Above the Knee Prosthetic Lining Using Braided Composites and Natural Fibers

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August 12, 2021

ABSTRACT

This project focuses on the design of an above the knee prosthetic lining made up of a natural and a synthetic fiber using a braided composite approach. Prosthetic linings are a part of an artificial limb that the amputee puts on their residual leg to protect the skin from any type of lacerations that may occur while in movement. Current linings are typically made only of silicone which traps heat inside and causes discomfort for amputees. The design that is explored in this report is composed of two separate layers which fixes present problems. Consequently, this allows amputees to wear their prosthetic without nuisances.

INTRODUCTION

A prosthetic for an above knee amputation is composed of a lining, a socket, a limb and any structural and mechanical components. Although not all prosthetic legs utilize one, a lining is used as a residual limb-socket buffer to prevent any further damage to the leg and skin while also providing comfort [1]. Traditionally speaking, the lining has been made with silicone, silica gel or polyurethane; even some with harder plastics [1]. However, each material has its own unique set of mechanical properties and disadvantages. With this in mind, the focus of this report is the reinvention of the traditional lining using a braided composite material. This method has fibers or yarns that are weaved together to form the desired shape and held together by a matrix, usually epoxy. Not to mention, this is an incredibly versatile yet low cost technique that gives strength and durability to the design. In fact, the more common applications of this method are structural columns and pressure vessels [2]. Nevertheless, this literature review explores the idea of using a less traditional material paired with a common one to improve and enhance the design of current linings.

IMPORTANCE & PURPOSE

After a tragic event such as an amputation, a patient can encounter many drawbacks to using a prosthetic. A common problem among leg amputees is adjusting to the fake limb and using it on a daily basis. Although it's used to facilitate movement, prosthetics tend to be heavy, uncomfortable and hot. This can lead to the patient using it very little, or not at all which defeats the purpose. In addition, leg amputees already have a much slower gait at 64m/min compared to an abled person who typically has a pace of 91m/min [1]. To ensure that a patient has a smooth transition to using an artificial limb, the lining should be as comfortable as possible [1]. This includes cushioning the leg from the socket which is typically hard and uncomfortable. This layer is usually made out of silicone, but because of its poor heat conductivity, sweating becomes a problem which can lead to the chaffing of the residual limb and can even cause more serious skin abrasions [1]. It's important to realize that in addition to the physical difficulties of having an amputated leg, patients also have to deal with the psychological distress associated with an amputation. Ideally, they would have a prosthetic that feels completely normal; and one way to do that is to improve the current linings.

STRUCTURE

The usual dissatisfaction in the prosthetic and more specifically the lining comes from the heat that gets trapped inside. As mentioned, this can potentially have harmful effects such as chafing. To allow air to circulate, there's the possibility of changing the material of the lining and choose something more porous or breathable [1]. However, this material needs to be elastic and rubber-like to provide some sort of cushion for the leg. Another possibility is to have the lining structured in such a way that there are large spaces between each fiber/yarn which permits air to flow. This means that the yarn would not be as tightly wound and there would be no matrix to maximize air circulation. While this would make other structures too malleable and flexible, it is perfect for this type of design where the lining should cover the residual limb in a similar fashion as a sock covers a foot. Furthermore, incorporating both these concepts in a single design would enhance the mechanical properties of the lining. With all this in mind, a two layer lining was devised. The surface closest to the skin would be made up of thin hemp fibers to allow for both protection and breathability and the second layer would be a thicker silicone that's loosely wound to provide support and padding.

MATERIAL SELECTION

Hemp

As of late, natural fibers are the preferred material because they're the more environmentally friendly option [3]. While this is true, they also offer a wide variety of attributes. Notably, they're biodegradable, less expensive and they're generally less of a health risk [3]. That being said, they tend to perform better when combined with a synthetic fiber. This synthesis has all the characteristics of natural and synthetic fibers which mean they have a wider range of qualities [3].

While choosing hemp, all its qualities had to be put under a microscope and analyzed to make sure that it was the ideal fiber for the prosthetic lining. Some of its key characteristics include it being aseptic, meaning that it's free of any bacteria, germs and other harmful microorganisms [4]. Seeing as the lining would be in a possibly damp environment, it would be the perfect breeding ground for germs. This can cause infections, and further problems to the residual limb. Furthermore, hemp very rarely causes allergic reactions and it doesn't hold moisture, ergo: no mold [4].

Cultivation wise, hemp is an environmentally friendly, high yielding crop [5]. It grows incredibly fast and is known to flourish in different environments–it can even withstand 0°C even though the ideal temperature is 7.8°C to 27°C, which is already a large range [4]. Another advantage: once hemp has completed the first couple of growing stages, it becomes drought resistant–perfect for dry places like Arizona and California. Conversely, the one shortcoming is that very heavy rain destroys the crop [4]. Having it grow in suboptimal conditions can and will lead to lower crop quality. However, this means that hemp can grow in many places around the world and is not contained to a single specific area or environment. It doesn't necessarily have to be cultivated in a dry and warm place. Hemp's versatility is one of its strong suits seeing as the weather is constantly changing and cannot be controlled. Whereas some crops will die when there's a slight environmental change, hemp is resilient and can power through.

The timing in which the hemp should be collected is controversial seeing as one source indicates that right before flowering is best [1] and the other says that harvesting once the hemp flowers is most optimal [5]. Although the practices are mostly circumstantial and there's limited research available, the cultivation of hemp will only improve throughout the years. Yet, since hemp is not a developed economy, it has little to no technology and equipment dedicated solely to its harvest and process. This means that while it gains traction and more people invest, the equipment traditionally used to harvest and process flax can be used for hemp [5]. Meanwhile, the technology to separate primary fibers (longer fibers more suitable for textiles) from the secondary fibers (shorter and better for pulp) can be developed [4]. Otherwise, the changes that would be made to the actual equipment is minimal, you'd only have to change its setting to make it more suitable for hemp cultivation.

In the future, as hemp is more widely used, there is a possibility to improve its characteristics using genotype selection but for all that to happen, the stigma around hemp will have to be battled by educating on how it differs from marijuana [3,4].

Regarding the process of growing hemp, it requires little water and little to no pesticides [5]. The latter not only ensures a healthier environment, but also a clean and safe product. In comparison to cotton, the world's leading textile material, hemp is more environmentally friendly while also having a similar performance to cotton. Not only does it only use up a third of the water that cotton does and produces three times more fiber per hectare, hemp also allows for a reduction in cost production of 77.63%. As a whole, hemp has a smaller ecological footprint than cotton [4].

The 3D model of the hemp layer of the lining accurately demonstrates how it would look once produced. This first layer will protect the skin from chafing and skin abrasions, will wick away

3D Model of Hemp Layer of Prosthetic Lining designed by Eric Lepp

the moisture with its breathable properties, and will ensure that there are no harmful microorganisms thanks to its aseptic nature.

This model was created using the dimensions of a leg. It will go approximately 20cm above the stump of the leg and hug it snugly to ensure no movement. It is 1.5mm thick and has 5% of empty space to have better air circulation while also protecting the skin.

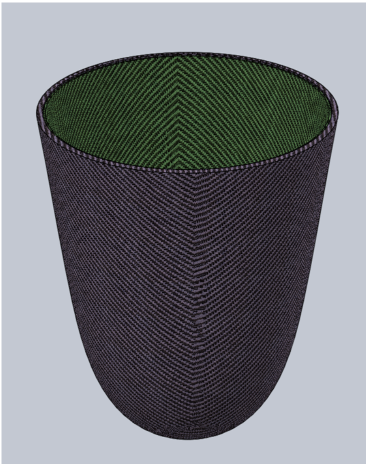
Silicone

A rubber like polymer, silicone has many attractive properties. Commonly used in prosthetic linings, silicone is used to provide padding all around the residual limb and provide it support. That being said, it usually covers the entire limb but seeing as silicone has some insulating properties, it heats up the socket and the patient's leg starts sweating. Cooling ducts and systems have been incorporated in socket designs to provide some relief but why not fix the problem at its root? To do so, this layer will feature large gaps in between each yarn to ensure that air passes by freely (not pictured accurately in 3D model).

3D Model of Silicone Layer of Prosthetic Lining designed by Eric Lepp

Eliminating silicone entirely from the design would complicate matters. As a cushion, silicone works effectively. Other alternatives like rubber would be too hard and wouldn't be most comfortable for the patient. Only using silicone with large gaps would risk the change of abrasions in the areas not covered by the silicone. This specific layer would have 25% empty space to ensure as little heat as possible gets trapped in the lining.

RESULTS AND CONCLUSION



3D Model of Both Layers of Prosthetic Lining designed by Eric Lepp

This literature review attempted to find a better design for the current above the knee prosthetic linings. Two alternatives were considered: finding a perfect material that is breathable and that offers cushion or an open mesh design to allow for air circulation. Instead, the better solution was to combine these two ideas. Hemp was chosen as a first layer to cover the skin and protect it from any lacerations while silicone was chosen as a second layer to provide comfort and cushion.

In the future, the focus of this design would be to explore the cultivation of hemp in regards to making it more widespread. This allows the overall cost of the lining to decrease and be more readily available to all amputees, specifically those from low-income households. Amputees already suffer from an array of difficulties that include but are not limited to: psychological trauma, instability, skin problems and discrimination in the work force. While not a panacea, providing them a comfortable prosthetic is one step forward in their recovery and aids them with reintegration into society.

ACKNOWLEDGEMENTS

Thank you so much to WISEST–specifically Bridget, AJ and Hannah–for creating this amazing program and for offering me a spot to complete a summer's worth of research. A very special thank you also goes out to my PI, Dr. Jason Carey and my supervisors, Mr. Lepp, Mr. Ead and Ms. Belisle. You four have guided me this summer and have helped immensely in the realization of this project by offering advice, by answering all my questions and by creating a comfortable and safe environment. Thank you to Holly Pougnet, my fellow researcher, for supporting me and for being someone to relate to during this experience. Thank you to my dad for strongly encouraging me to apply to the program and finally, thank you to my family and friends–especially Natalia–for bearing through the rants of my project. You have all played a role in this paper and I am forever grateful.

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