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Cody L. McDonald

An Exploration of Global Prosthetist/Orthotist Education, Projected Workforce Need, and Information Access Among Faculty

Cody L. McDonald

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Reading Committee:

Deborah Kartin, Chair

Sarah Westcott McCoy

Sara J. Morgan

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Abstract

An Exploration of Global Prosthetist/Orthotist Education, Projected Workforce Need, and Information Access Among Faculty

Cody L. McDonald

Chair of the Supervisory Committee:
Professor Deborah Kartin
Department of Rehabilitation Medicine

People around the world experience disability due to unaccommodated physical impairments. Prosthetic and orthotic devices serve to accommodate many physical disabilities, thereby restoring mobility, function and participation in society. Successful prosthetic and orthotic service provision relies upon a well-trained and accessible workforce of prosthetists/orthotists. Education of prosthetic and orthotic professionals requires a thorough understanding of the current personnel need and state of prosthetist/orthotist education. To date, the global need for and education of prosthetists/orthotists is largely undocumented. The studies in this dissertation address three aims (1) estimate region specific prosthetist personnel need to serve the population of people with amputation based on estimates of global amputation prevalence due to trauma and diabetes, (2) examine the prosthetic and orthotic education, curriculum and teaching methods

described in prosthetic and orthotic literature and (3) explore how prosthetic and orthotic faculty in Ghana and the U.S. access information. Global Burden of Disease (GBD) amputation estimates were used in a secondary data analysis to provide descriptive interpretation for prosthetic and orthotic service provision and calculate estimates of prosthetist need globally. A systematic review of current prosthetic and orthotic education research was used to aggregate the body of literature and identify areas for development. Lastly, a social network analysis was conducted to explore information access and exchange among faculty at two prosthetic and orthotic professional preparation programs. Together this body of work explores the global prosthetic and orthotic workforce at three different levels. The first chapter provides global amputation prevalence estimates to contribute to the current knowledge of prosthetist need and service provision planning. GBD estimates of amputation incidence could build upon this work, provide evidence of amputation rates and change over time to better guide and assess prevention efforts. Additionally, GBD estimates of etiologies that could benefit from orthoses could be used to estimate global orthotic need. The second chapter synthesizes current evidence in prosthetic and orthotic education and in doing so, highlights a recent shift in the field and identifies key strategies to build upon recent efforts. The paucity of prosthetic and orthotic education research points to a strong need for a professional shift toward evidence-based education which could include increased support for education researchers, international collaborations and a culture shift toward peer-reviewed publication in prosthetic and orthotic education. Lastly, an exploratory application of social network analysis provides an example of how unique research methodologies can be applied in prosthetic and orthotic education to enrich the body of knowledge. This exploration of information access and exchange in the U.S. and Ghana identifies areas for intervention including a need for increased peer-reviewed journal access in

Ghana and improved faculty collaboration in the U.S. Additionally, the social network analysis can be replicated among students at these same institutions and among faculty and students at other institutions to provide a more thorough understanding of information exchange in prosthetic and orthotic education. Together, the three studies of this dissertation provide insight into global need for prosthetist personnel, prosthetic and orthotic education practices and information access and exchange among prosthetic and orthotic faculty.

This research was conducted with an exempt status determination
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Plain Language Summary

Around the world, people have physical problems that make their lives more difficult. People with physical problems can often benefit from prostheses or orthoses. Prostheses and orthoses are devices to replace or support injured arms or legs. However, many of the people who need devices, do not have access to them. Prostheses and orthoses are very specialized. They must be provided by trained medical professionals, called prosthetists/orthotists. There are only a small number of schools that teach prosthetics and orthotics around the world. This research explored three topics. First, we estimated the worldwide need for prosthetists. Then, we looked at how prosthetists/orthotists are educated. Lastly, we described how teachers in prosthetics and orthotics get information.

Our first study used data from a much larger study called the Global Burden of Disease. This larger study estimated the number of people around the world who have different health issues. One of these health issues was having an arm or leg amputation. We used the amputation estimates to describe the global need for prostheses. We also estimated the number of prosthetists needed to care for all the people with amputations. From this study, we learned that nearly 67 million people around the world currently live with an amputation. Most of these amputations were caused by falls or car accidents. East and South Asia have the most people living with amputation. Lastly, we learned that about 88,000 prosthetists are needed. This is many more prosthetists than currently exist. More prosthetists are needed globally. Education and prosthetic clinics require government funding. This information could be used to advocate to governments and policy makers to support more prosthetic services.

For the second study, we looked for all research on prosthetic and orthotic education. We assessed the quality of the research we found. We also described similarities and differences in

the research we found. Areas that need more research were also identified. We found that there is not a lot of research published on this topic. The research we found covered many topics. The research was about what to teach, how to teach it and individual education program descriptions. We learned from this review that more emphasis on prosthetic and orthotic education research is need. Additionally, there are many opportunities for more research to be done.

In the last study, we looked at how teachers at two prosthetic and orthotic schools in Ghana and the U.S. get information. We asked teachers about where they get information when they teach prosthetics and orthotics classes. We also asked about how they share information with other teachers. The data we collected can help us improve how prosthetics and orthotics teachers get and use information. We found that teachers at the Ghana school were more connected. They shared information more often than the teachers at the U.S. school. We also found that the Ghanaian teachers did not use published research very often but would like to. This research can help us improve how teachers and students get information.

Together, this research tells us about prosthetic need and education. We now know that many people around the world need prostheses. We also know that we need more prosthetists. More prosthetic and orthotic education research is needed to train prosthetists. Lastly, we learned that sharing of information varies among teachers and schools.

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Dedication: For Arturo and Avery

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Chapter 1. INTRODUCTION

1.1 GENERAL INTRODUCTION

Improvement in health care systems for equitable access to prosthetic and orthotic (P&O) services in low and middle-income countries (LMICs) is an important step toward restoration of function and mobility for millions of people with physical impairments (Ikeda, Grabowski, Lindsley, Sadeghi-Demneh, & Reisinger, 2014). Article 20 of the Convention on the Rights of Persons with Disabilities (CRPD) details the need for countries to ensure access to the highest level of independence through personal mobility for people with disabilities (United Nations, 2006). For many people with physical disabilities, personal mobility can be facilitated and/or achieved through access to affordable, timely and appropriate P&O services. However, it is estimated that only 5-15% of the global population has access to the assistive devices they need (World Health Organization, 2017b). To better guide global development of P&O services, the World Health Organization (WHO) recently developed and published detailed international service provision guidelines for prostheses and orthoses (World Health Organization, 2017b). These guidelines highlight four essential aspects of prosthetic and orthotic service provision in healthcare systems; policy, products, personnel and provision (Figure 1.1) (World Health Organization, 2017b). The three studies that comprise this dissertation explore the need for prosthetist/orthotist personnel and education of personnel for prosthetic and orthotic service provision globally.

Figure 1.1. The four key areas of health systems addressed by the WHO standards for P&O service provision. Reprinted from "WHO standards for prosthetics and orthotics. Geneva: World Health Organization; 2017." Reprinted with permission.

Judicious provision of rehabilitation technologies, like prostheses and orthoses, requires personnel trained with discipline-specific skills (World Health Organization, 2017b). Limited published information exists about the current prosthetist/orthotist personnel in comparison to the present need. Regional data from the International Society of Prosthetics and Orthotics (ISPO) reported by WHO suggests that all world regions are understaffed (World Health Organization, 2017a). High-income countries (HICs) collectively have just over 2 prosthetists/orthotists per 1 million population while LMICs all have less than 1 prosthetist/orthotist per 1 million population (World Health Organization, 2017a). WHO estimated a projected need for 40,000 prosthetists/orthotists worldwide in 2010 (WHO & ISPO, 2005). More recent estimates based on the same general assumption that 0.5% of the global

population requires P&O services suggest a need of 47,000 to 53,000 prosthetists/orthotists worldwide (World Health Organization, 2017b). This estimate, however, fails to differentiate among prosthetists, orthotists and those who are dually-trained prosthetists/orthotists and is not based on country or regional data. A more accurate understanding of regional physical impairment prevalence and etiologies would allow more detailed estimation of global prosthetist/orthotist need. In turn, accurate estimation of personnel need would enable governments and collaborating non-governmental organizations to examine current capacity to fulfill prosthetist/orthotist need.

Published literature on prevalence of trained prosthetists/orthotists to meet regional and global need is largely unknown. Efforts to aggregate global data on rehabilitation personnel have highlighted the fragmentation and poor quality of available data (N. Gupta, Castillo-Laborde, & Landry, 2011). The WHO began the Global Health Workforce Statistics database in response to the Sustainable Development Goal (SDG) 3.c to "...increase health financing and the recruitment, development, training and retention of the health workforce in developing countries…"(United Nations, 2015, p. 21) Unfortunately, while the database includes physiotherapists, it does not report statistics on prosthetists/orthotists. Published reports on prosthetist/orthotist personnel are available for some high and middle-income countries such as the United States (DaVanzo et al., 2015), Australia (Ridgewell, Dillon, O'Connor, Anderson, & Clarke, 2016) and Peru (Fuhs et al., 2018), however, workforce data in most regions are unpublished. WHO asserts that substantial shortages of prosthetist/orthotist personnel exist in all parts of the world (World Health Organization, 2017b). To fill this gap between personnel needs and available capacity, we look toward the education of P&O professionals.

Globally, education of prosthetists/orthotists has and continues to evolve from a skilled trade taught through apprenticeship to an allied health profession taught through formal education, internship and continuing professional development. The evolution of P&O education is ongoing in many countries and has resulted in regional variation of education requirements, standards and practices. Efforts to standardize international education of prosthetists/orthotists were first documented as the published proceedings of a meeting held in Denmark in 1968 (United Nations, 1969). Since then, ISPO has developed and revised educational philosophy and international standards for global P&O education in collaboration with WHO (International Society for Prosthetics and Orthotics, 2018b).

ISPO recently published revised education standards and an associated handbook to guide P&O professional preparation programs seeking ISPO accreditation. Currently, there are thirty-six (36) ISPO recognized P&O professional preparation programs listed on the ISPO website (ISPO, n.d.). It is important to note that some listed programs, such as the National Commission on Orthotic and Prosthetic Education (NCOPE) in the U.S., represent multiple distinct academic institutions resulting in underreporting of the global number of recognized institutions. Even so, the number of accredited programs educating prosthetists/orthotists worldwide are few. As international P&O professional preparation programs in LMICs continue to develop and seek ISPO accreditation, educators and administrators worldwide will seek teaching resources, educational references and model programs to emulate.

Resources to guide prosthetist/orthotist education and curriculum are not readily available. While the ISPO standards and handbook provide general requirements for P&O professional preparation programs and an example outline of curriculum content, they are not intended to inform teaching methods or specific curriculum. A recent scoping review examined associations

between P&O education and quality of clinical services, however, no conclusions were drawn due to insufficient evidence (Forghany et al., 2018). This review, despite the focus on clinical services, infers that only a small body of P&O education evidence exists. A systematic review of the state-of-the-science in P&O education is needed to provide insight into the published literature available for educators and administrators in LMICs who are seeking examples and assistance.

In addition to published peer-reviewed literature, direct collaboration between educators in LMICs and HICs is one approach to develop curriculum and education of the future workforce (Haugland, Sørsdahl, Salah, & Salah, 2014). One such collaboration exists between Brother Tarcisius Prosthetic and Orthotic Training College (BTPOTC) and the University of Washington (UW) in Ghana and the U.S. respectively. BTPOTC is a new prosthetic and orthotic professional preparation program that opened in 2013 and offers a three-year diploma in P&O in collaboration with Kwame Nkrumah University of Science and Technology (KNUST). The UW P&O program was established in 1972 and has since transitioned to a Master of Prosthetics and Orthotics (MPO) to fulfill entry level educational requirements in the U.S. In 2016, BTPOTC sought collaboration with UW to improve their P&O curriculum, teaching methods and eventually achieve ISPO accreditation. The collaboration between BTPOTC and UW provides an opportunity for a pilot study of intercultural P&O education research to examine information access in P&O education in two distinct settings. Research collaborations between educators, students and researchers in HICs and LMICs can provide a model for stakeholder-driven prosthetic and orthotic service development.

Given the identified gaps in the literature, there is a need for foundational research to guide future directions in the provision of prosthetic care in LMICs with a specific focus on personnel.

This dissertation aimed to address the absence of baseline information by answering the following three questions: 1) What is the global need for prosthetic services and prosthetists?, 2) What are the educational resources available to guide prosthetist/orthotist education and faculty in LMICs?, and 3) How do P&O faculty in both HICs and LMICs access the information necessary for successful P&O education? This research is the first necessary step towards global development of P&O education and a skilled workforce to provide high quality prosthetic and orthotic services worldwide.

1.2 Summary of studies

The general purpose of this three-study dissertation is to examine the global need for and education of prosthetists/orthotists. The first study in the dissertation "Global Prevalence of Non-Fatal Limb Amputation Due to Traumatic and Diabetic Causes" was designed as a secondary analysis of existing data interpreted through the lens of prosthetic service provision. Using Global Burden of Disease (GBD) estimates from the Institute for Health Metrics and Evaluation (IHME), the purpose of this study was to explore the global distribution of limb amputation prevalence, implications for prosthetic service provision and global need for trained prosthetists.

The second study in the dissertation "A Systematic Review of Prosthetic and Orthotic Education Research", examined the current peer-reviewed literature in prosthetist/orthotist education. The purpose of this study was to assess and synthesize current research in P&O education and identify areas for future research.

The third and final study in the dissertation "Information access and sharing among prosthetic and orthotic faculty in the United States and Ghana", was designed as an exploratory cross-sectional social network analysis to explore information access and sharing among faculty at two prosthetic and orthotic professional preparation programs. This exploratory study provides

an example of how international collaboration can be used to examine and improve current prosthetic and orthotic professional preparation programs.

1.3 FLOW OF DISSERTATION

This is a three-study dissertation that follows the independent studies format. Chapter one provides an introduction and overview, chapters two through four are three independent studies for submission to peer-reviewed journals. Each study contains an abstract, introduction, methods, results, discussion, conclusion and reference list. Chapter five provides a summary of the dissertation.

Chapter 2. GLOBAL PREVALENCE OF NON-FATAL LIMB AMPUTATION DUE TO TRAUMATIC AND DIABETIC CAUSES

2.1 Abstract

Purpose: This article estimates and describes the global prevalence of limb amputation due to trauma and diabetes.

Materials and methods: A secondary database descriptive study was conducted to report amputation prevalence and prevalence rate per 100,000 due to trauma and diabetes using the extensive 2017 Global Burden of Disease results.

Results: In 2017, 57.7 million people were living with major limb amputation due to traumatic causes worldwide. An additional 8.9 million people were living with lower limb amputation due to diabetes. Leading traumatic causes of limb amputation were falls (36.2%), road injuries (15.7%), other transportation injuries (11.2%) and mechanical forces (10.4%). Among children, conflict and terrorism was the third leading cause of unilateral lower limb amputation. The highest number of prevalent cases due to trauma and diabetes was in East Asia and South Asia followed by Western Europe, North Africa and the Middle East, High-income North America and Eastern Europe. Regions with the highest prevalence rates per 100,000 were Central Europe, Australasia and Eastern Europe. Based on amputation prevalence estimates, approximately 87,600 prosthetists are needed globally for adequate prosthetic service provision.

Conclusions: Amputation prevalence estimates and patterns are essential to understand global need for prosthetic services. Estimates provide foundational information to inform prosthetic service provision, including future workforce need.

2.2 INTRODUCTION

Limb amputation impairs the physical functioning and mobility of people around the world. Diabetes, dysvascular complications and trauma are the leading causes of limb amputation globally (Moxey et al., 2011; Ziegler-Graham, MacKenzie, Ephraim, Travison, & Brookmeyer, 2008). Regardless of the underlying etiology, amputation results in the absence of biological structures and negatively impacts a person's function (Amtmann, Morgan, Kim, & Hafner, 2015), mobility (Fortington, Rommers, Geertzen, Postema, & Dijkstra, 2012), vocation (Burger & Marinček, 2007) and avocation (Couture, Caron, & Desrosiers, 2010). For those living in low and middle-income countries (LMICs), the negative impact of amputation is often exacerbated by lack of resources, social stigma and denial of human rights (Harkins, McGarry, & Buis, 2013). Rehabilitation and prosthetic service provision after amputation can mitigate disability and restore individual participation, however, prosthetic services have largely been neglected in global health initiatives.

Development of national prosthetic services in LMICs is an essential step toward restoration of mobility, function and participation for millions of people with amputations worldwide. Prosthetic service provision includes complex procedures of evaluation, treatment plan development, device design and fabrication, fitting, alignment, gait training and follow-up (Nielsen & Jorge, 2013). Additionally, people with amputation need regular and lifelong prosthetic care that requires trained prosthetists, therapists, specialized equipment and materials, and a coordinated healthcare system (World Health Organization, 2017b).

Recent shifts in global health toward non-communicable diseases and health system strengthening support the global development of prosthetic services. However, current literature on prosthetic services in LMICs is largely limited to prosthetic componentry development and

evaluation such as that of feet, (Arya & Klenerman, 2008; Chen, Lee, & Zhang, 2006; Craig, 2005; Hansen, Meier, Sam, Childress, & Edwards, 2003; Sofia Hussain, 2011; Jensen & Raab, 2006; W. C. C. Lee & Zhang, 2006; Lenka & Kumar, 2010; Meier, Sam, Hansen, & Childress, 2004; Sam, Hansen, & Childress, 2004) knees, (Andrysek et al., 2011; Hamner, Narayan, & Donaldson, 2013) socket design (Chen et al., 2006; Jensen, Nilsen, & Zeffer, 2005; Jensen et al., 2006; Sathishkumar, Manigandan, Asha, Charles, & Poonoose, 2004) and structure (Chen et al., 2006). Underrepresented in current literature is the need for service delivery (Andrysek, 2010; Harkins et al., 2013), skilled professionals (N. Gupta et al., 2011) and education of professionals (Aminian & O'Toole, 2011; Aminian, O'Toole, & Mehraban, 2015; Heim, 1995; Kheng, 2008; Magnusson & Ramstrand, 2009; Wong, 2007; Wong, Lemaire, Leung, & Chan, 2004).

Limited information exists about both the current availability of prosthetist/orthotist personnel and the present global need for prosthetic services. The World Health Organization (WHO) estimates that up to ninety percent of the people who need prostheses and orthoses do not have access to them (World Health Organization, 2017b). In 2005, WHO estimated that approximately 40,000 prosthetists/orthotists would be required to treat the 30 million people worldwide (0.5% of the global population) in need of prosthetic and orthotic services in 2010 (World Health Organization, 2005). More recent estimates suggest that 35-40 million people are in need of prosthetic and orthotic services (World Health Organization, 2017b) requiring by WHO estimations, 47,000 to 53,000 prosthetists/orthotists. Neither of these estimates take into account regional variation in impairment prevalence and neither has been verified at the country or regional levels. Further, worldwide increases in population, life expectancy and non-communicable diseases and musculoskeletal disorders suggest that by 2050, nearly 1% of the

world population will require prosthetic and orthotic services (World Health Organization, 2017b).

While some countries, such as England and Australia, have published epidemiologic data on limb amputation (Ahmad, Thomas, Gill, Chan, & Torella, 2014; Dillon, Kohler, & Peeva, 2014), these data are primarily available for high-income countries. A review of the literature on lower limb amputation highlighted the paucity of empirical evidence from LMICs (Moxey et al., 2011). An accurate understanding of global limb amputation prevalence (i.e., the number of people living with amputation) could inform national prosthetic service planning and personnel needs.

The Global Burden of Disease (GBD) studies are a rich resource to provide worldwide amputation prevalence estimates. The first Global Burden of Disease and Injury (GBD) study was commissioned by the World Bank in the early 1990s and described the burden of disease of 98 diseases, 9 injuries and 10 health risk factors for eight world regions (C. J. Murray, Lopez, & World Health Organization, 1996). Since then, GBD methods have evolved to include 359 diseases and injuries, and 67 health related risk factors for 195 countries and territories (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018).

In this study we quantified and interpreted patterns in global distribution and prevalence of limb amputation due to trauma and diabetes by cause, region, and age using GBD 2017 data.

2.3 METHODS

This study was a secondary descriptive study of the GBD 2017 data to focus on traumatic and diabetic amputation prevalence and prevalence rates (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018). Methods for the GBD 2017 estimates used in this descriptive study have been previously described (GBD 2017 Disease and Injury Incidence

and Prevalence Collaborators, 2018; Haagsma et al., 2016). Summaries of the previously described estimation methods are provided below.

2.3.1 *Trauma data*

Definition of traumatic amputations

The GBD 2017 study produced estimates of prevalence and prevalence rate of traumatic amputation using country data on International Classification of Diseases (ICD) codes. ICD codes were categorized into 30 mutually exclusive and exhaustive external causes-of-injury codes (E code). ICD codes were also used to categorize injuries by nature-of-injury (N code), which includes amputation. Limb amputation was divided into four categories (i.e., N1= lower limb bilateral (LL(B)), N2= upper limb bilateral (UL(B)), N4=lower limb unilateral (LL(U)), N5=upper limb unilateral (UL(U))) with associated ICD 9 and ICD 10 codes (Table 2.1) (Haagsma et al., 2016). Amputation of fingers (N3), thumb (N6) and toes (N7) due to trauma were excluded from this study.

Table 2.1

Nature-of-injury Codes and Associated ICD 9 and 10 Codes

N code	Nature-of-injury	ICD 9	ICD 10
N1	Amputation of lower limbs, bilateral	896.2-896.3, 897.6-897.7	T05.3, T05.5
N2	Amputation of upper limbs, bilateral	887.6-887.7, 888.1-888.2, 888.9	S68.4, S68.7-S68.9, T05.0, T05.2, T05.6
N4	Amputation of lower limb, unilateral	896.0-896.1, 897.0-897.5	S78.0, S78.1, S78.9, S88-S88.1, S88.9, S98.0, S98.3-S98.4, S98.9
N5	Amputation of upper limb, unilateral	887.0-887.5	S48-S48.1, S48.9, S58-S58.1, S58.9, T05.1, T05.4, T11.6

Note. ICD: International Classification of Diseases, N code: Nature-of-injury code

Traumatic amputation data sources

Many countries report injuries by either N and/or E codes for the causes-of-injury such as motor vehicle road injury or assault by a sharp object. Cause-of-injury was divided into three main categories; transport, unintentional and intentional with seventeen subcategories with associated ICD 9 and ICD 10 codes (Appendix A). Several countries report injuries by both codes, which was the basis for creating an E and N matrix to estimate the global prevalence of injuries by both E and N code. The matrix is applied to estimate the proportion of each E code category that results in a particular N code category (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018; Haagsma et al., 2016). This matrix was developed based on dual code inpatient and emergency room data sets from 28 countries: Argentina, Bulgaria, China, Colombia, Cyprus, Czech Republic, Denmark, Egypt, Estonia, Hungary, Iceland, Iran, Italy, Latvia, Macedonia, Malta, Mauritius, Mexico, Mozambique, Netherlands, Norway, Portugal, Slovenia, Spain, Sweden, Uganda, USA, and Zambia. Because the matrix is based on relatively few countries, greater confidence can be placed in regional summary estimates rather than detailed national estimates. Estimates in this paper are reported for all 21 world regions (Appendix B) (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018).

Traumatic amputation data estimation methods

GBD estimates of non-fatal injuries such as amputation are complex. DisMod-MR 2.1 was applied to estimate the long-term prevalence for each combination of nature-of-injury and cause-of-injury from incidence and mortality risk (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018). DisMod-MR 2.1 is a Bayesian descriptive epidemiological meta-regression and disease modeling computational tool (GBD 2017 Disease and Injury

Incidence and Prevalence Collaborators, 2018). It is the standard GBD modelling approach for non-fatal health outcomes such as morbidity due to trauma or diabetes (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018). Amputation prevalence estimates are calculated in the process of estimating years lived with disability (YLDs) due to trauma (Haagsma et al., 2016). Detailed methods for injury estimates have been described elsewhere (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018; Haagsma et al., 2016). We used unpublished GBD estimates of 1,000 draws for prevalence rates for each five-year age category, and region for amputation N-codes. To aggregate injury prevalence data, the 1,000 prevalence rate draws were multiplied by the regional population to estimate the number of cases per age-region category, E code, and N code. Cases were then aggregated by broader age categories (i.e., 0-4, 5-14, 15-49, 50-69, 70+ years) for each N code. The mean prevalence, prevalence rate, and uncertainty intervals were calculated from the 1,000 draws for each broader age category for each N code. Additionally, prevalence and prevalence rate of amputations by cause (E code) were aggregated for each N code (Table 2.2). The cases per region, age category, E code and N code were also aggregated by E code categories (i.e., mechanical forces, road injuries) for each N code. Finally, the mean prevalence, prevalence rate, and uncertainty interval were then calculated from the 1,000 draws for each E code category within each N code.

2.3.2 *Diabetes data*

<u>Definition of diabetic amputations</u>

For GBD 2017 estimates, diabetes mellitus was defined as fasting plasma glucose greater than 126 mg/dL or being on treatment for diabetes (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018; Tandon et al., 2018). Overall prevalence of diabetes was estimated by sex, age and location for 2017 using DisMod-MR, version 2.1 (GBD 2017 Disease

and Injury Incidence and Prevalence Collaborators, 2018). Amputation due to diabetes was estimated as part of the direct diabetes burden estimation and as a sequela related to diabetic neuropathy (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018). Amputation estimates were modeled to include but not differentiate between all major and minor lower limb amputations. Therefore, prevalence of all lower limb amputation due to diabetes is reported in this study.

Diabetic amputation data sources

Data were systematically screened from household surveys from the Global Health Data Exchange. Additionally, an updated literature review for amputation related to diabetes mellitus was conducted (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018). The data extracted from published literature were then used for modelling of amputation due to diabetes. All data sources used for nonfatal estimation (such as amputation) in GBD 2017 are available through an online tool (http://ghdx.healthdata.org/).

Diabetic amputation data estimation methods

The overall prevalence of diabetes and the prevalence of amputation due to diabetes mellitus was estimated using DisMod MR-2.1. The incidence of either above or below knee amputation pulled only from available literature was crosswalked (i.e., mapping of data from the literature review to the model for diabetes-related amputation) to the incidence of all amputations (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018).

We used unpublished GBD estimates of 1,000 draws for prevalence rates of amputation due to diabetes for each five-year age category, sex, and region for amputation. To aggregate

diabetes prevalence data, the 1,000 prevalence rate draws were multiplied by the regional population to estimate the number of cases per age-sex-region category. Cases were then aggregated by broader age categories (i.e., 0-14, 15-49, 50-79, 80+ years). Note that age groups slightly differ between trauma and diabetes data pulls due to moderate differences in data requests. The mean prevalence, prevalence rate, and uncertainty intervals were calculated from the 1,000 draws for each broader age category.

2.3.3 *Uncertainty*

Uncertainty in prevalence estimates results from available data, data adjustments and statistical models. We report the mean of the 1,000 draws and uncertainty intervals (UI) rather than point estimates to account for uncertainty in estimates (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018).

2.4 RESULTS

2.4.1 *Global prevalence of amputation*

In 2017, we estimated that worldwide 57.7 million (UI 54.3-61.9 million) people were living with limb amputation due to traumatic causes. Of people with traumatic amputation, an estimated 50.2% had LL(U) amputations (28.9 million, UI 26.9-32.1 million), 19.6% had UL(U) amputations (11.3 million, UI 10.6-12.1 million), 19.1% had UL(B) (11.0 million, UI 10.3-11.9 million), and 11.1% had LL(B) (6.4 million, UI 5.9 to 7.0 million). The most common traumatic cause of amputation for all levels was falls, accounting for 52.2% of LL(B), 38.1% of UL(B), 36.9% of UL(U) and 31.7% of LL(U) amputations (Table 2.3). Additional leading causes of traumatic amputation varied by amputation level. Road injuries were the second leading cause of amputation for LL(U) (18.6%), LL(B) (13.9%), UL(U) (13.8%). The second leading cause of

UL(B) amputation was mechanical forces (15.1%) (Table 2.2). Also notable was the role conflict and terrorism played in LL(U) amputation globally (Figure 2.2). Among children under 5 (9299 UI 2203-27440) and 5-14 years (83197 UI 20423-24657), conflict and terrorism was the third leading cause of LL(U) amputation. These figures were largely driven by amputations in North Africa and the Middle East and Eastern Sub-Saharan Africa.

An additional 8.9 million (UI 6.0-12.6 million) people were living with LL amputation due to diabetes (Figure 2.1). This data set did not allow for estimation of LL(U) and LL(B) prevalence.

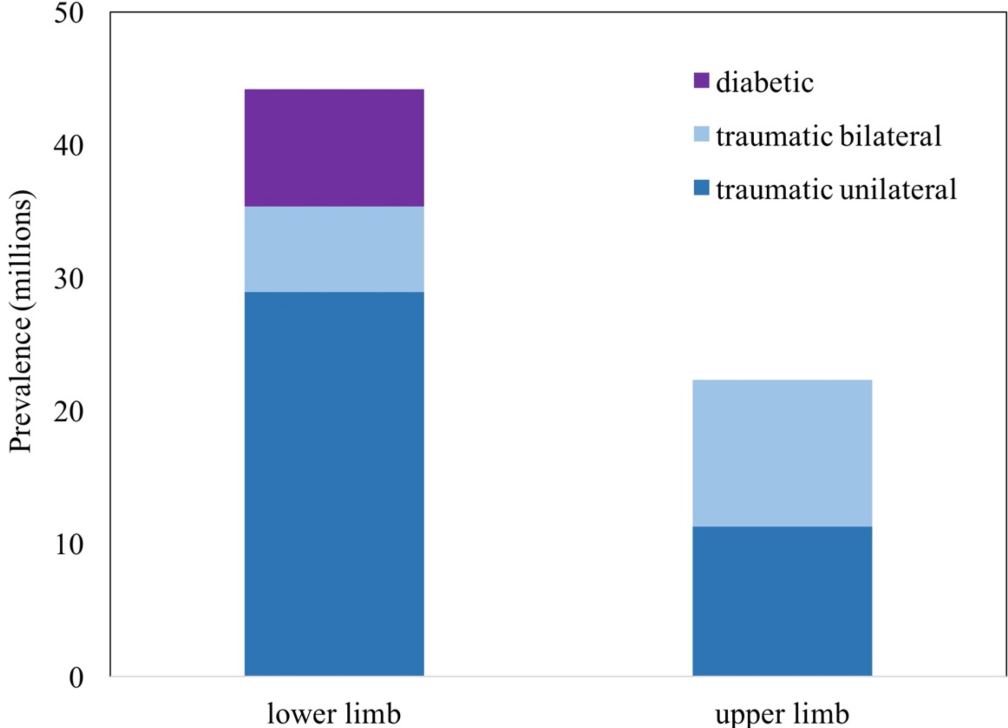


Figure 2.1. Estimated Global Limb Amputation in 2017

Table 2.2

Estimated Global Prevalence of Amputation by Traumatic Cause of Injury, 2017

	Unilateral UL (N5)		Bilateral UL (N2)		Unilateral LL (N4)		Bilateral LL (N1)	
Cause	Prevalence Mean (UI) (thousands)	Rate per 100,000 Mean (UI)	Prevalence Mean (UI) (thousands)	Rate per 100,000 Mean (UI)	Prevalence Mean (UI) (thousands)	Rate per 100,000 Mean (UI)	Prevalence Mean (UI) (thousands)	Rate per 100,000 Mean (UI)
Transport								
Road injuries	1561 (1421-1704)	20.4 (18.6-22.3)	1235 (1130-1347)	16.2 (14.8-17.6)	5384 (4935-5934)	70.5 (64.6-77.7)	886 (798-975)	11.6 (10.4-12.8)
Other transport	1162 (935-1394)	15.2 (12.2-18.2)	858 (688-1023)	11.2 (9.0-13.4)	3612 (3004-4236)	47.3 (39.3-55.4)	841 (684-993)	11.0 (9.0-13.0)
Unintentional								
Falls	4161 (3691-4731)	54.5 (48.3-61.9)	4199 (3714-4791)	55.0 (48.6-62.7)	9175 (8347-10133)	120.1 (109.2-132.6)	3339 (2944-3826)	43.7 (38.5-50.1)
Drowning	33 (28-38)	0.4 (0.4-0.5)	41 (34-49)	0.5 (0.4-0.6)	51 (44-59)	0.7 (0.6-0.8)	32 (27-37)	0.4 (0.4-0.5)
Fire	159 (137-188)	2.1 (1.8-2.5)	152 (131-179)	2.0 (1.7-2.3)	230 (202-263)	3.0 (2.6-3.4)	126 (109-149)	1.7 (1.4-2.0)
Poisoning	52 (46-59)	0.7 (0.6-0.8)	53 (46-61)	0.7 (0.6-0.8)	65 (56-75)	0.8 (0.7-1.0)	51 (44-58)	0.7 (0.6-0.8)
Mechanical forces	1305 (1113-1507)	17.1 (14.6-19.7)	1668 (1419-1933)	21.8 (18.6-25.3)	2567 (2235-2922)	33.6 (29.2-38.2)	471 (401-559)	6.2 (5.3-7.3)
Animal contact	518 (454-590)	6.8 (5.9-7.7)	525 (461-596)	6.9 (6.0-7.8)	633 (520-745)	8.3 (6.8-9.7)	0	0
Foreign body	493 (418-573)	6.5 (5.5-7.5)	491 (417-570)	6.4 (5.5-7.5)	576 (497-655)	7.5 (6.5-8.6)	0	0
Environmental heat and cold	259 (216-315)	3.4 (2.8-4.1)	305 (249-373)	4.0 (3.3-4.9)	1409 (1233-1622)	18.4 (16.1-21.2)	115 (98-137)	1.5 (1.3-1.8)
Forces of nature	240 (77-586)	3.1 (1.0-7.7)	232 (72-566)	3.0 (0.9-7.4)	294 (95-683)	3.8 (1.2-8.9)	0	0
Other unintentional	719 (616-819)	9.3 (8.1-10.7)	601 (515-699)	7.9 (6.7-9.1)	1596 (1405-1786)	20.9 (18.4-23.4)	368 (315-425)	4.8 (4.1-5.6)
Intentional								
Self-harm	140 (113-172)	1.8 (1.5-2.2)	133 (108-163)	1.7 (1.4-2.1)	515 (420-605)	6.7 (5.5-7.9)	110 (89-136)	1.4 (1.2-1.8)
Interpersonal violence	429 (372-496)	5.6 (4.9-6.5)	482 (418-557)	6.3 (5.5-7.3)	867 (759-979)	11.3 (9.9-12.8)	0	0
Conflict and terrorism	0	0	0	0	1880 (530-5264)	24.6 (6.9-68.9)	0	0
Executions and police conflict	55 (18-136)	0.7 (0.2-1.8)	58 (187-126)	0.8 (0.2-1.6)	95 (29-236)	1.2 (0.4-3.1)	56 (19-138)	0.7 (0.2-1.8)
Total	11281 (10595-12070)	147.6 (138.7-158.0)	11032 (10336-11855)	144.4 (135.3-155.2)	28949 (26902-32073)	378.9 (352.1-419.8)	6395 (5918-6979)	83.7 (77.5-91.3)

Note. UL: upper limb, LL: lower limb, UI: uncertainty interval

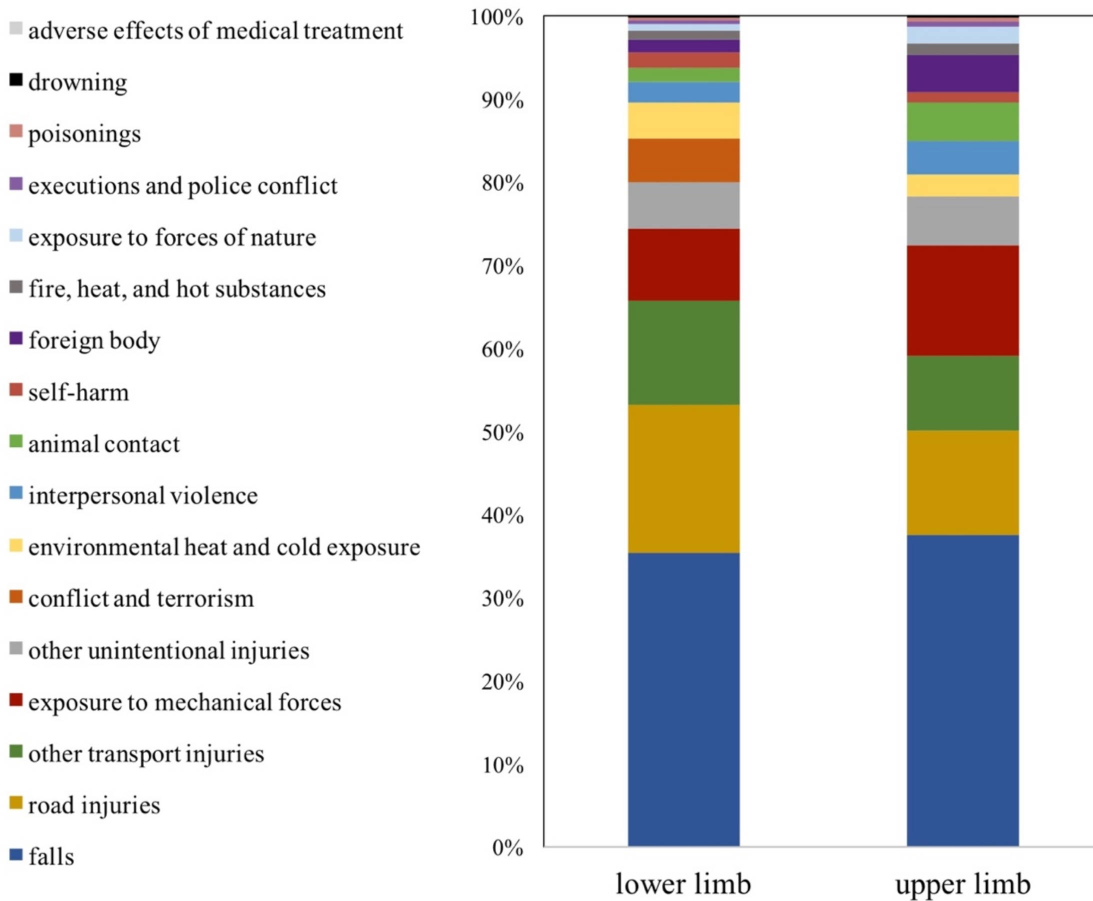


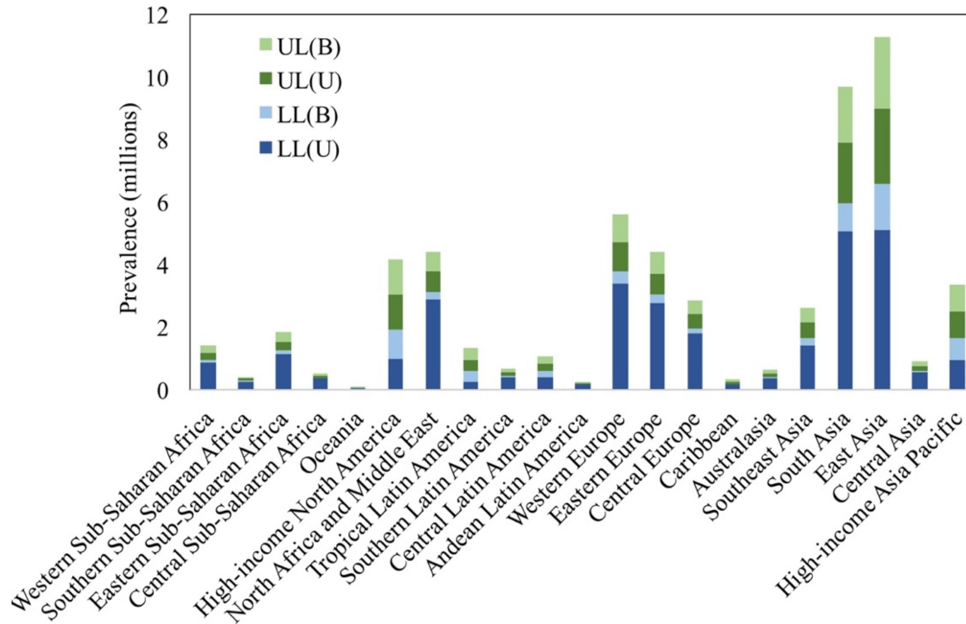
Figure 2.2. Estimated traumatic limb amputation causes by amputation level

2.4.2 *Regional prevalence and prevalence rates*

GBD estimates provide insight into regional trends of traumatic (Figure 2.3) and diabetic (Figure 2.4) limb amputation. Prevalence of both traumatic (11.2 million; UI 10.6-12.0 million) and diabetic (1.8 million; UI 1.2-2.6 million) amputation are highest in East Asia. South Asia has the second highest prevalence for traumatic amputation (9.7 million; UI 9.1-10.3 million) and third highest for diabetic amputation (1.2 million; 0.8-1.8 million). High-income North America has the second highest prevalence of diabetes-related amputation (1.3 million; 0.9-1.7 million).

However, comparatively modest amputation rates per 100,000 for both trauma and diabetes in East (trauma 757; UI 712-807, diabetes 120 UI 92-143) and South Asia (544; UI 512-576, diabetes 68 UI 42-95), suggest the high prevalence stems from large populations rather than high rates. Regions with high prevalence rates per 100,000 for traumatic amputations (Figure 2.5) include Central Europe (2478 UI 2316-2674), Australasia (2220 UI 2068-2422) and Eastern Europe (2096 UI 1973-2235). These regions, despite their high prevalence rates per 100,000, account for only small portions of total global traumatic amputation prevalence (5.2%, 1.2%, and 8.1% respectively). Two regions stand out with both low prevalence and rates per 100,000 population; Oceania (prevalence 55247; UI 44293-54703, rate 438; UI 410-470) and Andean Latin America (prevalence 242284; UI 223619-270309, rate 394; UI 364-440).

Diabetic amputation prevalence rates per 100,000 (Figure 2.6) were highest in Southern Sub-Saharan Africa (389 UI 305-462), Central Sub-Saharan Africa (191 UI 154-235) and Central Europe (185 UI 154-213). These regions, despite their high prevalence rates per 100,000, account for small portions of total global diabetic amputation prevalence (3.4%, 2.6% and 2.4% respectively). Only High-income North America has both high prevalence (1.3 million; 0.9-1.7) and prevalence rate per 100,000 (356 UI 301-395) accounting for 14.5% of global diabetes-related amputations.



Note. LL(B):bilateral lower limb, UL(B):bilateral upper limb, LL(U):unilateral lower limb, UL(U):unilateral upper limb

Figure 2.3. Estimated prevalence of traumatic limb amputation by level and region

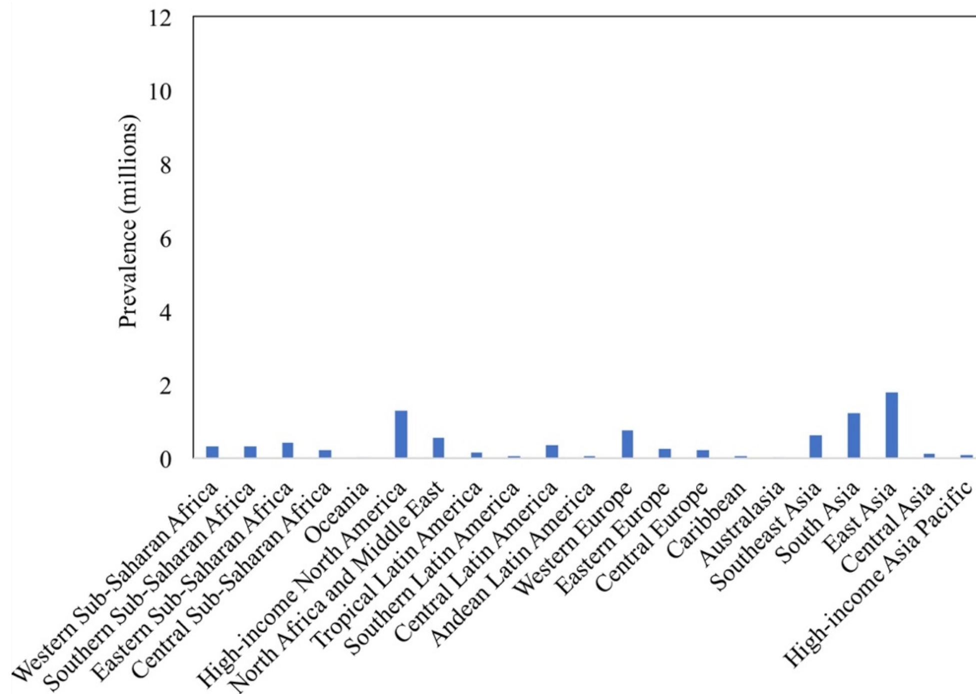
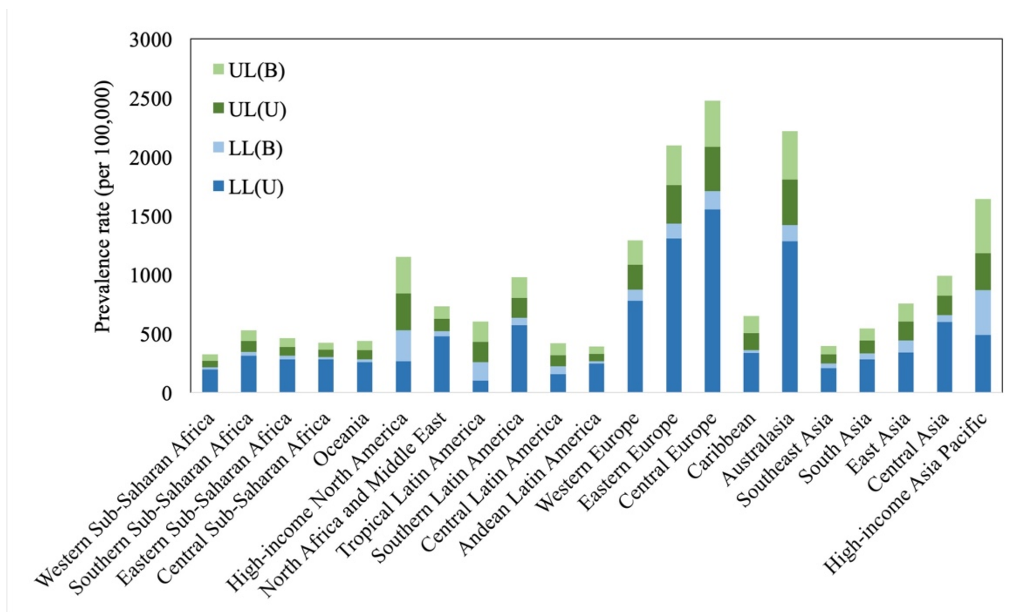


Figure 2.4. Estimated prevalence of diabetic lower limb amputation by level and region



Note. LL(B):bilateral lower limb, UL(B):bilateral upper limb, LL(U):unilateral lower limb, UL(U):unilateral upper limb

Figure 2.5. Estimated prevalence rate of traumatic limb amputation by level and region

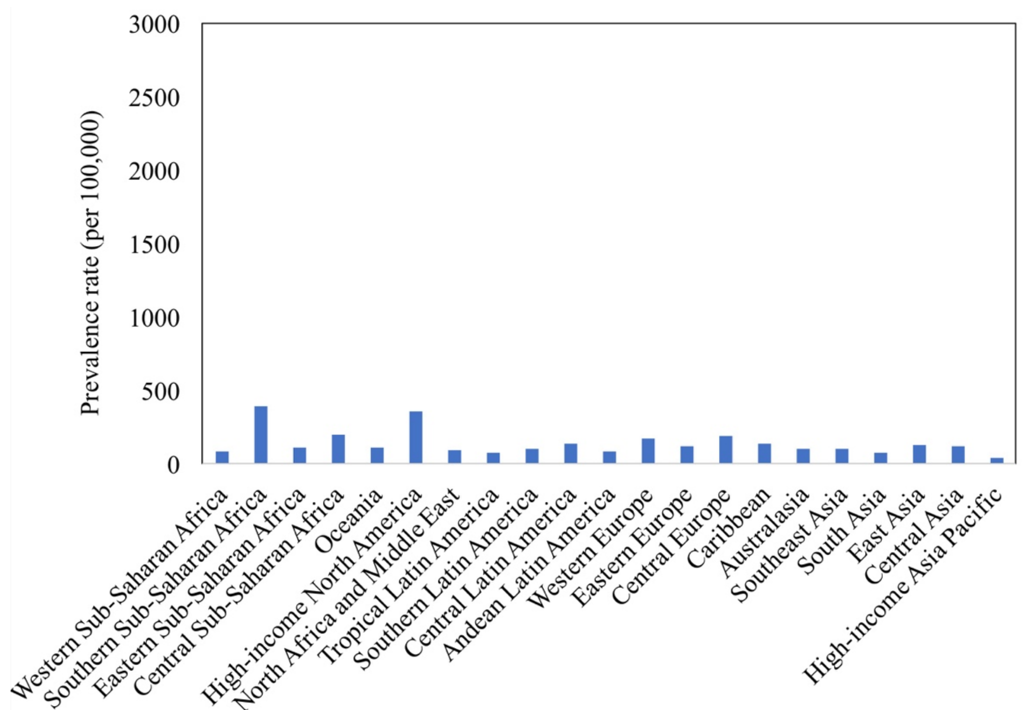


Figure 2.6. Estimated prevalence rate of diabetic lower limb amputation by level and region

Prevalence by region and age

In children aged under 5 and 5-14 years, the highest prevalence of traumatic amputation is found in South Asia (60333; UI 49134-72355 and 468553; UI 409415-537369), North Africa and Middle East (33681; UI 26114-49145 and 243682; UI 26114-49145) and East Asia (29174; UI 24387-35020 and 233098 UI 201527-270206). For adults 15-49 years, the highest prevalence is also found in South Asia (4.9 million; UI 4.5-5.3 million), followed by East Asia (4.8 million; UI 4.4-5.1 million) and North Africa and Middle East (2.5 million UI 2.1-3.5 million). For adults 50-69 East Asia leads (4.4 million; UI 4.1-4.7 million), followed by South Asia (2.9 million; UI 2.8-3.1 million) and Western Europe (1.9 million; UI 1.8-2.1 million). Adults over 70 have the highest prevalence in East Asia (1.8 million; UI 1.7-1.9 million), Western Europe (1.7 million; UI 1.6-1.8 million) and South Asia (1.3 million; UI 1.2-1.4 million) (Figure 2.7).

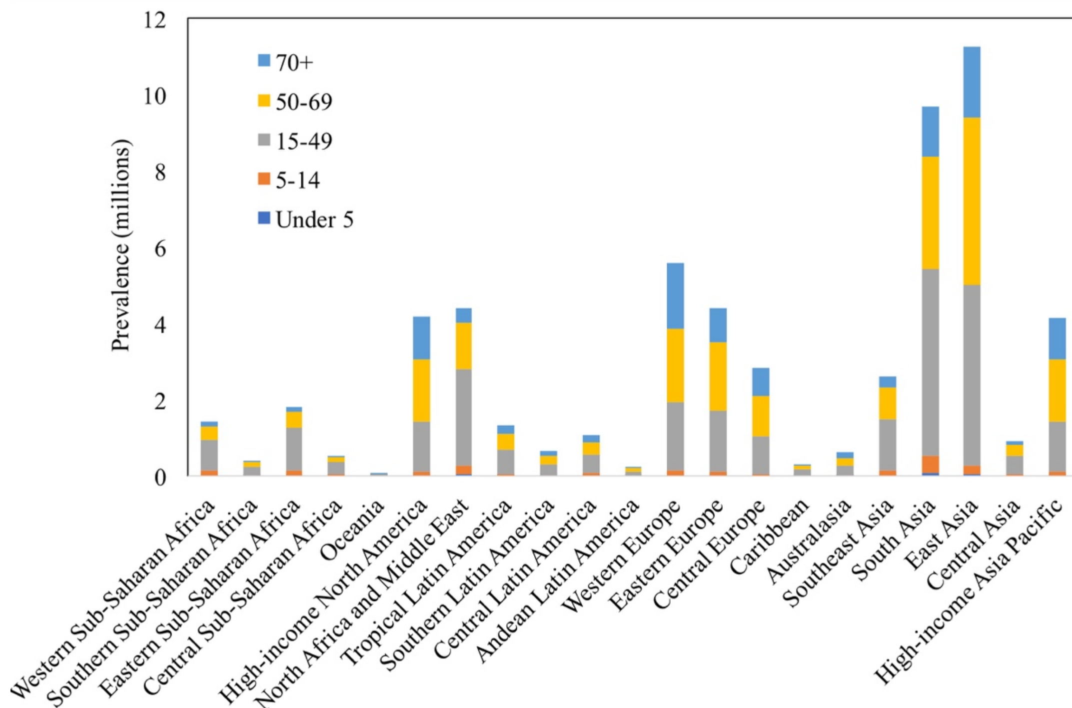


Figure 2.7 Estimated traumatic limb amputation prevalence in 2017 by age group

Diabetes-related amputations among 0-14 year-olds are comparatively quite rare but have the highest prevalence in South Asia (82; UI 44-156), Eastern Sub-Saharan Africa (53; UI 28-97), and Western Sub-Saharan Africa (48; UI 25-86). In adults 15-49 years, prevalence of diabetes-related amputation is highest in East Asia (755198; UI 509811-1117891), South Asia (470151; UI 316371-668001) and Southeast Asia (279077; UI 187268-405812). Among those 50-79, prevalence is highest in East Asia (922639; UI 641515-1327947), followed closely by High-income North America (897602; UI 656925-1186405), and South Asia (652752; UI 449432-951359). For people 80 years or older, the prevalence is highest in High-income North America (207051; UI 123528-288760), Western Europe (194358; UI 116584-269363), and East Asia (110311; UI 62108-158013) (Figure 2.8).

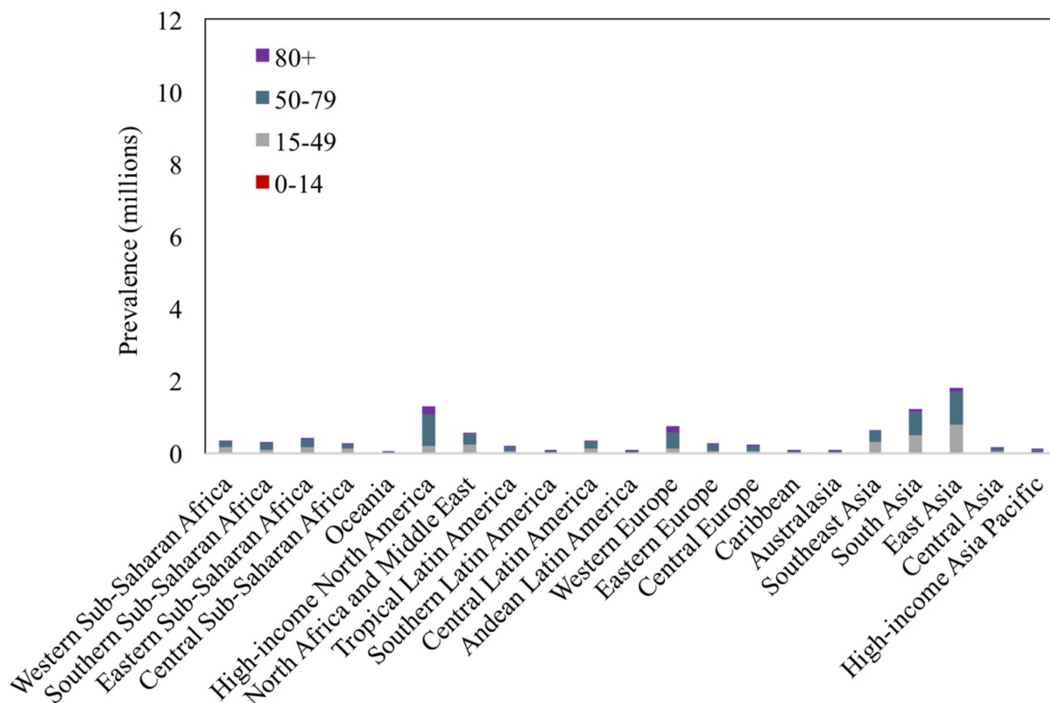


Figure 2.8. Estimated diabetic lower limb amputation prevalence in 2017 by age group

Upper limb amputation

Nearly forty percent of all prevalent traumatic amputations globally are upper limb. Upper limb amputation varies regionally. Prevalence is highest in South Asia (UL(U) 1.9 million, UI 1.7-2.0 million; UL(B) 1.8 million, UI 1.7-2.0 million), East Asia (UL(U) 2.4 million, UI 2.2-2.6 million; UL(B) 2.3 million, UI 2.1-2.5 million), High-income North America (UL(U) 1.1 million, UI 1.0-1.2 million; UL(B) 1.1 million, UI 1.0-1.2 million), and Western Europe (UL(U) 917693, UI 861795-984123; UL(B) 896195, UI 833289-969403).

Prevalence rates per 100,000 are highest in Australasia (UL(U) 386, UI 351-425; UL(B) 411, UI 368-466), High-income Asia Pacific (UL(U) 467, UI 427-514; UL(B) 462, UI 420-510), and Central Europe (UL(U) 378, UI 352-410; UL(B) 390, UI 359-428).

Prosthetist personnel

GBD 2017 amputation estimates can serve to inform regional and country level prosthetist personnel needs. We can use the WHO guidelines including; 1) a person with an amputation needs a new prosthesis every 3 years; 2) a trained prosthetist can, on average, treat 250 people a year (World Health Organization, 2005) to make these estimations. This average of 250 people is then weighted by the location at which a clinician works, with larger (i.e., national) clinics treating more complex and time consuming cases (district level; 250*1.2=300, provincial; 250*1.0=250, national; 250*0.5=125) (World Health Organization, 2005). Using this information, we estimate that approximately 87,600 prosthetists are needed worldwide to treat people with limb amputation. Regional estimates are provided in Table 2.3.

Table 2.3

Estimated Regional Prosthetist Need Based on 2017 Prevalence

Region	Prosthetist need
Western Sub-Saharan Africa	2306
Southern Sub-Saharan Africa	934
Eastern Sub-Saharan Africa	2950
Central Sub-Saharan Africa	983
Oceania	90
High-income North America	7165
North Africa and Middle East	6523
Tropical Latin America	1953
Southern Latin America	932
Central Latin America	1859
Andean Latin America	381
Western Europe	8352
Eastern Europe	6124
Central Europe	4021
Caribbean	474
Australasia	865
Southeast Asia	4270
South Asia	14343
East Asia	17154
Central Asia	1327
High-income Asia Pacific	4520

2.5 Discussion

GBD 2017 prevalence and prevalence rate results can be leveraged to provide a global picture of traumatic and diabetic amputation and explore implications for prevention and prosthetic rehabilitation. Regional prevalence estimates can provide insight into the current population of people living with amputation and allow for current and future prosthetic service provision planning. Additionally, prevalence rates allow comparison between regions while accounting for variability in regional population.

LL(U) is the most common prevalent amputation level. Most LL(U) amputations are caused by

falls, road, and transport injuries. South and East Asia have the most people living with amputation due trauma and diabetes. High prevalence in Asia is driven by large regional populations with only modest amputation rates. Regions with the highest prevalence rates are Central and Eastern Europe, Australasia, High-income Asia Pacific and High-income North America.

Notably, the majority of people living with limb amputation globally experienced traumatic rather than diabetes-related amputations. Mortality associated with amputation among people with diabetes is the most likely explanation. Mortality rates for people who experience a lower limb amputation due to diabetic or vascular etiologies have been reported to be as high as 70% within 5 years from amputation (Stern et al., 2017). Further, people most often experience diabetes-related amputations later in life, when normal life expectancy is less. Increased mortality and an older population undergoing diabetes-related amputation likely explains why there are 6.5 times more people living with traumatic amputations than amputation due to diabetes. Incidence data could further describe global relationships between annual amputation rates, mortality and prevalence of amputation.

2.5.1 *Prevention*

Trauma

Amputation is a largely preventable injury especially in those cases resulting from trauma or diabetes. While traumatic injuries are multifactorial, prevalence by cause provides some insight into the most common injury mechanisms that result in amputation and those which may be modifiable through prevention measures.

GBD 2017 estimates show falls to be the leading cause of traumatic limb amputation globally. Mechanisms of injurious falls such as those resulting in spinal cord injury, vary between LMICs and HICs due to demographic and economic differences (B. B. Lee, Cripps, Fitzharris, & Wing, 2014). Countries with aging populations have increasing incidence of low height injurious falls (B. B. Lee et al., 2014). In LMICs, injurious falls more commonly occur among children at play (B. B. Lee et al., 2014) and young adults falling from trees, rooftops or when carrying heavy loads (Cripps et al., 2011). Primary prevention for falls includes implementation of fall prevention programs for older adults (Chang et al., 2004), structural safety measures for children (e.g., window guards, limited spacing between balcony railings) (Istre, 2003; Spiegel & Lindaman, 1977) and occupational safety practices and education for working adults (Dakoure et al., 2015; S. Gupta et al., 2015). Secondary prevention may focus on healthcare access and surgical techniques to treat fall related injuries and prevent late amputation (i.e., more than 12 weeks after the initial injury) due to infection, non-union fractures or painful deformities that may lead to subsequent amputation (Agarwal-Harding, von Keudell, Zirkle, Meara, & Dyer, 2016).

Road traffic and other transportation injuries are the second and third leading causes for lower limb amputation. Strategies to prevent injuries due to road traffic accidents are well established as road traffic injuries have gained increased awareness in LMICs in recent years (Peden, 2005). A recent systematic review found that road safety legislation (e.g., prohibition of cell phone use, child restraint use) with strong enforcement initiatives was the most successful intervention followed by multifaceted campaigns to improve public awareness and speed control (Staton et al., 2016). Despite increased awareness, success rates of traffic injury prevention

strategies vary regionally and require continued implementation and monitoring (Staton et al., 2016).

Diabetes

Two key amputation prevention strategies exist for people with diabetes; 1) multidisciplinary management of the diabetic foot and 2) early diagnosis and intervention for peripheral vascular disease and ischemia (Apelqvist & Larsson, 2000; Larsson, Apelqvist, Agardh, & Stenstrom, 1995). Diabetic foot management has gained increasing attention in recent years due to positive evidence supporting better outcomes with comprehensive team management (Schaper, Apelqvist, & Bakker, 2012). Such management includes simple and repetitive education campaigns for both providers and patients, provision of appropriate footwear, regular inspection of the foot and footwear and early medical intervention for foot ulcers (Abbas & Archibald, 2007; Apelqvist & Larsson, 2000). Availability of vascular specialists varies regionally with many LMICs lacking what have been deemed essential vascular services and training (Stewart et al., 2016). Efforts to develop and expand existing vascular services in LMICs could serve to both reduce the number of dysvascular amputations and address the large and growing burden of other vascular conditions.

2.5.2 *Prosthetic rehabilitation*

Prosthetic service provision is multifaceted and tailored specifically to each individual with amputation. We will address two essential aspects of prosthetic service provision to provide interpretation and implications of GBD 2017 amputation prevalence estimates. These two categories are prosthetist workforce and education.

Prosthetist workforce

Prevalence of non-fatal limb amputation due to trauma and diabetes provides the most accurate estimate of prosthetic need worldwide to date. Using WHO guidelines for prosthetist personnel, we estimate that approximately 87,600 prosthetists are needed worldwide to treat the 66.6 million people living with limb amputation globally (World Health Organization, 2005). These estimates are not inclusive and can be considered underestimates as they do not consider people who experience amputation due to cancer (less than 2% in the U.S.) or congenital anomalies (less than 1% in the U.S.) (Ziegler-Graham et al., 2008). Additionally, orthotic need is not included in these estimates. However, despite the conservative nature of these estimates, they greatly exceed current WHO estimates that 47,000 to 53,000 prosthetists/orthotists are needed globally to care for the 35-40 million people in need of orthotic and prosthetic services (World Health Organization, 2017b).

Prosthetist education

Education for prosthetists includes both foundational knowledge and skills and specialized content related to amputation levels, etiologies, and prosthetic componentry. ISPO recommends that prosthetic curriculum be tailored to the context of the education program. Additionally, clinicians in LMICs may require more training and technical skill than clinicians practicing in HICs to compensate for technology, material and societal constraints (Cummings, 1996). For example, manufacturing of prosthetic components is not within the scope of prosthetists in HICs but has been identified as essential to sustainable prosthetic service provision in many LMICs (Cummings, 1996; Pearlman et al., 2008). New ISPO education

standards emphasize the need for prosthetic and orthotic curriculum to "be based on the demographics and epidemiology of the programme setting" (International Society for Prosthetics and Orthotics, 2018b, p. 37). GBD 2017 estimates describe regional populations of people with amputation. This information can inform prosthetist education to better align with the services and skills most required and utilized in clinical practice. Three examples of specific patient populations that vary by region and require special consideration in planning prosthetic services and education of prosthetists are discussed below.

Diabetes

Prosthetic care for people with diabetes has added complexities. Peripheral vascular disease, peripheral neuropathy, retinopathy and nephropathy are all sequelae of diabetes and are often comorbid conditions for people who experience diabetes-related amputation (Roberts et al., 2006). Prosthetic treatment of people with diabetes-related amputations therefore entails the complex management of multiple compromised systems which place prosthesis users at increased risk of prosthesis related injury (Roth, Pezzin, McGinley, & Dillingham, 2014; Uustal H, 2009). Literature on prosthetic service provision for people with diabetes-related amputations in LMICs is largely absent. To date, literature has primarily focused on amputation prevention through diabetic foot management (Abbas & Archibald, 2007; Harrison-Blount, Cullen, Nester, & Williams, 2014; Lowe et al., 2015).

Advanced technology in HICs, such as gel liners and volume management systems, are used by prosthetists to safely fit people with diabetes-related amputations and reduce the risk of further injury and infection. In LMICs, without similar technology, prosthetists require additional skill and education to ensure proper prosthetic socket fit, patient education and safe self-

management. A survey of clinician priorities identified diabetes comorbidity as a concern with regard to socket fit among clinicians in LMICs with emphasis on the lack of appropriate materials such as those used in HICs (Wyss, Lindsay, Cleghorn, & Andrysek, 2015). Development of appropriate protective technology and treatment protocols specific to prosthetic care for people with diabetes could be useful in regions with high prevalence of diabetes-related amputation to promote safe and accessible prosthetic rehabilitation for this specific population.

Regions with high diabetes-related amputation prevalence and prevalence rates could collaborate to develop and/or adapt technology and treatment protocols to LMIC contexts. High-income North America, specifically, is in the unique position of having both high prevalence and prevalence rate for diabetes-related amputations and the resources to develop technology and techniques. Collaboration between clinicians and organizations in High-income North America and LMICs with high diabetes amputation prevalence (East and South Asia) and rates (Southern, Central and Eastern Sub-Saharan Africa) could allow for important knowledge transfer and potentially result in the development of low cost, sustainable and context appropriate prosthetic interventions for people with diabetes in LMICs.

Upper limb

Our study provides clear evidence of need for upper limb prostheses in many regions of the world, but most specifically prevalence is high in South Asia, East Asia, High-income North America and Western Europe. Specialized UL componentry such as hooks, hands, elbows, cables, harnesses etc. can be expensive (Biddiss & Chau, 2007; Waldera, Heckathorne, Parker, & Fatone, 2013), challenging to acquire and often must be imported to LMICs (Sitek et al., 2004). Additionally, provision of functional UL prostheses (i.e., prostheses with active control of a

terminal device) requires specific clinical and technical skills. Low tech, low cost UL prostheses have been developed and described in published literature in an effort to improve access to functional UL prostheses in LMICs (Sitek et al., 2004; Wu, Casanova, & Ikeda, 2009; Zuniga et al., 2015). However, evidence supporting uptake and functional outcomes of such devices is limited, and people with UL amputation still lack access to functional UL prostheses in many regions of the world. While technological developments may improve access to devices in LMICs, such developments must also be accompanied by appropriate education of prosthetists and subsequently education of people with amputations (Pearlman et al., 2008).

UL prosthetic curriculum should be emphasized in these four regions (South Asia, East Asia, High-income North America, and Western Europe) with higher prevalence. Due to the relatively small proportion of people with amputation who have UL amputation, many prosthetists only occasionally fabricate and fit UL prostheses. Until recently, UL prosthetic curriculum was deemed an optional component of required curriculum for Category II prosthetists (now termed Associate Prosthetist/Orthotist) (World Health Organization, 2005). New ISPO education standards emphasize the need for curriculum to be based on the region's population and prosthetic needs (International Society for Prosthetics and Orthotics, 2018b), such as those needs identified in this study.

Pediatric

Our study identifies three regions with the highest prevalence of pediatric traumatic amputation; South Asia, North Africa and Middle East and East Asia. These regions require special consideration for pediatric and life-long prosthetic care as these children age (D. G. Smith, 2004). Prosthetic care for children with amputation involves more frequent prosthetic

adjustments and replacement due to high activity levels, growth and development (D. G. Smith, 2004). For example, ten-year olds with lower limb amputation will likely require 25 or more prosthesis over the course of their life (Landmine Survivors Network & The Swiss Agency for Development and Cooperation, 2006). Without appropriate and ongoing prosthetic care, children with amputation experience restricted mobility and function. Such disability can subsequently lead to exclusion from education (Carrington, Tangen, & Beutel, 2019; World Health Organization, 2015) and discrimination in their community (Cameron, Nixon, Parnes, & Pidsadny, 2005). Disability and lack of education are closely associated with poverty and poor health outcomes (Kuper et al., 2014; Ross & Wu, 1995).

Prosthetists who care for pediatric patients require additional education in pediatric development, etiologies, complications and specialized componentry. Prosthetists in HICs who treat children often specialize in pediatric prosthetics. They participate in professional communities (ACPOC, 2017) and receive targeted professional development courses (American Academy of Orthotists & Prosthetists, n.d.), which provide education beyond standard prosthetic curriculum. Resources such as these are rarely available in LMICs but are well suited to capacity building and knowledge transfer efforts through collaboration and digital continuing professional development such as deemed compulsory in the 2017 WHO standards for P&O (World Health Organization, 2017b).

Beyond specialized education, prosthetic care of children with amputation requires specific componentry. Prosthetic components for children are distinct from adult components in size, weight, design and control mechanisms (D. G. Smith, 2004). Published literature on pediatric prosthetic components in LMICs is limited (Andrysek, 2010; Wyss et al., 2015) but

should inform local manufacturing efforts in regions with high prevalence of pediatric amputation.

2.5.3 *Beyond prosthetic service provision; Amputation surgery*

Successful prosthetic use begins with a skilled and thoughtful amputation surgery. Goals of amputation surgery include a residual limb with sufficient length and muscular control, adequate soft tissue coverage and mobility, and pressure tolerant weight bearing surfaces (D. G. Smith, 2004). Quality of amputation surgery directly impacts the difficulty of prosthetic service provision and the eventual user outcomes. One way to promote optimal amputation surgery is through increased knowledge of the most common amputation causes and levels. Education on best practices for amputation surgery can be focused to address amputation surgeries most often conducted in geographic regions. Additionally, where appropriate, education on surgical techniques for limb salvage rather than amputation can serve to prevent unnecessary amputation (Bar-On, Lebel, Blumberg, Sagi, & Kreiss, 2013; Carey, Caldwell, Coughlin, & Hansen, 2015). Organizations such as the Institute for Global Orthopedics & Traumatology (Carey et al., 2015) and the Orthopaedic Trauma Care Specialist (OTCS) Program (Slobogean, Sprague, Furey, & Pollak, 2015) can leverage estimates provided in this study to improve future amputation and limb salvage education efforts.

2.5.4 *Study Limitations*

General limitations of the GBD methodology have been described elsewhere (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018). Limitations specific to this secondary description are described below. Many common etiologies of limb amputation were

not considered in this study, including congenital birth defects, cancer and infection. The data included do, however, provide a comprehensive overview of diabetes and trauma related amputations. Additionally, while prevalence accounts for people in 2017 living with amputation, it does not provide information on new amputation rates or change in amputation rates over time. Incidence estimates would provide insight into rates of new amputations, better inform prevention strategies and over time allow for assessment of prevention efforts.

GBD estimates lack the specificity in amputation level that a prosthetist and other rehabilitation providers would require for detailed prosthetic treatment planning. For example, clinical care and expected outcomes for a person with a long transtibial amputation would differ substantially from that of a person with a short transfemoral amputation. The data in this study therefore cannot guide detailed treatment planning. Further, diabetes estimates include all lower limb amputations including toes and do not disaggregate by unilateral or bilateral. These data therefore have limited utility in guiding prosthetic treatment planning.

Estimates in this paper are provided at the regional level rather than country level. Reporting data at the regional level may result in over or underestimates. For example, one country with civil war may be averaged into the estimate of people living with amputations for other countries within the same region and thereby underestimate people living with amputations in the country at war.

The GBD 2017 study imposed a hierarchy to select the nature-of-injury category that resulted in the largest burden when a person experienced multiple injuries. Specifically, people who experienced multiple severe injuries including a limb amputation, such as spinal cord injuries or traumatic brain injuries, would not be accounted for in traumatic amputation

estimates. This hierarchy may have resulted in an under estimation of traumatic amputation prevalence.

2.6 Conclusions

In 2017, we estimated that 66.6 million people were living with a limb amputation due to trauma and diabetes. Prevalence of amputation varied by cause, age and geography. Regions that had the highest prevalence were East Asia, South Asia, High-income North America and Western Europe. Differences between age groups and regions can serve to inform prevention strategies and planning for future prosthetic service provision and rehabilitation services.

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Chapter 3. A SYSTEMATIC REVIEW OF PROSTHETIC AND ORTHOTIC EDUCATION RESEARCH

3.1 ABSTRACT

Background: University-based prosthetic and orthotic education has evolved greatly since its inception in the 1950s. The International Society for Prosthetics and Orthotics has established guidelines and recognition for prosthetic and orthotic professional preparation programs worldwide. However, a systematic evaluation of the current state-of-the-science in prosthetic and orthotic education research is needed to guide educators and educational organizations in the field.

Objectives: To evaluate and synthesize available prosthetic and orthotic education research and identify priorities for future work.

Design: Systematic review

Methods: A single author searched three bibliographic databases and assessed quality of the included research reports using the criteria from the National Institute for Health Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies and the Critical Appraisal Skills Programme Qualitative Research Checklist.

Results: Twenty-one research reports from twenty independent studies were included in this review. Included studies explored curriculum development, country-level review and pedagogy. Studies were conducted in seventeen countries and published in ten journals. Methodological quality was rated moderate in eight publications and low in thirteen. Due to the disparate nature of available literature, content synthesis was not possible.

Conclusion: The results of this systematic review suggest that prosthetic and orthotic education research is only being conducted at a limited level. There is a strong need for high quality,

collaborative education research to be conducted and published in peer-reviewed journals to improve prosthetic/orthotic education and build a global community and conversation.

3.2 Introduction

Globally, prosthetics and orthotics (P&O) is a relatively young discipline within rehabilitation medicine. The first formal university-based P&O professional preparation programs were established in the 1950s in the United States (Fishman, 2002) with New York University producing the first graduates with a degree in Orthotics and Prosthetics in 1965 (Perry & Friz, 1970). The first published documentation on international education of prosthetists/orthotists was from a meeting held in Denmark in 1968 (United Nations, 1969). The International Society for Prosthetics and Orthotics (ISPO), established in the 1970s, has since used this foundational document and numerous subsequent meetings to develop and refine educational philosophy and international standards for global P&O education (International Society for Prosthetics and Orthotics, 2018b).

ISPO has gone to the extent of detailing appropriate professional preparation programs for both professional prosthetists/orthotists and orthopedic technologists who work under the supervision of prosthetists/orthotists (International Society for Prosthetics and Orthotics, 2018b). Meetings and publications developed through ISPO largely guide current educational standards worldwide (International Society for Prosthetics and Orthotics, 2018b). There are currently 36 ISPO recognized P&O professional preparation programs listed on the ISPO website (International Society for Prosthetics and Orthotics, 2019). As international educational programs in low and middle-income countries (LMICs) continue to be developed, educators worldwide will seek teaching resources, educational references and model programs to emulate.

In many high-income countries (HICs), educational standards in P&O have evolved to a Bachelor's entry-level degree with a subsequent internship (also termed a residency). In the US, a Master's entry-level degree is now required. These higher educational requirements are directly linked with the global healthcare transition toward evidence-based practice. Prosthetic and orthotic students are now being trained not only as clinicians but also as consumers, implementers and producers of scientific evidence (Ramstrand & Brodtkorb, 2008). This shift toward evidence-based practice has been made possible through a growing network of doctoral level P&O researchers and an expanding knowledge base of peer-reviewed literature. However, this development of scientific evidence has largely focused on clinical practice with less emphasis on the need for evidence in P&O education (Malas, 2002).

In 2014, ISPO initiated a Global Educators Meeting (GEM) with "the purpose of ongoing exchange, professional development and supportive learning" (International Society for Prosthetics and Orthotics, 2018a, para. 1). GEM reflects a growing demand for educator collaboration and development yet stops short of establishing and promoting the development of a peer-reviewed literature base for P&O education. While a recent review attempted to draw associations between P&O clinician education and patient outcomes, the review focused upon clinical impact rather than outcome assessment in education (Forghany et al., 2018). Therefore, the first step toward an established P&O education knowledge base is an assessment of the current state-of-the-science in formal P&O education.

The aim of this systematic review was to describe the range of formal education research that has been conducted and published in the peer-reviewed literature. The specific objectives were twofold; (1) to evaluate and synthesize the educational methods and techniques researched in P&O education worldwide, (2) to identify priorities for future research to expand existing

evidence in P&O education. Understanding the current state-of-the-science in P&O education has a number of far-reaching implications for global P&O professional preparation programs in terms of how they design, implement and evaluate their programs.

3.3 METHODS

For studies to be included in this systematic review, they had to describe the outcome of a formal P&O educational study. Both qualitative and quantitative study designs were included in the review to ensure a complete description of current evidence in global P&O education.

Literature Search

A systematic search of the literature was conducted in January 2019 using several healthcare databases, including PubMed (1966 to January 2019), CINAHL (1981 to January 2019), and Web of Science (1900 to January 2019). Databases were searched using generic keywords related to formal education and keywords related to the field of P&O. The keywords were combined by Boolean operators to standardize the search across databases. The syntax used in PubMed, CINAHL and Web of Science was as follows; ("prosthetics and orthotics" OR "prosthetist and orthotist") AND ("education" OR "bachelors" OR "training" OR "curriculum" OR "school" OR "teaching" OR "masters"). Additionally, the references of key P&O education documents (International Society for Prosthetics and Orthotics, 2018b; World Health Organization, 2005) were hand searched. Lastly, conference proceedings available online from ISPO (2004- 2016), American Academy of Orthotists and Prosthetists (AAOP) (2013-2018), GEM (2014 & 2018) and OTWorld (2018) were hand searched for relevant abstracts. Authors of identified abstracts were then contacted to inquire about current or future plans for publication.

Eligibility Criteria

Specific inclusion and exclusion criteria were established *a priori* to ensure inclusion of relevant literature, written or translated into English and relevant to the stated purpose of this review. Publications were restricted to those published in peer-reviewed journals. Conference proceedings, grey literature, dissertations and theses were examined, and authors contacted to inquire about current or future peer-reviewed publication. Opinion papers or those which were not original research were excluded from this review. Only research studies that examined formal P&O education were included in this review. Research that focused solely on patient education in the clinical context was excluded. Additionally, research on continuing education for P&O practitioners was also excluded. Beyond this, publications were not excluded based on study design or methodological quality. All observational, experimental, and qualitative studies were considered to ensure adequate review of the state-of-the-science in P&O education.

Data extraction, analysis and synthesis

Pertinent study characteristics, including teaching methods (e.g., type, duration, etc.) and measured outcomes, were extracted and organized into an evidence table (Appendix C). Information regarding robustness of methods was also extracted to allow for assessment of methodological quality.

To further guide evaluation and synthesis of heterogeneous studies, a modified version of Kirkpatrick's model of educational outcomes entitled the joint evaluation team (JET) classification was used (Barr, Koppel, Reeves, Hammick, & Freeth, 2006) (Table 3.1). JET expands the Kirkpatrick four-point typology of educational outcomes (learner reaction, acquisition of learning, behavioral change, and changes in organizational practice) to include six

categories. The six categories are: (1) learner reaction (level 1), (2) modification of attitudes/perceptions (level 2a), (3) acquisition of knowledge/skills (level 2b), (4) behavioral change (level 3), (5) changes in organizational practice (level 4a), (6) benefits to patients/clients (level 4b) (Table 3.1). Outcomes are discussed as broken down by this model of classification.

Table 3.1

Joint Evaluation Team (Barr et al., 2006) Classification Definitions and Examples

Level	Definition related to P&O education	Examples
Level 1-reaction	learners' views on the learning experience	perceived challenges and benefits of a specific learning experience or program
Level 2a – modification of attitudes/perceptions	changes in attitudes or perceptions as related to clinical care	perceived or measured change in confidence, self-efficacy, or attitude
Level 2b – acquisition of knowledge/skills	including knowledge and skills linked to P&O clinical care	measured change in academic knowledge, critical thinking skills
Level 3 – behavioral change	identifies individuals' transfer of specific skills or knowledge to clinical practice	integration of current clinical evidence into clinical decision making
Level 4a – change in organizational practice	wider change in the educational organization	faculty behaviors, curricula, programmatic changes
Level 4b – benefits to patients/clients	improvement in the outcomes of patients/clients associated with increased skill or knowledge of students	improved self-reported patient mobility or improved patient scores on performance based measures

Assessment of Methodological Quality

Methodological quality and study design were assessed separately. Study design was assessed using the classification scale adapted by American Academy of Orthotists and Prosthetists (AAOP) State-of-the-Science Evidence Report Guidelines in 2008 (Hafner et al., 2008). Methodological quality was assessed using one of two checklists, as determined by study design. Qualitative studies were assessed using the Critical Appraisal Skills Programme (CASP) qualitative research checklist (Public Health Resource Unit, 2006).

CASP has a twenty-five-year history of training health professionals and developing critical appraisal tools. The CASP qualitative checklist has a history of use to assess qualitative prosthetic literature (C. D. Murray & Forshaw, 2013). Observational study quality was assessed using the National Institute for Health Quality Assessment Tool for Observational Cohort and Cross-sectional Studies (National Heart, Lung and Blood Insitute, 2014). The NIH tool was developed as one of a set of quality assessment tools to assist reviewers with critical appraisal of the internal validity of studies (National Institute for Health, n.d.). Mixed methods studies were assessed using a combination of both checklists as applicable.

3.4 RESULTS

A total of 520 research reports were retrieved after eliminating duplicates. One reviewer scanned the titles and abstracts to ensure appropriateness to the research question. Those not addressing formal P&O education were removed. Full text was retrieved and reviewed for thirty-six research reports. Of these thirty-six, fifteen were excluded as opinion papers without outcome data or as not examining formal P&O education. Twenty-one research reports from twenty independent studies were included in the final review (Table 3.2). Given that this review is exclusively descriptive, two publications from the same study have been included (Aminian & O'Toole, 2011; Aminian et al., 2015). Figure 3.1 illustrates the study selection process.

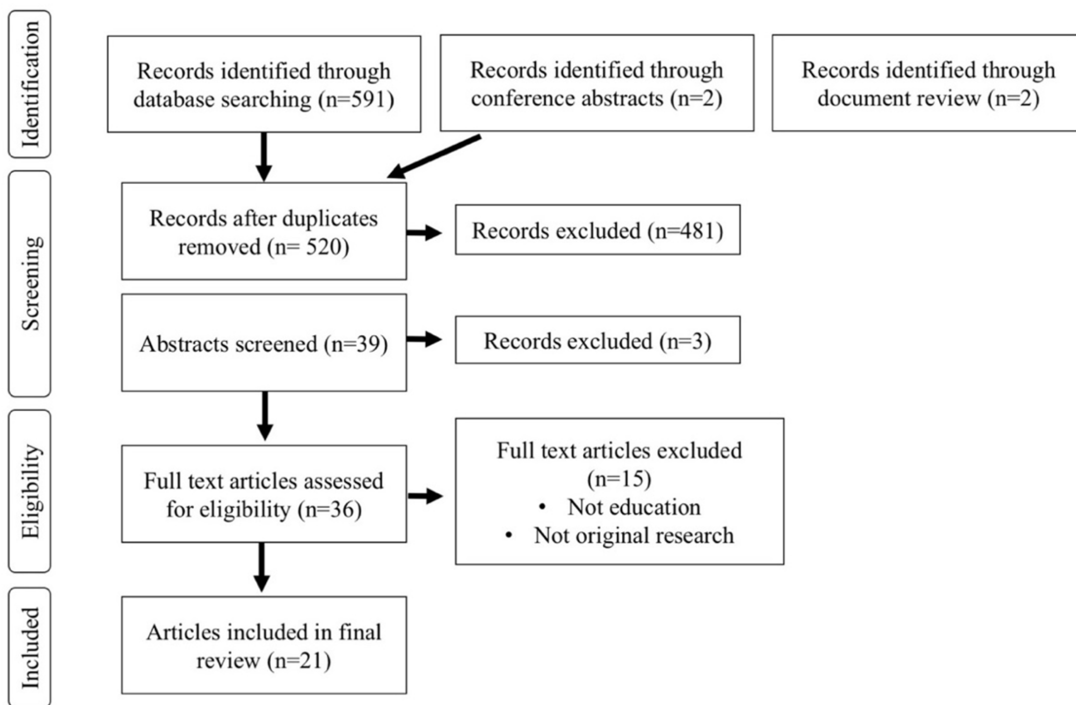


Figure 3.1a. Flow diagram of conference abstract screening process

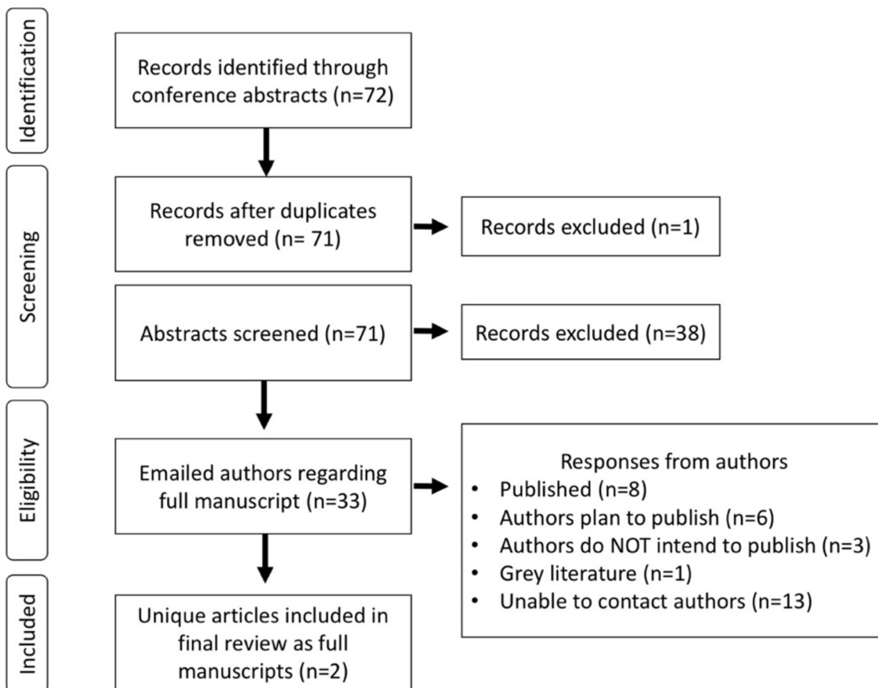


Figure 3.1b. Flow diagram of article selection process

Table 3.2

Description of Research Reports and Conference Abstracts on Prosthetics and Orthotics Education

Author	Journal or conference	Topic			Type of study	Topic of study	Quality
		Curr	Program review	Pedagogy			
Full research reports							
Boe *et. al,* 2019	J Prosthet Orthot		X		Cross-sectional	Graduate competency	Mod
Ramstrand *et. al,* 2018	Prosthet Orthot Int	X			Delphi/ Qual.	Competency standards for P&Os	Mod
Miro *et. al,* 2017	Prosthet Orthot Int	X			Cohort	Board exam results association	Mod
Fiedler *et. al,* 2017	ZEFQ			X	Cohort	Short term study abroad	Mod
Hill *et. al,* 2017	Prosthet Orthot Int	X			Qualitative	Threshold concepts in prosthetics	Mod
Magnusson *et. al,* 2016	Afr J Disabil		X		Qualitative	Tanzania and Malawi education	Mod
Ash *et. al,* 2015	Int J Evid Based Healthc	X			Delphi/Qual.	Competency standards for P&Os	Mod
McFadyen et. al, 2010	J Interprof Care			X	Cohort	Interprofessional attitudes	Mod
Magnusson *et. al*, 2009	Disabil Rehabil Assist Technol		X		Qualitative	Pakistani P&O education	Mod
Wong *et. al*, 2004	Prosthet Orthot Int			X	Case-control	e-Learning	Mod
Aduayom-Ahego *et. al,* 2018	Niigata J Health Welfare		X		Cross-sectional	Japanese P&O education	Low
Aduayom-Ahego *et. al,* 2017	EC Orthopaedics		X		Cross-sectional	Togolese P&O education	Low
Aduayom-Ahego *et. al,* 2016	Niigata J Health Welfare		X		Cross-sectional	Ghanaian P&O education	Low
Al Qaroot *et. al*, 2014	Prosthet Orthot Int			X	Qualitative	Problem-based learning	Low
Aminian *et. al,* 2015*	Prosthet Orthot Int	X			Delphi Method	P&O teaching methods	Low
Aminian *et. al,* 2011*	Prosthet Orthot Int	X			Delphi Method	P&O programme objectives	Low
Hussain, 2011	J Ayub Med Coll		X		Cross-sectional	Pakistani P&O education	Low
Kheng, 2008	Prosthet Orthot Int			X	Cross-sectional	Bachelor distance education	Low
Wong *et. al*, 2007	Prosthet Orthot Int			X	Cohort	Critical thinking	Low
Simpson *et. al,* 2002	J Prosthet Orthot			X	Cross-sectional	Open learning	Low
Raschke *et. al,* 2002	J Prosthet Orthot	X			Delphi/Qual.	Curriculum review	Low
Conference abstracts							
Cruz *et. al,* 2018	AAOP			X	Cross-sectional	Entrustment in residency	NA
Mullen *et. al,* 2018	AAOP		X			Type of residency P&O cases	NA
Davis *et. al,* 2017	ISPO		X		Cross-sectional	Gender	NA
Kaewtip *et. al,* 2017	ISPO			X	Unclear	Self-assessment via video	NA
Kazuhiro *et. al,* 2017	ISPO	X			Cross-sectional	P&O need in Japan	NA
Longini, 2017	ISPO		X			Description of TATCOT	NA
Ndosil *et. al,* 2017	ISPO		X		Cross-sectional	Blended learning	NA
Pandian *et. al,* 2017	ISPO		X		Cross-sectional	Self-reported study behavior	NA
Pettersson *et. al,* 2017	ISPO			X	Qualitative	P&O education staff exchange	NA
Starholm *et. al,* 2017	ISPO			X	Cross-sectional	Participation in research	NA
Lindquist *et. al,* 2017	AAOP			X	Mixed-methods	IPE P&O & social work students	NA
Boland *et. al,* 2015	ISPO			X	Program eval	Blended learning	NA
Figgins *et. al,* 2015	ISPO	X			Qualitative	Clinical placement assessments	NA
Kaewtip *et. al,* 2015	ISPO			X	Qualitative	Formative assessment	NA
Ruder *et. al,* 2015	ISPO		X		Cross-sectional	Canadian P&O education	NA
Seng-iad et. al, 2015	ISPO, AAOP		X		Cross-sectional	Thai P&O education	NA
Spaulding *et. al,* 2015	ISPO	X			Lit review	Educational framework	NA
Yamane *et. al,* 2015	ISPO	X			Action research	Prof. learning community	NA
Ghosh *et. al,* 2013	ISPO			X	Cross-sectional	Learning style assessment	NA
Kheng *et. al,* 2013	ISPO		X		Cross-sectional	Disability inclusion in P&O	NA
Kim *et. al,* 2013	ISPO			X	Cross-sectional	KD prosthesis for education	NA
Samala *et. al*, 2013	ISPO	X			Mixed methods	Student research	NA
Oda *et. al,* 2010	ISPO			X	Cohort	Prosthetic casting simulator	NA
Ritchie *et. al,* 2010	ISPO			X	Unclear	PBL for UL prosthetics	NA

Note. Curr: curriculum, Qual: qualitative, P&O: Prosthetics and Orthotics, Ed: education, Mod: Moderate, ISPO: International Society of Prosthetics and Orthotics, TATCOT: Tanzania Training Centre for Orthopaedic Technologists, IPE: interprofessional education, eval: evaluation, Lit: literature, Prof: professional, KD: knee disarticulation, PBL: Problem based learning, UL: upper limb, *denotes research reports from the same study

Thirty-three conference abstracts on P&O education were retrieved through hand searching of available conference proceedings. Of these abstracts, eight were already published as full manuscripts in peer-reviewed journals. Authors of abstracts were contacted to inquire about future plans for publication. Authors of six abstracts reported currently seeking publication or having plans to publish in the near future. Three had no plans for publication; two reported a lack of time and one stated that this was not the intention of the study. Seventeen inquires received no response. Two unique publications not previously identified were found through this search of abstracts and included in this review (Figure 3.1a).

Characteristics of the conference abstracts not included in this review as full manuscripts are provided in Table 3.2. Conference abstracts were not assessed for quality nor synthesized due to variability and inconsistency in abstract reporting. Conference abstracts were split across topics with eleven abstracts examining specific teaching approaches, eight provided descriptions of current P&O education and five address curriculum level topics. Topics ranged from physical tools for teaching in P&O to novel P&O assessment methods. Most studies used cross-sectional methods with a number of studies providing insufficient detail to determine study methods (Table 3.2).

Study Characteristics

Of the twenty-one research reports from twenty unique studies included in this analysis, four were mixed methods, twelve were quantitative studies, and five were qualitative studies. Researcher developed surveys (Aduayom-Ahego & Ehara, 2016, 2018; Aminian & O'Toole, 2011; Aminian et al., 2015; Ash, O'Connor, Anderson, Ridgewell, & Clarke, 2015; Boe & Gardner, 2019; Fiedler & Kremer, 2017; Hill, 2017; Sajjad Hussain, 2011; Kheng, 2008, 2008;

Ramstrand & Ramstrand, 2018; Raschke SU & Ford N, 2002; Wong et al., 2004), using semi-structured interviews (Hill, 2017; Magnusson & Ramstrand, 2009; Magnusson, Shangali, & Ahlström, 2016) or Delphi methods (Aminian & O'Toole, 2011; Aminian et al., 2015; Ash et al., 2015; Ramstrand & Ramstrand, 2018; Raschke SU & Ford N, 2002) were used in most studies. Included studies represented a wide international breadth with multiple multi-country collaborations. Countries of conduct included Australia, Cambodia, Canada, China, Ghana, Iran, Japan, Jordan, Malawi, Norway, Pakistan, Scotland, Sweden, Tanzania, Togo, United Kingdom, and United States (Figure 3.2).

♦♦♦ 3 studies were conducted online with participants from multiple countries

Note. The number of diamonds is not equal to the number of articles included in the review. Two studies were conducted in multiple countries and three studies were conducted online with participants from multiple countries.

Figure 3.2. World map of locations of included prosthetic and orthotic education studies

Methodological Quality Assessment

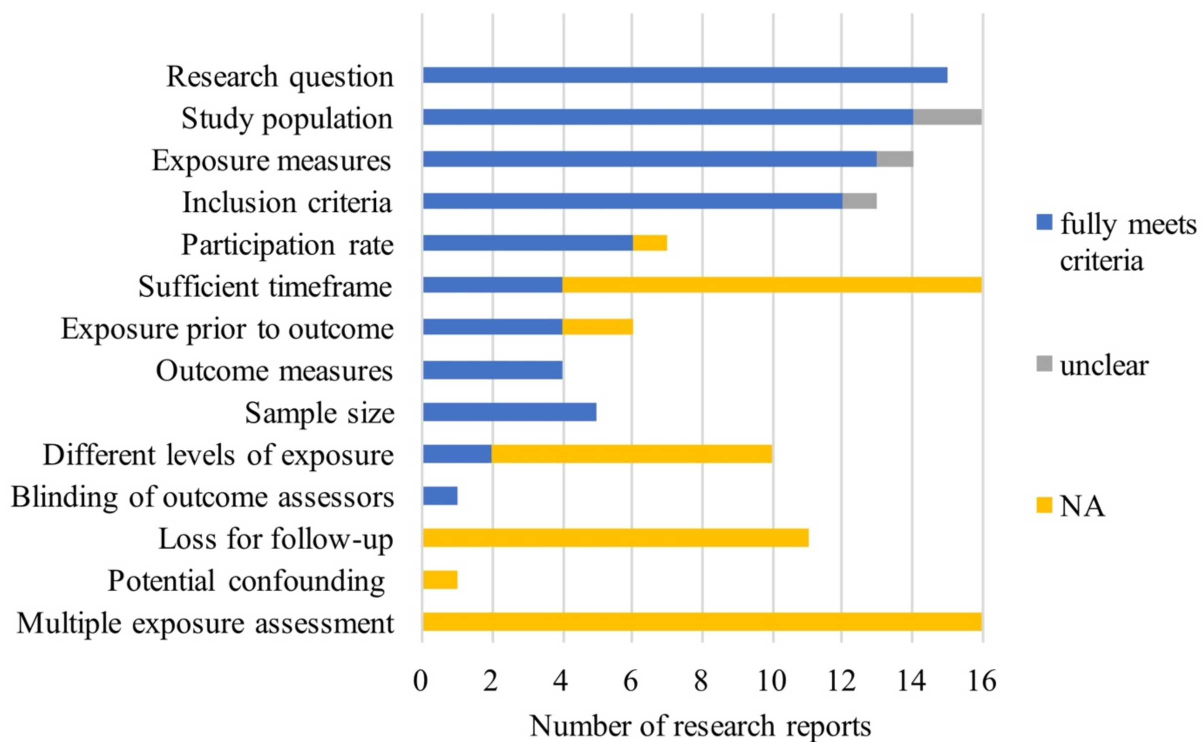
Of the twenty-one research reports included in this review, fourteen were assessed with the NIH Observational and Cross-sectional quality checklist (Figure 3.3), five were assessed with the CASP qualitative checklist (Al Qaroot & Sobuh, 2014; Hill, 2017; Magnusson & Ramstrand, 2009; Magnusson et al., 2016; Ramstrand & Ramstrand, 2018) and two were assessed through a combination of the two (Ash et al., 2015; Raschke SU & Ford N, 2002).

Quality was assessed based on the percentage of applicable checklist criteria each study met. High quality was defined as >75% of checklist criteria, moderate quality as between 60% and 75% of checklist criteria met and low quality was <60% of checklist criteria met (Table 3.2). Through this methodological assessment, evidence was found to be of low-to-moderate quality.

Ten studies were rated as moderate quality, while the remaining eleven research reports were of low quality (Table 3.2). Numerous limitations were identified in the reviewed studies. Most predominant was an overall deficit in reporting. For example, participation rates were less than 50% (Aduayom-Ahego & Ehara, 2018; Aminian & O'Toole, 2011; Kheng, 2008; Raschke SU & Ford N, 2002) or not reported appropriately (Aduayom-Ahego, Ehara, & Kpandressi, 2017; Aminian et al., 2015; Sajjad Hussain, 2011; Wong, 2007; Wong et al., 2004). Only two studies identified small sample size as a study limitation (Boe & Gardner, 2019; Fiedler & Kremer, 2017) or provided justification for the study sample size (McFadyen, Webster, Maclaren, & O'neill, 2010).

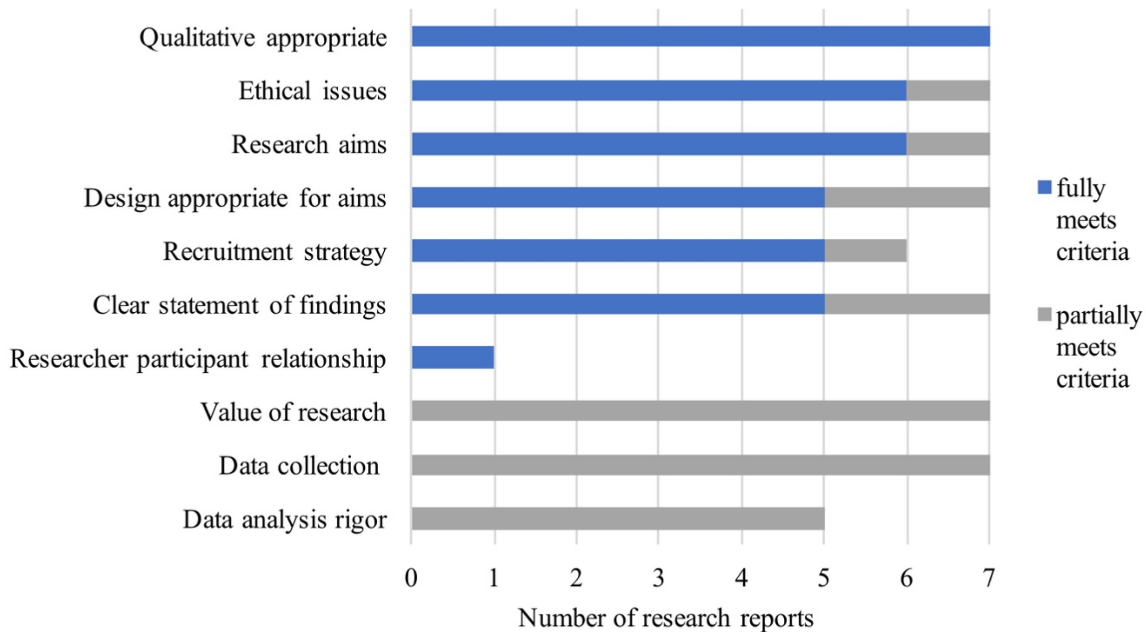
Among qualitative studies, the most common omission was the failure to discuss the prior relationship between researchers and participants. Five studies failed to report on prior relationships (Al Qaroot & Sobuh, 2014; Ash et al., 2015; Hill, 2017; Magnusson et al., 2016; Ramstrand & Ramstrand, 2018; Raschke SU & Ford N, 2002). In qualitative research, these

relationships must be explicitly disclosed to allow the reader to understand the context of data collection and identify potential influences the researcher may have had on participant responses and interpretation of participant responses. Additionally, saturation of data (i.e., the point at which no new information is discovered during data analysis) was not mentioned in any of the qualitative studies, which impedes the readers ability to assess transferability of study findings. Topic guides and interview questions were omitted in two studies (Ramstrand & Ramstrand, 2018; Raschke SU & Ford N, 2002), described in two studies (Hill, 2017; Magnusson & Ramstrand, 2009) and provided verbatim in three studies (Al Qaroot & Sobuh, 2014; Ash et al., 2015; Magnusson et al., 2016) (Figure 3.4).



Note. Two articles were assessed with both the NIH and CASP criteria.

Figure 3.3. Number of research reports that met each NIH quality criteria



Note. Two articles were assessed with both the NIH and CASP criteria.

Figure 3.4. Number of research reports that met each CASP quality criteria

Teaching techniques and methods

Table 3.2 provides a summary of described teaching methods and employed study designs. Of the twenty-one research reports included, three attempted to establish current baselines on teaching method, program objectives and threshold concepts in P&O education globally (Aminian & O'Toole, 2011; Aminian et al., 2015; Hill, 2017). Three presented country specific curriculum development processes (Ash et al., 2015; Ramstrand & Ramstrand, 2018; Raschke SU & Ford N, 2002). Six studies conducted country or region specific reviews of current practice and education (Aduayom-Ahego & Ehara, 2016, 2018; Aduayom-Ahego et al., 2017; Sajjad Hussain, 2011; Magnusson & Ramstrand, 2009; Magnusson et al., 2016). Three others explored web-based and e-learning (Kheng, 2008; Simpson D, 2002; Wong et al., 2004). Two studies assessed graduate outcomes and competency (Boe & Gardner, 2019; Miro, Young,

Dedrick, & Highsmith, 2017). The remaining four studies explored various aspects of P&O pedagogy including research informed clinical practice (RICP), study abroad experiences, interprofessional education and critical thinking development in student prosthetists/orthotists (Al Qaroot & Sobuh, 2014; Fiedler & Kremer, 2017; McFadyen et al., 2010; Wong, 2007).

Given the heterogeneity of the available evidence, no conclusions are drawn regarding efficacy of specific techniques or methods. Rather, a descriptive review of evaluation methods and reported outcomes is presented, followed by a suggested way forward and call to action.

Evaluation methods

Nearly all studies conducted evaluation either during or following the activity or program of interest with one time point for data collection. Only two studies conducted a longitudinal (i.e., three or more data collection points) design, reflecting an overall focus on short-term outcomes and the difficulty with assessing educational retention long-term (McFadyen et al., 2010; Wong, 2007). Six studies included follow-up with graduates, providing some assessment of longer term outcomes (Aduayom-Ahego et al., 2017; Boe & Gardner, 2019; Fiedler & Kremer, 2017; Magnusson & Ramstrand, 2009; Magnusson et al., 2016; Miro et al., 2017).

Only two of the twenty studies collected data from the same subjects at more than one point in time (McFadyen et al., 2010; Wong, 2007). Single time point data collection considerably limited the ability for conclusions to be drawn from the data. Additionally, only three studies included a comparison group (Fiedler & Kremer, 2017; McFadyen et al., 2010; Wong et al., 2004).

Not surprisingly, survey was the most common method to collect data. Surveys ranged from Likert-type scales and statistically assessed agreement (Aminian & O'Toole, 2011;

Aminian et al., 2015; Boe & Gardner, 2019; Sajjad Hussain, 2011) to strengths, weaknesses opportunities, and threats (SWOT) analysis (Kheng, 2008). Only two studies employed outcome measures with published evidence of reliability and validity (McFadyen et al., 2010; Wong, 2007), reflecting the need for access, awareness and availability of instruments with published evidence of psychometric properties in P&O education research.

Seven of twenty studies used more than one data source (i.e., students, instructors, graduates). Students were the most common source of data collection used in twelve research reports, followed by instructors in five research reports. Those which attempted to compile data from multiple sources included instructors (Hill, 2017; Kheng, 2008; Ramstrand & Ramstrand, 2018), technicians (Aduayom-Ahego & Ehara, 2016), clinicians (Ash et al., 2015; Boe & Gardner, 2019; Ramstrand & Ramstrand, 2018; Raschke SU & Ford N, 2002), other rehabilitation professionals (Ramstrand & Ramstrand, 2018; Raschke SU & Ford N, 2002), and recent prosthetist/orthotist graduates (Aduayom-Ahego et al., 2017; Ash et al., 2015; Boe & Gardner, 2019; Magnusson & Ramstrand, 2009; Magnusson et al., 2016; Miro et al., 2017; Raschke SU & Ford N, 2002).

Reported learner outcomes

Reported learner outcomes were categorized by the JET classification (Barr et al., 2006). Six research reports did not report learner outcomes but rather conducted descriptive research at the programmatic level (i.e., curriculum development or review, defining education concepts) (Aminian & O'Toole, 2011; Aminian et al., 2015; Ash et al., 2015; Hill, 2017; Ramstrand & Ramstrand, 2018; Raschke SU & Ford N, 2002; Simpson D, 2002). These research reports were not categorized using the JET classification (Table 3.3).

Table 3.3

Joint Evaluation Team Classification of Outcomes

	Source	Outcomes studied 1	2a	2b	3	4a	4b	NA
Boe *et. al,* 2019	Self-report			■				
Aduayom-Ahego *et. al,* 2018	Self-report	■						
Miro *et. al*, 2017	Self-report			■				
Fiedler *et. al,* 2017	Self-report		■					
Aduayom-Ahego *et. al,* 2017	Self-report	■						
Magnusson *et. al,* 2016	Self-report	■						
Aduayom-Ahego *et. al,* 2016	Self-report	■						
Al Qaroot *et. al*, 2014	Self-report	■	■	■	■			
Hussain, 2011	Self-report	■						
McFadyen et. al, 2010	Self-report		■					
Magnusson *et. al*, 2009	Self-report	■						
Kheng, 2008	Self-report	■		■				
Wong *et. al*, 2004	Self-report		■					
Wong *et. al*, 2007	Self-report	■		■				
Ramstrand *et. al,* 2018								■
Hill *et. al,* 2017								■
Ash *et. al,* 2015								■
Aminian *et. al,* 2014								■
Aminian *et. al,* 2011								■
Simpson *et. al,* 2002								■
Raschke *et. al,* 2002								■

Note. 1: reaction, 2a: modification of attitudes/perceptions, 2b: acquisition of knowledge/skills, 3: behavioral change, 4a: change in organizational practice, 4b: benefits to patients/clients

Level 1: Reaction. Nine studies assessed learner reaction. (Aduayom-Ahego & Ehara, 2016, 2018; Aduayom-Ahego et al., 2017; Al Qaroot & Sobuh, 2014; Sajjad Hussain, 2011; Kheng, 2008; Magnusson & Ramstrand, 2009; Magnusson et al., 2016; Wong et al., 2004). Reaction included students' satisfaction, perception of program usefulness, program challenges and perceived value of the activity. Students' reactions were most often measured with a researcher-developed survey immediately following the program or activity.

Level 2a Attitudes/perceptions. Four studies assessed changes in attitudes and perceptions of students (Al Qaroot & Sobuh, 2014; Fiedler & Kremer, 2017; McFadyen et al., 2010; Wong, 2007). Examples of attitudes and perceptions included self-efficacy, enthusiasm to conduct research, positive professional identity, and readiness for interprofessional learning. Changes in attitudes and perceptions were measured by interview or self-report measure. Two studies used self-report measures with evidence of reliability and validity. One used a researcher-developed survey.

Level 2b Knowledge/skills. Five studies assessed changes in student knowledge and skills (Al Qaroot & Sobuh, 2014; Boe & Gardner, 2019; Kheng, 2008; Miro et al., 2017; Wong, 2007). Skills acquired by students were critical appraisal of scientific literature, clinical reasoning and critical thinking. Surveys and interviews were used to assess change in knowledge and skills. The only performance-based measure used was the ABC Prosthetist Board Exam (pass/fail) (Miro et al., 2017).

Level 3: Behavior change. One study reported on behavior change among students (Al Qaroot & Sobuh, 2014). The examined behavior was the use of scientific literature in clinical decision-making. Behavior change was self-reported rather than measured through performance-based measures.

Level 4a: Organizational practice. No studies assessed organizational practice. Examples of organizational practice might include development of new programs or curricula, retention of faculty, change in teaching methods.

Level 4b: Patient benefit. No studies assessed patient benefit. Examples of patient benefit might include self-report or performance-based outcomes of students' patients as they relate to

student skill and knowledge (i.e., assessment of patient outcomes before and after a student provides an intervention).

3.5 DISCUSSION

This systematic review provides the first detailed overview of the current state of peer-reviewed P&O education literature. It therefore sets the stage for future considerations regarding integration of empirical assessment in P&O education. The small body of evidence resulted in an exclusively descriptive review of the wide range of heterogeneous studies. Consensus statements were not possible given the paucity of consistent evidence, however, some patterns in methodology and outcome assessment were found.

The twenty-one reports from twenty studies included in this review can be categorized into one of three general categories; 1) Curriculum level research to describe or develop standards, concepts or objectives, 2) Country or region level description of current education and/or clinical practice, 3) Assessment of a specific teaching practice or activity.

Seventeen of the twenty-one reports included in our review were published within the last decade (Table 3.2), suggesting a recent shift toward education research and publication. While this shift is encouraging, room for improvement exists as the majority of included studies were rated as low quality. Only two studies assessed outcomes with an established outcome measure that has evidence of reliability and validity (Wong, 2007). Instead, most studies employed researcher-developed surveys, which provided descriptive information but had limited value without published evidence of psychometric properties (Roach, 2006). Researchers in P&O education can look to other rehabilitation disciplines for examples of tools with published evidence of validity and reliability to measure student skills and knowledge such as clinician decision-making (Macauley et al., 2018) and patient education (Forbes & Mandrusiak, 2019).

Reliance on self-reported data is a common thread throughout the available evidence, likely associated with the ease of collection. Some evidence exists that self-reported student learning is closely associated with actual performance, this association has not been examined among P&O students (Forbes & Mandrusiak, 2019). Additionally, while students can self-report perceptions at all levels of the JET classification, performance-based assessment may more accurately reflect changes in student knowledge/skill, behavior change and patient benefit. Currently in the literature reviewed, the most common level of assessment was JET classification level 1: reaction which is the student's view on the learning experience. Level 1 is the easiest level to measure but also provides limited evidence on the impact of the teaching method of interest. Future education research should seek assessment at multiple levels and strive to include higher levels of assessment such as level 3: behavioral change, level 4a: organizational change or level 4b: benefit to patients. While seven studies in this review included multiple data sources, no studies collected data at the level of P&O patients, thereby excluding a key stakeholder in P&O education. Integration of measures such as those used in physical therapy to assess professional competency (Benton, Duchon, & Pallett, 2013) and patient outcomes (Judd, Scanlan, Alison, Waters, & Gordon, 2016), into P&O education research would strengthen study conclusions and promote holistic assessment of teaching practices.

Despite the limited literature available for this review, we found consistent objectives for conducting P&O education research. Primarily authors noted the deficit of P&O specific educational evidence and emphasized the need to scientifically explore P&O education and publish the results in peer-reviewed journals to establish a knowledge base in P&O education. Compared to other rehabilitation professions such as occupational and physical therapy, which have journals dedicated to education research (i.e., Journal of Physical Therapy Education

(JOPTE), Journal of Occupational Therapy Education (JOTE)), P&O currently lacks an established forum for peer-reviewed education research. The twenty-one research reports included in this review were published in ten different journals (Table 3.2). Such diffuse publication may impede access to, dissemination and implementation of research findings, especially in low-resource settings.

Limitations

This review has several limitations. First, we primarily searched bibliographic databases and conducted limited hand searching of references. Additionally, authors of published research reports were not contacted to request unpublished data or further unpublished details. This search strategy provided an efficient source of material but also limited us to the resources included in the databases we chose to search (PubMed, CINAHL, Web of Science). Second, the geographic distribution of the journals included in these databases potentially limited the number of research reports from LMICs. Finally, this review was conducted by a single reviewer (C.M.).

On the basis of this review, we propose the following recommendations for future research in P&O education. First, researchers and educators in countries with well-established professional preparation programs (e.g., United States, United Kingdom, Canada, Australia, Cambodia) should approach program evaluation and self-review with an eye toward publication. Raschke *et. al* (2002), Ramstrand *et. al* (2018) and Ash *et. al* (2015) serve as examples for how curriculum development processes can be conducted systematically and disseminated. Transparency in program development, critique and refinement could serve as invaluable

learning tools and models for fledgling P&O professional preparation programs working to pursue ISPO recognition.

Funding for such P&O education research and publication must become a priority for relevant organizations such as ISPO and the Orthotic and Prosthetic Education and Research Foundation (OPERF). A recent Best Evidence in Medical Education (BEME) review explored ways to support education research among clinical educators (Ahmed, Farooq, Storie, Hartling, & Oswald, 2016). Identified interventions to promote education research are directly applicable to P&O educators and largely rely upon organizational and institutional investment: 1) protected time, 2) mentorship and/or collaboration, 3) departmental and institutional commitment and leadership and 4) financial support (Ahmed et al., 2016). P&O educational institutions, national and international organizations must work together to support P&O educators to make a foundational shift toward evidence-based education.

ISPO's GEM provides an excellent opportunity for collaboration among P&O educators, however, the current structure is limited to in-person participation every four years (Ahmed et al., 2016). Publication of abstracts, presentations and/or collaboration to publish a special issue of the ISPO journal, Prosthetics and Orthotics International, could expand the impact of GEM and contribute to a movement toward peer-reviewed publication of P&O education research. Dissemination is key to building a global community and prompting conversation among international P&O educators, administrators and governing bodies. With only 36 ISPO recognized institutions globally (International Society for Prosthetics and Orthotics, 2019), P&O education is a uniquely intimate discipline with huge potential for international collaboration.

Multisite studies and collaborative research could allow for growth of an international conversation, as well as, more compelling empirical evidence. Multisite studies can also explore

the complex ways in which different cultural, organizational and contextual factors shape the success of a P&O educational program. Continued and more robust collaboration between researchers in LMICs and HICs will result in improved methodological quality and reporting, further advancing the quality and quantity of available evidence. Mixed methods designs should be encouraged to provide rich multidimensional data (Kroll & Morris, 2009). By combining both quantitative and qualitative methods research can explore both the teaching processes and the outcomes of these processes. Additionally, including a wider range of data collection sources (i.e., patients, educators) and outcomes assessed will allow for a more inclusive reflection of program efficacy and identification of areas for further exploration.

Finally, the need for the use of theoretical frameworks in designing evaluation studies is essential to the growth and substance of P&O education literature (Steinert et al., 2016). A substantial body of literature exists on graduate level education, providing an accessible foundation upon which to build the evolving education of prosthetists/orthotists. Examples of relevant frameworks include principles of adult learning (Knowles, 1984), experiential learning (Kolb, 2014) and reflective practice (Schön, 1983). The trend of evidence based medical education and the Best Evidence Medical Education (BEME) initiative (Harden, Grant, & Buck, 1999) serve as key examples in support of empirical foundations for teaching methods and curriculum development in P&O education.

3.6 Conclusion

In conclusion, the findings of this review demonstrate a paucity of P&O education research worldwide. An increase in publications in recent years points toward a growing interest in P&O education research. As P&O educators and members of the global community, we must

capitalize on this interest to mirror recent efforts in evidence-based practice by: 1) increasing attention on and funding for evidence-based education, 2) collaborating where appropriate with the international community of P&O educators, and 3) instituting a culture shift toward peer-reviewed publication in P&O education.

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Chapter 4. INFORMATION ACCESS AND SHARING AMONG PROSTHETIC AND ORTHOTIC FACULTY IN THE UNITED STATES AND GHANA

4.1 Abstract

Study Design: Cross-sectional survey, social network analysis (SNA)

Background: Information access is essential for quality healthcare provision and education. Despite technological advances, access to prosthetics and orthotics (P&O) information in low and middle-income countries is not ubiquitous. The current state of information access, resource availability and exchange of information among P&O faculty is unknown.

Objectives: Describe information exchange networks and access at two P&O programs in Ghana and the U.S.

Methods: An online survey was administered to P&O faculty using a standard data collection tool (REDCap). The survey included a social network analysis, demographics, and P&O information resources and frequency of use. Descriptive statistics were calculated.

Results: Twenty-one faculty members completed the survey (84% response). Ghanaian faculty were on average younger, had less teaching experience and less education than U.S. faculty. Textbooks were the most commonly-used resource at both professional preparation programs. The Ghanaian network had more internal connections with few outside sources. The U.S. network had fewer internal connections, relied heavily upon four key players, but had numerous outside contacts.

Conclusions: Ghana and U.S. faculty networks reflect the structure, longevity and resource availability of the P&O programs. SNA is a useful methodology to explore information sharing among P&O faculty and may help identify areas for further examination and intervention.

Clinical Relevance: Information access and exchange networks among P&O faculty can inform interventions to improve quality of education for P&O students and professional development for P&O faculty. Knowledge translation in P&O education is essential for students to receive high-quality, current information. Information exchange networks can identify key players and barriers to dissemination among P&O faculty to promote successful knowledge translation of current scientific literature and technology development. Identification of information sources and frequency of use can inform interventions to improve information access.

4.2 INTRODUCTION

Access to reliable health information for health workers in low and middle-income countries (LMICs) has been suggested as the most achievable and cost-effective strategy to improve health outcomes (N. Pakenham-Walsh, Priestly, & Smith, 1997). Similarly, lack of access to information has been identified as a key barrier in medical education (Haddad & MacLeod, 1999; N. Pakenham-Walsh et al., 1997) and health service provision (Neil Pakenham-Walsh & Bukachi, 2009) in LMICs.

Recent advancements in internet availability, open source education tools, and general connectivity have been theorized to improve access to health information in LMICs (Noordin, Wright, & Howard, 2008; H. Smith et al., 2007; Williams, Pitchforth, & O'Callaghan, 2010). In addition to technological advancements, humanitarian efforts to promote access to resources such as *Open Access for Africa* and *Free Software and Open Source Foundation for Africa* seek to reduce barriers to information in LMICs. However, awareness and use of these free-access

initiatives among medical providers is limited (H. Smith et al., 2007) and has not yet been examined among prosthetists/orthotists.

Like many health professions, prosthetists/orthotists not only require foundational knowledge acquired during formal education but also require access to continuing education and professional development activities to maintain proficiency in the profession. Prior research has highlighted student-reported deficiencies in information availability in LMICs such as limited access to prosthetics books and journals (Aduayom-Ahego & Ehara, 2016; Magnusson & Ramstrand, 2009; Magnusson et al., 2016), biomechanics information (Aduayom-Ahego & Ehara, 2016), continuing education opportunities (Aduayom-Ahego et al., 2017), advanced technology information (Magnusson & Ramstrand, 2009; Magnusson et al., 2016) and internet connectivity (Magnusson & Ramstrand, 2009). However, prior research has not examined the current state or frequency of information access in prosthetics and orthotics (P&O) education. Because advancement in P&O education in LMICs is dependent upon timely, relevant and easily accessible information for both students and faculty, a thorough understanding of current information access is essential.

To fully understand information access in P&O education, we must examine both how reference materials are accessed and how information is exchanged among individuals (i.e., faculty, students and clinicians). Exchange of information can be examined through social network analysis (SNA). SNA is a method used to study individual relationships and the larger social structure. An information exchange network is an SNA that focuses on how people within a network share a specific type of information (Haythornthwaite, 1996). SNA has been used to examine information exchange networks among healthcare providers (Bae, Nikolaev, Seo, & Castner, 2015), research faculty (Hara, Chen, & Ynalvez, 2017) and undergraduate students

(Saqr, Fors, Tedre, & Nouri, 2018). Additionally, the potential to apply SNA in medical education has recently been described (Isba, Woolf, & Hanneman, 2017). To our knowledge, SNA methodology has not been applied to P&O faculty.

To explore the application of SNA in P&O education, we chose to examine information access and networks of information exchange at two professional preparation programs in two countries; Ghana and the United States (U.S.). As exploratory research, our goal was to describe how information is obtained and shared among P&O faculty at these programs, and how network analyses may inform development and evaluation of these professional preparation programs. A more thorough understanding of information access and educational resources used by P&O faculty can inform interventions to improve access, mitigate barriers to information in LMICs and leverage technological advances to bolster P&O education and clinical practice globally.

4.3 Methods

Participants and recruitment

We conducted an online survey from December 2018 to March 2019 to examine information exchange networks among P&O faculty at two P&O professional preparation programs, one in the U.S. and one in Ghana. These two programs had an established and ongoing P&O professional learning community in which the author was a participant. The primary faculty member for each course taken by P&O students at the two professional preparation programs was identified by the academic coordinator of each program. All primary faculty members were then recruited via email to complete the two-part survey. A total of 25 faculty (14 U.S., 11 Ghana) were invited to participate in the study.

This study was given a non-research determination from the Human Subjects' Division at the University of Washington (institutional review board). All study participants were provided

information regarding the study aims and design. Participants were assured that their study data would be kept confidential, and they could withdraw from the study at any time.

Measures

All online surveys were administered and managed using REDCap (Research Electronic Data Capture) electronic data capture tools hosted at the University of Washington (Harris et al., 2009). REDCap is a secure, web-based application designed to support data collection for research studies, providing 1) an intuitive interface for validated data entry; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures to common statistical packages; and 4) procedures for importing data from external sources.

The survey included two components (Appendix D). The first part of the survey included basic demographic information (e.g., age, sex, institution) and questions about sources for P&O information and frequency of use in teaching during the past 2 weeks. Response options for frequency of use included: *never, 1 time, 2 times, 3 times, 4 times, 5 or more times.* Additional questions were asked about the types of resources accessed and any desired additional resources.

The second part of the survey was a SNA to identify information exchange networks. The surveys were personalized and included all faculty relevant to the study participant (e.g., a U.S. faculty member would be asked about all other U.S. faculty members) and two questions regarding the frequency of giving and receiving information related to P&O teaching (i.e., the information exchange relationship). The survey had eight response options on an ordinal scale: *never this is me=0, never=1, occasionally but less than once a month=2, once or twice a month=3, once or twice a week=4, about once a day=5, 2 or 3 times a day=6, 4 or more times a day=7.* Reciprocal data were collected for each faculty interaction (e.g., participant A reported

on giving participant B information and participant B reported on receiving information from participant A). Reciprocal data was used to confirm frequency of information sharing in each information exchange relationship. In the case that participants reported different frequency of information sharing, the greater of the two categories was used for analysis. Data analysis was conducted using both the lesser and greater reported categories for each pair with no substantial difference in network characteristics. Frequency categories were recorded to provide a hierarchy to information sharing relationships but are not reported as a numerical value due to the ordinal nature of the data. Participants could also list up to 15 additional contacts outside the defined network with whom they share P&O related information.

Data analysis

Demographic characteristics were compiled by participant group and analyzed with descriptive statistics. Sources of P&O information and frequency of use were analyzed with descriptive statistics. The SNA data were used to develop an information exchange network for each university (Valente, 2010). In the network, each faculty member and additional contact listed is a node. The edges between nodes are based on directional (indicated by an arrow), reciprocal data. Reported edges that lack reciprocal data for confirmation (due to missing data or additional contacts outside the defined network) are based on the data available. The weight of the edges represents the frequency of information exchange with thicker edges indicating greater frequency, however, weight is not directly proportional to frequency and should not be interpreted as such.

Characteristics of the SNA were reported at both the network and node level (Table 4.1). Network characteristics are those that describe the network as a whole. Network characteristics

include density, average degree, clustering coefficient (transivity) and diameter. Node level characteristics are those specific to an individual within the network. Node level characteristics include degree, in-degree, out-degree, betweenness centrality and closeness centrality. All analyses were conducted using STATA and Gephi software. Gephi is an open-source software for visualization and analysis of network data (Bastian, Heymann, & Jacomy, 2009).

Table 4.1

Social Network Analysis Terminology

Level	Term	Definition
Network		The group of interconnected individual actors (nodes) and their connections (edges)
	Density	The proportion of edges in a network to the total number of possible edges within the network
	Average degree	The average number of connections (i.e., edges) a faculty member has within the network
	Clustering coefficient (transitivity)	The completeness of relational triads (i.e., whether contacts of one participant were also in contact with one another)
	Diameter	The longest path between any two nodes in the network
Node		An individual (faculty member) within the network
	In degree	The number of connections from which a person received information
	Out degree	The number of connections to which a person gave information
	Degree	The total number of connections (give and receive) a person has
	Betweenness centrality	The degree to which a node is ‘between’ a pair of other nodes within the network
	Closeness centrality	The “reach” of an individual node or how close a node is to every other node within the network
Edge		The information exchange relationship between two individuals (faculty members)
	Weight	The frequency with which a pair of individuals share information

4.4 RESULTS

Study participants included 11 Ghanaian and 10 U.S. faculty for a total of 21 participants and an overall response rate of 84% (11/11 Ghana, 10/14 U.S.). Ghanaian participants included 9 males and 2 females with a median age of 26 years (Interquartile range (IQR) 7.5). Ghanaian participants had a median of 2.5 years (IQR 1.4) teaching P&O students and 2.0 years (IQR 3.5)

teaching at their current institution. U.S. participants included 3 males and 7 females with a median age of 43 years (IQR 9.5). U.S. participants had a median of 9.0 years (IQR 20.0) teaching P&O students and 6.0 years (IQR 7.9) teaching at their current institution (Table 4.2).

Table 4.2

Participant Demographics

	Ghana (n=11/11)		USA (n=10/14)	
	Median	IQR	Median	IQR
Age, years	27.0	7.0	43.0	9.5
Time teaching, years	3.0	1.0	9.5	19.8
Time at current institution, years	2.5	2.9	8.0	8.5
Time spent teaching, %	85.0	37.5	50.0	50.0
	n	%	n	%
Sex, male	9	81.8%	3	30.0%
Highest degree held				
diploma	4	36.4%	0	0%
bachelor's	6	54.5%	0	0%
master's	1	9.1%	4	40.0%
doctorate	0	0%	6	60.0%
Additional responsibilities				
clinical practice	4	36.4%	2	20.0%
administration	4	36.4%	5	50.0%
research	3	27.3%	4	40.0%
grant writing	1	9.1%	3	30.0%
service	0	0%	5	50.0%

Note. IQR: interquartile range

Sources of information

The most commonly reported sources of P&O information among Ghanaian faculty were textbooks (100% of faculty reported textbook use in the past 2 weeks), Google (100%), YouTube (100%) and Wikipedia (82%). Among U.S. faculty, textbooks (80%) were also the predominant source of information, followed by other P&O faculty (80%), Google (70%) and peer-reviewed

journals (70%). Frequency of use for these sources varied among faculty at both professional preparation programs (Figure 4.1). Textbooks were the most common and most frequently used source of P&O information among both groups. Among Ghanaian faculty, frequency of use was highest for textbooks, followed by Google, YouTube and Wikipedia. Among U.S. faculty, frequency of use was highest for textbooks, followed by Google, peer-reviewed journals and other websites. In general, Ghanaian faculty used more resources, more frequently than their U.S. counterparts (Figure 4.1). Specific resources (e.g., websites and journals) and desired resources for both faculty groups are listed in Table 4.3.

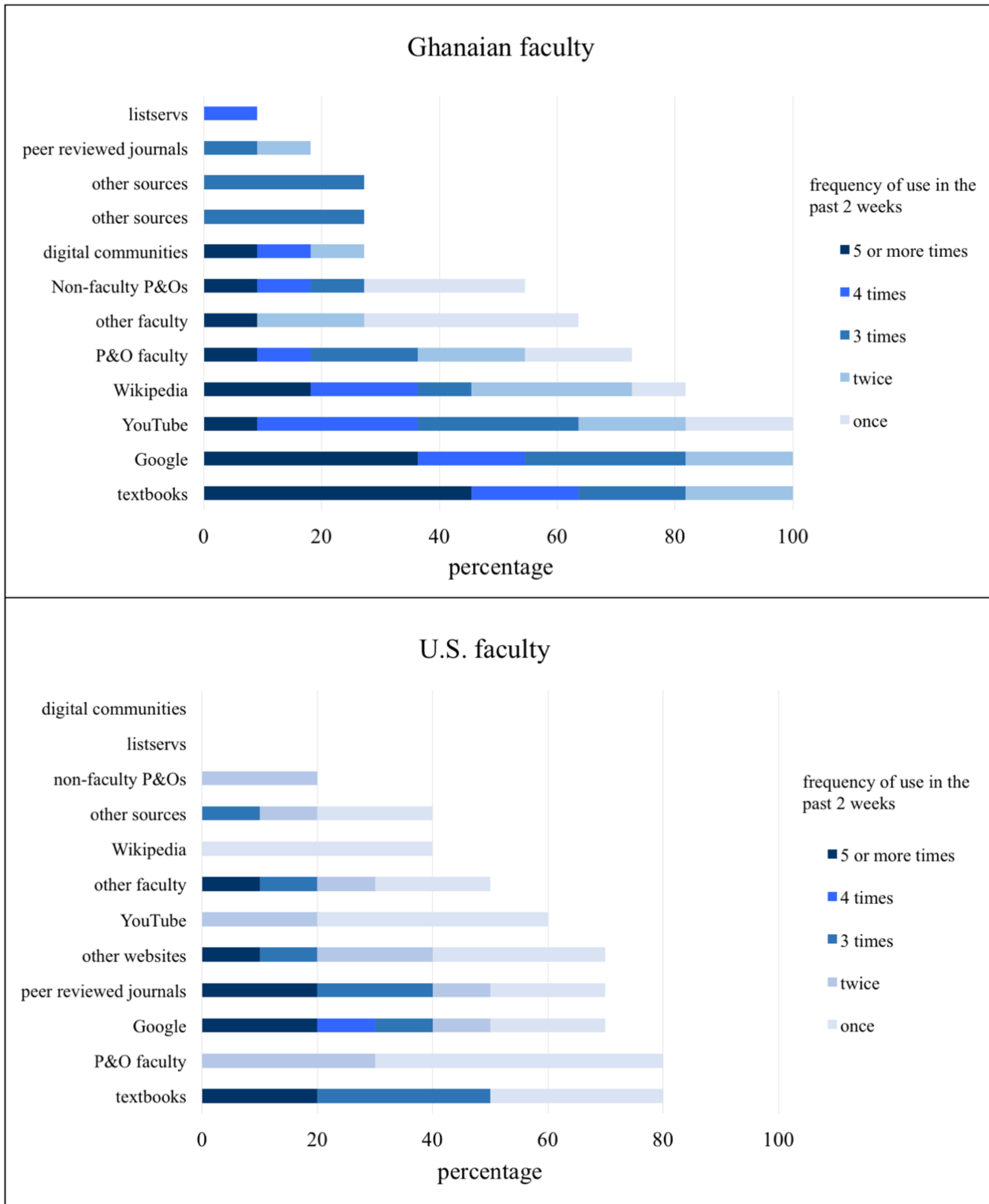

Figure 4.1. Frequency of faculty reported sources of P&O information

Table 4.3

Specific and Desired Sources of Information Ordered from Most to Least by Category

	Ghanaian Faculty		US Faculty	
	Resource	n (%)	Resource	n (%)
websites	various clinic websites	2(18%)	AAOP OLC	3(30%)
	clarkPO.com		Rehabmeasures.org	2(20%)
	WHO website	1(9%)	various clinic websites	2(20%)
	ICRC website	1(9%)	Mayo clinic	
	O&P virtual library	1(9%)	Boston brace	
	Orthopedic weblinks	1(9%)	Align clinic	
	drfop.org	1(9%)	material sciences resources	1(10%)
			Medicare resources	1(10%)
			manufacturer websites	1(10%)
			university library	1(10%)
			UpToDate	1(10%)
			Canchild.ca	1(10%)
			ACA website	1(10%)
journals	Pros Ortho Int	2(18%)	Pros Ortho Int	6 (60%)
	J Prosthet Orthot	1(9%)	J Prosthet Orthot	5(50%)
	J Rehabil Res Dev	1(9%)	Arch Phys Med Rehabil	4(40%)
	Can Prosthet Orthot J	1(9%)	Disabil Rehabil Assist Technol	2(20%)
			Disabil Rehabil	2(20%)
			Gait Posture	2(20%)
			J Phys Ther Sci	2(20%)
			Clin Biomech	1(10%)
			J Rehabil Res Dev	1(10%)
			Phys Med Rehabil Clin N Am	1(10%)
			Clin Orthop Relat Res	1(10%)
			J Pediatr Phys Ther	1(10%)
			J Phys Ther Ed	1(10%)
			Int J Rehabil Res	1(10%)
other resources	listservs	1(9%)	trade magazines	1(10%)
	360oandp.com	1(9%)	teaching hospital websites	1(10%)
	WHO GATE community	1(9%)		
	OTC (Ghanaian P&O clinic)	1(9%)		
	ISPO world congress	1(9%)		
resources desired, not currently available	peer reviewed journals	4(36%)	none	5(50%)
	textbooks	4(36%)	P&O material science resources	2(20%)
	other P&O websites	3(27%)	videos of technical skills in P&O	1(10%)
	ISPO website	1(9%)	component information	1(10%)
	anatomical models and charts	1(9%)	innovative treatment options	1(10%)
	orthotic fabrication process info	1(9%)	information sharing with P&O faculty at different schools; like GEM	1(10%)
	P&O material science resources s	1(9%)		
	prosthetic componentry info (knees)	1(9%)		
			P&O program overview and certification exam questions	1(10%)

Note. WHO: World Health Organization, AAOP OLC: American Academy of Orthotics and Prosthetics Online Learning Center, ICRC: International Committee of the Red Cross, P&O: prosthetics and orthotics, O&P: orthotics and prosthetics, DRFOP: Digital Resource for Orthotics and Prosthetics, ACA: Amputee Coalition of America, GATE: Global Cooperation on Assistive Technology initiative, OTC: Orthopaedic Training Center, ISPO: International Society of Prosthetics and Orthotics, GEM: Global Educators Meeting

Information exchange networks

We first used a sociogram graph to depict the information exchange networks among faculty at the two P&O professional preparation programs (Figure 4.2). Participants in the survey (i.e., faculty who teach P&O students at the two programs) are denoted by blue circles. Other contacts who were not surveyed but were reported as giving or receiving information to survey participants are denoted by grey circles. Lines between participants denote the direction and frequency of information exchange. The thicker the line, the greater the frequency of information exchange. However, line thickness is a representation and not directly proportional to frequency. Concurrence in reported information sharing relationships are shown in Figure 4.3.

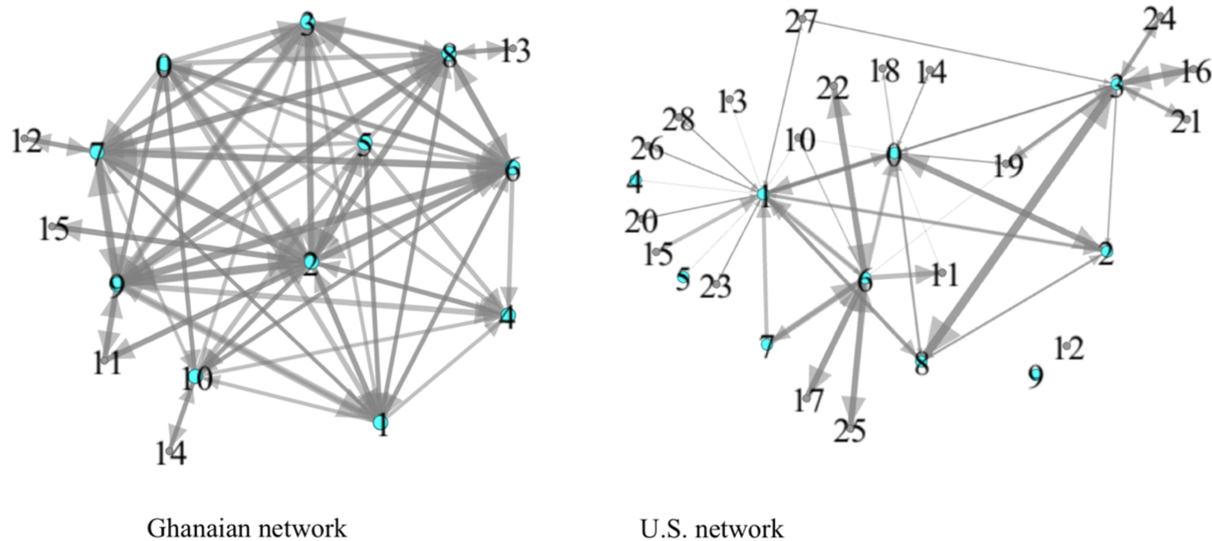

Figure 4.2. Ghanaian and U.S. faculty information exchange network sociograms

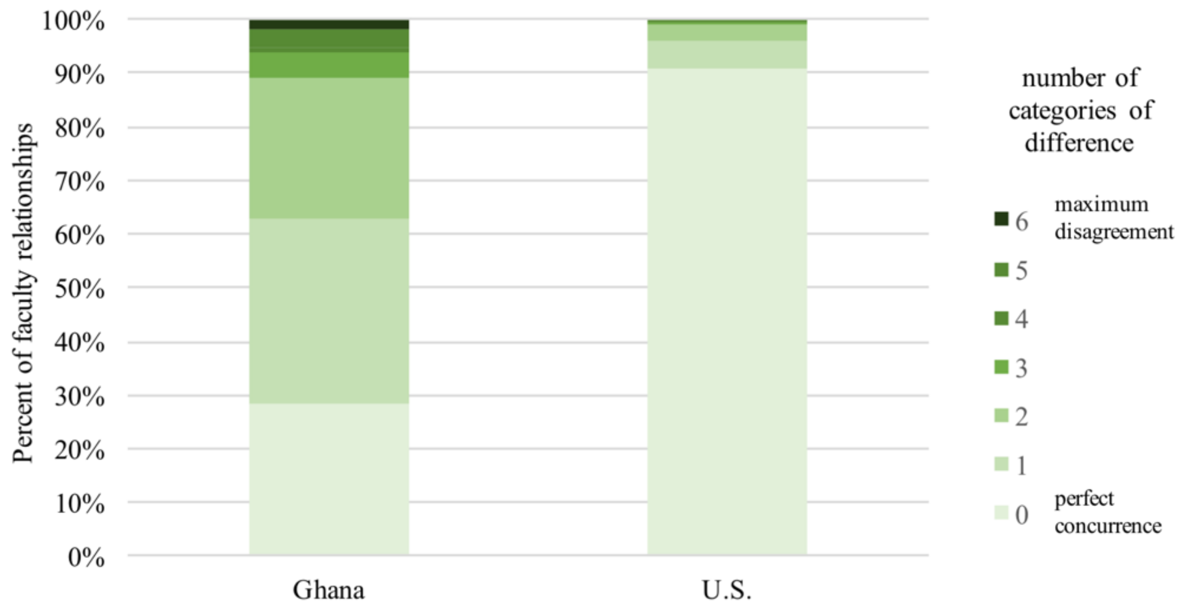

Figure 4.3. Concurrence in reported faculty information sharing relationships

Network measures for the two networks are reported in Table 4.4. Overall structure of information exchange networks at the two professional preparation programs were quite different. Both networks have a diameter of 4. The diameter is the longest distance between two nodes and is a reflection of the size of the network more so than the structure. All other network level measures vary between Ghana and the U.S.

Table 4.4

Descriptive Network Level Characteristics

	Ghana network	U.S. network
Density	0.383	0.084
Average degree (SD)	11.5 (7.1)	4.69 (6.39)
Clustering coefficient (transitivity)	0.528	0.265
Diameter	4	4

Overall density of the networks is quite different. The Ghanaian network had a density of 0.383 implying that 38% of the potential information exchange relationships actually exist. By

contrast, the U.S. network has a density of 0.084, where only 8% of the potential information exchange relationships exist. Average degree, similarly, reflects a more densely connected Ghanaian network (11.5) compared to the U.S. network (4.69), however, both have substantial variability in individual degree. Clustering coefficient or transitivity is a measure of the completeness of triad ties (e.g., A, B and C nodes are all connected). Higher transitivity indicates clustering within a network. The Ghanaian network has greater transitivity (0.528) than the U.S. network (0.265) indicating that the U.S. network is less connected with fewer triads that share information among themselves.

Node level characteristics can provide insight into an information exchange network that is not readily available through network measures (Table 4.5). For example, betweenness centrality is a measure of individuals who exist within communication paths of other nodes. Nodes with high betweenness centrality are key to communication within a network. In the Ghanaian network, a few nodes have high betweenness centrality (i.e., 2, 7, 10 and 8), however, due to the density of the network, betweenness for all nodes is relatively low. Communication within the Ghanaian network is not funneled through a few key players but rather occurs through multiple avenues. In contrast, the U.S. network has 4 key nodes with very high betweenness (i.e., 0,1,3,6) and 6 nodes with no betweenness. This implies a network that is heavily dependent upon 4 key players for successful communication. If any of these 4 nodes were removed from the network, communication within the network would be greatly affected and potentially break down.

Table 4.5.

Descriptive Node Level Characteristics for Surveyed Faculty

Ghana faculty						U.S. faculty					
Nodes (n=11)	In degree	Out degree	Degree	Betweenness centrality	Closeness centrality	Nodes (n=10)	In degree	Out degree	Degree	Betweenness centrality	Closeness centrality
0	5	10	15	5.2	0.75	0	7	10	17	105.3	0.63
1	7	9	16	5.0	0.71	1	12	14	26	265.8	0.69
2	12	12	24	68.0	0.83	2	4	4	8	0.0	0.5
3	9	5	14	2.5	0.58	3	9	10	19	147.7	0.63
4	7	1	8	0.0	0.47	4	1	0	1	0.0	0.0
5	3	10	13	0.2	0.75	5	1	0	1	0.0	0.0
6	9	9	18	8.4	0.71	6	7	8	15	149.2	0.56
7	9	8	17	30.3	0.68	7	1	2	3	0.0	0.46
8	9	7	16	28.2	0.63	8	4	4	8	0.0	0.5
9	9	9	18	12.2	0.68	9	0	0	0	0.0	0.0
10	7	6	13	29.1	0.58						

Note. Only survey participants are included in this table. In degree: the number of connections from which a node receives information, Out degree: the number of connections to which a node gives information

Closeness centrality is a measure of how close (i.e., how many edges) a node is to the other nodes within a network. High closeness centrality helps identify nodes who are able to disseminate information quickly within a network. Some variability in closeness centrality is seen in the Ghanaian network, however, most nodes are similarly able to disseminate information to their colleagues (range: 0.47-0.83). Closeness centrality among U.S. faculty is lower (range: 0-0.69) and reflects a less efficient system for dissemination of information (Table 4.4).

Through examination of the visual networks, network and individual level measures, differences between the Ghanaian and U.S. P&O faculty networks can be seen. The Ghanaian network has only 16 nodes, 11 of which are P&O faculty. The core network of 11 faculty frequently exchange information among themselves but have few resources for P&O information outside the faculty. Ghanaian faculty are consistent in the frequency with which they exchange information among the core network. One individual is at the center of the network (node 2),

however, most individuals within the network are well connected and share information regularly.

The U.S. network has 29 nodes, 10 of which are faculty who teach P&O students. This implies numerous resources for P&O information outside the core faculty network. Additionally, this network relies upon 4 key players (nodes 0,1,3,6) with one individual who is at the center of the network (node 1). The network is heavily dependent on these 4 key players for communication and dissemination of information. Faculty within this network share information with variable frequency indicating both strong and weaker collaborations.

4.5 Discussion

This study describes information access and information exchange networks among faculty at two P&O professional preparation programs in different countries, cultures and time points in their development. As such, this research describes two distinct networks. The Ghanaian network is a densely connected yet insular network with few external connections. The Ghanaian network has one key player who is central to the network, however, concerns of fragmentation of the network if this key player were removed are mitigated by high network density. In contrast, the U.S. network is less dense with four key players, one individual at the center of the network, and two isolates with no network connections. Individuals within the U.S. network each maintain relatively distinct networks of clinical experts who serve their specific P&O education content areas. As a more diffuse network, the U.S. faculty are at higher risk of fragmentation and impaired communication if key players leave the network. This exploratory research provides a proof of concept for the application of SNA in P&O education. Below we will focus on implications of the described information sources and networks, and possible

explanations for differences in networks interventions to strengthen information access and dissemination.

Differences in networks are most likely attributable to organizational characteristics of the P&O programs. The U.S. program is an R1 institution (i.e., a doctoral university with very high research activity) within the School of Medicine which also has occupational therapy and physical therapy and research doctorate education programs. Faculty who teach P&O students may also teach physical therapy and occupational therapy students. The program has only a small core P&O faculty. The U.S. program is well established with more than forty years in existence. Additionally, faculty at the U.S. program are on average older (and therefore may have more clinical experience and a larger network of information sharing colleagues), have more years of teaching experience and more time teaching at their current institution. This higher level of experience and higher individual level of education may reduce the need for frequent information exchange among faculty and may explain the larger individual networks outside the core faculty. Additionally, U.S. faculty, on average, spend less time teaching, which may explain less frequent exchange of information for teaching purposes.

Ghana is a P&O professional development program that does not teach other disciplines. All faculty only teach P&O students. The Ghana education program was established six years ago, and faculty are on average, quite young with limited teaching experience and less advanced education. This may explain the limited contacts outside the core faculty network and may also explain the need for frequent information exchange among faculty as they assist one another to develop their teaching skills and curriculum.

Beyond programmatic differences, survey responses represent a cross-sectional perspective of information exchange, an activity likely to vary by quarter and individual

workload. It is possible that faculty were not able to accurately report information exchange frequency due to teaching and non-teaching schedules (e.g., a non-teaching faculty member may experience greater recall bias). Concurrence in reported frequency of information exchange was greater in the U.S. network with more disagreement about frequency of sharing information in the Ghanaian network. This likely reflects the fewer number of information sharing relationships within the U.S. network. That is, it is easier for two people to agree that a relationship does not exist than to agree upon the exact frequency of information sharing within a relationship.

Other differences are more challenging to explain. However, potential causes should be considered and could be further researched. In Ghana, there may be fewer local clinicians or fewer specialized clinicians near the P&O school who can provide P&O expertise (Larbi, 2013). In the U.S., low teaching network density may reflect the proportion of time spent teaching versus conducting other professional responsibilities such as research and grant writing. Network connections not explicitly used for teaching purposes were not examined in this study and may therefore provide an incomplete picture of the U.S. faculty networks and interactions.

Information sources used by faculty in Ghana and the U.S. varied both in type of resource and frequency of use. U.S. faculty accessed information sources less frequently than Ghanaian peers, however, tended to focus on specific sources such as peer-reviewed journals, manufacturer and clinical websites. U.S. faculty may use their networks of outside contacts to cover specific clinical content and thereby rely on people as sources rather than texts and websites. Ghanaians may lack this network of specialized clinicians and instead must rely on faculty peer, texts and websites. Reliance upon text rather than websites may be further encouraged by the often unreliable internet service reported in many African countries (Smith et. al, 2007). A recent survey conducted in Ghana identified key challenges in P&O education to be a lack of

professionals, lack of teaching material in biomechanics and P&O, and limited access to prosthetic books and journals (Aduayom-Ahego & Ehara, 2016).

Peer-reviewed journal use in clinical education is part of a larger movement toward evidence-based practice and the integration of scientific literature into clinical decision making (Sackett, Straus, Richardson, Rosenberg, & Haynes, 2000). This recent shift in P&O clinical practice and education is reflected in the reported use by U.S. faculty. In Ghana, peer-reviewed journals were infrequently accessed but were identified as a desired but inaccessible resource. A study of information-seeking behavior among health science faculty in Ghana found that while nearly all faculty members used the internet to access information, they were largely unaware of the World Health Organization HINARI database (Katikireddi, 2004) that provides free access in Ghana to full text articles in LMICs (Sulemani & Katsekpor, 2007). Additionally, computer literacy and inexperience in database searching were identified as barriers to information access among faculty in Ghana (Sulemani & Katsekpor, 2007), however, these challenges have also been noted among U.S. Health Sciences faculty (De Groote, Shultz, & Blecic, 2014). Further research should examine barriers to journal use among faculty in Ghana to identify ways to improve access.

Strategies to improve information networks

The U.S. faculty network is vulnerable to faculty changes due to the low density of network connections and reliance upon a few key individuals. The network is likely to fragment if key players leave the network due to retirement, illness or change of position. Efforts to promote information exchange among faculty may serve to improve density and safeguard against changes in individual participation within the network. Interventions directed at

influencing organizational culture, perceived management support and organizational structure can improve knowledge sharing within an organization (Wang & Noe, 2010). This study may help U.S. faculty identify members within the network who are not currently engaged and serve as a roadmap to improve network connections for all.

The insular nature of the Ghanaian faculty network points to a need to expand information networks beyond the core P&O faculty. Ghanaian faculty could benefit from connections with clinical experts to diversify their sources of information and provide clinical expertise and insight to their students. International collaboration could serve this role if Ghanaian clinical experts are not available as has been indicated in prior research (Aduayom-Ahego & Ehara, 2016; Larbi, 2013).

Limitations

Results of this study are not generalizable to other education programs without further research. The methods employed in this study can be implemented to assess information access and networks in other P&O professional preparation programs. Additionally, this study was cross-sectional and therefore only provides a snapshot of a single time point of the examined networks. Due to the nature of the academic year and teaching responsibilities that vary throughout the year, the timing of such a survey may substantially influence the results. Data collection at multiple time points would provide a more complete picture of networks throughout the academic year.

Data collection in this study was conducted through a researcher developed self-report survey which is subject to various types of bias. First of all, the administered survey has not been examined for psychometric properties such as reliability or validity among P&O faculty.

Additionally, participants may be subject to response bias. For example, social desirability bias could prompt participants to respond in a way that makes them look favorable (e.g., using resources more frequently than they actually do). Recall bias is also a concern as participants were asked to remember who they shared information with over the past month of teaching. While this period of time is not unreasonable, degradation of memory over time is still a concern. Further, for those faculty members who infrequently teach P&O students, the past month of teaching may be many months ago. Finally, a number of U.S. faculty did not complete the survey and therefore do not have reciprocal data to support information exchange. Participants who chose not to complete the survey may be those who are less connected within the network but without their participation this information is only available through their colleagues' self-report

4.6 CONCLUSION

Information access and exchange networks in P&O education vary by education program. Ghana and U.S. faculty networks reflect the structure, longevity and resource availability of the two P&O programs. Ghanaian faculty could benefit from access to peer-reviewed journals and connections with clinical experts outside the core faculty to provide specialized clinical content and relieve faculty of providing all course content. The U.S. network could benefit from redundancy within the faculty network to increase density of connections and ensure timely and efficient transmission of information. SNA is a useful methodology to explore how information is shared among faculty teaching in P&O programs and may serve to identify areas for further examination and intervention.

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Chapter 5. CONCLUDING STATEMENTS

5.1 Summary of studies

Together, the chapters in this dissertation present an examination of the workforce and education needs in global prosthetics and orthotics (P&O). Additionally, this body of work identifies both gaps in current knowledge and explores opportunities and resources available to bolster development of global P&O. The findings of this work provide foundational information to guide both further research and future development in global P&O.

In Chapter 2, global estimates of amputation prevalence due to trauma and diabetes were described. These estimates provide insight into the need for prosthetic services globally and can inform regional and country-level service provision planning. Amputation prevalence data by cause, region, age and sex informs both prevention efforts and prosthetic rehabilitation. Additionally, global and regional prosthetist personnel need was estimated using 2017 prevalence estimates. Beyond interpretation of amputation prevalence estimates, this work provides an example of how Global Burden of Disease estimates can and should be leveraged to inform global rehabilitation need and service.

In Chapter 3, the current state of research in prosthetic and orthotic education was reviewed. Conclusions of this review were limited due to the small body of knowledge available. The paucity of prosthetic and orthotic education research available points to a substantial barrier for prosthetic and orthotic development globally. Conduct and dissemination of education research is essential to inform and support evidence-based education and provide an information base for developing prosthetic and orthotic professional preparation programs. Through compilation of the current body of literature in prosthetic and orthotic education, the following opportunities were identified; 1) collaborations between academic institutions could be formed to improve

methodological rigor in published research and leverage limited resources 2) transparency and publication of program review should be enhanced to facilitate dissemination of programmatic development and provide guidance for new P&O professional preparation programs and 3) support and funding for P&O education research should increase to establish a foundational knowledge base, identify best practices and support evidence-based education.

In Chapter 4, information access and exchange at two P&O professional preparation programs was examined through the use of social network analysis. This exploratory study assessed use of social network analysis within P&O education to describe individual information sharing relationships and larger networks within P&O professional preparation programs. Two distinct networks were described and informative characteristics for network improvement were identified. Additionally, information sources of faculty at both professional preparation programs were examined and areas for improvement identified.

The Ghana network was found to be more insular with fewer contributions from outside experts but high connectivity among faculty. Additionally, peer-reviewed journals were identified as a desired but underutilized source of information among Ghanaian faculty. The Ghanaian P&O program could 1) cultivate relationships with community clinicians to bolster clinical curriculum and reduce teaching load from core faculty, 2) identify and remove barriers to peer-reviewed journals.

The U.S. network was less connected internally indicating heavy reliance upon a few key individuals, but faculty made better use of clinical experts from the community. The U.S. P&O program could explore methods to influence organizational culture and structure to improve connectivity to safeguard against fragmentation if key individuals leave the network. Both networks could benefit from further investigation to explore barriers to information exchange and

impact of faculty networks on students and student learning. Overall, the work described in this dissertation will add to prior knowledge of global prosthetic need, P&O personnel need and education.

Overall Limitations

The work presented in this dissertation is limited by the paucity of evidence on global P&O personnel and their education. Chapters 2 and 3 were dependent upon preexisting data and published literature and thereby limited to existing methodology that may limit the conclusions we can draw. Both of these chapters leveraged existing evidence to inform the current state of P&O personnel and education globally. Chapter 4 involved primary data collection with a researcher developed survey. Data, therefore, may be subject to participant response bias such as social desirability or recall bias. Specific methodological limitations described in each of these chapters may be addressed in future research efforts to improve the quality of evidence on P&O personnel and within P&O education programs.

5.2 FUTURE DIRECTIONS

Next steps for this body of work include further exploration of global estimates. Global estimates of amputation incidence and incidence rate could be examined to provide insight into leading causes and regions for new amputations. These data could more accurately inform prevention efforts and be examined over time to assess impact of prevention strategies. Additionally, etiologies commonly associated with orthosis use could be identified to provide general estimates of global orthotic need and better inform prosthetist/orthotist personnel need.

Information access and exchange networks among prosthetic and orthotic students in Ghana and the US can be examined to compliment the exploration of faculty patterns. Relationships between faculty and student information sharing networks could be examined. Additionally, specific barriers to information access identified in Chapter 4 could be further explored through qualitative methods to guide interventions to improve information access. Results from the exploratory study in Chapter 4 will be used to apply for future grant funding to further examine information exchange and establish a base of knowledge to guide P&O education worldwide.

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APPENDIX A

Cause-of-injury categories and examples

	Examples	ICD 9	ICD 10
Transport			
Road injuries	Car, two-wheeled vehicle, pedestrian/car	V01-V04.99, V06-V80.929, V82-V82.9, V87.2-V87.3	V01-V04.99, V06-V80.929, V82-V82.9, V87.2-V87.3
Other transport	Aircraft, cable car, fall from watercraft	E800.0, E800.1, E800.2, E801.0, E801.1, E801.2, E802.0, E802.1, E802.2, E803.0, E803.1, E803.2, E804.0, E804.1, E804.2, E805.0, E805.1, E805.2, E806.0, E806.1, E806.2, E807.0, E807.1, E807.2, E810.7, E820.7, E821.7, E826.2, E827.2, E828.2, E830.0, E830.1, E830.2, E830.3, E830.4, E830.5, E830.6, E830.7, E830.8, E830.9, E831.0, E831.1, E831.2, E831.3, E831.4, E831.5, E831.6, E831.7, E831.8, E831.9, E832.0, E832.1, E832.2, E832.3, E832.4, E832.5, E832.6, E832.7, E832.8, E832.9, E833.0, E833.1, E833.2, E833.3, E833.4, E833.5, E833.6, E833.7, E833.8, E833.9, E834.0, E834.1, E834.2, E834.3, E834.4, E834.5, E834.6, E834.7, E834.8, E834.9, E835.0, E835.1, E835.2, E835.3, E835.4, E835.5, E835.6, E835.7, E835.8, E835.9, E836.0, E836.1, E836.2, E836.3, E836.4, E836.5, E836.6, E836.7, E836.8, E836.9, E837.0, E837.1, E837.2, E837.3, E837.4, E837.5, E837.6, E837.7, E837.8, E837.9, E838.0, E838.1, E838.2, E838.3, E838.4, E838.5, E838.6, E838.7, E838.8, E838.9, E840.0, E840.1, E840.2, E840.3, E840.4, E840.5, E840.6, E840.7, E840.8, E840.9, E841.0, E841.1, E841.2, E841.3, E841.4, E841.5, E841.6, E841.7, E841.8, E841.9, E842.6, E842.7, E842.8, E842.9, E843.0, E843.1, E843.2, E843.3, E843.4, E843.5, E843.6, E843.7, E843.8, E843.9, E844.0, E844.1, E844.2, E844.3, E844.4, E844.5, E844.6, E844.7, E844.8, E844.9, E845.0, E845.8, E845.9, E849.0, E849.1, E849.2, E849.3, E849.4, E849.5, E849.6, E849.7, E849.8, E849.9, E929.1	V00.1, V00.2, V00.3, V00.8, V05.1, V05.2, V05.3, V05.4, V05.9, V81.0, V81.1, V81.2, V81.3, V81.4, V81.5, V81.6, V81.7, V81.8, V81.9, V83.0, V83.1, V83.2, V83.3, V83.4, V83.5, V83.6, V83.7, V83.8, V83.9, V84.0, V84.1, V84.2, V84.3, V84.4, V84.5, V84.6, V84.7, V84.8, V84.9, V85.0, V85.1, V85.2, V85.3, V85.4, V85.5, V85.6, V85.7, V85.9, V86.0, V86.1, V86.2, V86.3, V86.4, V86.5, V86.6, V86.7, V86.9, V88.2, V88.3, V90.0, V90.1, V90.3, V90.8, V91.0, V91.2, V91.3, V91.4, V91.5, V91.6, V91.8, V92.0, V92.1, V92.2, V92.7, V92.8, V93.0, V93.1, V93.2, V93.3, V93.4, V93.5, V93.6, V93.7, V93.8, V93.9, V94.0, V94.1, V94.2, V94.3, V94.7, V94.8, V94.9, V95.0, V95.1, V95.2, V95.3, V95.4, V95.8, V95.9, V96.0, V96.1, V96.2, V96.8, V96.9, V97.0, V97.1, V97.2, V97.3, V97.8, V98.0, V98.1, V98.2, V98.3, V98.8
Unintentional			
Falls	Fall due to ice or snow, fall from ladder, tree, building, cliff	E880-E886.99, E888-E888.9, E929.3	W00-W19.9
Drowning	Accidental drowning in bathtub, pool, natural water	E910-E910.99	W65-W70.9, W73-W74.9
Fire	Uncontrolled fire, ignition of clothing, exposure to smoke	E890-E899.09, E924-E924.99, E929.4	X00-X06.9, X08-X19.9
Poisoning	Accidental poisoning by narcotics, alcohol, gases, pesticides, chemicals,	E850.3-E858.99, E862-E869.99, E929.2	J70.5, X40-X44.9, X47-X49.9, Y10-Y14.9, Y16-Y19.9, J70.5, X47-X47.9, X40-X44.9, X49-X49.9, Y10-Y14.9, Y16-Y19.9
Mechanical forces	Struck by object, contact with agricultural equipment, hand tools, lawn mower, explosion, fireworks unintentional firearm discharge	E913-E913.19, E916-E922.99, E928.1-E928.7	W20-W38.9, W40-W43.9, W45.0-W45.2, W46-W46.2, W49-W52, W75-W76.9
Animal contact	Snake bite	E905-E906.99	W52.0-W62.9, W64-W64.9, X20-X29.9
Foreign body	Foreign body entering through skin (nail or other object)	360.5-360.69, 374.86, 376.6, 709.4, 770.1-770.18, E911-E912.09, E913.8-E915.09	H02.81-H02.819, H44.6-H44.799, M60.2-M60.28, W44-W45, W45.3-W45.9, W78-W80.9, W83-W84.9
Enviro. heat and cold	Exposure to radiation, exposure to excessive man-made heat or cold	E900-E902.99, E926-E926.99, E929.5	L55-L55.9, L58-L58.9, W88-W94.9, W97.9, W99-W99.9, X30-X32.9, X39-X39.9
Forces of nature	Lightning, earthquake, avalanche	E907-E909.9	X33-X38.9
Other unintentional	Exposure to electric current	E903-E904.99, E913.2-E913.39, E923-E923.99, E927-E928.09, E928.8-E928.89	W39-W39.9, W77-W77.9, W81-W81.9, X50-X58.9
Intentional			
Self-harm	Intentional self-harm by firearm, poison	E950-E959	X60-X64.9, X66-X84.9, Y87.0
Interpersonal violence	Physical violence by fire arm, by sharp object, by other means	E960-E969	X85-Y08.9, Y87.1-Y87.2
Conflict and terrorism	Terrorism involving firearms, destruction of aircraft	E979-E979.9, E990-E999.1	U00-U03, Y36-Y38.9, Y89.1
Executions and police conflict	Legal execution, legal intervention such as gas, firearms, blunt objects	E970-E978	Y35-Y35.93, Y89.0

APPENDIX B

Global Burden of Disease categorization of countries by region

Location	Region
Afghanistan	North Africa and Middle East
Albania	Central Europe
Algeria	North Africa and Middle East
Andorra	Western Europe
Angola	Central Sub-Saharan Africa
Antigua and Barbuda	Caribbean
Argentina	Southern Latin America
Armenia	Central Asia
Australia	Australasia
Austria	Western Europe
Azerbaijan	Central Asia
Bahrain	North Africa and Middle East
Bangladesh	South Asia
Barbados	Caribbean
Belarus	Eastern Europe
Belgium	Western Europe
Belize	Caribbean
Benin	Western Sub-Saharan Africa
Bermuda	Caribbean
Bhutan	South Asia
Bolivia	Andean Latin America
Bosnia and Herzegovina	Central Europe
Botswana	Southern Sub-Saharan Africa
Brazil	Tropical Latin America
Brunei	High-income Asia Pacific
Bulgaria	Central Europe
Burkina Faso	Western Sub-Saharan Africa
Burundi	Eastern Sub-Saharan Africa
Cambodia	Southeast Asia
Cameroon	Western Sub-Saharan Africa
Canada	High-income North America
Cape Verde	Western Sub-Saharan Africa
Central African Republic	Central Sub-Saharan Africa
Chad	Western Sub-Saharan Africa
Chile	Southern Latin America
China	East Asia

Colombia	Central Latin America
Comoros	Eastern Sub-Saharan Africa
Congo	Central Sub-Saharan Africa
Costa Rica	Central Latin America
Cote d'Ivoire	Western Sub-Saharan Africa
Croatia	Central Europe
Cuba	Caribbean
Cyprus	Western Europe
Czech Republic	Central Europe
Democratic Republic of the Congo	Central Sub-Saharan Africa
Denmark	Western Europe
Djibouti	Eastern Sub-Saharan Africa
Dominica	Caribbean
Dominican Republic	Caribbean
East Midlands	Western Europe
East of England	Western Europe
Ecuador	Andean Latin America
Egypt	North Africa and Middle East
El Salvador	Central Latin America
England	Western Europe
Equatorial Guinea	Central Sub-Saharan Africa
Eritrea	Eastern Sub-Saharan Africa
Estonia	Eastern Europe
Ethiopia	Eastern Sub-Saharan Africa
Federated States of Micronesia	Oceania
Fiji	Oceania
Finland	Western Europe
France	Western Europe
Gabon	Central Sub-Saharan Africa
Georgia	Central Asia
Germany	Western Europe
Ghana	Western Sub-Saharan Africa
Greater London	Western Europe
Greece	Western Europe
Greenland	High-income North America
Grenada	Caribbean
Guatemala	Central Latin America
Guinea	Western Sub-Saharan Africa
Guinea-Bissau	Western Sub-Saharan Africa
Guyana	Caribbean
Haiti	Caribbean

Honduras	Central Latin America
Hungary	Central Europe
Iceland	Western Europe
India	South Asia
Indonesia	Southeast Asia
Iran	North Africa and Middle East
Iraq	North Africa and Middle East
Ireland	Western Europe
Israel	Western Europe
Italy	Western Europe
Jamaica	Caribbean
Japan	High-income Asia Pacific
Jordan	North Africa and Middle East
Kazakhstan	Central Asia
Kenya	Eastern Sub-Saharan Africa
Kiribati	Oceania
Kuwait	North Africa and Middle East
Kyrgyzstan	Central Asia
Laos	Southeast Asia
Latvia	Eastern Europe
Lebanon	North Africa and Middle East
Lesotho	Southern Sub-Saharan Africa
Liberia	Western Sub-Saharan Africa
Libya	North Africa and Middle East
Lithuania	Eastern Europe
Luxembourg	Western Europe
Macedonia	Central Europe
Madagascar	Eastern Sub-Saharan Africa
Malawi	Eastern Sub-Saharan Africa
Malaysia	Southeast Asia
Maldives	Southeast Asia
Mali	Western Sub-Saharan Africa
Malta	Western Europe
Marshall Islands	Oceania
Mauritania	Western Sub-Saharan Africa
Mauritius	Southeast Asia
Mexico	Central Latin America
Moldova	Eastern Europe
Mongolia	Central Asia

Montenegro	Central Europe
Morocco	North Africa and Middle East
Mozambique	Eastern Sub-Saharan Africa
Myanmar	Southeast Asia
Namibia	Southern Sub-Saharan Africa
Nepal	South Asia
Netherlands	Western Europe
New Zealand	Australasia
Nicaragua	Central Latin America
Niger	Western Sub-Saharan Africa
Nigeria	Western Sub-Saharan Africa
North East England	Western Europe
North Korea	East Asia
North West England	Western Europe
Northern Ireland	Western Europe
Norway	Western Europe
Oman	North Africa and Middle East
Pakistan	South Asia
Palestine	North Africa and Middle East
Panama	Central Latin America
Papua New Guinea	Oceania
Paraguay	Tropical Latin America
Peru	Andean Latin America
Philippines	Southeast Asia
Poland	Central Europe
Portugal	Western Europe
Puerto Rico	Caribbean
Qatar	North Africa and Middle East
Romania	Central Europe
Russia	Eastern Europe
Rwanda	Eastern Sub-Saharan Africa
Saint Lucia	Caribbean
Saint Vincent and the Grenadines	Caribbean
Samoa	Oceania
Sao Tome and Principe	Western Sub-Saharan Africa
Saudi Arabia	North Africa and Middle East
Scotland	Western Europe
Senegal	Western Sub-Saharan Africa
Serbia	Central Europe
Seychelles	Southeast Asia

Sierra Leone	Western Sub-Saharan Africa
Singapore	High-income Asia Pacific
Slovakia	Central Europe
Slovenia	Central Europe
Solomon Islands	Oceania
Somalia	Eastern Sub-Saharan Africa
South Africa	Southern Sub-Saharan Africa
South East England	Western Europe
South Korea	High-income Asia Pacific
South Sudan	Eastern Sub-Saharan Africa
South West England	Western Europe
Spain	Western Europe
Sri Lanka	Southeast Asia
Sudan	North Africa and Middle East
Suriname	Caribbean
Swaziland	Southern Sub-Saharan Africa
Sweden	Western Europe
Switzerland	Western Europe
Syria	North Africa and Middle East
Taiwan	East Asia
Tajikistan	Central Asia
Tanzania	Eastern Sub-Saharan Africa
Thailand	Southeast Asia
The Bahamas	Caribbean
The Gambia	Western Sub-Saharan Africa
Timor-Leste	Southeast Asia
Togo	Western Sub-Saharan Africa
Tonga	Oceania
Trinidad and Tobago	Caribbean
Tunisia	North Africa and Middle East
Turkey	North Africa and Middle East
Turkmenistan	Central Asia
Uganda	Eastern Sub-Saharan Africa
Ukraine	Eastern Europe
United Arab Emirates	North Africa and Middle East
United States	High-income North America
Uruguay	Southern Latin America
Uzbekistan	Central Asia
Vanuatu	Oceania
Venezuela	Central Latin America

Vietnam	Southeast Asia
Wales	Western Europe
West Midlands	Western Europe
Yemen	North Africa and Middle East
Yorkshire and the Humber	Western Europe
Zambia	Eastern Sub-Saharan Africa
Zimbabwe	Southern Sub-Saharan Africa

APPENDIX C

Systematic review evidence table

Author, year	Population description	Sample size	Response rate	Attrition	Sampling strategy	Study design	Teaching method
Boe et. al, 2019	recent P&O graduates and residency supervisors from one P&O university in the US	graduates (n=25), supervisors (n=16)	graduates (25/34=74%) supervisors (16/30=53%)	NA	entire population invited to participate	cross sectional survey	program review: assessment of graduate's competency
Ramstrand *et. al,* 2018	P&O experts, prosthetists/orthotists in clinical practice, sales, manufacturing and research, employers of prosthetists/orthotists, and PTs, OTs, engineers	two focus groups (n=6 and n=7) survey (n=41)	(1) focus group (not reported) (2) survey (35/45=78%)	survey: (20%) focus group: (29% and 33%)	purposive	mixed methods: modified Delphi, focus groups, surveys	curriculum: development of competency standards in Sweden
Aduayom-Ahego *et. al,* 2018	P&O students at 11 universities and colleges in Japan	students from 6 schools (n=136)	overall (136/1000=13.6%)	NA	entire population invited to participate	cross sectional survey	country review: P&O education in Japan
Fiedler *et. al,* 2017	P&O students at 1 US Master of Science program	travel students (n=7) non-travel students (n=12)	overall (19/32=59%)	NA	entire population invited to participate	cohort	pedagogy: study abroad
Hill *et. al,* 2017	P&O students and lecturers at two universities in	students (n=18) lecturers (n=8)	No attrition but unclear response rate.	NA	purposive (university B) convenience (university A) not reported (lecturer)	qualitative primarily interviews with some surveys	curriculum: threshold concepts in P&O
Aduayom-Ahego *et. al,* 2017	alumni and students from ENAM in Togo	students (n=19) alumni (n=12)	students (19/28=67.8%) alumni (12/30=40%)	NA	convenience	cross sectional survey	country review: P&O education in Togo
Miro et. al, 2017	US prosthetic candidates who completed their residency in 2011 or 2012	candidates (n=158)	NA	NA	NA	secondary data analysis (cohort)	curriculum: characteristics associated with board exam results
Magnusson *et. al,* 2016	P&O graduates from Tanzania Training Centre for Orthopaedic Technologists (TATCOT)	graduates (n=19)	overall (19/19=100%)	NA	purposive sampling based on sex and employment	qual. semi-structured interviews	country review: P&O education and clinical practice in Tanzania & Malawi
Aduayom-Ahego *et. al,* 2016	P&O technicians and students in Ghana	technicians (n=13) students (n=7)	techs (13/16=81.2%) students (7/11=63.6%)	NA	convenience	cross sectional survey	country review: P&O education in Ghana
Ash *et. al,* 2015	recent P&O graduates in Australia, members of the Australian Orthotic and Prosthetic Association (AOPA)	two focus groups: graduates (n=8) experts (n=10) survey: members of AOPA (n=56)	focus groups: not reported survey: (56/107=52%)	Delphi: (21%)	purposive	mixed methods: modified Delphi, focus groups, surveys	curriculum: development of competency standards in Australia
Al Qaroot *et. al,* 2014	4th year P&O students at University of Jordan	students (n=4)	overall 4/7 =57%	NA	randomized selection of half of the students	qual. structured interviews	pedagogy: research informed clinical practice (RICP)
Aminian *et. al,* 2014*	Bachelor P&O programs around the world, P&O experts	P&O programs for qual. (n=10), surveys from 14 programs (n=47) P&O experts for Delphi (n=14)	qual. review (10/26=38%) P&O programs for survey (14/21=67%) not reported for Delphi	not reported for Delphi	convenience	mixed methods: (1) review school documents, (2) survey, (3) Delphi rounds	curriculum: P&O teaching methods
Aminian *et. al,* 2011*	Bachelor P&O programs around the world, P&O experts	P&O programs qual. (n=10), surveys from 14 programs (n=47) P&O experts: Delphi (n=14)	qual. review (10/26=38%) P&O programs for survey (14/21=67%) not reported for Delphi	not reported for Delphi	convenience	mixed methods: (1) review school documents, (2) survey, (3) Delphi rounds	curriculum: P&O program objectives
Hussain, 2011	P&O students at the Pakistan Institute of Prosthetic & Orthotic Science (PIPOS)	students (n=48)	Not reported	NA	not reported	cross sectional survey	country review: P&O education in Pakistan
McFadyen et. al, 2010	1st year undergrads in 6 professions; nursing, OT, podiatry, P&O, PT, radiography at 1 US institution	cont. group (n=260) exp. group (n=313)	cont. 91% exp. 98%	cont. 75%, exp. 62%, not by discipline	entire population invited to participate	cohort	pedagogy: interprofessional education (IPE)
Magnusson *et. al,* 2009	Pakistan Institute of Prosthetic & Orthotic Science (PIPOS) graduates	graduates (n=15)	Not reported	NA	criterion	qual. semi-structured interviews	country review: P&O education in Pakistan
Kheng, 2008	P&O students from Cambodian School of Prosthetics and Orthotics (CSPO) seeking a Cat 1 upgrade through La Trobe University in Australia	students (n=9) other (n=2)	11/23 = 47.8% all students responded	NA	entire population invited to participate	cross sectional survey	pedagogy: distance education in P&O
Wong *et. al,* 2004	P&O Bachelors students at Hong Kong Polytech	students (n=12)	not reported	none	convenience	cohort	pedagogy: critical thinking development in P&O students
Wong *et. al,* 2007	e-learner P&O students, standard curriculum health sciences students and other university students at Hong Kong Polytech	P&O e-learners (n=20), health sciences (n=61), other students (n=1532)	not reported	NA	convenience	cohort	pedagogy: e-learning using a WebCT forum
Simpson *et. al,* 2002	professional personnel involved in rehabilitation who took an online continuing education course	rehab professionals (n=162)	overall (162/191=85%)	NA	not reported	cross sectional survey	pedagogy: open learning modules
Raschke *et. al,* 2002	clinicians, BCIT graduates, engineers, doctors, orthopedic surgeons in Canada	focus groups (between 5 and 26 participants) survey (n=82)	focus groups: not reported surveys (82/353=23%)	NA	focus groups: not reported, survey: entire population invited to participate	mixed methods: focus groups, surveys	curriculum: British Colombia Institute of Technology (BCIT) curriculum review

Author, year	Intervention	control	Outcomes measured	Method of measurement	Key findings	Key limitations	CASP /NIH	Study quality
Boe et. al, 2019	NA	NA	competency in prosthetics	researcher-developed survey of Likert-type scale based on the ABC practice analysis	Both graduates and supervisors rated graduate competence high. Graduates rated their ability to "assess patient's skin condition" and "assess device fit" highly in contrast to supervisor ratings. Feedback in these areas may need to be revised. Documentation was rated highly by supervisors indicating an area where recent graduates excel.	Likert-type ordinal data treated as ratio Small sample size Limited to one institution so hard to generalize	60%	mod
Ramstrand *et. al,* 2018	NA	NA	competency domains and items in Sweden	focus group, researcher-developed survey of 5-point Likert-type scale	Competency domains: Multidisciplinary practice, provision of clinical care, provision of services and devices, professional values and quality improvement and lifelong learning. Leadership, allocation of work tasks to others and coordination of manufacturing did NOT reach consensus. Importance of EBP emphasized. Similar to published competencies and scopes of practice in other countries but with some regional differences.	No mention of data saturation for focus groups Possible response bias	70%	mod
Aduayom-Ahego *et. al,* 2018	NA	NA	perceptions of Japanese P&O education	researcher-developed survey of 13 questions	61% male, 39% female. Mean age of 21. 37% freshman, 30% sophomore, 17% junior, 16% senior. 99.3% Japanese. 63.2% will work in P&O industry, 2.2% attend grad school. Biomechanics was most difficult (65.4%). Most student research was being conducted in LLO (33.8%), LLP (31.6%) and shoes (31.6%).	Possible response bias, low response rate, survey questions not provided, nature of data is unclear (open ended questions?). Translated survey with no reported psychometric properties. No description of verification of translation or cultural adaptation.	36%	Low
Fiedler *et. al,* 2017	study abroad experience in Germany	no study abroad	self-efficacy	researcher-developed survey of professional tasks/scenarios, confidence (0-10)	Increased self-efficacy in dealing with challenging professional situations. Only beneficial for some situations, not all. No long term effects.	Small sample size, possible response bias, no random assignment, all from one program so may not represent all P&O students. Unclear how open-ended survey data was analyzed. Incorrectly refers to survey data as qualitative. Unknown psychometric properties of the survey questions.	73%	Mod
Hill *et. al,* 2017	NA	NA	threshold concepts in prosthetics	semi-structured interviews research-developed survey	Threshold concepts involve both conceptual and ontological transformations. The experience of becoming a prosthetist orthotist. Disciplinary language (vocabulary, concepts and transformation into a prosthetist). Componentry knowledge and putting the user at the center of prosthetic management. Becoming a prosthetist involves a change in identity as well as a change in knowledge. Educators can explore tacit knowledge and connections between basic, procedural and disciplinary concepts and progress.	No mention of data saturation, purposive sampling only for one sample, no demographic information of participants to allow reader to assess transferability of results, some participant data was collected through survey rather than interview but no separate analysis or results presented.	75%	Mod
Aduayom-Ahego *et. al,* 2017	NA	NA	description and perceptions of P&O in Togo	online researcher-developed survey of open and closed-ended questions	Low level of training for P&Os in Togo. Limited participation in professional society. Additional training in biomechanics and relevant biomechanical instruction equipment and materials is necessary.	Very limited description of data analysis and no description of analysis for open ended questions. Survey questions not provided. Possible response bias. Translated survey with no reported psychometric properties. No description of verification of translation or cultural adaptation.	45%	Low
Miro et. al, 2017	NA	NA	association between characteristics & ABC exam outcome	linear regression to examine association	Pass rates are similar among various institutions. Extending credentials is the only characteristic statistically significant associated with exam outcome. Sex and type of institution were not associated with exam outcome.	Limited to data previously collected, many important variables not collected, time between exposure and outcome is unknown. Mentions prediction when study design can only identify association.	70%	mod
Magnusson *et. al,* 2016	NA	NA	perceptions of TATCOT education and clinical practice	in-person interviews, demographics	Students need information about P&O prior to school. Teaching methodology and inequality in treatment of students needs to be addressed. Increase time regarding clinical management of different groups (less technical drawing, metalwork, woodwork). More resources for those serving the rural and underserved. Need for continuing ed. and in-service training in specific topics.	Conducted in English language (not first language of participants or interviewers), limited description of analysis, no discussion of data saturation, multiple interviewers may result in inconsistencies, no description of prior relationship between researchers and participants.	75%	Mod
Aduayom-Ahego *et. al,* 2016	NA	NA	perceptions of P&O education in Ghana	paper researcher-developed survey	Need to train more professionals and provide continuing education. Students need education materials and biomechanics books. More research for advanced technology. Lack of: funding, infrastructure and facilities, machines, professionals, patient awareness, training, professionals in education, teaching materials, access to prosthetic books and journals	No description of data analysis, especially open-ended questions. Possible response bias. No reported psychometric properties of survey. No description of verification of cultural adaptation in Ghana.	36%	Low
Ash *et. al,* 2015	NA	NA	competency standards and performance measures in Australia	focus group, researcher-developed survey of 5-point Likert-type scale	Current gaps in current competency standards; evidence-based and ethical practice with a client focus, need for continuing professional development and mentoring, scope of practice. 6 domains, 18 activities, and 68 performance criteria were agreed upon.	No discussion of saturation of data for focus groups. No discussion of prior relationship between researcher and focus group participants. Possible response bias for the survey. Small sample size and high attrition rate.	65%	Mod
Al Qaroot *et. al*, 2014	NA	NA	perceptions of RICP	structured interviews; no interruptions, no follow-up questions	All participants were positive about RICP. Allowed students to work with numerous patients. Self-learning and evidence based practice were employed by students. Students reported increased confidence. Induction week and supervision were said to be helpful. Conflicting feedback from supervisors was a challenge. Students sought additional feedback if one supervisor provided insufficient feedback. Students developed critical appraisal skills. Students were more enthusiastic about conducting research after RICP.	Sampling strategy is not justified. Small sample size. No discussion of saturation. No rational for interview methodology over other qualitative approaches. No demographic information of participants to allow reader to assess transferability of results. No discussion of prior relationship between researcher and participants. Researcher participation in data analysis is unclear.	50%	Low

Author, year	Intervention	control	Outcomes measured	Method of measurement	Key findings	Key limitations	CASP /NIH	Study quality
Aminian *et. al,* 2014*	NA	NA	teaching methods in curriculum documents	(1) survey of P&O programs (2) 6 point Likert-type scale survey P&O curriculum (3) Delphi method for consensus	Developing countries focus on teacher responsibility for student learning. Clinical learning is focused on skill development. More optimistic about online uses. Focus on quality of devices. Separate O&P. Developed countries focus on student responsibility. Clinical learning is for developing critical thinking. Focus on clinical reasoning. Teach P&O together. Small group emphasis. Less PBL than expected all around.	Inclusion/exclusion criteria not defined, attrition rate not mentioned. Delphi method items not described in sufficient detail to understand the objectives in question. Possible response bias. Very few details about participating institutions. No methodology described for qualitative review of documents. Survey questions not provided. Delphi round description is unclear. No justification for number of Delphi rounds. No response rate reported for surveys. Limited sample size.	22%	Low
Aminian *et. al,* 2011*	NA	NA	objectives in P&O curriculum	(1) review of P&O program objectives (2) 6 point Likert-type survey (3) Delphi method for consensus	Disagreement about effectiveness of various teaching approaches. Variation in objectives depending on region.	Inclusion/exclusion criteria not provided Possible response bias among participating institutions. Very few details about participating institutions. Limited sample size.	28%	Low
Hussain, 2011	NA	NA	perceptions of education in Pakistan	paper researcher-developed survey	Favoritism among teachers was noted as the biggest challenge at PIPOS. Use of teacher authority was also deemed fair. Teaching methodology was noted as a concern among students. Comfort of class chairs was the most concerning aspect of classroom facilities.	Inclusion/exclusion criteria not provided, response rate not reported. Possible response bias, limited demographic data provided. Survey questions not provided. No discussion on rationale for sample size. No rationale for methodology. Researcher developed survey without psychometric properties. No analysis described for open ended questions. Inappropriate conclusions drawn from collected data.	27%	Low
McFadyen et. al, 2010	an interprofessional education module	standard curriculum	readiness for interprofessional learning	2 modified surveys with 7 subscales;	Timing of clinical placements may influence interprofessional education. Most students enter school with idealistic readiness for interprofessional learning. IPE may provide a more realistic understanding of interprofessional care. Knowledge of roles and responsibilities improves over time regardless of IPE. Perceived need for cooperation was initially negatively affected but became more positive over time with IPE.	Response rate by profession not reported (unknown sample size by profession, unknown attrition rate by profession).	75%	Mod
Magnusson *et. al*, 2009	NA	NA	P&O education entering the workforce professional development	semi-structured interviews	Need teacher training. Curriculum review. Access to internet/resources. Gender inequality. Move internship toward residency type programs.	No discussion of pre-understanding by researchers of context. Researchers are not from Pakistan. No discussion of data saturation. No discussion on rationale for sample size. No rationale for methodology. No interview guide was provided. No discussion of contradictory data. Limited actions to improve credibility of findings (no triangulation or respondent validation). No demographic information of participants to allow reader to assess transferability of results.	75%	Mod
Kheng, 2008	upgrade to a B.S. through La Trobe University	NA	strengths weaknesses opportunities threats	researcher-developed survey with open-ended questions	Key limitations of distance programs include reduced face to face interaction, concerns over technology and logistics, and an increased student workload. Substantial resources and support are required to ensure success.	Data analysis unclear. No description of how data was analyzed. Presents qualitative results but no supportive data. Survey development not described. No quantitative analysis of responses. No participant description/demographics. Collected data from students and lecturers but results are not presented for the two groups.	36%	Low
Wong *et. al*, 2004	NA	NA	critical thinking	California Critical Thinking Disposition Inventory (CCTDI)	Perception of critical thinking did increase in positivity over P&O curriculum but more can be done.	Small sample size. No discussion of recruitment, population size or attrition rates. No participant demographics or examination of individual analysis despite small sample. Group analysis may washout individual change over time. No discussion of potential confounders.	58%	Mod
Wong *et. al*, 2007	one semester of e-learning in prosthetics	2 controls: 1. Health science majors 2. Other university students	career relevance learning outcomes critical thinking creative thinking lifelong learning communication skills interpersonal skills problem solving adaptability workload	researcher-developed survey: 5 point Likert-type scale	Not significant, P&O students rated all measures except interpersonal and communication, higher than students in regular curriculum. Overall equivalent results to regular curriculum and university as a whole.	Inappropriate control groups with many confounders. No examples of ad hoc questions provided. Not replicable. No response rate provided. No description of data or statistical analysis. P values provided but no description of statistical analysis conducted. Outcome measure has no evidence of reliability or validity. No demographics provided for participants or participant groups.	46%	Low
Simpson *et. al,* 2002	open learning (e-modules)	NA	completion rates, int. interest	survey as part of a course	International interest in the online courses was unexpected. Participants had positive feedback on the course.	Simply reporting enrollment and completion rates. No true methodology so conclusions are limited. No reporting of recruitment method so population from which sampling occurred is unknown.	45%	low
Raschke *et. al,* 2002	NA	NA	current educational needs in Canada P&O	focus groups, researcher-developed survey	Most graduates work in a business environment but receive little to no business and marketing training in school. The orthotic market is large compared to the number of orthotists available. New technology is being developed and assessed by people outside of P&O.	Very limited description of methods, no data analysis description, not replicable.	44%	Low

APPENDIX D

Information exchange survey

Faculty survey

Please complete the survey below.

Thank you!

Think about your experience teaching prosthetics and orthotics (P&O) students. When teaching P&O students, how often during a 2 week period did you use the following sources to obtain information related to prosthetics and orthotics to prepare for teaching?

	never	1 time	2 times	3 times	4 times	5 or more
textbooks	○	○	○	○	○	○
fellow P&O faculty	○	○	○	○	○	○
other faculty	○	○	○	○	○	○
prosthetist orthotists that are not faculty	○	○	○	○	○	○
listservs	○	○	○	○	○	○
digital communities	○	○	○	○	○	○
peer reviewed journals	○	○	○	○	○	○
Youtube	○	○	○	○	○	○
Wikipedia	○	○	○	○	○	○
Google	○	○	○	○	○	○
other websites not listed	○	○	○	○	○	○
other source of information not listed	○	○	○	○	○	○

What type of textbooks do you access?

- ☐ physical, hard copies
- ☐ copied pages from textbooks
- ☐ digital, soft copies
- ☐ online access to digital texts
- ☐ other

((mark all that apply))

Please describe other types of textbooks you use.

____

Please name the listserv(s) you use.

____

Please name the digital community or communities you use.

____

Please name the peer reviewed journal(s) you use.

____

Please name the other websites you use.	________________
Please describe other sources of P&O information you use.	________________
What resources for P&O information do you wish you had more or better access to? Please describe.	________________

The following questions will ask you about the people you share P&O related information with other than your students. To answer these questions, think about the past month. Please do NOT list your students, rather consider colleagues, faculty, mentors, friends etc. You will be asked specifically about some of your colleagues. You will also have the opportunity to list up to 15 additional people. You can stop adding people at any point. When you are done adding people, please submit the survey.

During the past month, how often did you GIVE P&O related information to....

	never, this is me	never	occasionally but less than once a month	once or twice a month	once or twice a week	about once a day	2 or 3 times a day	4 or more times a day
Participant 0	○	○	○	○	○	○	○	○
Participant 1	○	○	○	○	○	○	○	○
Participant 2	○	○	○	○	○	○	○	○
Participant 3	○	○	○	○	○	○	○	○
Participant 4	○	○	○	○	○	○	○	○
Participant 5	○	○	○	○	○	○	○	○
Participant 6	○	○	○	○	○	○	○	○

During the past month, how often did you GIVE P&O related information to....

	never, this is me	never	occasionally but less than once a month	once or twice a month	once or twice a week	about once a day	2 or 3 times a day	4 or more times a day
Participant 7	○	○	○	○	○	○	○	○
Participant 8	○	○	○	○	○	○	○	○
Participant 9	○	○	○	○	○	○	○	○
Participant 10	○	○	○	○	○	○	○	○
Participant 11	○	○	○	○	○	○	○	○
Participant 12	○	○	○	○	○	○	○	○

Participant 13	○	○	○	○	○	○	○	○

During the past month, how often did you RECEIVE P&O information from...

	never, this is me	never	occasionally but less than once a month	once or twice a month	once or twice a week	about once a day	2 or 3 times a day	4 or more times a day
Participant 0	○	○	○	○	○	○	○	○
Participant 1	○	○	○	○	○	○	○	○
Participant 2	○	○	○	○	○	○	○	○
Participant 3	○	○	○	○	○	○	○	○
Participant 4	○	○	○	○	○	○	○	○
Participant 5	○	○	○	○	○	○	○	○
Participant 6	○	○	○	○	○	○	○	○

During the past month, how often did you RECEIVE P&O related information from....

	never, this is me	never	occasionally but less than once a month	once or twice a month	once or twice a week	about once a day	2 or 3 times a day	4 or more times a day
Participant 7	○	○	○	○	○	○	○	○
Participant 8	○	○	○	○	○	○	○	○
Participant 9	○	○	○	○	○	○	○	○
Participant 10	○	○	○	○	○	○	○	○
Participant 11	○	○	○	○	○	○	○	○
Participant 12	○	○	○	○	○	○	○	○
Participant 13	○	○	○	○	○	○	○	○

Please name an additional person with whom you share P&O related information.

____
(If you are done listing people, leave blank and submit the survey.)

What is your relationship with [name_f_w1]?

- ☐ fellow P&O faculty
- ☐ other non-P&O faculty
- ☐ non-faculty P&O
- ☐ non-faculty therapist
- ☐ graduate student
- ☐ mentor
- ☐ family
- ☐ friend
- ☐ other

((mark all that apply))

Please describe your relationship with [name_f_w1].

____

During the past month...

	never	occasionally but less than once a month	once or twice a month	once or twice a week	about once a day	2 or 3 times a day	4 or more times a day
how often did you GIVE P&O related information to [name_f_w1] ?	○	○	○	○	○	○	○
how often did you RECEIVE P&O related information from [name_f_w1]?	○	○	○	○	○	○	○

This item was repeated up to 15 times to allow participants to name 15 people in addition to their faculty peers with whom they share P&O related information.

VITA

Cody McDonald is a certified and licensed prosthetist/orthotist and doctoral candidate in Rehabilitation Science at the University of Washington. She graduated from the University of Washington prosthetics and orthotics program in 2006, completed both residencies at the University of California San Francisco and continued to work at UCSF in clinical practice until 2011. She then spent a year as an orthotist mentor at the Cooperative Orthotic and Prosthetic Enterprise (COPE) in Vientiane, Laos PDR. She returned to Seattle, Washington in 2013 to pursue her doctorate. She continued to work in international prosthetics and orthotics and received an MPH in Global Health at the University of Washington in 2017. While completing her dissertation, Ms. McDonald served on the US ISPO executive board and conducted research and taught P&O and PhD in Rehabilitation students at the University of Washington.