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Research Paper

Review of Modern Bionic Prostheses Development and Application

Eva Siao

Abstract
Prostheses are an extremely important part of life for amputees, as more than a tool to cope with disability. The goal of bionic prostheses is to replace the biological limb as much as possible, and to try to maximise the human experience, and this paper explores the technologies that help move towards that goal.
Modern bionic fields have made many advancements in recent years, most notably in osseointegration and haptic feedback, but there are still limitations to the technology. There are also promising clinical trials in progress, and those are also analysed and discussed.

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I. Introduction

This paper is on bionic prosthetics, with particular focus on developments in haptic feedback and weightbearing improvements through osseointegration. It is mostly focussed on reviewing recent developments in osseointegration to improve weight bearing, usability, and comfort, and its relation and compatibility with the haptic feedback that marks advanced prosthetics. In addition to those major and mainstream advancements, promising trials-in-development and ethical limitations are also discussed, as well as pros and cons of each prosthetic choice.

The bionic prosthetics discussed are limited to bionic limbs in amputees, and so does not address prostheses such as dental or joint replacements. The main review is on technologies that are already in mainstream use today, and contains explanations of the application and function of the various technologies that comprise an advanced bionic limb, as well as analysis of how it should be used.

In the following sections, the main components of modern day bionics are explored. The interaction between the abiotic wires and metal and biotic nerves and muscle is key to successful and intuitive use of bionic limbs, and the paper discusses the two most developed technologies that solve this problem, as well as new technologies that, once finished with clinical trials, may revolutionise the field. The most important part of all this technology is the application to the patient, so all of the technology will be analysed in relation to application to amputees.

Though development in this field is very promising, there are still many limitations. With the sensitivity of human identity to the biological body, there are also ethical debates that should be had before the technology makes more leaps. The key components to bionic technology are explored in three sections, concluding with the author's summary of the advancements and limitations.

Osseointegration

There are currently many systems in use for osseointegration, but there are five that are most commonly used, but they all aim to achieve the same goal of successful integration of non-biological implants with the bone to increase load bearing success. This paper focuses on limb prostheses. The current state of the art technology is based on very careful patient selection, preoperative preparation, and finally the successful implantation of a reliable osseointegration system. There is also a technology in development of osseointegrated haptic feedback for bionic limbs, however it is not yet approved or widespread.

The patient selection criteria evaluates bone integrity, skeletal maturity, and the length of residual bone to determine if a patient has low enough risk to proceed with the operation. Because of risks involved with osseointegration that could potentially hurt the amputee further, the patient must have demonstrated difficulties with the traditional socket system (external prosthetic that is attachable and detachable from the soft tissue of the amputation site). One of the most commonly used and safest is the Hagberg et al. report of the OPRA system, with no reported femoral fracture or septic failure, however there is still a 5.6% rate of aseptic failure and 11.2% rate of superficial infection, and this is only under observation after surgery with no data submitted by OPRA on the follow-up. The OPRA system has been FDA approved.

The advantage to osseointegration is mainly weight bearing, mobility, and solution of socket problems. Because the implant is directly attached to the bone, it eliminates problems such as the socket-tissue interface being too unstable to bear much weight. More importantly in arm prostheses, patients are now able to pick up heavier objects since the implant distributes weight through the bone. The amputee also has a much better feel and control of the prosthetic since haptic feedback is now provided through vibrations they feel in the bone instead of or in addition to artificial vibration transmitters (See Section Haptic Feedback). The bone-implant interface allows more bone and muscle around it to grow back since they are exercised, and it significantly increases mobility and comfort of the amputee. With the procedure done, the socket and all of its related problems are also eliminated: sores, poor fit, skin irritation, etc. are no longer a worry.

A disadvantage to any procedure are the risks. While rare, failures and fractures do still happen, and will render the amputee not only unable to proceed with osseointegration, but also have even more difficulties with a socket prosthetic. According to Dr. Laurent Fossart, 100% of osseointegration patients experience superficial infection, and 41% experience deep infection, both of which are treatable but cause a lot of pain. Osseointegration is considered a safe procedure however, especially with proper patient screening.

Haptic Feedback

Haptic feedback in the context of bionics refers to technology that gives the user a simulation of touch. The current most reliable and advanced technology are custom-made vibrations in the socket or around the amputation site. The vibrations stimulate the remaining nerves at the amputation site, and send signals to the brain as if the lost limb was still intact. The current most advanced technology is still in clinical trials: the developing project of osseointegrated haptic feedback is making a lot of progress, but has not yet been approved for use. This technology would allow better integration of the osseointegration protheses and haptic feedback devices, and the electrodes and vibrations would be applied directly to the surviving nerves under the skin. There have been a few cases of successful integration of implanted electrodes in the nerves, but the current most reliable technology is external.

The main advantages of haptic feedback are sense of grip, texture, control, and spatial awareness. A major complaint of prosthetics even in bionics is that most movement is sight based. The amputee has to keep their eyes on their prosthetic instead of knowing where they are as they would a biological limb. Haptic feedback allows them to know where they have positioned their limb and allows much better control. Haptic feedback also allows the user to have a sense of grip strength and texture of the object they are holding, and it allows them to hold delicate objects as well as hold children without fear of hurting them.

A disadvantage to haptic feedback are its high costs. Haptic feedback is by necessity coupled with bionic prostheses which are already expensive by their robotic nature, and implanted electrodes have even higher procedure costs. If the patient wants vibrations that correspond to their intact muscles and nerves, the equipment must be custom-made, raising the price threshold. If the vibrations are not custom-made, however, the user has to learn to interpret the haptic feedback given with no assistance of the natural nerves. If there was no osseointegration involved, those electronics also increase the weight of the bionic limb, potentially causing more mobility difficulties.

In the developing electrodes method, electrodes are implanted in the nerves left over from before amputation, and it feels remarkably similar to a real hand as it stimulates the nerves and muscles that the biological hand would have used. External vibrations are placed in and around the socket, corresponding to the muscles and nerves left behind. The sensors in the bionic fingertips have pressure pads, and in more advanced versions thermometers, and can transmit pressure and heat through the vibrations and temperature on the socket.

Brain-Computer Interface (BCI)

The Brain-Computer Interface (BCI) is a system that allows the human brain to control a robotic device without physical contact through the reading, interpretation, and execution of brain waves. This allows amputees with very little residual limb or poor muscle function who cannot use MyoElectronics to have access to bionic limbs. MyoElectronics is a technology that is partnered with haptic feedback, usually in the form of an armband around the residual limb that reads muscle use. With BCI, using non-invasive electrodes in a headcap, patients are able to control movements such as locking and unlocking of the knee of their bionic prosthetics without manual support.

One of the biggest advantages to BCI is its intuitiveness. Prosthetics usually require a long term of physical therapy to acclimate to, but in this case, the signal comes directly from the brain. The patient does not need to learn which muscles to activate, which buttons to press, and more. Instead they only have to think about it, as one would a biological arm. Another advantage is the access it provides to amputees with little or incapable residual limb, who would otherwise be limited to non-bionic options or manually controlled bionics.

The technology is however still limited in its accuracy: non-invasive methods are most common, but those electrodes read through the layers of the skull, skin, and muscle that can disrupt the signal. But invasive implantation of electrodes, while allowing much better signal, can cause complications in the brain.

Ethical and Technological Limitations

With the development of more complex and sophisticated movement as well as better sensory technology, bionic limbs are becoming more and more lifelike, but it is important to also understand the limitations of today's technology. Current existing and widespread technologies are still rather uncomfortable, especially for patients that do not qualify for osseointegration.

The most promising technologies such as widespread BCI use and osseointegrated haptic feedback are still in clinical trials, but will likely make leaps in improvement very soon. There is a limit of how much bionic prostheses can imitate biological limbs, but eventually the technology is likely to develop to the point of surpassing normal human physical capabilities.

However, with such drastic improvements to this technology, it raises the important question of the ethical limitations of how far enhancement past human force should go. Some may argue that we might just cross that bridge when we come to it, but I believe that the progress of technology is inevitable, and we need to have discussions and reach conclusions before it will be too late. To what degree ought we develop and use technologies that blur the line between human and machine?

II. Conclusion

Bionic technologies are now the most widespread form of limb prosthetics, and advancements are still being made very quickly. The central components analysed in this paper are osseointegration, haptic feedback, and BCI, with focus on exposition of technology and real life applications. Osseointegration is currently the best solution to problems with weight bearing and intuitive usage, and it is now working more and more closely with haptic feedback, which really adds to the human experience even using abiotic limbs. Brain-Computer Interface, once fully integrated into bionics, completely removes the intuition inhibition factor of prosthetic limbs that prevents many amputees from using one regularly, and with all of the modern technologies, bionic prosthetics are coming closer to imitation a biological limb.

With the momentum of the current developments in the field, the ultimate technological limitations are very little, but it is necessary to understand that we are not there yet. However, discussions should be started about ethical limitations that may be needed to be imposed.

Future developments in the field include safer electrode implantation, more techniques for osseointegration that doesn't exclude a percentage of amputees, more accurate BCI technology, and cheaper and more accessible haptic feedback. All of it is achievable and within reach, and will make a significant impact in amputees' lives.

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