MEMORANDUM 10 March, 2017

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Subject: Materials of Prosthetic Limbs

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Winter 2017

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ABSTRACT

This paper will take a deeper look into prosthetic devices for limbs. A clear definition will be provided along with a brief history and evolution of prosthetic technology. Then, current materials and their properties will be examined. To conclude, this paper will discuss the future possibilities and areas of research in terms of their significance in the field of bioengineering and to the world.

INTRODUCTION

Prosthetics devices are becoming more and more common in both the medical and engineering fields, and now almost every body part can be replaced by a prosthetic. Prosthetics are part of the field of bio-mechatronics which is the science of using mechanical devices with human muscle, skeleton, and nervous systems to assist or enhance motor control lost by trauma, disease, or defect. (1) The creation of a prosthetic is tricky business as each piece is custom made for its user to fit their particular needs. These devices can help the individual accomplish tasks that they previously could not due to their disability, significantly improving their quality of life. No two prosthetics are the same as the users vary in size, weight, lifestyle, and amputation. Thus there is not one material or design that will fit all needs.

When beginning to create a new prosthetic, the designer should strongly consider the material and the main load bearing structure. The prosthetic should be lightweight yet strong enough for an active and heavyweight amputee (9). It should definitely be aesthetically pleasing and waterproof to some degree (10).

There have been many developments over the years as prosthetics are becoming more and more common. Major material properties to compare and analyze include but are not limited to the following; compressive, torsional, tensile, and shear strength, specific density, energy storage characteristics, stiffness, shock absorption (damping), fatigue resistance, fracture toughness, creep, yield stress, and biocompatibility. All these properties and characteristics are being continually improved, and designs are increasingly beginning to reflect the real functions of human limbs (2).

BACKGOUND

Prosthetic research and development has been an area of interest to medics and engineers for centuries. When beginning to develop a new product it is interesting to see its evolution and understand how the technology came to be where it is today. In this section, the history of prosthetics will be studied.

The first prosthetic in the world dates back to the 18th dynasty in ancient Egypt during the 15th century BC. It is currently housed in a museum in Cairo, Egypt and is known as The Greville Chester Toe. It is a big toe prosthetic made of cartonnage and is strapped onto the foot in a fashion similar to an Egyptian sandal. Cartonnage is a material comparable to paper mache and is made of layers of linen or papyrus covered in plaster (4). The purpose for prosthetics during this time period, were for spiritual and religious reasons. It was necessary for the ancient Egyptian to maintain physical wholeness in order to have spiritual wholeness in both their lives on Earth and in the afterlife.

Centuries later, in the ancient civilizations of Greece and Rome the first true rehabilitation aids were recognized. These prosthetics were made of wood and leather. History text and artifacts can place a prosthetics in 484 BC made of copper and wood. There is also evidence of an iron prosthetic in use by a Roman general in the year 218 BC.

Serious advancement was made during the During the Dark Ages when prostheses were made for battle and hiding deformity. Such demand was heavy and technology was crude; devices were made of available materials such as wood, metal and leather. Such were the materials available to Ambroise Pare´ who invented both upper-limb and lower-limb prostheses. His 'Le Petit Lorrain', a mechanical hand operated by catches and springs, was worn by a French Army captain in battle. Subsequent refinements in medicine, surgery and prosthetic science greatly improved amputation surgery and the function of prostheses. What began as a modified crutch with a wooden or leather cup and progressed through many metamorphoses has now developed into a highly sophisticated prosthetic limb made of space-age materials (10).

War has always been a catalyst for technological change, initiating and enabling new breakthroughs. The start of the twentieth century saw the introduction of lightweight metals such as aluminum and magnesium and of additional functions – design, however, remained ancient and exoskeletal. In other words ,weight and impact forces were carried by a hard outer shell suitable for much greater forces (2).

MATERIALS

METALS

A variety of metals are used for prosthetics limbs; Aluminum, Titanium, Magnesium, Copper, Steel, and many more. They are each used in a varied amount and for various applications, either pure or alloyed. Copper, iron, aluminum and nickel have all been used for the load bearing structure in the past, but are currently used primarily as alloys or for plating.

This paper will focus on analyzing Titanium and the primary load bearing structure and current favorite in the biomedical field. Titanium was discovered in the late 18th century. It is a common metal used for medical and engineering applications because of its many favorable properties. It has good strength to weight ratio, goo strength to density ratio, excellent corrosion resistance, low density and it is lightweight (3). It is commonly alloyed with other metals to improve certain properties, most commonly aluminum and vanadium. In its unalloyed condition, titanium is as strong as some steels, but less dense. Being lightweight, strong, resistant to corrosion and biocompatibility are its most desirable properties for the application of prosthetics. Its low modulus of elasticity makes it similar to that of bone. This means that the skeletal load of its user will be distributed relatively evenly between the bone and the implant making for a more natural gait. When its characteristics are well understood and designed properly, this can be a very economical option for the lifetime of the product.

POLYMERS

Polymers are not often used for as the main load bearing structure for limbs. They are more common with phalanges, joints, and other smaller body parts. When it comes to limb prostheses, polymers are more common for the smaller components or specialized features.

Common polymers used are polyoxymethylene (POM), which is a hard polymer, pliable polyurethane (PU), which is much softer, and poly vinyl chloride (PVC), which is used as a coating.

Polyethylene is a more flexible form of plastic and it ideally used in larger quantities when the prosthetic needs to be waterproof (7). N.S. Schreiber and R.T.T. Gettens write an interesting article for the Department of Biomedical Engineering at Western New England University regarding prostheses for aquatic sport. The design, fit and material are all highly specialized because it need to be waterproof, capable of performing swim motions, and comfortable while doing so. Everyday prosthetics are not intended to be used in such an environment nor in such a motion.

PVC first developed in the early part of the 20th century and by 50s it was one of the most important plastics PVC is very durable but has limited color range. Silicone resists stains but is less durable. PVC is unstable when exposed to heat and light so it requires the addition of stabilizers (9).

Ionometic polymer metal composites (IPMC) are attractive types of electro-active polymer actuation materials because of their characteristics of large electrically induced bending, mechanical flexibility, low excitation voltage, low density, and ease of fabrication (1)

CARBON FIBERS

The use of carbon fibers came about in the 20th century when medics and engineers were in search of a lighter load bearing material. The properties of carbon fibers, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion, high specific strength and

specific modulus. It was determined that it could be strong enough for even a heavy weight amputee. Materials with high elastic modulus are usually not very ductile: the specific modulus of wood is comparable to that of steel, magnesium, titanium, or aluminum, whereas that of carbon fiber reinforced composites is about three times as high. Carbon fiber reinforced composites also have very high specific tensile and compressive strengths, as well as high responsive elastic deformation (2).
The Northrup Aircraft Corporation was doing research after being contracted by the Veteran's Administration. It was determined that the material was brittle and susceptible to impact damage that was great cause for concern (8). Carbon fiber can also be costly compared to other material with similar properties.

SUPPORTING MATERIALS

Biocompatibility refers to materials that are not harmful to living tissue. This is most often considered when making surgical tools or other objects that interact with the body internally. Another aspect of biocompatibility is how a material interacts with the surface of the skin or the external body. When prosthetics are attached to the exterior of the limb, and constant movement is occurring, the skin can be subject to a variety of painful and uncomfortable side effects. The distribution of mechanical stress at body support interfaces can influence the risk of tissue breakdown. Excessive pressure and shear stress can lead to skin blisters, cysts, or ulceration. Interface materials influence the pressure and shear distribution on skin and underlying tissues principally via their elastic property and their frictional characteristics with skin. Supporting materials used in prosthetics are Spenco, Poron, Nylon-reinforced silicone, Nickelplast, to name a few. These are all commonly used and have been carefully tested and selected based on their performance during compression testing. They have all been evaluated based on their coefficients of friction with some exceptions. Nylon-reinforced silicone was not tested because it tended to crack during shear loading and Spenco was not tested because it became extremely thin after short term loading (6.)

IMPACT & FUTURE RESEARCH

The goal as a doctor is to improve the quality of life for your patients. The goal as an engineer is to enhance a system and improve the quality of life for the world. In creating a prosthetic, those two goals come together and make a huge difference in the life of the user. Prosthetics are not only becoming more functional and comfortable but also lifelike and aesthetically pleasing. The more life like a piece is, the less social stigma or pity a user will receive. Between the improvements in design, fit, and appearance an amputee can walk with a more normal and confident gait. This new technology and better material selection, an amputee can gain its mobility, freedom, and life back.

The next step in this research is to find a suitable material to take to third world countries. A metal alloy that is strong, lightweight, and affordable for amputees of developing nations should be next in this line of research. In her article, Mangera

Taahirah discusses the importance of this material to be discovered. She calls for a simplification in adult prosthetics so that they can be designed as children and easily adaptable to their growing bodies, for example she suggests interchangeable components. A key issue in this discussion is the ability of this material to be sourced locally. South Africa and larger cities in Central and South American can handle the manufacturing aspects; the concern is attaining the material. Producin the material locally has many socioeconomic advantages. It will create commerce for the community and present a more affordable prosthetic for the user (5).

CONCLUSION

In this paper, many materials were discussed as they pertained to prosthetic limbs. Prosthetic are mechanical devices that replace or enhance the use of a body part. The body parts in question are arms and legs. Doctors and engineers work together to find the best design and material to make the best piece for the patient. Pure metals and metal alloys have replaced the wooded materials of the past for the main load bearing structure. Carbon fibers and polymers have replaced leather straps and the supporting components. The material for each piece is carefully selected based on the users environment and needs in conjunction with the material's properties. The next step in this research is to find a suitable material to use for prosthetic devices in the developing world.

REFERENCES

(1) Aravinthan, P., & GopalaKrishnan, N., & Srinivas, P.A., & Vigneswaran, N. (2010). Design, Development and Implementation of Neurologically Controlled Prosthetic Limb Capable of Performing Rotational Movement, *IEEE*

(2) Gutfleisch, O. (2003). Peg legs and bionic limbs: the development of lower extremity prosthetics, *Maney for the Institute of Materials, Minerals and Mining, 28(2)*

(3) Hanson, B.H. (1986). Present and Future uses of Titanium in Engineering. *Materials & Design, 7(6), 301-307*

(4)Finch, J. (2011) The Ancient Origins of Prosthetic Medicine. *The Lancet, 377(9765), 12-18*

(5) Mangera, T., & Govender, G., & Conning, M. (2015). Light metals for the functional requirements of developing world lower extremity paediatric prosthetics: A review of current material & technology trends. *Materials Science Forum, 828-829, 499-505*

(6) Sanders, J. E., & Greve, J. M., & Mitchell, S. B., & Zachariah, S. G. (1998). Material properties of commonly-used interface materials and their static coefficients of friction with skin and socks. *Journal Of Rehabilitation Research & Development, 35(2), 161*

(7) Schreiber, N.S., & Gettens, R.T.T. Aquatic Design for Individuals with Disabilities: Upper Limb Prosthesis. *Department of Biomedical Engineering, Western New England University.*

(8) Shorter, J.J. (1986) Carbon Fibers- Uses and Prospects. *Proceedings of the 3rd PRI International Conference. Carbon Fibres 3.*

(9) Smith, M. J., & Kirk, S., & Tate, J., & Cox, D., (2014). Material characterization and preservation guidance for a collection of prosthetic limbs developed since 1960. *Studies in Conservation, 59(4)*

(10) Thurston, A.J., (2007) Pare and Prosthetics: The Early History Of Artificial Limbs Proceeding of the 2006 Cowlishaw Symposium.