67	13.1	174	34.1	186	36.5	58	11.4	25	4.9	510	100
Emergency department utilization												
Yes	26	16.6	46	29.3	58	36.9	18	11.5	9	5.7	157	30.9
No	41	11.6	128	36.3	128	36.3	40	11.3	16	4.5	353	69.1
Amputation level												
Transtibial or below knee	33	8.5	141	36.6	150	39.0	46	12.0	15	3.9	385	75.4
Transfemoral or above knee	34	27.2	33	26.4	36	28.8	12	9.6	10	8.0	125	24.6
Sex, n (%)												
Male	40	11.2	142	40.0	121	34.0	41	11.5	14	3.9	355	70
Female	27	17.4	32	20.6	65	42.0	17	11.0	14	9.0	155	30
Diabetes/Vascular Status												
Yes	37	11.3	123	37.6	120	36.7	33	10.1	14	4.3	327	64.1
No	30	16.4	51	27.9	66	36.1	25	13.6	11	6.0	183	33.9
	No Prosthesis		**0-3 mon**		**4-6 mon**		**7-9 mon**		**10-12 mon**		**Total**	
Age, mean (SD)	52.1 ± 0.69		52.4 ± 0.69		52.4 ± 0.68		53.2 ± 1.2		50.7 ±2.5		52.2 ±0.42	

TABLE 4. 3: Logistic regression results for model 1. Unadjusted results represent the bivariate or crude relationship between the independent variable and outcome variable. The adjusted estimates are while controlling for covariates.

	Model 1- Timing & ED Use	
Variables	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
Amputation level (AKA versus BKA)	1.08 (0.70-1.66)	1.09 (0.69-1.73)
Sex (female versus male)	0.93 (0.62-1.40)	0.93 (0.61-1.41)
Age	1.02 (0.99-1.04)	1.01 (0.98-1.03)
Diabetes/Vascular Status (no versus yes)	0.68 (0.46-1.02)	0.71 (0.47-1.07)
Length of Time, LLA to Prosthesis		
0-3 mon	0.47 (0.35-1.42)	0.52 (0.28-0.97)*
4-6 mon	0.64 (0.26-1.55)	0.68 (0.28-1.26)
7-9 mon	0.76 (0.34-1.93)	0.69 (0.32-1.48)
10-12 mon	1.03 (0.30-2.15)	0.92 (0.35-2.41)
No Prosthesis (Reference)	-	-

*Statistically significant based on 95% confidence interval

TABLE 4. 4: Logistic regression results for model 2 the association of prosthesis receipt and fall/FRI with ED utilization. Adjusted estimates are while controlling for covariates.

	Model 2 - FRI & ED Use	
Variables	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
Receipt of Prosthesis (no versus yes)	1.51 (0.89-2.57)	1.52 (.87-2.66)
Fall/FRI (yes versus no)	3.13 (1.40-7.12)	2.86 (1.23-6.66)*
Amputation level (AKA versus BKA)	1.08 (0.70-1.66)	0.93 (0.58-1.48)
Sex (female versus male)	0.93 (.62-1.40)	0.87 (0.56-1.34)
Age	1.02 (0.99-1.04)	1.01 (0.98-1.03)

Diabetes/Vascular Status (no versus yes)	0.68 (0.46-1.02)	0.69 (0.45-1.04)

*Statistically significant based on 95% confidence interval

CHAPTER 4 FIGURES

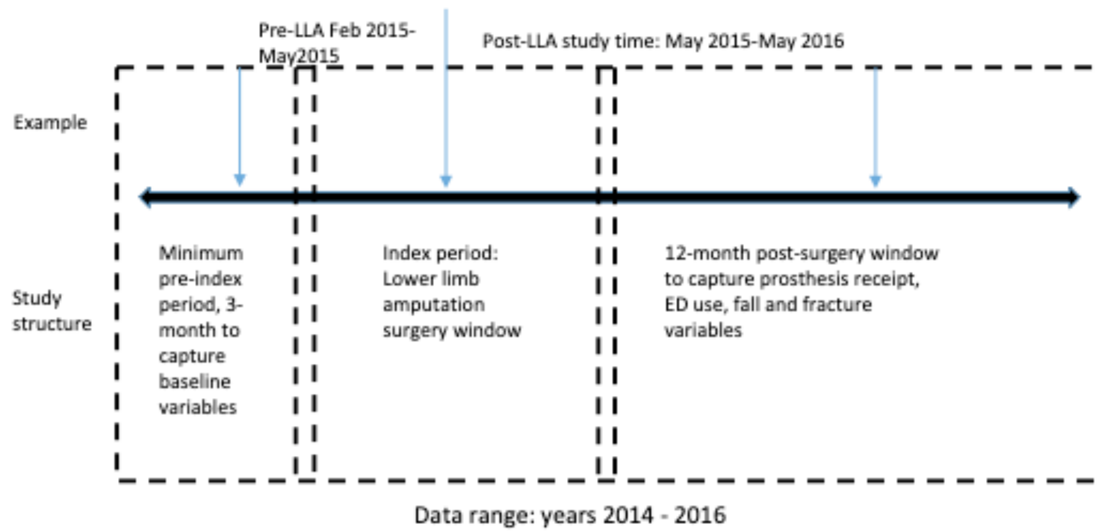

FIGURE 4. 1: Structure of participant episode definitions and creation of sample. LLA: lower limb amputation, ED: emergency department

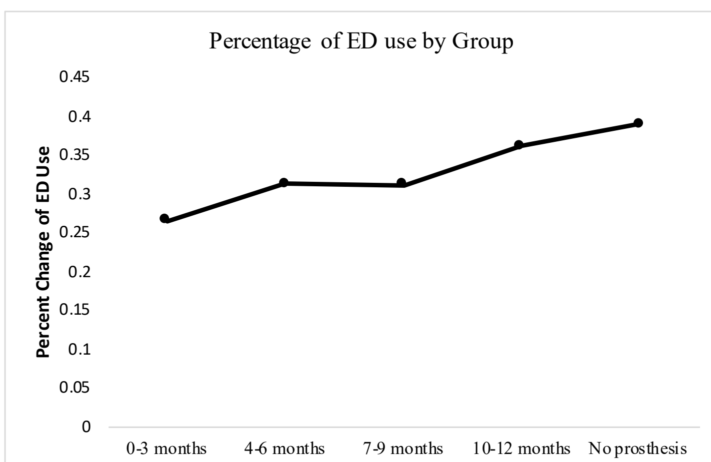

FIGURE 4. 2: Comparison of percent of emergency department (ED) use that changes based on timing of prosthesis receipt proportional to group size.

No prosthesis group, Group 0-3 months, 4-6 months, 7-9 months, 10-12 months - post-amputation prosthesis receipt

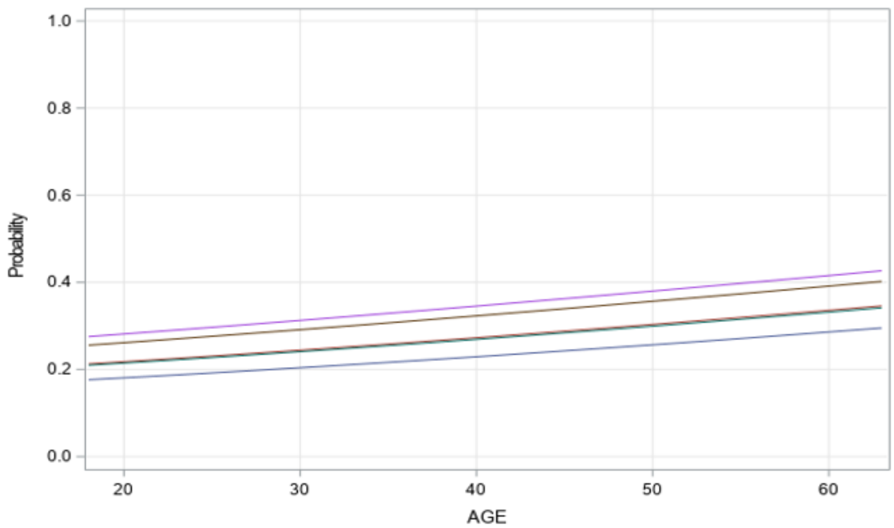

FIGURE 4. 3: Predicted probability of emergency department (ED) use versus age stratified by time to prosthesis receipt.

The purple line represents the “no prosthesis” referent group and is the highest line on the graph demonstrating a consistently higher probability of ED use. The grey line, the next one down, represents the 10-12 months group for prosthesis receipt, while time periods 4-6 month and 7-9 months are the overlapping red and green lines. The lowest probability of ED use is seen with the blue line, which represents those who receive a prosthesis between 0-3 months.

CHAPTER 5: THE ASSOCIATION OF FUNCTIONAL MOBILITY AND INJURIOUS FALLS AMONG ADULTS WITH LOWER LIMB AMPUTATION

5.1 Introduction

Approximately 29 million Americans fell in 2014 resulting in an estimated $31 billion in Medicare costs [1]. Fall-related injury and deaths have increasingly become a significant public health issue across the US. Falls are a leading cause of injury among those 65 years or older with multiple risk factors including history of falls, increasing age, a variety of chronic health conditions, and functional impairment [2,3]. Approximately one third of older adults fall at least once per year [4]. Among adults that fall, 20 to 30% suffer an injury [5–7]. Individuals with LLA are at a particularly high risk of fall-related injury with more than half of people with LLA reporting a fall at least once per year [8,9].

Increased incidence of falls among adults with LLA may be attributed to the combination of common risk factors that are associated with falls in general and unique conditions present as a result of prosthesis use [10]. A fall or fall-related injury can result in pain, the need for medical treatment, increased fear of falling again, and self-induced isolation or activity reduction – all factors that can reduce QoL [11]. Individuals with chronic disease and disability consistently report having lower functional mobility likely further contributing to a reduced QoL compared to people without chronic conditions [12,13]. This is consistent with recent work reporting a relationship between mobility with QoL among adults with LLA, suggesting improved mobility can enhance QoL [14]. Thus, increased functional mobility may be able to mitigate the negative impact of falls on QoL and possibly even other negative sequalae of falls such as pain, associated medical costs, self-induced isolation or activity reduction. The role of functional mobility and its relationship with injurious falls among lower limb prosthesis users has conflicting evidence, potentially confounded by several studies assessing falls early in the rehabilitation process while fewer focus on established prosthesis users.

Achieving independent walking or ambulation has been noted as a primary goal of prosthetic rehabilitation [14,15]. However, a paradox exists in that most adults with a lower limb amputation report some falls during ambulation [16]. Some of the confusion in the prosthetic rehabilitation literature may be due to lack of differentiation with investigating falls in general versus falls that result in an injury (i.e., an injurious fall) that requires medical attention. While falls that do not result in injury are important in their potential for negative consequences (e.g., increased fear of falling, activity avoidance and reduction, injurious falls have additional significance due to their implications for healthcare costs and future healthcare spending.

The purpose of this study was to estimate the influence of functional mobility on the likelihood of having an injurious fall among adults who utilize a lower limb prosthesis. We hypothesized that lower functional mobility would result in an increased risk for injurious falls. A better understanding of this relationship has the potential to assist healthcare providers in assessing individuals for fall risk, aid in clinical decisions regarding prosthetic design, and inform policy.

5.2 Methods

Study design & data source

A retrospective cross-sectional analysis was conducted using clinical outcomes data collected from a large, multi-site prosthetics provider with clinics in regions across the US. To address the primary hypothesis, two analyses were carried out: (1) a model applying mobility levels derived from the PLUS-M quartiles; and (2) a model applying mobility levels mapped to clinically derived levels. A convenience sample of 19,654 individual observations was extracted from a lower limb prosthesis user database. Individuals were excluded if the file indicated they had bilateral LLA or if they had not yet received a prosthesis as a prosthesis is required to capture mobility. Cases were included if data on patient-reported outcomes were complete.

This study was approved and deemed exempt from patient consent by Western Investigational Review Board (Protocol #20170059). This study is considered a secondary analysis with de-identified data that does not contain any of personal health information identifiers.

Falls and mobility assessment

At various timepoints within the care pathway for patients with a lower limb prosthesis, a patient reported outcomes instrument that includes a fall history assessment is administered. These assessments record patient reports of falls over a 6-month recall period (i.e., “Have you had a fall in the previous 6 months that resulted in a hospital or physician visit?”). While it is recognized that each fall or near fall represents increased risk for a fall with injury, the purpose of this study was to specifically examine falls with injury appreciating the subsequent impact to patients’ well-being with respect to the cost of healthcare. Anchoring the recall to an outcome requiring a visit to a healthcare professional was viewed as mitigating recall bias [17].

Mobility was measured via the Prosthetic Limb Users’ Survey of Mobility (PLUS-M) 12 question short-form [15]. The PLUS-M is a self-report mobility instrument administered to the patient that quantifies individual functional mobility. The resultant score is a normalized T-score ranging from 21.8 to 71.4. Higher T-scores on the PLUS-M indicate greater mobility while a score of 50 represents the mean mobility as reported by the development sample [15]. For all individuals, their mobility score from the first outcomes assessment associated with an initial evaluation appointment was extracted for analysis as this was considered to represent a baseline for mobility.

Mobility was entered as an independent categorical variable. In order to understand the influence of mobility on injurious falls, two separate regression models were constructed and applied to the sample resulting in 2 final models. The separate models were based on two different ways to categorize mobility. The first approach (noted as QUARTILE approach) utilized mobility categories based on the quartile ranges from the PLUS-M instrument [15,18]. These quartiles for the PLUS-M, however, do not map to the Medicare Classification Functional Level (e.g., K-level) system. The K-level index, as described by Medicare and subsequently utilized as an industry standard in the US, is important because consequently mobility level classification determines access to prosthetic componentry and financial reimbursement for the prosthesis provided (Table 5.1) [15,19,20]. The Health Care Financing Administration requires all Medicare patients to be classified into one of the K-levels and note, the letter K is an arbitrary letter assigned to the index [19,20]. In the US the K-level system is presently a critical part of evaluating a patient clinically to determine mobility potential and prosthetic component selection for all patients regardless of payer. It is relied upon for guiding prosthetic prescription and care planning.

In response to limitations of the PLUS-M quartiles, the second approach categorized individual's mobility into three tiers (low, middle, high) based on scores that were resultant decision points within a classification tree analysis (i.e., CART). This recent study was intended to assist in mobility level determination as it maps to the clinically relevant K-levels [21]. The noted classification tree analysis heavily relies upon the PLUS-M score but additionally includes other factors such as age, etiology, and body morphology. This second approach (noted as CLINIC approach) is intended to provide increased clinical guidance [21].

Confounding (control) variables

Individual baseline characteristics were also included such as age, sex, amputation level, and cause of amputation. Age was entered as a continuous variable. Cause of amputation was self-reported as a specific question (i.e., "What was the cause of your amputation?") with an option of six answers ranging from vascular or diabetes, trauma/injury, cancer/tumor, infection (without diabetes), congenital/birth, or other. The cause or etiology was collapsed into either diabetes and/or secondary to vascular disease or else combined into non-dysvascular/traumatic/other category [22]. Amputation level was collapsed into two levels. Above-the-knee amputation (AKA) was noted if amputation level was reported as knee disarticulation or proximal. Below-the-knee amputation (BKA) was indicated if the amputation level was reported as transtibial or distal excluding toe amputations. Partial foot amputations (i.e., transmetatarsal and proximal) and hip disarticulation were included in appropriate BKA/AKA categories. There were no cases of individuals with an amputation proximal to a hip disarticulation within the sample.

Statistical analyses

Descriptive statistics were used to summarize demographic and clinical characteristics for both groups (injurious fall reported versus no injurious fall reported). Differences between groups were assessed using Chi-square test for categorical and t-test for continuous variables. We assessed the likelihood of falling and stratified by mobility level using the QUARTILE and CLINIC methods. Logistic regression function estimates were used to calculate odds ratios and determine individual effects of several variables on fall-related injury occurrence. A fall was characterized as a fall requiring hospitalization or physician visit. All independent variables were assessed for collinearity. There were no significant correlations that required variable transformation. Logistic regression was conducted to assess mobility level against the outcome of injurious fall versus no injurious fall reported (QUARTILE and CLINIC methods) as independent variables. Again, the QUARTILE model implemented a four-tier mobility classification mapping to the quartiles from the PLUS-M and the CLINIC model utilized a three-tier mobility classification that can subsequently be used within the classification tree analysis for informing K-level [21].

A multivariable logistic regression model was used to assess the influence of mobility level on the likelihood of an injurious fall while controlling for baseline characteristics and additional variables deemed important for individuals with LLA. Two separate multivariable logistic regression models were conducted to assess the influence of mobility level on the likelihood of an injurious fall. Odds ratios (OR) with 95% confidence intervals (CI) were calculated.

A sensitivity analysis was used to evaluate the influence of excluding incomplete cases (e.g., those with missing cause of amputation responses). A logistic regression model was applied to assess the extent that incomplete information on cause of amputation possibly had on the sample covariates. All data management and analyses were performed in R-studio (version 3.6.2).

5.3 Results

From the clinical database of 19, 654 individuals with lower limb amputation, after exclusion criteria were applied, 15,665 unilateral lower limb prosthesis users were found. Those with missing data were identified (n=3,621) as missing cause of amputation response resulting in a final sample of 12,044 that were analyzed (Figure 5.2). Within the final cross-sectional sample, 1,529 individuals reported an injurious fall requiring medical attention, which represents a prevalence of 12.7% (Table 5.2).

Sensitivity analysis

Those with available cause of amputation (n=12,044) were compared to those with missing cause of amputation data (n= 3,621). This differential attrition analysis was to assess if the data were missing at random or not at random and the extent to which exclusion may influence the results. It turns out that these missing data were not significantly associated with the covariates (Table 5.3). Therefore, the final sample assessed included only those with complete data and those with missing cause of amputation were excluded from the final adjusted analysis.

QUARTILE Model 1: Four tiers of mobility using PLUS-M T-score quartiles

Logistic model results

The demographic variables that were adjusted for in the model included age, sex, cause of amputation and level of amputation. Mobility was significantly associated with injurious falls (Table 5.4). The adjusted model showed OR of 3.68, 95% CI: [3.11, 4.39] when comparing lowest to the highest. The odds of falling for those individuals classified in QUARTILE mobility levels 2 and 3 as compared to the highest (QUARTILE 4) were also both significant (QUARTILE 2: OR: 2.61, 95% CI: [2.18, 3.12]; QUARTILE 3: OR: 1.96, 95% CI: [1.62, 2.37]). The odds of incurring an injurious fall for an individual in lowest mobility (QUARTILE 1) approached two times those compared to an individual in the highest mobility level (OR: 3.68, 95% CI: [3.11, 4.39]) (Table 5.4). The remaining variables in the model (i.e., age, sex, cause of amputation and level of amputation) were not statistically significantly associated with odds of an injurious fall that results in hospitalization or need for medical attention.

CLINIC Model 2: Three tiers of mobility using CART analysis decision points

Logistic model results

The same covariates were controlled in the CLINIC model as were controlled in the QUARTILE model. After adjusting for demographic variables such as age, sex, and level of amputation, mobility remained significantly associated with the odds of falling (Table 5.4). Mobility was significantly associated with injurious falls. The lowest level of mobility had an adjusted OR of 2.48 (95% CI: [2.15, 2.85]) compared to the highest mobility level. CLINIC 2 (middle level) was also significantly associated with an increased risk of falling with an adjusted OR of 1.98 (95% CI: [1.77, 2.22]). Individuals in the lowest mobility tier had over twice the odds of incurring an injurious fall as compared to those in the highest tier (OR: 2.23, 95% CI: [1.90, 2.63]). Individuals in the second mobility tier have almost 2 times the odds of incurring an injurious fall as compared to those in the highest tier (OR: 1.98 95% CI: [1.77, 2.22]). This indicates that mobility is inversely associated with the likelihood of incurring an injurious fall.

Model diagnostics

The two models differing by mobility categorization were evaluated by comparing an information criterion (AIC) for performance of the model with the PLUS-M based quartile mobility predictor versus the CLINIC based mobility predictor respectively. The lower the AIC, the better a model is inferred to perform. Model 1, which used the QUARTILE levels based on T-scores, had a slightly lower AIC, 8942.4 as compared to the CLINIC based model (AIC=8999.5). Additionally, the goodness of fit (GoF) was assessed for each model with the CLINIC based model potentially fitting the data better than the QUARTILE based model (0.07 and 0.001 respectively, Table 5.5). Finally, each of the four models was assessed using the relative operating characteristic (ROC) curve and the area under the curve (AUC) was calculated. The ROC curve plots the probabilistic forecast for a range of thresholds and the AUC provides a measure of the individual model accuracy based on the data. A measure of 1 is a perfect model and a measure of 0.5 would indicate a random forest. The ROC curves are provided with the AUC listed (Figure 5.2). The AIC, AUC, and GoF are presented for each model (Table 5.5).

5.4 Discussion

Using data from a large multi-site clinical database, this study quantified the associated risk of injurious falls among adults with LLA who wear a prosthesis based on different mobility categories. These results demonstrate that individuals in the lowest category of mobility have a significantly higher likelihood of falling and requiring medical attention as compared to those at the highest mobility levels when comparing baseline results in a cross-sectional manner. The difference appears to decrease as individuals improve in their functional mobility. While the causes of limited mobility are multifaceted, mobility has been shown to be a key determinant in QoL and wellbeing among older adults [23–25]. A recent study among near elderly adults (ages 50-69), found that higher self-reported mobility was also associated with a positive impact on pain, anxiety, and self-care [23]. In the context of those with LLA, a higher self-reported mobility may also lead to lower fall risk. Alternatively, a lower self-reported mobility that is associated with increased odds of experiencing an injurious fall, may indicate the individual is experiencing pain, comorbid medical conditions, or fear of falling, which all contribute to a risk of falling [16,26,27]. Furthermore, as higher functional mobility is associated with reduced injurious falls, then this highlights the economic value of a prosthesis at reducing potentially unnecessary healthcare utilization.

Mobility methods

Two different methods for categorizing patients based on their mobility levels are presented because in practice the QUARTILE method does not match any clinical criteria. However, the CLINIC method, which was developed using a classification and regression analysis tree, used multiple clinical characteristics to predict individual functional potential [21]. The current K-level system has no scientific underpinning that relates to actual mobility or potential mobility, however tools such as PLUS-M or the Amputee Mobility Predictor (AMP) have been created to assist clinicians to objectively determine mobility [15,19]. The CLINIC method as presented, appears to have similar results as the QUARTILE method, while being more clinically relevant as it is associated with household ambulator or low unlimited community ambulator (CLINIC level1 or <36.75 PLUS-M t-score), low to mid-range unlimited community ambulator (CLINIC level 2 or between 36.75 and 49.45 PLUS-M t-score), or an unlimited community ambulator or active individual (CLINIC level 3 or >49.45 PLUS-M t-score).

Fall rates and implication

Incidence of falls and fall risk among people with LLA is high, specifically among those immediately post-amputation or early in the rehabilitation process [27,28]. A fall after an amputation can negatively affect the rehabilitation process and may even lead to increased length of stay at a hospital or admission to a long-term care facility further reducing QoL and associated health outcomes [8]. Yet, this current study is unique in that self-reported injurious fall was assessed after the individual had a lower limb prosthesis and had some experience walking with their prosthesis. While injurious falls are more severe than non-injurious falls and more of an economic burden, injurious falls occurred only about 12.5% among all individuals included in the sample with LLA. The estimated prevalence of injurious falls among this sample is lower than estimates from previous literature [27,29,30]. Yet, in contrast, this study included both transtibial and transfemoral patients and includes a diverse sample of prosthesis users with the outcome specifying injurious falls as opposed to any fall. A recent study by Dobson et al (2016), suggested the receipt of a prosthesis may reduce long term health costs. Our results suggest that perhaps, having a prosthesis improves overall mobility, which reduces the odds of injurious falls. As functional mobility improves and risk of injurious falling is reduced, this evidence further demonstrates the value of a prosthesis with respect to an economic impact by reducing the burden of injuries and falls.

Predisposing factors

As presented in this study, we found no significant increased risk of injurious fall across different amputation levels, cause of amputation, sex, or age implying that functional status in terms of mobility may be more influential when considering the needs of those with LLA. We do not propose that individual predisposing characteristics such as age or amputation level are not risk factors for injurious falls, but that functional mobility is perhaps more impactful within this population. Muscle weakness and loss of lower body strength are well-known risk factors for falling and may reduce mobility [6,31]. Over time as individuals regain strength and walking confidence with a prosthesis, their risk of falling reduces [6,32]. The reduced odds of experiencing an injurious fall for those who have the highest level of mobility with a median time since amputation of 5 years supports the previous finding by Miller [6], but this current study extends their findings by including more experienced prosthesis users.

Sex was not significant in the current model, while this is not consistent with other studies that found females are more likely to have reduced overall physical activity and have increased fall risk [6,16,30]. The discrepancy between our results and others may be due to the possibility that this sample represents adults who have a prosthesis and are not currently hospitalized and most likely had some physical therapy after their LLA.

Strengths & limitations

While this study has strengths such as the large sample size that represents those with LLA from across the US, which increases external validity. Nonetheless, there are limitations as well. First, those who do not have a prosthesis whether because their amputation was recent or due to other factors, were excluded from the study. This is primarily because the PLUS-M mobility score is currently only validated for prosthesis users and the fact that it is collected consistently as a part of clinical practice standards. Also, this means the sample may disproportionally represent those who have access to care as opposed those who may have difficulty due to socioeconomic reasons or other social determinants.

Second, these results do not control for amount of time using their current prosthesis. This may impact fall risk. Potentially if someone is a new or inexperienced prosthesis user or having socket issues, this could increase risk of falling or reduce mobility score. It has been demonstrated that increased self-reported mobility is associated with balance confidence [33] yet the impact of user experience perhaps should be explored further.

Third, this study relies on self-reported data provided to prosthetists at clinical appointments. While anchoring to an injury may improve recall of the incident, there is potential recall bias surrounding the injurious fall outcome thus reducing the reported falls. Additionally, PLUS-M mobility measure is a self-perceived mobility tool that has been validated [15], yet it does not rely on clinician observed measurement. We suggest the use of patient-reported functional mobility superior for assessing a patient's perception of mobility status while their performance may not represent their actual ability to perform functional tasks that are captured in the PLUS-M (e.g., carrying a grocery bag or walking in a parking lot).

Finally, this is a cross-sectional study and consequently cannot provide information on cause and effect nor predict a future fall. However, there is evidence in the literature that fall history increases risk of future falls among adults in the general population [2,7]. More studies should evaluate the nuanced relationship between functional mobility and injurious falls with longitudinal data among those with LLA who have a prosthesis.

5.5 Conclusion

The findings that none of the covariates were significant in the adjusted models indicate the importance of focusing on an individual's functional health, mobility and independence. A lower functional mobility is associated with an increased risk of injurious falls, which are associated with healthcare utilization (e.g., doctor visits or emergency department use) and thus more of an economic burden. Rehabilitation plans and care coordination that target a timely prosthesis receipt with the goal to increase functional mobility may have rippling positive effects on patient outcomes and have an economic impact.

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CHAPTER 5 TABLES

TABLE 5. 1: Medicare Functional Classification Levels or K-level descriptions

K-LEVEL or MFCL	**Description**
K-0	Non-ambulator, does not have ability or potential to ambulate or transfer safely with or without a prosthesis. Prosthesis does not enhance quality of life
K-1	Has ability or potential to use a prosthesis. A household ambulator, limited or unlimited on level surface at a fixed cadence
K-2	Has the ability or potential to traverse low environmental barriers (e.g. curb or stairs) A limited community ambulator
K-3	Has the ability or potential for ambulation with variable cadence, can traverse most environmental barriers, may have vocational, therapeutic or exercise activity that requires use of a prosthesis. Unlimited community ambulator
K-4	Has the ability or potential for ambulation with a prosthesis that exceeds basic ambulation skills, a high impact user or energy. Typical of a child, active adults or athlete

TABLE 5. 2: Demographic characteristics of cross-sectional data stratified by fall status (n=15,665)

	Injurious Fall		
Independent variable	**Yes**	**No**	**P-value**
Total n(%)	1529 (12.7)	10515 (87.3)	
QUARTILE (Mobility status), n (%)			
25th percentile or below (1)	746 (6.2)	3564 (29.6)	<0.001*
26-34 percentile (2)	391 (3.2)	2503 (20.8)	
35-55 percentile (3)	254 (2.1)	2145 (17.8)	
75th percentile or above (4)	138 (1.1)	2303 (19.1)	
CLINIC (Mobility status), n (%)			
Low	363 (3.0)	1719 (14.3)	<0.001*
Middle	740 (6.1)	4126 (34.3)	
High	426 (3.5)	4670 (38.8)	
Sex, n (%)			
Male	1071 (8.9)	7721 (64.1)	0.01*
Female	458 (3.8)	2794 (23.2)	
Age			
Median	59	60	0.74
Interquartile Range	51-68	50-69	
Cause of Amputation, n (%)			
Peripheral/vascular	893 (7.4)	5771 (47.9)	0.01*
Trauma/other	636 (5.3)	4744 (39.4)	
Level of Amputation, n (%)			
BK (Transtibial/Symes)	1102 (9.1)	7866 (65.3)	0.02*
AK (Transfemoral)	427 (3.5)	2649 (22.0)	
Time since Amputation (years)§			
Median	4.9	5.3	0.98
Interquartile Range	1.7 - 14.1	1.7 - 16.8	

*: statistically significant at the 95% level (p<0.05)

§ - median and IQR are based on only those with time since amputation reported (n=11,513)

Ŧ - reported based on those who provided a cause for amputation (n=12,044)

TABLE 5. 3: Sensitivity analysis results, logistic regression with missing cause of amputation was the outcome compared to the covariates of interest.

Characteristics	**Adjusted model**
	OR [95% CI]
Injurious fall (ref = no fall)	1.08 (0.96, 1.22)
Mobility level: Tscore	0.99 (0.98, 1.00)
Female (ref = male)	0.94 (0.86, 1.02)
Age	0.99 (0.99, 0.99)
Amputation Level:	
Transtibial/Symes (ref = AK)	1.02 (0.94, 1.11)

TABLE 5. 4: Results of injurious fall risk among adults with major LLA with cause of amputation excluded from sample (n=12,044).

Mobility level reference is to the highest mobility group. Those in the lowest quartile mobility level have increased odds of falling as compared to those in the highest mobility level.

Characteristics	**Unadjusted OR (QUARTILE)**	**Adjusted OR (QUARTILE)**	**Unadjusted OR (CLINIC)**	**Adjusted OR (CLINIC)**
	OR [95% CI]	OR [95% CI]	OR [95% CI]	OR [95% CI]
Mobility level				
1 vs 4 (low v high)	3.49 (2.90, 4.24)	3.49 (2.87, 4.28)*	2.31 (1.99, 2.69)	2.23 (1.90, 2.63)*
2 vs 4 (middle v high)	2.61 (2.14, 3.20)	2.60 (2.12, 3.21)*	1.97 (1.73, 2.23)	1.92 (1.69, 2.19)*
3 vs 4	1.98 (1.60, 2.46)	1.98 (1.60, 2.47)*	-	-
Female (ref = male)	1.18 (1.05, 1.33)	1.02 (0.99, 1.15)	-	1.04 (0.92, 1.17)
Age	1.00 (0.99, 1.01)	0.99 (0.99, 1.00)	-	0.99 (0.99, 1.00)
Amputation Level: Transtibial/Symes (ref = AK)	0.87 (0.77, 0.98)	0.97 (0.86, 1.10)	-	0.94 (0.83, 1.06)
Cause of amputation: Diabetes/vascular (ref=Trauma)	1.15 (1.04, 1.29)	0.90 (0.80, 1.10)	-	0.94 (0.83, 1.06)

**statistically significant at p<0.05*

TABLE 5. 5: Model diagnostics for the cross-sectional dataset n=12,044

Cross-section Models	AIC	AUC	GoF
CLINIC mobility	8999.5	0.60	0.07
QUARTILE mobility	8942.4	0.62	0.001

CHAPTER 5 FIGURES

FIGURE 5. 1: Flow chart depicting sample selection for cross-sectional data.

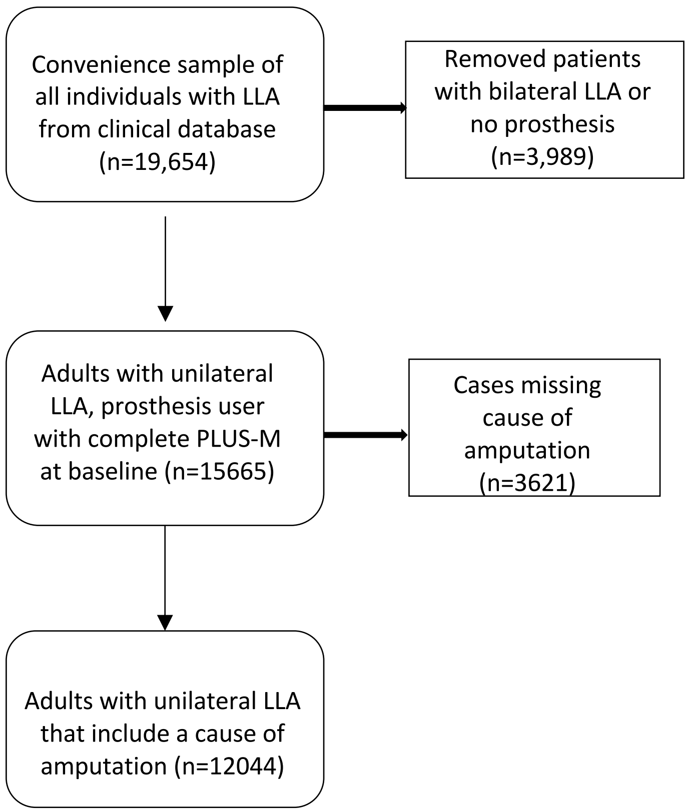
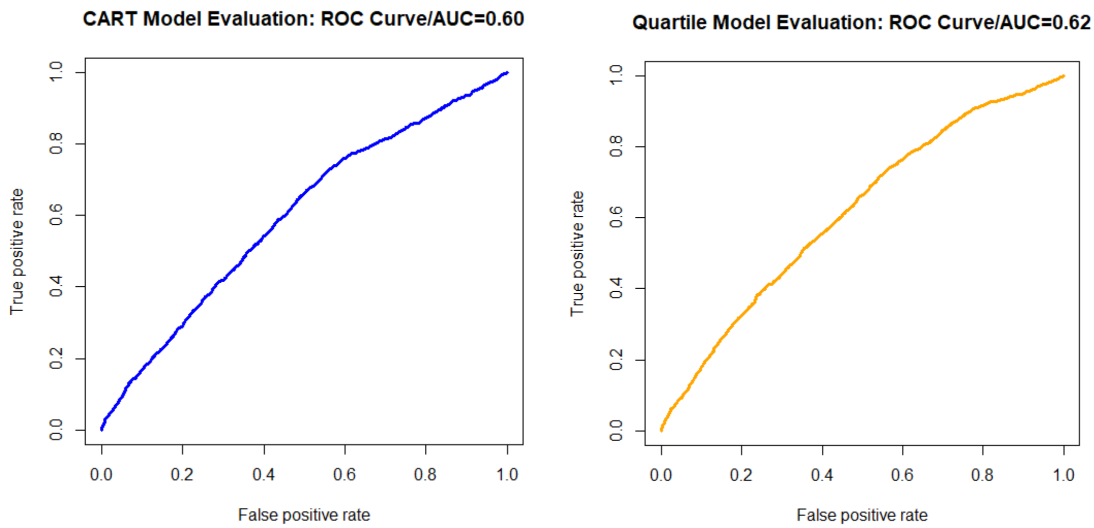


FIGURE 5. 2: ROC Curves for each of the models assessed, CLINIC model in blue and QUARTILE model in yellow.



CHAPTER 6: CONCLUSION

6.1 Summary

Individuals who have a LLA experience numerous, overlapping difficulties with respect to overall physical health including functional recovery as well as social and mental health[35,50,54,55]. As healthcare costs have increased, the economic burden associated with care for those with chronic conditions, especially functional impairment and disability, remains high[15,26,56,57]. Postamputation rehabilitation is essential for individuals to regain functional independence, return to ADLs, and overall health. Yet, real-world evidence (RWE) on rehabilitation outcomes among those with LLA in terms of timing of prosthesis receipt, overall costs and utilization are sparse. Hence, there is a need for more RWE on factors that influence timing of prosthesis receipt, potential disparities, healthcare utilization post-LLA, and adverse events (e.g., injurious falls) may inform clinical practice to guide clinicians and influence patient-health while being cost-effective[24,27].

In response to this need for evidence, this dissertation employed retrospective methods using an administrative claims (Watson) database and a clinical outcomes database together to inform on the median survival time to prosthesis receipt, group differences in time to receipt based on patient characteristics, and illustrated the overall impact of a lower limb prosthesis on costs, healthcare utilization, and adverse events in this population. The Anderson Behavioral model suggests that predisposing factors, enabling factors and perceived factors all influence healthcare utilization and outcomes. This work demonstrated that it is possible to assess healthcare resource utilization and costs through the use of a population-based, nationally validated claims dataset of patients under 65, and using a clinical outcomes database with diverse patients.

This project contains discussion linking prosthetic rehabilitation to health outcomes beyond prosthesis performance but looking deeper at the economic burden often associated with LLA while controlling for the enabling factor of insurance status. As examined in this dissertation, predisposing factors (e.g., amputation level and age) and perceived need factors (e.g., comorbid conditions) are associated with prosthesis receipt. In turn, receipt of a prosthesis has a profound influence on health-related outcomes (e.g., functional mobility), indirectly on quality of life, and healthcare costs. Therefore, the clinical benefits associated with a lower limb prosthesis as compared to no prosthesis, can serve to reduce costs and healthcare resource utilization as represented among those with commercial insurance between the ages of 18 to 64 in the US.

Chapter two, which is the first article, establishes the overall median time to prosthesis receipt was 107 days (or approximately 3.5 months). In both the KM analysis and adjusted Cox model, a shorter time to prosthesis receipt is associated with having a more distal amputation (i.e., BKA) and males have an increased likelihood of receiving a prosthesis earlier than females. While amputation level and sex are not modifiable by the patient, it is worth considering how to improve access to prosthetic rehabilitation for these groups in order to reduce the disparity.

Moving from the description and assessment of timing between LLA surgery and prosthesis receipt, the second and third articles (or chapters three and four) focus on the economic outcomes associated with prosthesis receipt, stratified by timing of device provision, in terms of both cost and utilization. Earlier prosthesis receipt was associated with reduced total spending and with reduced healthcare utilization as measured by ED use compared to those who do not receive a prosthesis within 12 months.

Finally, in chapter five, or the fourth paper, there is a shift from viewing administrative data to clinical outcomes data, which are able to inform on some of the contextual factors that are lacking in a claims-type of analyses. Among a sample of those who have a prosthesis, with median time since amputation of about 5 years, a lower perceived functional mobility was strongly associated with increased odds of an injurious fall.

6.2 Informing Perspective on the Field

With more pressure from payers to efficiently and effectively provide prosthetic devices, continued RWE to demonstrate and describe the effect of prosthetic rehabilitation is crucial [3,25]. As prosthetic technology continues to improve and provide benefit to all lower limb prosthesis users, manufacturers should work collaboratively with key stakeholders and clinical sites to sponsor and disseminate real world evidence (RWE) studies. In contrast, controlled clinical trials are unable to capture more broad lived experiences of individuals with LLA as it is a heterogeneous, diverse population with different rehabilitation needs.

RWE studies should include elements that focus on the enabling factors and perceived needs to further inform on how devices are accessed, utilized, and the subsequent associated outcomes in diverse populations. RWE is a useful tool to engage physicians and patients following specific product launches[27]. Publishing observational studies of real-world data offers an important opportunity for manufacturers to provide physicians with additional effectiveness and safety evidence, particularly related to long-term outcomes, and efficacy in extrapolated outcomes such as cost analyses. These types of studies can also include additional outcomes, such as patient-reported information and economic evidence, which are growing in demand by payers and regulatory agencies.

6.3 Strengths & Limitations

The four studies presented were retrospective observational studies, which have limitations by design. First, retrospective studies may suffer from selection bias as certain individuals based on predisposing characteristics or other clinical factors may or may not receive the same services as different individuals. However, observational studies can examine a wider range of effects than experimental (e.g., clinical trials) studies and observational studies are efficient. Cross-sectional studies are beneficial to assess the association of patient factors while increasing the generalizability of the results because they represent broader patient populations and inform future planning of patient care or subsequent research.

The first three articles of this dissertation utilize administrative data, which have their strengths and limitations due to the nature of the data. First, administrative databases are nationally representative while designed for administrative purposes, but provide insight into otherwise potentially rare or difficult to study populations[58]. This is why the sample size of 510, is fairly large relative to this special population of those with LLA. Second, using administrative coding or billing data (e.g., ICD-9 or 10 procedure codes) has inherent weakness is that it is intended for billing purposes and if financial incentive is lacking for certain codes, those codes may be underrepresented[58,59]. For example, while the Watson sample may have limited generalizability due to only including commercially insured adults, a strength is that we were able to account for a level of access, which is an enabling factor (insurance status) by ensuring continuous enrollment was maintained. Therefore, we are able to observe real-world patterns and outcomes among a unique population.

Finally, administrative data lacks clinical details such as functional level, which is quite important in prosthetic rehabilitation. The Watson database specifically, does not include information on other enabling factors such as social network, income or education levels, which if the information were available, may have provided another level of understanding and detail. In contrast, the clinical outcomes database contained clinical information including mobility level, however, as often is a limitation with clinical data, much of the information relies on patient recall.

6.4 Future Research and Direction

Although this project contributes to the knowledge base regarding those with LLA and the resultant process of prosthetic rehabilitation, there is still much work to do. It is recommended that future studies consider the incorporation of data on additional enabling factors (i.e., income and education levels, social networks) and perceived need factors (i.e., adherence to medication, use of prosthesis), and other modifiable risk factors (i.e., smoking). Social determinants continue to influence the health outcomes of adults who have sustained a lower limb amputation. Illness that leads to amputation disproportionately affects persons with lower socioeconomic status, older patients, and persons who are racial/ethnic minorities, which results in disproportionately lower mobility and quality of life outcomes[60]. A few disparities were found in this dissertation, such as individuals who have an AK amputation may experience longer wait times to receive a prosthesis and those with lower mobility levels more likely to experiences injurious falls.

While this dissertation used two separate databases, a future study with both patient functional information, more detail on specific prosthetic componentry and cost or utilization data could confirm these findings and expand our knowledge, which in turn can inform clinicians and policymakers to help improve patient access and outcomes. Inclusion of more details with large diverse samples could confirm and/or update the results within this dissertation. For example, some administrative datasets can be linked to survey data (e.g., Medicare claims with the Medicare Beneficiary Survey).

The association of injurious falls with functional mobility is important, but further studies that expand to using longitudinal cohort methods may allow for an increased understanding of the relationship between mobility and injurious falls relative to when an individual is wearing their prosthesis and predicting future falls. Fall prevention remains a critical part of the rehabilitation plan.

Finally, the three studies that utilized the Watson database included only individuals with continuous enrollment, yet it is recommended that future studies perhaps consider the effect of enrollment on prosthesis receipt and evaluate if there are disparities among those who receive a prosthesis or not based on enrollment varying.

6.5 Conclusion

As the demands increase in healthcare for value-based outcomes and RWE, it is imperative we continue to evaluate the impact of prosthetic rehabilitation services based on predisposing factors, enabling factors, and perceived need factors together. Health services research is a multidisciplinary field of scientific inquiry that can evaluates access, health economics, and outcomes with diverse methods that can help move research in this field forward[27]. Determining the value of prosthetic rehabilitation will help patients improve access to appropriate, high quality, and beneficial prosthetic componentry in a timely manner. As demonstrated in this dissertation, earlier provision of prosthetic devices is associated with lower direct costs and reduced healthcare utilization. For those who are currently using a prosthesis, maintaining and improving mobility may help to reduce the burden and risk of injurious falls. If rehabilitation and prosthetic services result in cost avoidance and improved quality of life for patients with LLA, then we should continue to connect clinicians and researchers so all patients have equity in access and health outcomes.

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APPENDIX

Table A.1 Amputation level determined by ICD-9 or ICD-10 procedure codes

Amputation level	ICD-9	ICD-10	CPT code
Transtibial or below knee	84.1	0Y6H0Z1	27880
	84.12	0Y6H0Z2	27881
	84.13	0Y6H0Z3	27884
	84.14	0Y6J0Z1	27886
	84.15	0Y6J0Z2	27888
		0Y6J0Z3	27889
		0Y6M0Z0	
		0Y6N0Z0	
Transfemoral or above knee	84.16	0Y670ZZ	27590
	84.17	0Y680ZZ	27591
	84.18	0Y6C0Z1	27592
	84.19	0Y6C0Z2	27594
		0Y6C0Z3	27596
		0Y6D0Z1	27598
		0Y6D0Z2	
		0Y6D0Z3	
		0Y6F0ZZ	
		0Y6G0ZZ	

Table A.2 Diabetes or vascular disease status identified as claims that included a diagnosis of diabetes mellitus type II, (specified or unspecified and with or without complications), atherosclerosis of the extremities, or peripheral vascular disease

Condition	ICD-9	ICD-10
Diabetes	250.00-250.99	E11.8-11.9
		E11.620-11.628
Peripheral vascular disease/Atherosclerosis	440.0	I70.0-79.9
	443.9	

Table A.3 Base prosthesis L-codes to determine receipt of prosthesis

Amputation level	HCPC/L-Code
Transtibial or below knee	L5050, L5060, L5100, L5105, L5301 L5050, L5060, L5100, L5105, L5301
Transfemoral or above knee	L5150, L5160, L5200, L5210, L5220, L5230, L5250, L5270, L5280, L5312, L5321, L5331, L5341

Table A.4 Fall diagnosis codes in outpatient services

Condition	ICD-9	ICD-10
Fall	E880.00-E888.9	W00-W19