Prosthetics

Biology term paper by Hans, Vince and Deborah

Preface

Prosthetics is an interesting field of science. The idea of cyborgs; people who are fused with machines, is fascinating and prosthetics are the first step into that direction. The fact that we can replace body parts with synthetic ones to help people live their lives is amazing.
Some of our questions with respects to the current topic are:
How are genetic variations related to prosthetic design and function?
What are the potential implications of using genetic information in prosthetic customization?
How can genetic research be used to improve prosthetic durability and longevity?

Introduction

The field of prosthetics is always relevant. There are new revelations on how to implement prosthetics and make them more efficient every day. First, I should clarify the terminology. Prosthetics refers to the field of research and design of artificial limbs, while prosthesis refers to the actual artificial limb.[1] Recently a third thumb was designed to go on the other side of your palm. The idea of making a new limb to augment the abilities of the body instead of replacing a missing limb is something I never considered. The body is capable of a lot of things but there are always possible improvements. The origin of the word prosthetic has a Greek root, prostithenai, or "addition," and an early meaning of "that which is added to the body". The third thumb explores the original meaning of the word instead of the usual use of prosthetics.[2]

The recent scientific history of prosthetics

Ambroise Paré (1510-1590) was an official royal surgeon and is also regarded as the father of modern surgery. He improved amputation techniques and survival rates during his time as a war surgeon. He was the first to invent an above-knee prosthesis with an adjustable harness and a hinge-knee with lock control.

Around 1690, Pieter Verduyn, a Dutch surgeon invented a lower leg prosthesis with specialized hinges and a leather cuff for improved attachment to the body. Many of the advances of Paré and Verduyn are still used in modern day prosthetic devices.

The discovery of gaseous anesthesia in the 1840s allowed doctors to perform longer, more meticulous amputation surgeries that allowed them to prepare the limb for the prosthesis while operating.

The surgical advances increased the success rates of amputations and increased the demand for prosthetic limbs.

As artificial limbs became more common, improvements of joint technology and suction-based attachment methods were made and advanced prosthetics.

There were no major advancements in prosthetics until post World War 2, when the American governmental agency 'The National Academy of Sciences' established the 'Artificial Limb Program'. The program was created in 1945 in response to the World War 2 veterans, who lost limbs and needed prostheses. Since then, many advances were made in the areas of materials, computer design methods and surgical techniques.[3]

Use of prosthetics

Prosthetics are used by people who either were born with a missing limb or lost a limb in an accident or due to an illness, which lead to an amputation. Prostheses help these people to function like a normal person would.

There are different kinds of prostheses for different uses and types of amputations. For example, there are specific leg prostheses for running.

Alternative Treatments

There are people who choose to use prostheses in specific situations or not at all. Some types of amputations or missing limbs make it harder to use and control prostheses. Some people learn to live and function without a prosthesis, like people who were born with missing limbs or people with amputations, who had no other choice while waiting for their prosthesis to be made. To be able to use a prosthesis, you need prosthetic training. If a patient receives no or insufficient training, they might choose not to wear it. Since prostheses differ, based on the intended use, being fitted with a prosthesis that doesn't provide the functional goal can also lead to someone not wearing it.[4]

Description of engineering technique

The engineering of functional prostheses that fit their patients properly requires a wide variety of methods. To ensure functionality, safeness and comfort of the prosthesis, developers and manufacturers make use of complicated and thorough techniques that must be done very precisely.

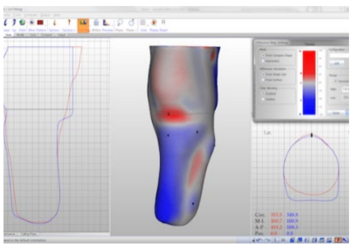
Computer-Aided Design

Computer-Aided Design also known as CAD is a fairly new technology that has revolutionized engineering. Prosthetics are no exception.

The software allows prosthetic designers to create digital 2D and 3D visualizations of prototypes of prosthetic devices, which can then be tested and refined before actual production. This allows developers to better think about functionality and design of the product, while being able to redesign each component more quickly.

Advanced CAD software allows for stress and movement tests, which can let the developer know if a certain product is functional, without wasting resources.

Socket fit is the most important part of a prosthetic device, especially for lower limb amputees, because it helps distribute the wearer's weight and allow fluid, comfortable movement. Developing this is especially easy with CAD.



Picture 1: CAD-software[20]

It also makes it easier to incorporate ergonomic considerations, such as ensuring that the prosthesis fits the patient's anatomy, is comfortable to wear and operates smoothly.

Naturally, CAD technology provides prosthetic designers with the ability to produce highly precise and accurate models. This is important in ensuring that the final product will meet the necessary specifications and will function as intended.[6,7]

3D printing

3D printing is a rapidly developing technology that has also made its way into the field of prosthetics. CAD and 3D printing are engineering methods that go hand in hand. The programmed prototypes can be printed out with the 3D printer and allow for better visualization, functionality of the prosthetic device.[10]
The Advantages gained by 3D Printing include:

An Increase of speed:3D printing allows for rapid customization, prototyping and production of prosthetics. Production usually takes up a couple of hours.[8,9]

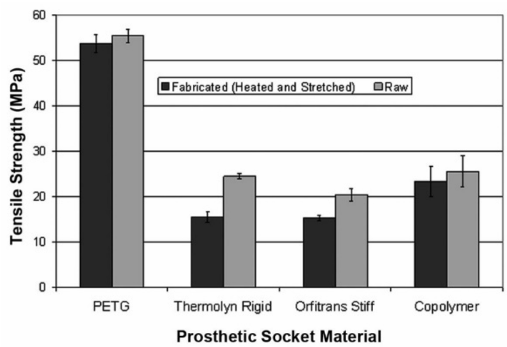
3D printing also has the potential to significantly reduce the cost of prosthesis. Thanks to its easier manufacture with more variable materials such as ABS and nylon, prosthetic devices can be produced for much lower costs and even be made available for people in developing countries[8,9]. A slight disadvantage they possess is, that they require a 3D digital file that is customized to the patient to enhance the functionality of the prothesis, which also means children need to be refitted a lot.[10]

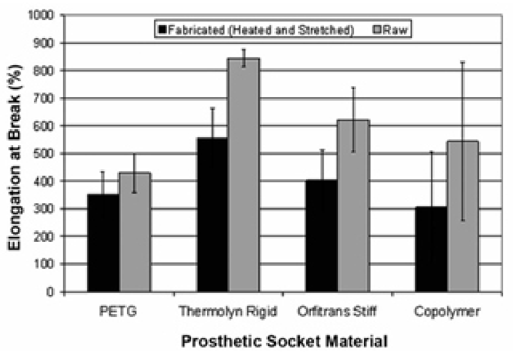
Another groundbreaking feature of the 3D printing is that it allows for the creation of complex shapes and structures that would be difficult or impossible to produce using traditional manufacturing methods.

Picture 2,3:3D printed prostheses.[9]

Materials:

3D printing can be done with a variety of materials, including plastics, other composites and metals, allowing to produce prosthetic components with the desired strength, weight, and flexibility. Ongoing research is being done to find optimal materials for each part of the prostheses to improve mobility and lengthen their lifespan.[8,9]





Picture 4: Tensile strength of different materials.[13] (Tensile strength is the maximum stress that a material can withstand while being stretched before breaking.)

Picture 5: Elongation at break.[13]

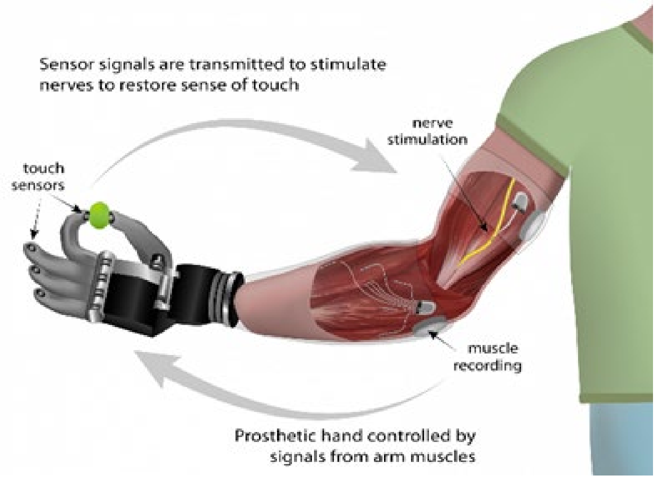
As this Graphic from a study by Ohio willow wood company shows, PETG or polyethylene terephthalate glycol Is a very resistant synthetic material with a tensile strength of up to 56MPA. It also is the most rigid among the materials resulting in a stretch distance of up to a little over 400 percent in its raw state. PETG along with other current synthetic materials are made to enhance stress resistance to optimize the prosthesis endurance, lifespan and function.

Function of bionic Prosthesis

Now that we have looked at the methods used to create the prostheses, we will look at how the prostheses, bionic prostheses in particular, function.

If a person has lost an arm, for example, all the corresponding nerves are still present but useless, then nerve transfer is performed in a surgical procedure.

In the process, the nerves are moved to the amputation stump so that they regain a certain functionality, along with interface signal receptors which are placed into the muscle tissue and bound to the nerves, allowing the bio signals from the brain to be properly transmitted to the prosthesis. It is certainly advantageous, that in this process the signals reach the prosthetic limb before the muscle even registers the brain signal, so the wearer doesn't experience an unwanted muscle contraction, just the brain-to-prosthetic limb movement. [5,10,11,14,15]



Picture **6**: Simple Model of a working Bionic Prosthesis.[14]

Importantly, to allow for a great prosthesis-user connection and great function, the socket fit must be custom fitted.[12,23] To do so the prosthetics specialist most commonly uses liquid plaster to recreate the traditionally form of the stump for the socket to then be modified manually and eventually digitalized into CAD so it can be comfortably modified. This may also be done directly via scanning the stump with a special camera device.[6,7,23] *The sockets may vary in function and comfort depending on price, quality and intended use.*

The socket is then implanted into the amputated stump along with sensors made from delicate electrodes which can also be placed on the skin. These signals are recorded and transmitted to a tiny computer in the prosthesis that converts certain electrical signals into movement commands for the desired prosthesis part.[5,10,11,12,14,15] These movements are powered by either a small motor, a battery[12] or a hydraulic system inside the prosthetic limb. Some very advanced prosthesis may also contain sensors that provide feedback to the patient. This had been an issue in this field for a long time, but thanks to advancements in technology, simple closed feedback loops were achieved, which are made possible by a cuff electrode, that is placed around a nerve to stimulate it and thus close the feedback loop.[11,12,15]

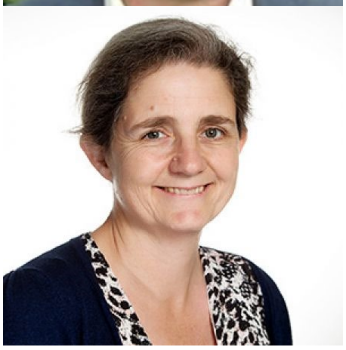
It must be stated that although advancements in the field have been made, this bionic limb is far from the mobility and feel of a natural limb. Even highly advanced prosthetic devices still face the issue of rather slow movement and a prolonged time in the feel of foreign objects. [12,15]

Interview with researchers and representatives of research institutions

Unfortunately, we didn't get any confirmations and often no replies from experts in the northwest region of Switzerland, which is why we decided to attempt to contact professors and doctors abroad specialized in the field of prosthetics and orthotics.

We received answers from

Laurence Kennedy, PhD, a professor in rehabilitation techniques, University of Salford, England. [21]



Elaine Washington, HND and OPTEC in Prosthetics and Orthotics and MSc in psychology, a professor on Prosthetics and Orthotics, University of Salford, England.[22]

The Questions as well as their answers are the following:

1. What are Innovative approaches and developments in Prosthetics that you find particularly exciting?

EW - Scanning and 3D printing. General advancements in componentry in terms of electronics and batteries. Those that really take into account what service users actually want rather than what clinicians/designers think they want. It is not always the same thing. For example, sitting comfort may for some be more important than being able to walk further.

LK – there are lots of interesting developments in the field. These include sensory feedback for users of prosthetic hands, and more robust methods for controlling prostheses. Sensory feedback is showing promise at boosting a person's embodiment of their prosthesis. The issue of robust control of prostheses is another interesting area. Our group showed that some users of myoelectric prostheses find it difficult to consistently control their prosthetic hand using the electrical signals from their residual muscles. To address this there are some exciting new developments coming illustrating alternative and potentially more robust ways of controlling hand prostheses, based for example on the use of real-time ultrasound. In lower limb prosthetics, there are several groups looking at powered prosthetic ankles and powered knees, which may make walking easier. Researchers are also starting to use technologies to study prosthesis users in their everyday lives, complementing data from lab-based studies. Insights from these studies may help researchers to gain a better understanding of the challenges faced by users of current devices, and hence focus engineering efforts on the most important problems.

More broadly, it is exciting to see the World Health Organization now making a *concerted effort* to improve access to assistive technologies (including prosthetics) – the majority of people in need of prostheses globally do not have access to high quality devices and many do not have any access at all.

2. How do you see prosthetics technology advancing in the future, and what impact do you think it will have on the lives of those who use prosthetics?

EW - The introduction of microprocessors in knees and ankle foot complexes has been really beneficial because it means that individuals are less likely to fall, and it reduces the cognitive burden, so individuals are not constantly having to be alert to what is in front of them or watch out for hazards because they know the prosthesis will adapt to assist them, in a similar way to non-amputees. I think the step that would make a huge difference especially in upper limb is if the prosthesis is integrated into the nervous system so it is not just a monitoring system as in lower limb, or a system of picking up nerve impulse as in myo-electric control but it takes information from the nerves in real time and makes an action. I would like to see sockets that adapt automatically to changes in shape and or volume to maintain the fit of the socket and can keep the residuum cool even in summer. The high tech being used to find devices that can improve safety, mobility and energy efficiency for those less mobile.

LK – I think advances will be made across many fields. 3d printing of prosthetics has received a lot of attention from researchers, but to date many designs have not been robust enough to be used routinely. This is changing and 3d printing of prosthetic sockets is now being used clinically.More automated methods for designing potentially more comfortable sockets are coming and these could have a big impact on the lives of users. The automation of the socket fitting and manufacturing process may also bring costs down in the longer term and hence address the issues raised by the WHO regarding access.

3. What are the current challenges facing the field of prosthetics and how are they being addressed?

EW - Achieving good socket fit and maintaining it. The cost of prosthetic componentry. The need to have true integrated care that starts before amputation which includes intensive physiotherapy, diet, hydration, psychological support etc. for the best outcomes for all.

LK – There are lots of challenges in prosthetics that remain to be solved. One of the challenges faced by clinicians is choosing from the many hundreds/thousands? Of prosthetic components on the market. By contrast to some other areas of healthcare, where clinicians can be guided by high quality, large clinical trials, there are surprisingly few large clinical studies of prosthetic devices. A longer terms solution to this could be the emergence of 'big data' approaches to studying the problem, but we are some way off this at the moment.

4. Does knowledge of genetical information possibly allow for a better prosthetic "fit" on the patient.

EW - Prosthetic devices need to deal with issues that may have causation/susceptibility linked to genetics or at least genes have a part to play such as likelihood of underlying disease/health, skin quality, bone density, allergies etc. but fit is down to the individual's characteristics such as health, skin quality, range of motion, muscle strength, hand dexterity, cognitive ability to don and doff correctly, amount of soft tissue, the weight of an individual, activities they take part it, whether the residuum has a constant volume or fluctuates etc. as well as the skill and knowledge of the clinician, materials/components available and the environment the person lives in.

LK – I'm not sure how genetic information could be used in this context.

Pictures and documentation of research institution:

As already stated, it was not possible for us to visit a research center which is why we decided to use shots of the laboratory of prosthetics of Salford University, captured in a short film as well as Information posted on Salford website to gain information of the resources used in prosthetics laboratories.

Picture 7: Measuring of the leg for an orthotic device to be implanted.[23]

Picture 8: Traditional Stump mold being polished for examining the optimal socket fit.[23]

Picture 9: Patient walking with new prosthetic leg.[23]

Picture 10: Prosthetic leg being adjusted.[23]

Picture 11: Socket fit recreation with plaster.[23]

Discussion

There have been many advancements in the field of prosthetics, that have allowed a new era to rise for amputees. Amputation is one of the oldest problems mankind has faced. Remains found in 1957 have shown signs of a neanderthal being testified to an amputation as far back as 45000 years.

The complexity of human extremities, particularly the upper extremity and the hand allow us to interact with the world. Prosthetists have been struggling to recreate the intuitive motor control, light touch sensation and proprioception of the innate limb in a manner that reflects the complexity of its native form and function, however, emerging technologies move experts closer to the goal of creating highly functional prostheses with elevated sensory and motor control. Surgical advances such as targeted muscle reinnervation, regenerative peripheral nerve interfaces, and targeted sensory reinnervation; development of technology designed to restore sensation, such as implanted sensors and haptic devices; and evolution of osseointegrated prostheses show great promise. Augmented and virtual reality platforms have the potential to enhance prosthesis design, pre-prosthetic training, incorporation, and use. [17]

Although scientists have made great progress in the last few years, there is still room for advancements in this field. "Eventually, we will have a prosthesis that approximates the dexterity of the human hand," says Dr. Sliman Bensmaia, assistant professor of organismal biology and anatomy at the University of Chicago, on a Curiosity.com podcast.[18] Currently, prosthetics cannot adjust to changing terrain, but scientists at the University of Houston have been researching how the brain plays a role in walking and believe that adding brain activity to the equation might allow amputees to have a wider range of motion.[19] Samantha Subramanian also states that she believes the future of prosthetics to be neural, by what she means that people are going to be able to hook up their nerves -and thereby their brains with their prosthetics to be able to control them with their thoughts and minds, the way they would control their natural limbs. Another great enhancement expected in prosthetics is exoskeletons, that are prosthetic frames that fit onto our limbs and can be controlled with neural commands. [18]

Ethical aspects of prosthetics

Prosthetic devices, like everything in our world, have disadvantages and advantages, and while these might differ in some cases, there are fundamental pros and cons one has to consider when talking about the ethical aspect of this field. First being the general question of health and safety. The functioning of a prosthesis for the remainder of someone's life cannot be predicted reliably on the basis of a couple of clinical trials with human subjects, therefore there is a real risk, that people will be fitted with prostheses or implants that malfunction, have harmful side-effects, or are even rejected by the body's autoimmune system. Secondly, having a prosthesis means being intrinsically dependent on technology. A prosthesis may also create dependence on others for maintenance, diagnosis and testing. Furthermore, implants process or store information or emit identifying signals that can be registered from a distance, that can affect one's privacy. Lastly, we would like to pose the question of justice. As mentioned before, prosthetic devices are very expensive, however, there is also a big division between prothesis and prothesis, therefore the development of increasingly sophisticated prostheses and implants raises issues of distributive justice: will there be a division between biological haves and have nots? Will there be a division between those who receive no prosthesis or a low-quality or high-risk one and those who receive the best medical care? Do people have a moral right to a replacement part for a malfunctioning organ, when such parts exist?

To conclude, prosthetics have a major role in the field of bioengineering by allowing people to experience individual autonomy once again. Although they are extremely useful as they are, there is still room for advancement, however, in our rapidly changing world, no cyborg-fantasy is unreachable, especially if we are talking about such a versatile topic as prosthetics.

Sources

[1], page 2 : https://www.amputee-coalition.org/resources/prosthetic-vs-prosthesis/

[2], page 2 : https://www.daniclodedesign.com/thethirdthumb

[3], page 3 : https://synergypo.com/blog/a-short-history-of-prosthetics/

[4], page 3 : https://www.armdynamics.com/upper-limb-library/why-do-some-people-choose-not-to-

[5], page 5 : https://www.medica-tradefair.com/en/Media_News/Worlds_of_experience/PHYSIO_TECH/Rehabilitation,_Training_Aids/Bionic_prosthesis_easy_to_put_on,_intuitive_to_use

[6], page 3,4 : What is Computer-Aided Design (CAD)? | Goodwin University

[7], page 3,4 : Was ist CAD? | Computer-Aided Design (CAD) |

[8], page 4 : 3D printing prosthetics in 2022: The great revolution (sculpteo.com)

[9], page 4 : How 3D Printed Prosthetics Can Change The Lives of Millions of Amputees - 3DSourced

[10], page 5,6 : A Look Into How Bionic Prosthetics Work (ranker.com)

[11], page 5,6 : Bionic prosthesis: device, installation, principle of operation. Bionic limb prostheses (unansea.com)

[12], page 5,6: Bionic limbs - Curious (science.org.au)

[13], page 4 : https://www.rehab.research.va.gov/jour/11/488/page987.html

[14], page 5,6 : bioCXNâ„¢ – An Ultraflexible Material to Enable Direct Communication Between Nerves and Prosthetics | Advancedphotonix

[15], page 5,6 : Movable Prosthetics: The Biomechanical Interface (technewsworld.com)

[17], page 11 : https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7340716/

[18], page 11 : https://qz.com/2141719/prosthetics-of-the-future-are-focused-on-boosting-the-able-bodied

[19], page 11 : https://redshift.autodesk.com/articles/prosthetic-technology

[20], page 3 : https://vorum.com/cad-cam-prosthetic-orthotic/canfit-design-software/

[21], page 6 : Elaine Washington | University of Salford

[22], page 6 : Laurence Kenney | University of Salford

[23], page 5-10 : Prosthetics and Orthotics Labs | University of Salford