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Honors Calc II

I. Background (1,4)

Prosthetics are a rapidly developing specialization offered in biomedical engineering, through modern advances such as silicone molds that replicate customer features to match skin tone and shape. Beyond the cosmetic, nervous system control of prosthetic devices is leading to the ultimate task of establishing patient sensory response, where people could be fully aware of their own assistive tools. With all its success in recent years, this report is meant to provide a comprehensive understanding of prosthetic assistance, from its history to development and design, culminating in an estimate of its impact in the future. Specifically, it looks to better explain the complexities of modern exoskeletons, and the mechanics involved, touching on possible commercial uses and expansions. However most importantly, a summation of the progress in development provides a clean representation of chronological improvements, critical for understanding modern application into the biological realm, explaining how prosthetics went from inadvisable to encouraged; now having the potential not only to restore, but to advance physical capabilities.

II. History (2,3)

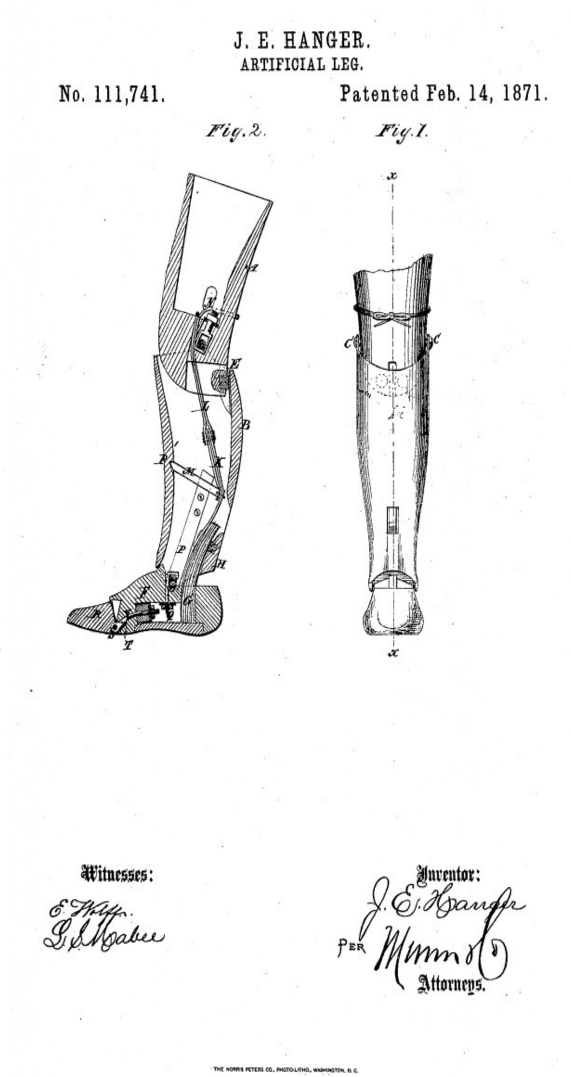
Credit for the first prosthetic device lends itself to the ancient Egyptians. A toe made of linen and plaster was constructed around 850 B.C, with evidence of wear to suggest that its use was for more than the cosmetic. However, for better comfortability, the toe needed to be supported by a sandal to keep the foot in line and avoid pressure sensitivity. Motor movement and balance were improved, with “87 percent of the flexion (amount of flexibility)” (3) in comparison to a normal toe.

The next documented attempt at prosthetic assistance was an artificial leg for an amputee, extending from the knee down. Dating back to 300 B.C, it was made of bronze and iron with a wooden core. We don’t have evidence of its functionality, but the jump between replacing a single toe to half of a leg is substantial.

However, it took centuries before improvements were made in design, with the peg leg and hand hook in the Dark Ages. Most of these devices were made in consideration of war and battle, and so some just held shields in place, or hid injury, lacking practical functionality. Only the elite had access to these devices able to assist in day-to-day activity, as some of the more advanced prosthetics had gears and other shifting components that required more specialized labor to create.

The push for real advances in prosthetics started with the Renaissance. In this time period, the construction and intricacy of the devices specifically evolved by advancing the pre-existing technologies for hand and leg replacement. To start, iron and heavy metals were replaced by “leather, paper, and glue”, to reduce weight while trying to maintain durability. Ambroise Pare invented an artificial leg that could be adjusted and locked into position, with the end goal of increasing the fluidity of prosthetic devices. Soon, upper-leg prosthetics came with non-locking knee joints, tendons meant to assist with natural walking, and pressure and balance distribution systems with “multi-articulated feet” (3), which are capable of motion in multiple joints.

Progressing through the Civil War, Americans adopted most of this Eastern technology as the number of amputees rose significantly.



This is the Hanger Limb, the adopted and improved version of the earlier Selpho Leg. The most prominent features of this device were the cable attaching the upper and lower parts, and the inner brace labeled as M and P to stabilize ankle function. Also notice the axis of symmetry running through the leg, with part G acting as the Achilles tendon. Mechanical advances were the most important for prosthetics at this time, leading to the development of the modern prosthetics.

III. Current Advances: (3)

After World War II, a stronger push was made for prosthetic research and development, led by the military. Comfortability and function were the two main goals, but cosmetic and mechanical upgrades were made as well. The pinnacle of these efforts is now represented by two different types of prosthetics, for the hand specifically: body-powered and myoelectric (powered by an external battery). Although lower body prosthetics are equally important, they more easily integrate into the body and currently provide higher quality limb replacement in comparison to hand and upper body prosthetics.

Hands have multiple complex functions, and because sensation is a work-in-progress, current devices have different designs for picking up a big cup versus a small cup, for instance. Myoelectric proportional control prosthetics look to increase functionality without also increasing stress on the existing limb, by providing energy through a battery outside of the body. Multi-articulated joints help with replicating the intricacies of the hand, so as to provide a set of programmable functions for one hand without being required to switch to another. These myoelectric sensors allow the client to use their existing limb, where electrons are still jumping around, and use the muscles remaining to control the particular functions of the hand. The actual design and components of some of these hand devices are rather simple, using ABS plastic for 3D printing of larger joints, attached by cables and adjusted through the control and feedback response of the client. These prosthetics provide more reliable, daily use without the impracticability of sitting next to a computer and pushing buttons for specific tasks.

To put into perspective just how revolutionary some of this technology is, it is important to identify the leaders in industry and production. In 2017, Ottobock advertised its BeBionic hand (5) as multi-articulated with “separate control of the index finger” to increase the efficiency of gripping patterns. The dexterity of the human hand is often taken for granted, as even the most technologically sound devices are only just now catching up with some of its movement capabilities.

However, the limited market for people who actually need prosthetics means most of the projects are government funded, and therefore myoelectric control comes at a hefty price.

A simple, motorized, single-grip prosthetic device retails at sufficiently low prices to be received by all people with varying necessity for limb replacement, but beyond its cosmetic appeal, these devices have many functional kinks that turn off potential clients. Another problem with myoelectric prosthetics are their weight. Clients already have less muscle meant to control the same amount of material, which is why the battery providing outside power was necessary in the first place, but all of the extra components add noticeable weight further away from the existing limb, meaning an exponentially greater amount of support is required. Consequently, modern advances in prosthetics are inevitably drawn towards neural stimulation, so as to provide enough instantaneous feedback with devices such as micro-electrode arrays (tiny signal receivers) to transform neural signals related to intended movements into control signals that can be interpreted by a computer. Full control of prosthetics would follow, getting the science of prosthetics closer to replicating the true potential of hands, and even superseding biological hand capability, which will be discussed in further detail in section 4.

III. Application through Development and Design (5)

A. Body-powered hand prosthetics

Multiple prosthetic hand designs exist due to varying patient utility and needs. Although body-powered prosthetics aren't as capable as the cutting edge myoelectric devices, they weigh considerably less than their competitors, being around half of the standard weight. Modeled for efficiency, the harness interface (the system most commonly seen in hand prosthetics) is either voluntary opening or closing, which changes the comfort and mechanics of the device. For voluntary opening systems, the gripping force comes primarily from springs, which is reliable but limited in its potential to provide biofeedback. Voluntary closing systems require actual body power, meaning they have a larger activation energy to operate. However, the consumer can have an understanding of the force being applied in basic activities, which is consistently rated as a significant priority. Also, springs are limited in their actual grip strength in comparison to the voluntary closed system that needs constant tension to operate, just like the natural hand when gripping objects.

B. Torque (6)

Another notable problem when designing hand prosthetics is generating torque through wrist strength and flexibility, especially when the prosthetic extends into the lower arm. Wrist units often have quick-release connectors, which allow for interchangeability when consumers are looking for a different type of functionality or relief. For instance, if the weight of the myoelectric hand was too taxing after a long day, it could quickly be separated from the arm and swapped for a cosmetic or body-powered prosthetic with significantly less weight. Often, due to the current limitations of these devices that most accurately resemble human hands, terminal devices such as hooks are substituted in as cheap alternatives with quality applications. Most consumers prefer utility over cosmetic appeal, which is completely understandable when realizing the amount of daily tasks completed with two hands. Although having control of five individual digits with modeled grip strength patterns would be ideal, these terminal designs often have advantages over human hands. For instance, they can withstand more mechanical and thermal stress, making them better situational tools, which is the primary reason for having quick release systems that can switch out devices for different tasks.

C. Shortcomings

Research in prosthetics isn't optimally positioned. Other specializations such as regenerative medicine or neural rehabilitation often take precedence over prosthetic advancements due to their scope and potential for massive breakthroughs. Consequently, more money is put into these other fields, resulting in less research grants and such that would allow biomechanics to progress towards optimized designs. Also, regardless of the funding, neural integration and sensory feedback response are very new in conjunction with prosthetics, and will need a lot of work to be functional enough for practical availability to the consumer. Proprioception (7), or the users knowledge of the position of the prosthetic without directly seeing it, is even farther away, and due to media raising expectations for the quality of these devices (i.e. Luke Skywalker's hand or the Winter Soldier's arm), people are often let down by the current capabilities of this technology.

IV. The Future of Prosthetics (7)

As previously mentioned, full awareness and feedback response are becoming more prioritized and researched as prosthetic design is shifting toward total integration in an effort to most closely model an actual human hand. However, there are other systems that are being worked on that will have equally important roles in developing this level of immersion into the body.

Osseointegration is where the metal component of the prosthesis would be grafted directly onto the bone, causing actual bone and tissue to grow over the device. Due to the nature of the metal and its honeycomb structure, bone tissue could actually grow inside the metal shaft to create a cohesive and stable foundation for a prosthetic device. Although this is most currently seen in hip or knee replacements, there would be significant application for an amputee who needs lower arm replacement beyond the hand and wrist devices.

Bio Augmentation Systems (5) have similar application, where the integration between technology and bone would allow for direct connection to the nerves, inducing electron stimulation automatically. There are some concerns for building a seal between the skin and the implant that exists outside of the body, and so biomaterials research is necessary to make these systems more of a reality.

V. Conclusion

Overall, the potential of prosthetics is great. Technological progress merits even greater possibilities, fantasized in superhero movies and such. However, work needs to be done in between to find some practical medium that supports potential consumers and their immediate needs, like any health device is supposed to do. For instance, if the prosthetic is too heavy, despite all of its incredible features, it has no real marketability. Consequently, the process of building a prosthetic requires a lot of user feedback and time.

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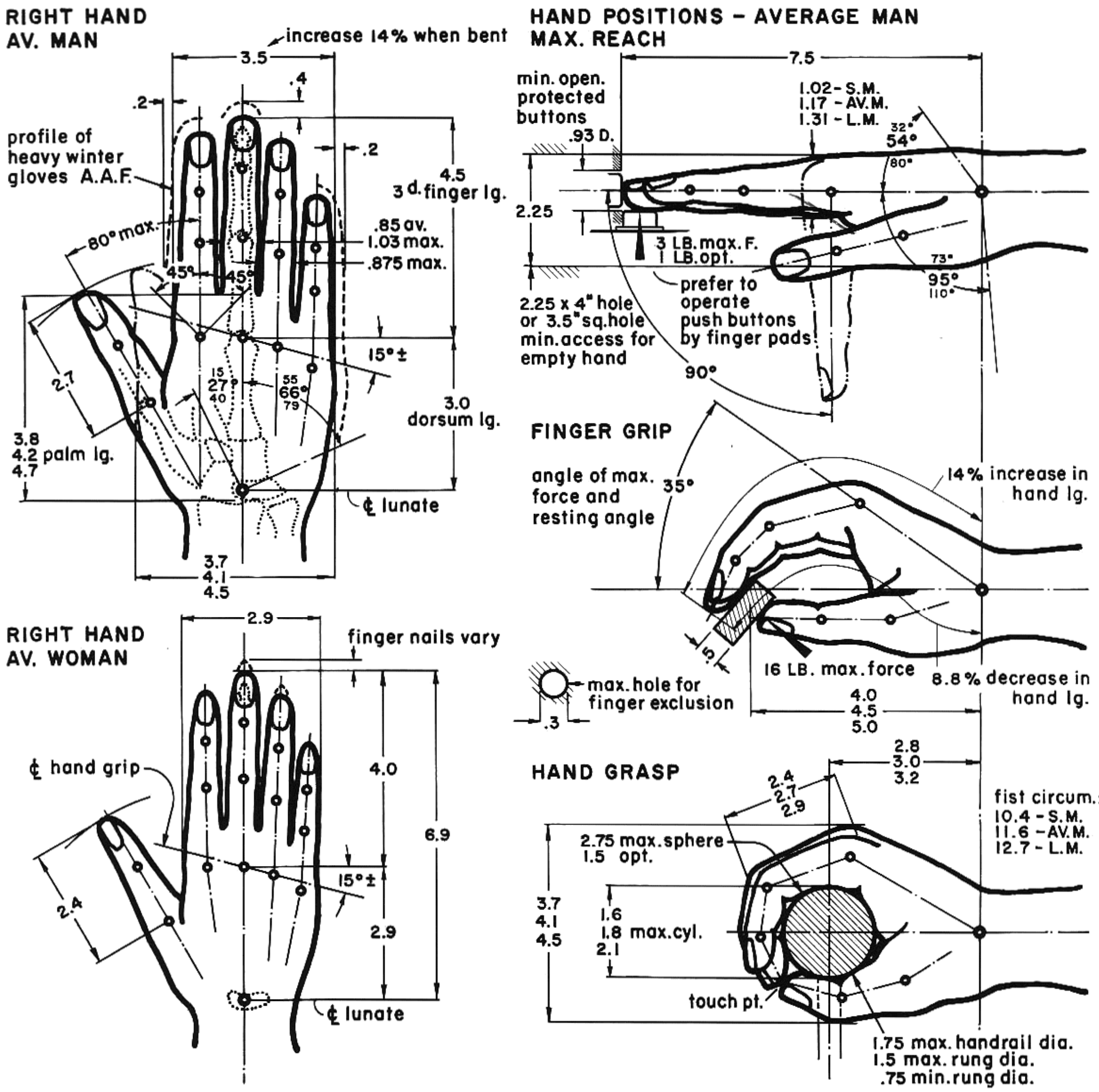
HAND MEASUREMENTS OF MEN, WOMEN AND CHILDREN



HAND DATA	MEN			WOMEN			CHILDREN			
	2.5 %tile	50. %tile	97.5 %tile	2.5 %tile	50. %tile	97.5 %tile	6 yr.	8 yr.	11 yr.	14 yr.
hand length	6.8	7.5	8.2	6.2	6.9	7.5	5.1	5.6	6.3	7.0
hand breadth	3.2	3.5	3.8	2.6	2.9	3.1	2.3	2.5	2.8	—
3d. finger lg.	4.0	4.5	5.0	3.6	4.0	4.4	2.9	3.2	3.5	4.0
dorsum lg.	2.8	3.0	3.2	2.6	2.9	3.1	2.2	2.4	2.8	3.0
thumb length	2.4	2.7	3.0	2.2	2.4	2.6	1.8	2.0	2.2	2.4