Designing for Human Variability

– student white paper –

Prostheses

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November 10 2010

Summary

Limb amputations are a fairly rare, but increasingly common event both in the U.S. and worldwide. After recovering from the trauma or surgical procedure, the victim is often left unable to return to a normal life due to diminished functionality. To attempt to recover some functionality, a prosthetic limb can be fitted to the person. Until recently, the benefits from these prostheses were marginal and often outweighed by the burden of their use or attachment to the body. Spurred by military and athletic demands, new prosthetic devices are entering the mainstream with dramatically increased functionality.

This paper will focus on the causes and frequency of amputation and highlight recent devices. The scope is limited to prosthetic limbs and will not include other novel prosthetics, such as joint replacements, artificial organs or neurological devices.

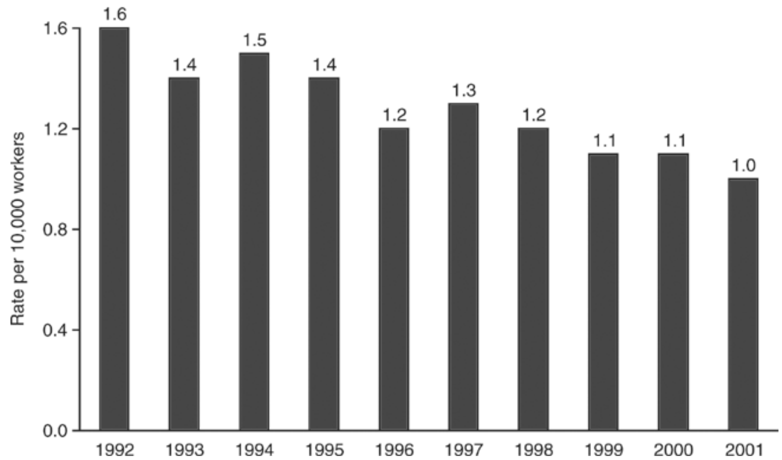
Background

Prevalence

In the United States, and across the world, limb amputation rates have been, and continue to be, on the rise.

Two current war-torn countries, Iraq and Afghanistan, have felt the effect with 0.1% and 0.15% of the population suffering the loss of at least one limb. Much of this can be attributed to terror-related attacks and unintentional damage. Additionally, in countries where active warfare has ceased, unexploded ordinance contributes to many limb-loss injuries every year. In Angola, for example, the amputation rate is almost 0.3%

The rate of amputation is actually higher in the United States than the previously mentioned nations; the availability of advanced medical care allows many people to survive otherwise lethal events with only an amputated limb. There are 185,000 amputations performed each year, contributing to more than 1.6 million amputees currently living in the country, about 0.5% of the population. In the next forty years, the number of amputees is projected to double. Despite these upward trending numbers, the workplace amputation rate in the U.S. is on a downward trend. This can be attributed, at least partially, to safety standards and -regulations designed to protect workers. [5]



U.S. Work-Related Amputation Rate 1992-2001 [5]

Worldwide, the World Health Organization estimates between 0.5% and 0.8% of any country's population have suffered limb loss: an approximate range of 34- 54 million people. [1]

Causes

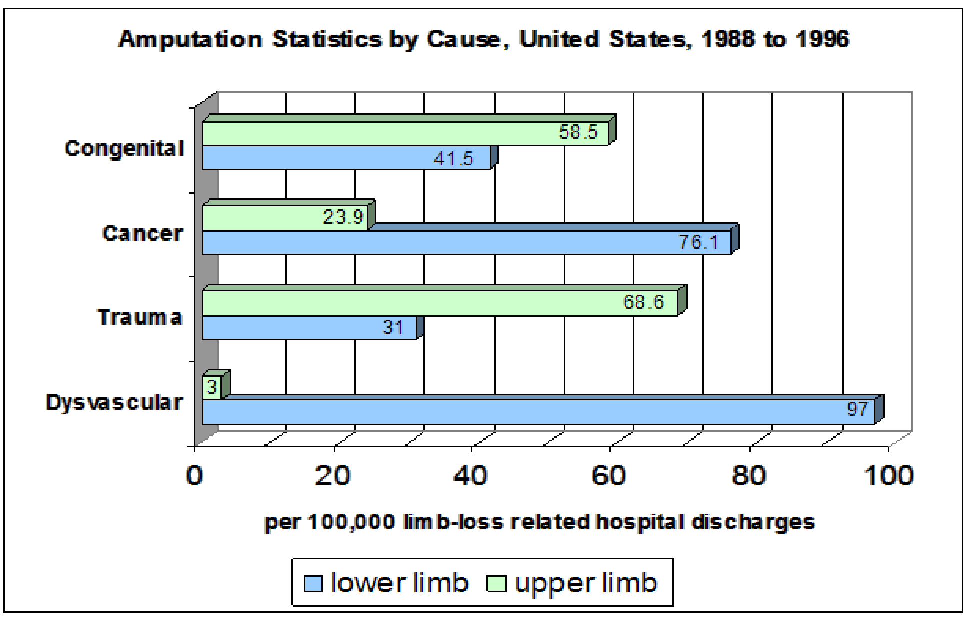
A recent, visible cause of an increase in amputation in the military world is the prevalence of road-side bombs and improvised explosive devices (IEDs). Operations Enduring Freedom and Iraqi Freedom had twice the rate of amputations to that of previous modern wars. Conversely, the death rate in these wars was very low in terms of total deaths as well as the percentage of casualties resulting in death. These low death numbers come from improvements in both battlefield medicine and the armoring of troops and vehicles. Injuries that would have resulted in death in the past are now survivable. The negative impact of these advancements is the number of troops that survive the war with amputations. [2, 3]

Table 3. Count of Individuals with Amputations by Service for OIF, OEF, and Unaffiliated Conflicts, 2001 to September 1, 2010

Theater	Type of Amputation	Army	Marine	Navy	Air Force	Foreign	Other	Total
OIF	Major Limb	620	158	18	8	4	8	816
	Partial (Hand/Foot, Toes/Fingers)	272	49	7	11	0	3	342
OEF	Major Limb	145	53	5	6	4	4	217
	Partial (Hand/Foot, Toes/Fingers)	24	6	0	2	0	0	32
Unaffiliated Conflicts	Major Limb	94	12	25	31	1	26	189
	Partial (Hand/Foot, Toes/Fingers)	20	1	2	1	0	1	25
Total								**1,621**

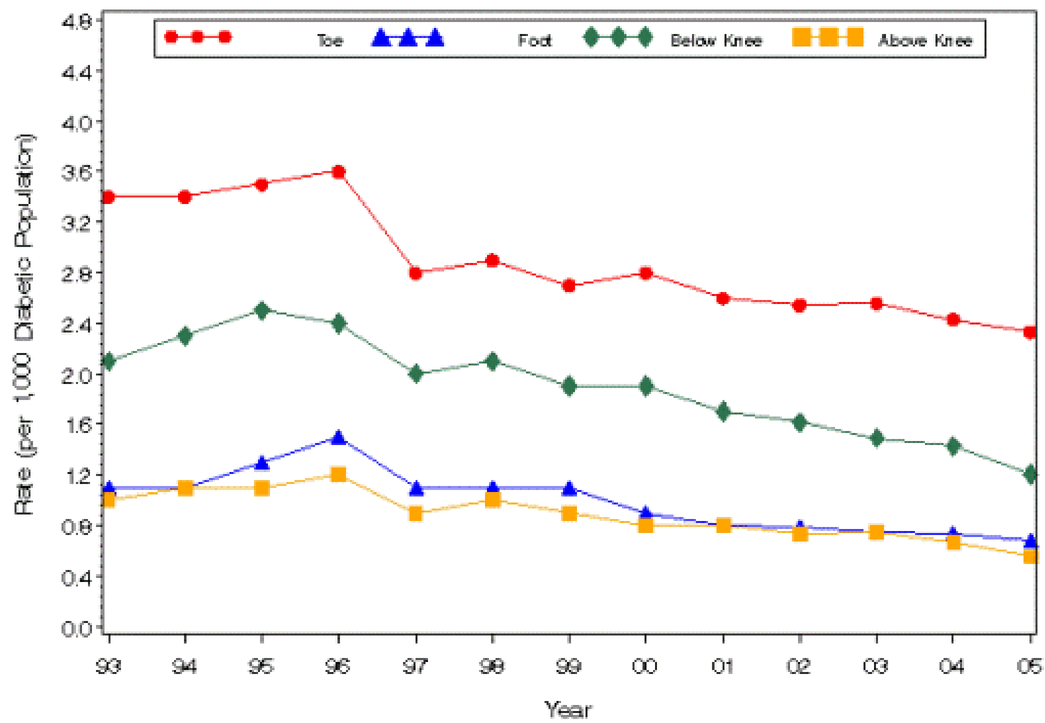
Amputation Rate in Afghanistan- and Iraq Theaters [2]

Although amputations due to the wars are highly publicized, they make up only a small part of the U.S. population with amputations. Like war injuries, a large portion of domestic amputations is made up of trauma-related injuries, about 45%. The largest single contributor, at 54%, is vascular related conditions, especially diabetes.



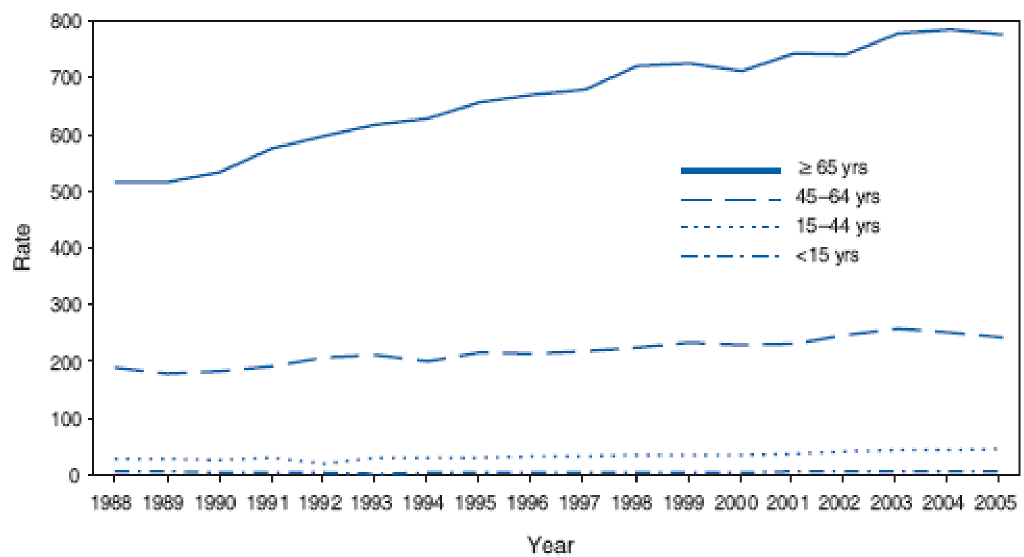
National Limb Loss Information Center [1]

Over the past decade, the percentage of diabetic patients requiring amputations has declined:



Diabetes Amputation Rate 1993 to 2005 [6]

Conversely, the rate of diabetes has also increased during that same time period: the rate of people over the age of 65 contracting diabetes increased by about 50% in the span of 1988 to 2005. More striking, the rate of people 15-44 also increased 50% in that time.



U.S. Diabetes Rate 1988 to 2005 [7]

These two counteracting trends result in, at best, stagnation in the number of patients with diabetes receiving amputations every year. The increasing trend in obesity will likely lead to an increase in the rate of diabetes in the near future.

In developing parts of world, spikes in amputations have occurred recently due to natural disasters. The 2010 earthquake in Haiti created up to 6000 amputees overnight. The earthquakes in Chile and China created additional amputees, but data from remote locations is difficult to collect and distribute.

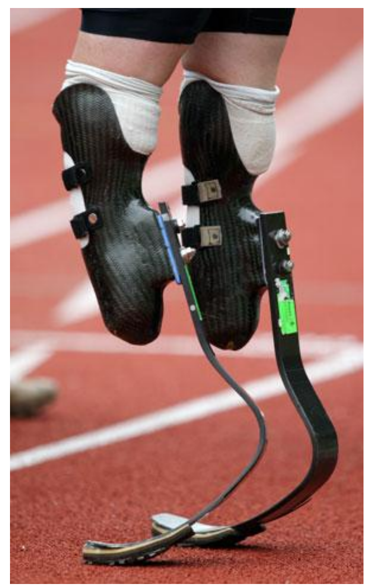
Application to DfHV

One goal of a prosthetic limb is to replicate the functionality of the original limb for the user to allow for a productive and normal lifestyle. Recent technology and research have allowed prosthetics to actually overtake the functionality of biological limbs.

Legs

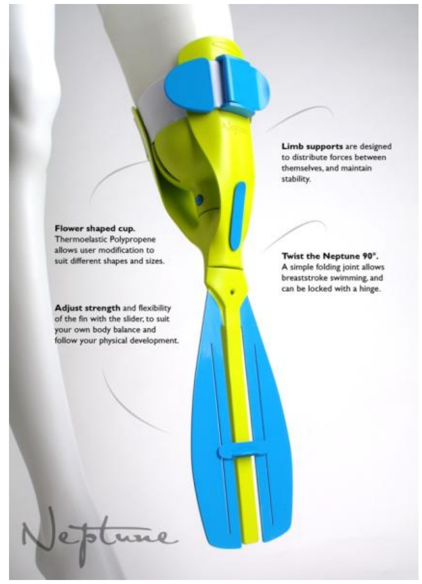
For lower limb amputations, numerous specialized prosthetics are now available depending on the application.

The "Cheetah Leg" is optimized for sprinting and become a debate in the athletic world before the 2008 Beijing Olympics. The prosthetic is built from carbon fiber, having high strength at about half the weight of a human leg. The decreased weight requires less torque to swing forward, allowing for faster rotation with less exertion. Additionally, the shape of the leg acts as a spring: storing energy on the heel-strike and releasing it at toe-off. Finally, the length of the leg increases the stride length of the runner in relation to their height.


Cheetah Legs [9]

The performance of the limb is remarkable for a prosthetic and possibly superior to a natural leg. The International Association of Athletics Federation (IAAF) deliberated over the fairness of allowing the Cheetah Leg to be used in Olympic competition due to its possible advantage. [9]

The design of the cheetah leg is impressive, but is not suitable for marine situations. A promising prototype device in this realm is the "Neptune" flipper.



Neptune Flipper [10]

The Neptune is configurable for below- and above-the-knee amputations and is purposed for balancing the power of the leg kicks for uni-lateral amputations. Also, for bi-lateral amputations, two could be used to add substantial power to the swim stroke.

Since the majority of amputations are due to health conditions, the flipper could allow users to exercise after their surgery. Hopefully, the initiation of an exercise routine will prevent further limb loss and improve the health of the patient.

Mobility for Each One [11]

Outside the realm of athletics, the "Mobility for Each One" prosthetic leg/foot is aimed at assisting the destitute in countries struck by natural disasters or unexploded ordinance. This prosthetic, like the Cheetah Leg, is an energy returning device making it more natural and easier to walk with than a crutch or a "peg leg." Though the design is not novel, the composition is. The leg is made of strong composite materials with relatively simple manufacturing techniques. The intention is for developing countries to produce the legs domestically and distribute them to those in need. The projected cost to produce a leg is only $8 compared to $1000 to $4000 for similar prosthetics composed of different materials. Since many developing countries have no form of social welfare program, amputation victims have to be able to work to stay alive. Having an affordably priced prosthetic makes this requirement possible. [11, 12]

Arms

Previous generations of prosthetic arms were cumbersome and provided little assistance to the wearer. The benefits were often so negligible, that owners opted not to wear them.

The most visible, state-of-the-art upper limb prosthetic is the so-called "Luke Arm." Funded by DARPA and developed by Deka, developer of the Segway, the Luke Arm's goal is to be a fully-functional and comfortable arm replacement. Unlike the prosthetic leg examples in this paper, this arm is powered and utilizes microprocessors and motors for motion. The inputs to initiate motion in the arm are customizable to the user's preferences and type of amputation, ranging from a non-invasive strap attachment to a surgical integration with remaining muscles and nerves in the user's residuum and chest. Also unlike the outlined leg examples, the Luke Arm gives the user feedback on its configuration. For example, if the user wishes to grasp an object, a motor will vibrate in the user's shoe with amplitude proportional to the tightness of the grip. This is allows for fairly fine motor control compared to hook-and-pulley systems of the past. [4]


Subject Demonstrating Dexterity of Luke Arm [4]

Discussion

Recent research efforts have propelled prostheses design from centuries-old technology to technically advanced devices. The functionality of new devices is approaching that of the original limb and, in some performance devices, exceeding it.

Research and development is only in its infancy of a feedback system in these devices. If the prostheses could be integrated into the wearer's nervous system, they could possibly relay tactile, temperature or other information like the natural extremity. Additionally, information could be sent in the opposite direction to control the articulation directly through a Brain-Computer interface. With these duplex information additions, the device could seem like a natural extension of the body.

The Design for Human Variability aspect is inherent in all designs as they are purposed to replace human appendages. It is however, difficult to make any device universal as a good fit is necessary for proper usage. Since all limbs are shaped differently and each injury is unique, the fitting must be highly customized to each user.

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