# Global incidence of major, non-fatal amputation due to traumatic causes

Cody Leah McDonald

A thesis

submitted in partial fulfillment

of the requirements for the degree of

Master of Public Health

University of Washington

2017

Committee:

Marcia Weaver

Juanita Haagsma

Sarah Westcott McCoy

Program Authorized to Offer Degree:

Global Health

University of Washington

## Abstract

Global incidence of major, non-fatal
amputation due to traumatic causes

Cody Leah McDonald

Chair of the Supervisory Committee:
Marcia Weaver
Department of Global Health

**Objective:** This article reports and interprets estimates of global incidence of major limb amputation due to traumatic causes.
**Design:** A secondary database descriptive study to report amputation incidence and incidence rate per 100,000 using the extensive 2015 Global Burden of Disease (GBD) results was conducted.
**Results:** In 2015, 1.2 million people sustained major limb amputations due to traumatic causes worldwide. Leading traumatic causes of limb amputation were war and legal intervention (27.1%), other unintentional injuries (18.4%), falls (13.3%), mechanical forces (10.5%) and road injuries (8.1%). The highest incidence is seen in Middle East and North Africa (370,800 UI 261,745 to 479,854) due to high incidence rate followed by South Asia (273,949 UI 249,694 to 298,203) and East Asia (144,268 UI 132,996 to 155,540) due to population size.
**Discussion:** GBD describes etiologies requiring rehabilitation, and regional need for prosthetic services such as upper limb prostheses, pediatrics and surgical considerations.
**Conclusions:** Amputation incidence estimates and patterns are essential to understand global prosthetic service needs. Estimates provide foundational information to assess change over time and to plan future prosthetic service development.

Global incidence of major non-fatal
amputation due to traumatic causes

Cody L. McDonald, CPO, PhC[1, 2] Juanita Haagsma,[3] PhD, Sarah Westcott-McCoy, PT, PhD[1],
Marcia Weaver, PhD[2]

[1]University of Washington, Department of Rehabilitation Medicine
[2]University of Washington, Department of Global Health
[3]Erasmus MC University Medical Centre, Department of Public Health, Rotterdam, The Netherlands
Corresponding author: Cody McDonald, 1959 Pacific St NE, Box 356490, Seattle, WA 98195
206-221-6347, codym@uw.edu

**Key Words:** amputation, incidence, Global Burden of Disease, trauma

**List of abbreviations**

ED-emergency department
GBD-Global burden of disease
ISPO-International Society of Prosthetics and Orthotics
LL-lower limb
LMICs-low and middle income countries
P&O-prosthetist orthotist
TF-transfemoral
TH-transhumeral
TR-transradial
TT-transtibial
UI-uncertainty interval
UL-upper limb
ULA-upper limb absence
ULP-upper limb prosthesis
WHO-World Health Organization

## Introduction

Amputation of a limb is a disabling condition that impacts the lives of people around the world. Trauma is a leading cause of major limb amputation, second only to diabetic and dysvascular complications.[1] Regardless of the underlying etiology, amputation results in the absence of biological structures and negatively impacts a person's function, mobility, vocation, and avocation. The need for rehabilitation after amputation to mitigate disability is well accepted, but has largely been neglected in global health initiatives.

After an amputation, prostheses are prescribed to replace the absent physical structures, restore function, and promote activity and participation in the community.[2,3] Prosthetic rehabilitation includes complex procedures of evaluation, treatment plan development, device design and fabrication, fitting, alignment, gait training and follow-up.[3] People with limb absence need life long prosthetic care that requires trained prosthetists and therapists, specialized equipment and materials, and a coordinated healthcare system.[2]

The development of prosthetic services in low and middle-income countries is an important step toward restoration of function and mobility for millions of people with amputations worldwide. Current literature reflects a strong focus on specific prosthetic componentry development and evaluation such as that of feet,[4–15] knees, sockets[5,16–19] and structure[5,17]. Underrepresented in current literature is the need for human resources[20,21], service delivery[22,23] and education[24–31] of prosthetists.

Specifically, rehabilitation human resources are not well reported.[20] Limited information exists about the current prosthetist orthotist (P&O) workforce in comparison to the present need. The World Health Organization (WHO) estimated that approximately 40,000 P&Os would be needed worldwide in 2010.[32] A more accurate understanding of regional traumatic amputation incidence by age and cause would enable governments and collaborating non-governmental organizations to both implement preventative efforts to reduce incidence of amputation and develop national plans and resource requirements to implement sustainable country wide prosthetic services.

National incidence and prevalence of limb amputation is increasingly reported in the scientific literature. A number of countries have started registries and published both current incidence of amputation and change over time. [33–36] However, a recent review of the literature on lower limb amputation highlights the paucity of empirical evidence from low and middle income countries (LMICs).[37] WHO estimated that people in need of prosthetic and orthotic services represent 0.5% of the population in LMICs, approximately 30 million people in 2010. This estimate has not been verified at the country or regional levels.[32] The Global Burden of Disease (GBD) studies are a rich resource to provide worldwide amputation incidence estimates and inform global prosthetic needs and development efforts.[38]

In this study we inform future research and global development efforts for the provision of prostheses in low and middle income countries by quantifying, analyzing, and interpreting patterns in global distribution and incidence of major traumatic limb amputation by cause, region, and age in 2015 using GBD 2015 results.

Within the GBD, the International Classification of Diseases (ICD) was used to classify injuries as a standard diagnostic tool. Major limb amputation was divided into four categories (bilateral lower limb, bilateral upper limb, unilateral lower limb, and unilateral upper limb) with associated ICD 9 and ICD 10 codes (Table 1).[40] Amputation of fingers, thumbs and toes were excluded from this study. Amputation is a nature-of-injury (N code) category with associated cause-of-injury (E code) categories. This is the first manuscript to report results by N codes with a focus on major limb amputation.

**Methods**

The GBD 2015 study produced estimates of both incidence and incident rate of traumatic amputation using country data on ICD codes, then categorized into 26 mutually exclusive and exhaustive external E code such as motor vehicle road injury or assault by sharp object.[40] Each E code was then further categorized into N codes. Many countries report injuries by either E codes or N codes. A few countries report injuries by both codes, which was the basis for creating an E and N matrix to estimate the global incidence of injuries by both E and N code. The matrix estimates the proportion of each E code category that results in a particular N code category.[40] This matrix was developed based on dual code inpatient and emergency room data sets from 27 countries: Argentina, China, Colombia, Cyprus, the Czech Republic, Denmark, Egypt, Estonia, Hungary, Iceland, Iran, Italy, Latvia, Macedonia, Malta, Mauritius, Mexico, Mozambique, the Netherlands, Norway, Portugal, Slovenia, Spain, Sweden, Uganda, USA, and Zambia. Due to the limited sample of countries on which the matrix is based, greater confidence can be placed in regional summary estimates rather than detailed national estimates. Estimates in this paper are reported for 21 world regions (Appendix 1).[40]

GBD estimates of non-fatal injuries such as amputation are complex and require consideration of both short and long-term disability. First, cause of injury incidence by age, sex, location, and year was estimated with DisMod-MR 2.0 (a descriptive epidemiological meta-regression tool that uses an integrative systems modelling approach to produce simultaneous estimates of incidence, prevalence, remission and mortality) using injury incidence data from hospital and emergency department (ED) records and survey data.[40] Second, a hierarchy was applied to identify the nature-of-injury code that contributes the largest burden when a person has multiple injuries. Third, we used the E and N matrix to estimate the proportions of incident cases in each of the 26 cause-of-injury codes that lead to each of the 47 nature-on-injury codes including the four major amputation codes. To make these estimations, two different matrices were created using hospital and ED data. The cause-nature-of-injury matrix for inpatient injuries was used to estimate limb amputations. The inpatient matrix was applied to the cause-of-injury data, producing incidence of inpatient injuries by cause and nature of injury.[40]

Uncertainty

Incidence is estimated with uncertainty. Uncertainty in estimates results from available data, data adjustments and statistical models. We applied the standard GBD method of creating 1,000 draw for each age-sex-region estimate by drawing from distributions. We report the mean of the 1,000 draws and uncertainty intervals rather than point estimates.[40]

## Results

In 2015, we estimated that 1.2 million (uncertainty interval (UI) 1 to 1.35) people sustained major limb amputation due to traumatic causes. Of major limb amputations due to trauma, the majority were unilateral lower limb (84.7%), followed by bilateral upper limb (7.5%), unilateral upper limb (7.2%) and bilateral lower limb (0.6%) (Figure 1). Major traumatic causes of amputation were war (27.1%), other unintentional injuries (18.4%), falls (13.3%), mechanical forces (10.5%) and road injuries (8.1%) (Figure 2). The most common cause of amputation varied by level of amputation, for example, upper limb amputations were more likely to be caused by mechanical forces or other unintentional injuries. Unilateral lower limb amputations were more likely to be due to war and bilateral lower limb amputations were largely related to transportation.

GBD estimates provide insight into regional trends of traumatic limb amputation. Figure 3 presents regional incidence and rates of traumatic limb amputation to allow a global perspective. Middle East and North Africa experiences both high incidence (370,800 UI 261,745 to 479,854) and rate per 100,000 population (65.5 UI 47.1 to 84) of traumatic amputation. Incidence of amputation is similarly high in South Asia (273,949 UI 249,694 to 298,203) and East Asia (144,268 UI 132,996 to 155,540), however, lower rates per 100,000 suggest the high incidence stems from large populations rather than high rates. Five regions stand out with consistently low incidence and rates per 100,000 population; High-Income North America, Southern Latin America, Western Europe, Australasia and High-Income Asia Pacific.

In children, aged 0-14 years, the highest incidence is in North Africa and the Middle East. In adults, 15-49 years, North Africa and the Middle East still have the highest incidence. However, South Asia and East Asia also emerge with high incidence among adults. For those over 50 years of age, incidence in South Asia is the highest followed by East Asia (Figure 4). For most regions, incidence rate increases with age, and is highest in the 80+ age group (Figure 5). North Africa and Middle East incidence rates among children and young adults are dramatically higher than any other region, however, incidence rates among those 50+ years are comparable with regions of LMICs.

In general, upper limb amputations account for a small percentage of all limb amputations. South Asia has the largest incidence of upper limb (i.e. unilateral and bilateral) traumatic amputation (49,690 UI 45,442 to 53,938), followed closely North Africa and Middle East (35533 UI 25,050 to 46,106). East Asia has the third highest incidence of upper limb amputation (22,876 UI 21,099 to 24,653).

In children, aged 0-14 years, rates of traumatic amputation range from a low of 0.204 per 100,000 population (UI 0.187 to 0.221) in High Income Asia Pacific to a high of 86 per 100,000 population (UI 61 to 111) in North Africa and Middle East. The next highest rate is 29 per 100,000 population (UI 26 to 32) in Western Sub-Saharan Africa. The dramatic rate of traumatic amputation in children in North Africa and Middle East is largely attributable to war (72.5 per 100,000 are due to war).

In adults aged 15 to 49 years, rates by region have a similar distribution but with less variability. Rates range from a low of 0.31 per 100,000 population (UI 0.29 to 0.34) in High Income Asia Pacific to 65 per 100,000 population (UI 43 to 88) in North Africa and Middle East. Eastern Europe has the next highest rate at 28 per 100,000 population (UI 25 to 31), followed closely by Western Sub-Saharan Africa at 25 per 100,000 population (UI 19 to 31). Traumatic amputation incidence is highest among this age group with incidence ranging from 51 (UI 47 to 55) in Australasia to 198375 (UI 130,366 to 266,384) in North Africa and Middle East.

Amputation rates among adults ages 50-79 years follow similar patterns but the difference between regions are less pronounced. The lowest rates are seen in Australasia at 0.21 per

100,000 population (UI 0.196 to 0.228) and the highest are in Western Sub-Saharan Africa at 25 per 100,000 population (UI 22 to 28). Incidence in this population ranges from 17 (UI 16.1 to 18.7) in Australasia to 50,809 (UI 46,581 to 55,036) in South Asia.

Among the elderly, 80+ years age, rates of traumatic amputation are similar to those of younger adults. The lowest rate is seen in Australasia at 0.47 per 100,000 population (UI 0.404 to 0.597) and a high in Western Sub-Saharan Africa of 68 per 100,000 population (UI 60 to 76.5). Traumatic amputation incidence among the elderly range from 5 (UI 4.6 to 6.03) in Australasia to a high of 8,630 (UI 7,851 to 9,409) in South Asia followed by 4,528 (UI 4,114 to 4,941) in East Asia.

**Discussion**

The GBD 2015 study provides estimates of incidence, prevalence and burden of disease for 310 diseases and injuries.[39] Many of these diseases and injuries result in physical and developmental disabilities that would benefit from rehabilitation services (e.g., physical therapy, occupational therapy, speech and language therapy). Global estimates and comparisons of disease and injury patterns by region, age, cause and gender can provide valuable information to guide global prevention and rehabilitation development efforts. Estimates of incidence and prevalence can inform estimates of human resource and training needs, national rehabilitation plans, and preventive public health interventions. This study provides one example of how GBD 2015 incidence and rate results can be leveraged to provide a global picture of traumatic amputation and explore implications for prosthetic care and development. We will discuss prevention and rehabilitation implications of GBD 2015 traumatic amputation estimates.

**Prevention**

Traumatic causes contribute to worldwide prevalence of amputation and associated disability. While traumatic injuries are often multifactorial, incidence by cause provides insight into the most common injury mechanisms that result in amputation and may be modifiable through prevention efforts.

GBD 2015 estimates show war and legal intervention to be the leading cause of major traumatic limb amputation globally. Primary prevention strategies for war related amputations include advocating for the use of more discriminate weapons, coordinated efforts to separate active combat from civilians, and the declaration of humanitarian ceasefires to allow civilian evacuations.[41] Secondary prevention strategies include methods to prevent infection of injuries[42], access to healthcare for timely treatment and trained healthcare workers[43]. In addition to active conflicts, the legacy of war and civilian casualties, such as those resulting from landmines[44–46] or unexploded ordinance[44] can be prevented through enforcement of international conventions prohibiting the use of land mines, mine clearing efforts, and awareness and education campaigns.[17]

Falls cause thirteen percent of traumatic amputation with most falls resulting in unilateral lower limb amputation. Primary prevention for falls includes implementation of fall prevention programs.[47] Secondary prevention may focus on healthcare access to treat fall related injuries and prevention of infection, non-union fractures or painful deformities that may lead to subsequent amputation.

Road traffic injury results in eight percent of all traumatic amputations. Injury prevention strategies for road traffic accidents are well established as road traffic injuries have gained increasing awareness in low and middle income countries.[48] A recent systematic review found legislation with strong enforcement initiatives to be the most successful.[49] However, success rates of traffic injury prevention strategies vary regionally and require continued implementation.

**Rehabilitation**

Prosthetic care, like management of any chronic condition, is multifaceted and differs between people with limb loss. We will address two key aspects of prosthetic care to provide interpretation and implications of GBD traumatic amputation incidence estimates. These two categories are human resources and education.

**Human Resources**

Prevalence of non-fatal major limb traumatic and diabetic amputations has been reported in the GBD 2015 seminal article.[39] Prevalence estimates provide the most accurate estimate of prosthetic need worldwide. GBD 2015 study results estimate 30,146,000 people living with traumatic limb amputation globally.[39] GBD 2015 results for diabetes related lower limb amputation 7,310,200 (UI 6,260,400 to 11,703,500) people living with diabetic limb amputation. Combined, 37,456,200 people worldwide are estimated to be living with limb absence due to trauma or diabetes. This estimate is not all inclusive but accounts for the two most common causes of limb amputation. However, even as an underestimate, this number exceeds the most frequently cited estimates, such as the WHO estimate of 30 million people in need of orthotic or prosthetic services.[32]

GBD amputation estimates can serve to inform regional human resource needs. With our estimate of 37.5 million persons living with limb absence worldwide, we can use WHO guidelines to estimate worldwide prosthetist need.[32] WHO guidelines state that a trained prosthetist can on average treat 250 people a year and one third of people with limb absence seek treatment in a given year.[32] Using these guidelines, we estimate that 150,000 prosthetists are needed worldwide to treat people with limb absence. This estimate excludes a number of etiologies for limb absence (e.g., infection, cancer, congenital) and does not address the need for orthotists who care for people with a variety of musculoskeletal and gait abnormalities (i.e., cerebral palsy, spina bifida, stroke, polio). As such, 50,000 prosthetists is a conservative estimate but far exceeds WHO's estimate of 40,000 prosthetist orthotists and speaks to a substantial unmet need.

**Prosthetist education**

Prosthetic education includes foundational skills and knowledge in addition to specific content related to amputation levels, etiologies and patient populations. It has been suggested that due to technology, material and societal constraints, clinicians in low and middle income countries require more training and technical skill than clinicians practicing in high income countries.[50] For example, local manufacturing of prosthetic components is a skill not required in high income countries that has been identified as essential to sustainable prosthetic care in low and middle income countries.[50,51] Through an accurate understanding of a region's population of people with limb absence, prosthetist education and training can better align with the services most required and most often utilized in clinical practice. Two examples of specific patient populations that vary by region and require special consideration in planning prosthetic services and education of prosthetists are discussed below.

**Upper limb**

Regions with higher incidence of upper limb absence (ULA) present a clear need for specialized upper limb componentry such as hands, hooks, elbows, cables, etc.[2] Such componentry can be expensive, challenging to acquire and often must be imported into LMICs. Additionally, provision of functional upper limb prostheses (ULPs) (i.e., those that provide active control of a prosthetic terminal device) requires very specific technical and clinical skills. In an effort to improve access to functional ULPs in low resource settings, numerous engineering solutions to provide low cost, low tech prostheses to people with ULA have been developed and published in the literature.[52–55] Evidence of functional outcomes and the uptake rate of such devices is limited and people with ULA still lack access to functional ULPs in many regions of the world. It has been noted that technological developments may aid access to devices but must also be accompanied by appropriate training and education of providers.[51]

Due to the relatively small population of people with ULA, most prosthetists may only rarely fabricate and fit ULPs. This is reflected in the WHO and ISPO education standards for Category II prosthetic technicians, the most common level of training in many LMICs, with ULP curriculum an optional component of required curriculum.[32] WHO and ISPO recommend that ULP curriculum be taught based on regional and population needs.[32] Our study provides clear evidence for need in many regions of the world, but most specifically South Asia (49,690 ULA), North Africa and Middle East (35,533 ULA), Western Sub-Saharan Africa (36,369 ULA) and

East Asia (22,876 ULA). These four regions are also those with the highest incidence of all major limb amputation, highlighting both a specific need for ULP componentry and education and a general need for well-trained prosthetists and prosthetic services.

**Pediatric**

Prosthetic care for children requires unique considerations beyond those of adult prosthetic care.[2] Children require more frequent prosthetic care for adjustments and replacement due to growth, body changes and high activity levels.[2] Children with limb absence who do not receive appropriate prosthetic care experience limited mobility and function. Such disability can lead to exclusion from education[56,57] and discrimination by the community.[58] Disability and lack of education are closely tied with poor health outcomes and poverty.[59,60]

Regions where children and young adults are more likely to suffer traumatic amputation will also have higher prosthetic service demand as children with limb loss require a lifetime of prosthetic care. For example, a ten-year old child with a lower limb amputation is likely to require 25 prosthesis over the course of his/her life.[61] Our study identifies four regions with the highest incidence of pediatric traumatic amputation; North Africa and Middle East (151,329), South Asia (77,769), Western Sub-Saharan Africa (50,273) and Eastern Sub-Saharan Africa (33,180). These regions require special consideration for pediatric prosthetic care and life long prosthetic care as these children age.

Pediatric prosthetic care requires prosthetists trained in pediatric development, common pediatric complications and specialized pediatric componentry. Clinicians in high income countries who treat children often specialize in pediatric prosthetics. Specialized courses, professional communities[62] and continuing education[63] provide education beyond standard prosthetic curriculum. These resources are rarely available in LMICs but are well suited to capacity building and knowledge transfer efforts.

In addition to specialized training, prosthetists require specific componentry for children with limb absence. Pediatric components are distinct from adult components both in size and weight, as well as, control mechanisms and design.[2] Literature on available pediatric components in LMICs is limited but may inform efforts for local manufacturing in regions with high incidence of pediatric limb absence.

**Beyond prosthetic service provision; Amputation surgery**

Quality, thoughtful amputation surgery lays the groundwork for successful use of a prosthesis. Goals of amputation surgery include a sufficient length of residual limb for prosthetic control, adequate soft tissue coverage and mobility, and pressure tolerant weight bearing surfaces.[2] Knowledge of the most common amputation causes and levels can improve surgical outcomes through improved surgical skill. Education and training directed at best practices for amputation surgery can be further focused to address amputation surgeries most often conducted in geographic regions. Additionally, surgical techniques for limb salvage rather than amputation can serve to prevent unnecessary amputation.[64] Organizations such as the Institute for Global Orthopedics & Traumatology (IGOT)[65] can inform future amputation and limb salvage training efforts and regional needs through estimates provided in this study.

**Study limitations**

The data presented in this study represents only a portion of all major limb amputations worldwide. Many etiologies of major limb amputation are not considered in this study include diabetes and dysvascular causes, infection, cancer and congenital birth defects.

The GBD estimates lack the specificity in level of amputation that a prosthetist or rehabilitation specialist would require for detailed treatment planning. Clinical care and expected outcomes for a person with a short transfemoral amputation would differ substantially from that of a person with a long transtibial amputation. This study was unable to provide this level of detail and therefore provides only a broad understanding of global amputation incidence.

Estimates in this paper are provided at the regional level rather than country level. National data would allow countries to develop national prosthetic service provision plans, however, is less reliable given limited number of low and middle income countries that report both E and N codes in injury data. Regional data may result in over or underestimates in a given country. For example, a country with civil war may be averaged into the estimate of amputations for other countries within the same region.

The GBD 2015 study imposed a hierarchy to select the nature of injury category that lead to the largest burden when a person experiences multiple injuries. Specifically, people who experienced multiple severe injuries in addition to limb amputation, such as spinal cord injury or traumatic brain injury, would not be accounted for in traumatic amputation estimates. This hierarchy may result in an under estimation of traumatic amputation incidence.

**Conclusions**

In 2015, we estimate that 1.2 million people experience a major limb amputation due to trauma. Incidence and rate of amputation varied by cause, age and geography. Five regions consistently had the lowest incidence and rate of traumatic amputation; High-Income North America, Southern Latin America, Western Europe, Australasia and High-Income Asia Pacific. Regions that had the highest incidence and rate were North Africa and Middle East, South Asia, Western Sub-Saharan Africa and East Asia. Differences between age groups and regions can serve to inform prevention strategies, future prosthetic care and rehabilitation services.

**Acknowledgments:** We would like to acknowledge IHME employees Nick Graetz, Paola Pedroza, Liane Ong and Cliff Mountjoy-Venning.

**Declaration of interest:** No declaration of interest

References


1. Ziegler-Graham K, MacKenzie EJ, Ephraim PL, Travison TG, Brookmeyer R. Estimating the prevalence of limb loss in the United States: 2005 to 2050. Arch Phys Med Rehabil. 2008 Mar;89(3):422–9.
2. Smith DG, Michael JW, Bowker JH. Atlas of Amputations and Limb Deficiencies. 3 edition. Rosemont, IL: Amer Academy of Orthopaedic; 2004. 965 p.
3. Lusardi MM, Jorge M, Jorge M, Nielsen CC. Orthotics and Prosthetics in Rehabilitation. Elsevier Health Sciences; 2013. 865 p.
4. Arya AP, Klenerman L. The Jaipur foot. Bone Jt J. 2008 Nov 1;90–B(11):1414–21.
5. Chen N-Z, Lee WCC, Zhang M. A numerical approach to evaluate the fatigue life of monolimb. Med Eng Phys. 2006 Apr;28(3):290–6.
6. Craig JC. Prosthetic Feet for Low-Income Countries. J Prosthet. 2005 Oct;17(4).
7. Hansen AH, Meier MR, Sam M, Childress DS, Edwards ML. Alignment of trans-tibial prostheses based on roll-over shape principles. Prosthet Orthot Int. 2003 Aug;27(2):89–99.
8. Hussain S. Toes that look like toes: Cambodian children's perspectives on prosthetic legs. Qual Health Res. 2011 Oct;21(10):1427–40.
9. Jensen JS, Raab W. Clinical field testing of vulcanized Jaipur rubber feet for trans-tibial amputees in low-income countries. Prosthet Orthot Int. 2006 Dec;30(3):225–36.
10. Jensen JS, Raab W. Clinical field testing of vulcanized Jaipur rubber feet for trans-tibial amputees in low-income countries. Prosthet Orthot Int. 2007 Mar;31(1):105–15.
11. Lee WCC, Zhang M. Fatigue test of low-cost flexible-shank monolimb trans-tibial prosthesis. Prosthet Orthot Int. 2006 Jan 1;30(3):305–15.
12. Lenka P, Kumar R. Gait comparisons of trans tibial amputees with six different prosthetic feet in developing countries. Indian J Phys Med Rehabil. 2010;21:8–14.
13. Meier MR, Sam M, Hansen AH, Childress DS. The "shape&roll" prosthetic foot: II. Field testing in El Salvador. Med Confl Surviv. 2004 Dec;20(4):307–25.
14. Sam M, Childress DS, Hansen AH, Meier MR, Lambla S, Grahn EC, et al. The "shape&roll" prosthetic foot: I. Design and development of appropriate technology for low-income countries. Med Confl Surviv. 2004 Dec;20(4):294–306.
15. Sam M, Hansen AH, Childress DS. Characterisation of prosthetic feet used in low-income countries. Prosthet Orthot Int. 2004 Aug;28(2):132–40.

16. Jensen JS, Nilsen R, Zeffer J. Quality benchmark for trans-tibial prostheses in low-income countries. Prosthet Orthot Int. 2005 Apr;29(1):53–8.

17. Meanley S. Different approaches and cultural considerations in third world prosthetics. Prosthet Orthot Int. 1995;19(3):176–180.

18. Sathishkumar S, Manigandan C, Asha T, Charles J, Poonoose PP. A cost-effective, adjustable, femoral socket, temporary prosthesis for immediate rehabilitation of above-knee amputation. Int J Rehabil Res Int Z Rehabil Rev Int Rech Readaptation. 2004 Mar;27(1):71–4.

19. Jensen JS, Raab W, Fisk J, Hartz C, Saldana A, Harte C. Quality of polypropylene sockets for trans-tibial prostheses in low-income countries. Prosthet Orthot Int. 2006 Apr;30(1).

20. Gupta N, Castillo-Laborde C, Landry MD. Health-related rehabilitation services: assessing the global supply of and need for human resources. BMC Health Serv Res. 2011;11(1):276.

21. Jensen E. Prosthetics and orthotics in Latin America. Prosthet Orthot Int. 1979 Dec 1;3(3):155–6.

22. Harkins CS, McGarry A, Buis A. Provision of prosthetic and orthotic services in low-income countries: A review of the literature. Prosthet Orthot Int. 2013 Oct 1;37(5):353–61.

23. Andrysek J. Lower-limb prosthetic technologies in the developing world: A review of literature from 1994-2010. Prosthet Orthot Int. 2010 Dec;34(4):378–98.

24. Wong MS. A prospective study on the development of critical thinking skills for student prosthetists and orthotists in Hong Kong. Prosthet Orthot Int. 2007 Jun;31(2):138–46.

25. Wong MS, Lemaire ED, Leung AKL, Chan MF. Enhancement of prosthetics and orthotics learning and teaching through e-Learning technology and methodology. Prosthet Orthot Int. 2004 Apr;28(1):55–9.

26. Kheng S. The challenges of upgrading from ISPO Category II level to Bachelor Degree level by distance education. Prosthet Orthot Int. 2008 Sep;32(3):299–312.

27. Aminian G, O'Toole JM. Undergraduate prosthetics and orthotics programme objectives:a baseline for international comparison and curricular development. Prosthet Orthot Int. 2011 Dec;35(4):445–50.

28. Aminian G, O'Toole JM, Mehraban AH. Undergraduate prosthetics and orthotics teaching methods: A baseline for international comparison. Prosthet Orthot Int. 2014 May 20;

29. Heim S. Advances in prosthetic and orthotic education and training in developing countries: A personal view. Prosthet Orthot Int. 1995 Jan 1;19(1):20–30.

30. Hughes J. Education: An investment in everyone's future. Prosthet Orthot Int. 1992 Aug 1;16(2):90–7.

31. Magnusson L, Ramstrand N. Prosthetist/orthotist educational experience & professional development in Pakistan. Disabil Rehabil Assist Technol. 2009 Nov;4(6):385–92.

32. UN World Health Organization (WHO), International Society for Prosthetics and Orthotics (ISPO). Guidelines for training personnel in developing countries for prosthetics and orthotics services. 2005 [cited 2015 May 18]; Available from: http://apps.who.int//iris/handle/10665/43127

33. Carmona GA, Lacraz A, Hoffmeyer P, Assal M. [Incidence of major lower limb amputation in Geneva: twenty-one years of observation]. Rev Med Suisse. 2014 Oct 22;10(447):1997–8, 2000–1.

34. Dillon MP, Kohler F, Peeva V. Incidence of lower limb amputation in Australian hospitals from 2000 to 2010. Prosthet Orthot Int. 2014 Apr;38(2):122–32.

35. Belatti DA, Phisitkul P. Declines in lower extremity amputation in the US Medicare population, 2000-2010. Foot Ankle Int. 2013 Jul;34(7):923–31.

36. Ahmad N, Thomas GN, Gill P, Chan C, Torella F. Lower limb amputation in England: prevalence, regional variation and relationship with revascularisation, deprivation and risk factors. A retrospective review of hospital data. J R Soc Med. 2014 Dec;107(12):483–9.

37. Moxey PW, Gogalniceanu P, Hinchliffe RJ, Loftus IM, Jones KJ, Thompson MM, et al. Lower extremity amputations--a review of global variability in incidence. Diabet Med J Br Diabet Assoc. 2011 Oct;28(10):1144–53.

38. Murray CJ, Lopez AD, Organization WH, others. The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020: summary. 1996 [cited 2017 Jul 18]; Available from: http://apps.who.int/iris/bitstream/10665/41864/1/0965546608_eng.pdf

39. GBD 2015 Disease and Injury Incidence and Prevalence Collaborators. Global, regional, and national incidence, prevalence, and years lived with disability for 310 diseases and injuries, 1990-2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet Lond Engl. 2016 08;388(10053):1545–602.

40. Haagsma JA, Graetz N, Bolliger I, Naghavi M, Higashi H, Mullany EC, et al. The global burden of injury: incidence, mortality, disability-adjusted life years and time trends from the Global Burden of Disease study 2013. Inj Prev. 2016 Feb 1;22(1):3–18.

41. Carlson LC, Lafta R, Al-Shatari S, Stewart BT, Burnham G, Kushner AL. Pediatric injury during conflict and prolonged insecurity in Iraq from 2003–2014. Surgery. 2016 Aug;160(2):493–500.

42. Murray CK, Obremskey WT, Hsu JR, Andersen RC, Calhoun JH, Clasper JC, et al. Prevention of infections associated with combat-related extremity injuries. J Trauma. 2011 Aug;71(2 Suppl 2):S235-257.

43. Mathieu L, Bertani A, Rongiéras F, Chaudier P, Mary P, Versier G. Wartime paediatric extremity injuries: experience from the Kabul International Airport Combat support hospital. J Pediatr Orthop Part B. 2015 May;24(3):238–45.

44. Duttine A, Hottentot E. Landmines and explosive remnants of war: a health threat not to be ignored. Bull World Health Organ. 2013 Mar 1;91(3):160–160A.

45. Meier RH 3rd, Smith WK. Landmine injuries and rehabilitation for landmine survivors. Phys Med Rehabil Clin N Am. 2002 Feb;13(1):175–87.

46. Durham J, Hill PS, Hoy D. The underreporting of landmine and explosive remnants of war injuries in Cambodia, the Lao People's Democratic Republic and Viet Nam. Bull World Health Organ. 2013 Mar 1;91(3):234–6.

47. Chang JT, Morton SC, Rubenstein LZ, Mojica WA, Maglione M, Suttorp MJ, et al. Interventions for the prevention of falls in older adults: systematic review and meta-analysis of randomised clinical trials. Bmj. 2004;328(7441):680.

48. Peden M. Global collaboration on road traffic injury prevention. Int J Inj Contr Saf Promot. 2005 Jun;12(2):85–91.

49. Staton C, Vissoci J, Gong E, Toomey N, Wafula R, Abdelgadir J, et al. Road Traffic Injury Prevention Initiatives: A Systematic Review and Metasummary of Effectiveness in Low and Middle Income Countries. PloS One. 2016;11(1):e0144971.

50. Cummings D. Prosthetics in the developing world: a review of the literature. Prosthet Orthot Int. 1996;20(1):51–60.

51. Pearlman J, Cooper RA, Krizack M, Lindsley A, Wu Y, Reisinger KD, et al. Lower-limb prostheses and wheelchairs in low-income countries. IEEE Eng Med Biol Mag Q Mag Eng Med Biol Soc. 2008 Apr;27(2):12–22.

52. Wu DY, Casanova HR, Ikeda AJ. Plastic soda bottles: A reusable material for making transradial sockets. Prosthet Orthot Int. 2009 Jan 1;33(2):100–6.

53. Sitek AJ, Yamaguchi GT, Herring DE, Willems CJ, Boninger D, Boninger RM. Development of an inexpensive upper-extremity prosthesis for use in developing countries. JPO J Prosthet Orthot. 2004;16(3):94–102.

54. About the Hand [Internet]. Give Hope Give a Hand. [cited 2017 Jul 21]. Available from: https://ln-4.org/about-the-hand/

55. Zuniga J, Katsavelis D, Peck J, Stollberg J, Petrykowski M, Carson A, et al. Cyborg beast: a low-cost 3d-printed prosthetic hand for children with upper-limb differences. BMC Res Notes. 2015;8:10.

56. World Health Organization. WHO global disability action plan 2014-2021: Better health for all people with disability. World Health Organization; 2015.

57. Ilagan V. Inclusive education in the Asia-Pacific region: Are the disabled included. In 2000. p. 120–7.

58. Cameron DL, Nixon S, Parnes P, Pidsadny M. Children with disabilities in low-income countries. ResearchGate. 2005 Jun 1;10(5):269–72.

59. Ross CE, Wu C. The Links Between Education and Health. Am Sociol Rev. 1995;60(5):719–45.

60. Kuper H, Monteath-van Dok A, Wing K, Danquah L, Evans J, Zuurmond M, et al. The Impact of Disability on the Lives of Children; Cross-Sectional Data Including 8,900 Children with Disabilities and 898,834 Children without Disabilities across 30 Countries. PLoS ONE [Internet]. 2014 Sep 9 [cited 2016 Oct 26];9(9). Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4159292/

61. Landmine Survivors Network, others. Prosthetics and Orthotics Programme Guide. 2006 Sep;5(8):e182.

62. Association of Childrens' Prosthetic-Orthotic Clinics [Internet]. 2017 [cited 2017 Aug 4]. Available from: www.acpoc.org

63. Paul E. Leimkuehler Online Learning Center (OLC) [Internet]. The Academy of Orthotists & Prosthetists. [cited 2017 Aug 4]. Available from: https://www.oandp.org/?page=OLC_NM

64. Bar-On E, Lebel E, Blumberg N, Sagi R, Kreiss Y. Pediatric Orthopedic Injuries Following an Earthquake: Experience in an Acute-Phase Field Hospital. J Trauma Nurs Off J Soc Trauma Nurses. 2015 Aug;22(4):223–8.

65. IGOT [Internet]. Institute for Global Orthopaedics & Traumatology. [cited 2017 Aug 4]. Available from: http://www.igotglobal.org