Upper Limb Soft Robotic Exoskeleton for Shoulder Mobility Rehabilitation in Stroke Patients

Social Determinism of the Da Vinci Surgical System in the United States

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

What qualities in a robotic device lead to the most successful cultural acceptance?

Stroke is a leading cause of disability and death around the world, affecting around 13.7 million people (Kuriakose & Xiao, 2020). Various chronic conditions which may follow after suffering from a stroke. Around 60% of stroke sufferers develop limitations in mobility, vision, and speech, which prevents the ability to do day-to-day tasks that most able-bodied people take for granted, such as preparing food or using the bathroom (Poomalai et al. 2023). As treatment and therapy options have improved over the years, the state of stroke patients has changed, and most are hopeful for their recovery.

With more innovation in stroke recovery technology, the implications of suffering a stroke may continue to improve and no longer warrant the same level of dependence. One of the most advanced forms of stroke recovery involves the use of assistive robotics, and these therapeutic robots have been shown to be effective in improving patients' muscle synergies and range of motion (Hong et al. 2024). However, these robots are still not available to much of the public and are generally limited to hospital access. The technology must be further developed and understood before it can become available enough to become a device that patients can buy and use to rehabilitate themselves at home.

The technical aspect of this project is to design a soft robotic upper-limb exoskeleton that can help patients through stroke rehabilitation. The goal is to make a device that will help stroke patients feel more independent at home. The STS portion of this project will study the cultural effects of other robotic devices in the medical community, particularly the Da Vinci robot system. By studying the Da Vinci's development, I hope to gain an understanding of what factors resulted in the cultural acceptance of the robotic system.

Soft Robotic Upper-Limb Exoskeleton for Stroke Rehabilitation

How can a soft robotic exoskeleton be designed to aid in stroke rehabilitation?

The technical aspect of the project aims to further develop this assistive technology using soft robotics. The usage of soft robotics allows the assistive robots to have a form factor which is lighter, safer, and less cumbersome to operate due to its soft nature. Additionally, it should also be far more affordable compared to hiring physical therapists or other robotic equipment, as it only requires the material for soft robotic “muscles,” 3-D printable mounting equipment to attach to one’s body, and what is essentially a programmed air compressor. The soft robotic muscles will be mounted on an exoskeleton for a person to wear. These muscles are positioned such that they can assist in shoulder adduction and flexion with a ninety-degree range of motion. Additionally, by using electromyography sensors on the patient’s body to detect electrical signals sent to the muscles, the exoskeleton can move with the user’s intention. As such, this exoskeleton would primarily be used to rehabilitate and assist in shoulder movement for stroke patients.

According to Chang, robotic-assisted stroke recovery excels the most at improving range of motion and muscle synergies (2013). As such, an important design goal for the soft exoskeleton is to maximize its range of motion. In the designs of previous capstone projects that have attempted a similar project, shoulder range of motion was very limited. The human shoulder has three degrees of freedom: abduction/adduction (raising/lowering your arm directly to the side), flexion/extension (raising your arm directly in front/behind you), and internal/external rotation. Previous capstone groups were only able to achieve one degree of freedom (abduction) with a range of motion that was limited to around 45 degrees. They achieved this using a singular soft muscle connecting from the top of the shoulder to the side of the elbow.

In order to improve on the previous design, the new exoskeleton is implementing a second soft muscle that is in series with the first one. The first soft muscle (connecting from the shoulder to the elbow) will contract first, achieving a ~45-degree range of motion. The second soft muscle, which connects from the top of the shoulder to the back of the neck, will contract second, achieving another 45 degrees of motion. This totals a 90-degree range of motion. A diagram of the general design can be seen in Figures 1, 2 and 3. The parts of the design that mount to the user will be 3D-printed, with some select parts being machined from steel.

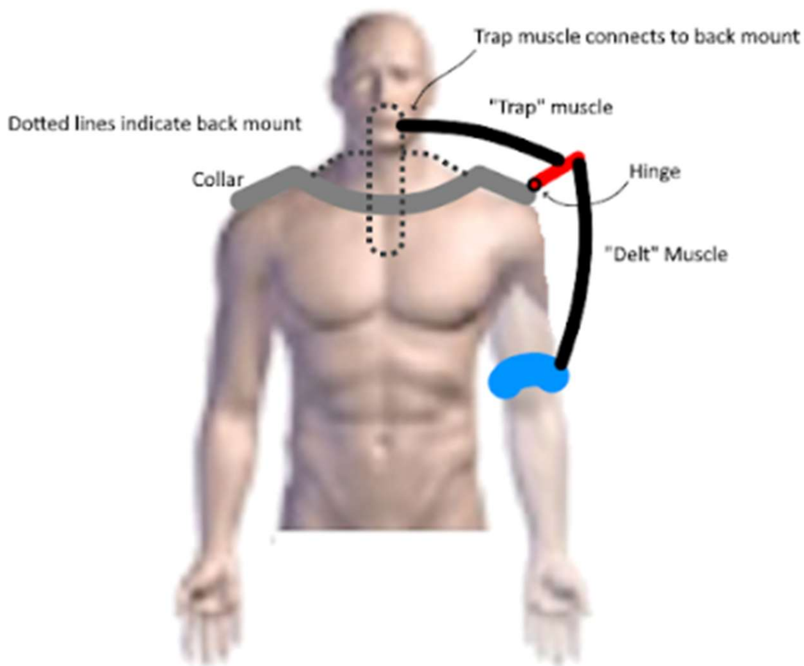

Figure 1. Design of muscle placements at resting position.

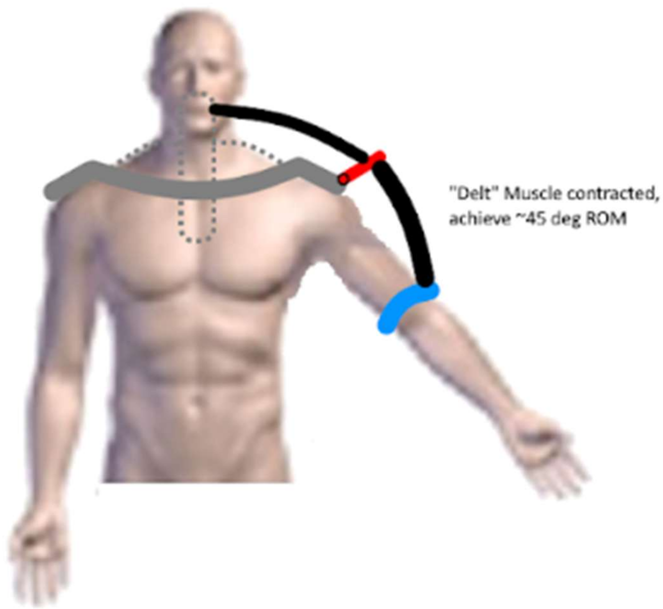

Figure 2. First muscle ("delt" muscle) contracted.

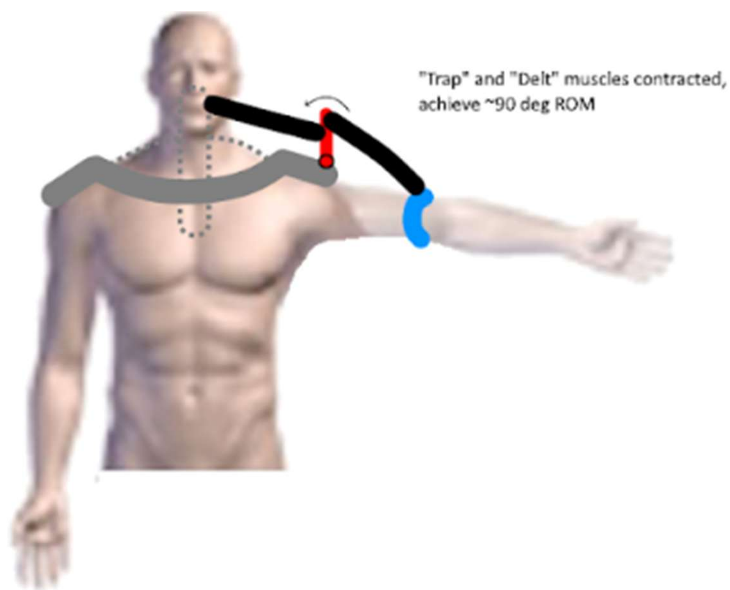

Figure 3. Both muscles contracted.

The new exoskeleton will be designed to be modular so that different degrees of freedom can be achieved. However, the exact designs for this are still in progress. Additionally, the exact materials and design of the air muscles are still to be determined, but the general working principle is that these muscles contract/expand like a balloon when filled with air. The inner shape of the muscle and the varying thickness of its outside layer affect the motion it produces. The pressure of the air and whether it is being pumped in or vacuumed out determines how strong and how large of a contraction will occur (Antonelli et al. 2022).

Social Determinism of the Da Vinci Surgical System in the United States

How will American culture respond to the implementation of robots when it comes to medicine practices?

The STS portion of this project will analyze the cultural response of Americans to the implementation of robots in the nursing and medical settings. This analysis will utilize the theories of mutual shaping and social determinism to the development of the Da Vinci Surgical robot system. I hope to gain a better understanding of the cultural response of Americans on robots being used in the medical setting. More specifically, I would like to determine what factors elicit a positive response and which factors elicit a negative response. A positive response will be defined as any form of cultural acceptance, such as a good review or statements placing trust in the robot over the hands of a surgeon. A negative response will be defined as any form of cultural rejection, such as any controversy around implementation of the robot that causes distrust so that people prefer the surgeon over the robot.

The concept of robots in medical settings began around 60 years ago. The goal of their development was to be used by the military so that a surgeon could remotely perform a surgery in a dangerous area (Morrell et al., 2021). As the technology progressed, the first robot that successfully began exploring this function was the AESOP system (Automated Endoscopic System for Optimal Positioning) released in 1994 (PUMA) (Morrell et al., 2021). The AESOP system was the first medical robot that featured arms and allowed remote control by a surgeon

(PUMA) (Morrell et al., 2021). However, the arms only provided a camera system, and the procedure itself still needed to be performed by hand. This led to the creation of the ZEUS robot in 1998, which featured an AESOP system along with two other arms that could hold surgical instruments (PUMA) (Morrell et al., 2021). A separate company that was also looking to improve on AESOP produced the early versions of the Da Vinci system, which had similar capabilities to the ZEUS but was significantly easier to learn and control (Sing & Gill, 2001). These two companies eventually merged in 2003, resulting in the Da Vinci system proceeding to become the most popular robotic surgical platform of today (Morrell et al., 2021).

The Da Vinci system has three components: the patient cart, surgeon console, and image system (Ngu et al., 2017). The patient cart contains robot arms with surgical instruments, and the surgeon controls the arms through the surgeon console (Ngu et al., 2017). The surgeon can see through the image system, which gave a 3D view of their procedure. This allowed the surgeon to move more precisely and not worry about hand tremors affecting the precision of their surgery (Morrell et al., 2021). Since 2003, many improved versions of the Da Vinci robot have been released, featuring improvements in arm capabilities, imaging systems, software, and ergonomics (Morrell et al., 2021). The most recent version of the Da Vinci is the Da Vinci 5, released in 2024. In 2014, there were a reported 2965 Da Vinci systems being used worldwide in 55 countries (Koh et al., 2018), and it is used for a wide variety of procedures. Its most popular use is in endocrine and gastrointestinal surgeries (Koh et al., 2018). However, its usage warranted a cost increase of about $3000 to $6000 dollars (Wilensky, 2016).

To better understand the factors that went into the success and acceptance of the Da Vinco system in the American medical community, I will study the opinions and experiences of the Da Vinci's stakeholders. The first of these are the patients. Factors such as surgery success rates, surgery costs, and overall trust in the system may affect whether patients are comfortable with accepting the Da Vinci as a good choice of medical device. For example, an article in 2016 raised some controversy about the Da Vinci, stating that in some cases the device did not have a significant effect on surgical outcome and only added to overall costs for the patient (Wilensky, 2016). In general, we want to look for articles that are critical about the use of Da Vinci, or direct patient case studies which discuss the patients' feelings about the implications of being operated on by a robot. These will help build an understanding of the public's opinion of the rising use of the Da Vinci. The second stakeholders are the surgeons and medical professionals in charge of operating the Da Vinci. Factors such as ease of use, complexity, ergonomics, and learning curve may be factors that cause medical professionals to reject or accept the use of Da Vinci. For example, a report in 2016 listed exact statistical rates of malfunctions in the Da Vinci and declared that malfunctions do not impact surgical outcomes (Cormier et al. 2017). Analysis of reliability reports and effect on surgery outcomes in conjunction with medical professional reviews will build a case for the medical community's opinion on the use of the Da Vinci. The third stakeholder is the company in charge of producing and manufacturing the Da Vinci. Factors such as customer demand and production costs can affect whether these companies deem it worthwhile to develop surgical robot systems. To study this, we can analyze sources that discuss the demand for the Da Vinci, such as statistics on its frequency of use in surgeries or the demand from hospitals. These factors can characterize the motivations behind companies continuing to produce and upgrade the Da Vinci.

Conclusion

Despite modern treatments and recovery methods, stroke recovery is still very associated with a high level of dependence on human resources in both medical and domestic settings. One of the most effective forms of physical therapy is robot-assisted, but the technology is far from being used outside of specialized hospitals. It is a very new technology but has incredible potential to improve the independence of stroke patients.

By using soft robotics, robot-assisted physical therapy can improve safety, usability, and affordability. Specifically, our project aims to design a soft robotic exoskeleton that can aid in upper-limb mobility, particularly the shoulder. The goal is to work towards bringing this technology to the homes of patients since soft robotics has the potential to be safer, more affordable, and more ergonomic than its motored and rigid counterparts that currently exist in hospitals.

To better understand how other medical robots on the market have achieved success in being incorporated into today's society, I will study the success of the Da Vinci surgical system. I hope to gain a better understanding of what factors went into the development of the Da Vinci that resulted in its popularity in the medical community, and hopefully somehow reflect these factors in the design and implementation of the soft robotic exoskeleton.

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