Implementation of Robotic Devices Into Healthcare System

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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

The effective use of medical equipment is often the deciding factor in patient outcomes, as is the case with stroke rehabilitation. As one of the leading causes of death globally, strokes are a significant contributor to acquired disabilities in adults. Roughly 80% of stroke survivors face upper limb motor impairments, severely impacting their capacity to engage in daily activities (Kwakkel et al., 2015).

There are many motor control recovery therapies in practice. A common recovery method is physical therapy, in which patients relearn how to move their bodies. A method known as constraint-induced motor therapy (CIMT) involves restraining unaffected limbs and having the patients practice moving the affected region (Clinic Staff, 2024). CIMT or modified versions of it are considered the most effective treatment regimens in physical therapy to improve the outcome of Post-Stroke Motor Dsyfunction (PSMD) (Kwakkel et al, 2015). However, there is a "golden window" for stroke rehabilitation. Patients who do not begin rehab during that crucial time frame are unlikely to recover full mobility. To address this, rehabilitative exoskeletons are used to increase patient access to rehab. Conventional rehabilitation treatments often depend on a patient's existing motor abilities, which can hinder recovery. If a patient cannot move their arm more than a few inches, they cannot complete the full range of motion required for CIMT therapy. To address this, researchers have developed robotic exoskeletons that cover the difference in strength, allowing them to complete the motions required for rehabilitation.

Exoskeletons are an evolving technology with the potential to help improve patient outcomes significantly, and as such it is important to examine how efficiently they are implemented. Implementation involves both the adoption of a new technology and the effective utilization of that technology once it is acquired. In a study examining the efficient use of medical equipment at public hospitals, 2 out of 5 pieces of medical equipment were found to be under-utilized, which could be significantly affected by the form in which the hospital received the equipment, its regular availability, equipment breakdown, availability of trained staff operating the equipment, performing preventive maintenance, and availability of adequate spare parts and accessories (Geta et al., 2023).

This paper seeks to determine what factors most affect the effectiveness of the implementation of medical technology and put that into the lens of the newly introduced rehabilitative exoskeletons. Exoskeletons are a emerging technology in the early stages of implementation, so this paper will examine the early steps being taken and how well it will likely be implemented as the field advances. This will be done by examining the top reasons for low adoption and inefficient utilization in cases related to exoskeletons. These case studies can be used as an indicator for possible outcomes in the field of rehabilitative exoskeletons.

Background

As technology has developed, modern research has begun to focus on the importance of medical equipment. Medical equipment is defined as any device, substance, or other item that may be used alone or in conjunction to diagnose, prevent, treat, monitor, or lessen a disease. When providing health services, medical equipment is utilized for several functions, including disease diagnosis and treatment as well as rehabilitation after illnesses or accidents, and its effective use can be the difference maker in patient outcomes (Geta et al., 2023). Medical devices can be basic devices such as syringes, catheters, and surgical masks, or very complex devices such as pacemakers or magnetic resonance. The World Health Organization, WHO, called medical devices "indispensable tools for quality healthcare (*Prioritizing Medical Devices*, 2021). Given their importance, researchers also began focusing on how effectively those devices are implemented, identifying maintenance, availability, and marketing as three of the largest factors in determining how effectively a device is utilized.

Each of the big three mentioned occurs during a different period of the machine's lifespan and affects a different aspect of implementation. Marketing affects the adoption of technology during the development phase, availability during pre-implementation, and maintenance affects post-implementation. Similarly, marketing and availability affect implementation through the technology adoption period, and maintenance affects the effective usage of that technology once adopted.

Marketing is a factor that focuses on the reputation a technology has. A popular theory regarding the acceptance and utilization of technology known as the Technology Acceptance Model (TAM) states that the adoption of a new device is drastically affected by the perceived use and ease of use of a technology (Luo et al., 2024). Perceived usefulness is the extent to which people think employing a certain technology would improve their productivity. People with a positive perception of technology are more likely to use it. The extent to which people believe a certain technology will be user-friendly and effortless is known as perceived ease of use. (Davis, 1989) Almost all researchers agree on the importance and role of TAM principles in the adoption of technology (Luo et al., 2024).

Availability is how easily a technology can be obtained. This focuses primarily on manufacturer interactions including pricing, quantity, services provided, ease of obtaining information, and more. The easier it is to find pricing options, information, and customer support, the more likely a hospital is to adopt the technology (Felgner & Ex, 2018). Availability also encompasses the amount of something available.

Once the technology is acquired, utilization can be greatly reduced by poor maintenance. In the process of maintenance and maintenance of large-scale medical equipment, most medical personnel have not established a corresponding quality management system, neglecting daily maintenance and maintenance (Li et al., 2022). A qualitative study on factors affecting

serviceability (the ease with which a device can be maintained and usable) identified preventative maintenance as one of the key factors in increasing the utilization of a piece of technology (Patnaik, 2025).

Methods

Robotic exoskeletons are a newly developing field and as such data regarding their usage is scarce. To learn more about potential problems, this paper will examine cases of technology similar to exoskeletons and examine which factors were relevant to the outcomes of that device.

Specifically, two cases will be examined: surgical robots and prosthetics. Surgical robots will be examined as a parallel because they have a complex robotic design just like exoskeletons. They also have similar maintenance demands as they share common components such as precise servo motors and actuators. The second case is prosthetic limbs. Comparisons can be drawn between exoskeletons and prosthetics as they both treat a similar population and may face similar concerns regarding availability and pricing.

This paper focuses on effective usage in terms of adoption and implementation. Maintenance and availability relate to the issue of implementation and marketing and availability influence adoption. Adoption focuses on how many hospitals and providers choose to include the technology in their practice. Implementation focuses on how well they use that technology; how often they use it compared to how often it could be used. Researchers call this the utilization coefficient, and it can be reduced by lack of maintenance or training.

For each case, a systematic literature review will be conducted to determine what caused inefficient utilization of that device. The analysis section will examine how this information can be related to exoskeletons and use this to make predictions about what may happen in the field.

Surgical Robots

Surgical robots represent a groundbreaking advancement in modern medicine, enabling unprecedented precision in minimally invasive procedures. These systems function by translating a surgeon’s hand movements—performed at a console—into ultra-precise, scaled-down motions of robotic instruments inside the patient’s body. Robotic-assisted surgery reduces the risk of human error, shortens recovery times, and minimizes complications such as infection and blood loss.

Globally, surgical robot usage has been on the rise. In 2012 surgical robots assisted in 1.8% of surgeries and in 2022 that number reached 17% (Strategic Market Research, 2023), with more growth on the way. Adoption of surgical robots has been slow and is still only partially

successful. While it is true that surgery robots cannot be used for all procedures (they are most useful in minimally invasive procedures), this adoption rate is still lower than it could be given that surgical robots could be assisting in more procedures still. Studies into why this number is low identified major reasons for low adoption as cost, perceived usefulness, and extremely high maintenance requirements.

A 2022 paper examining the barriers and enablers involved in the effective usage of surgical robots found a variety of factors stemming from both adoption issues and implementation issues. When deciding whether to adopt the technology, studies conducted at hospitals found that administrators and providers considering purchasing one resisted the idea because of the high cost and lack of belief in the usefulness of the technology (Lawrie et al., 2022).

Research also found that it was mostly only adopted by teaching hospitals. Data from the Healthcare Cost and Utilization Project showed that surgical robots were acquired by 45.5% of major teaching, 18.0% of minor teaching, and 8.0% of non-teaching hospitals during the early adoption phase. (Makarov et al., 2016)

However, hospitals that did adopt the technology did not do much comparative research. By 2008, 8 years after the Da Vinci robot received approval by the FDA, only 24 studies had been published evaluating outcomes between the two techniques. Of these, just 10 (41.7%) had adequate sample sizes to draw meaningful conclusions, and a mere 6 (25%) involved collaborations across multiple institutions. This lack of information on its usefulness contributed to the meager 1.8% adoption rate by 2012 mentioned previously. Comparative research is important. When interviewing surgeons who would adopt the technology in 2022, providers often quoted positive endorsements of the technology from key figures in their field as one of the reasons they ended up using it, saying, "…But when you get into the next realm, when you get into that earlier doctor group who come out of academic institutions who are good surgeons and they start to say, "This we think is good", that's massively influential." (Lawrie et al., 2022).

Robotic exoskeletons are currently similarly unresearched. Systematic reviews have found little to no concrete evidence of the efficacy of exoskeletons despite many positive patient reviews. The technology is considered investigational and premature by members of the community, though there is interest in their potential (Ehrlich-Jones et al., 2020).

If a technology such as surgical robots or exoskeletons were to be adopted, it still must be effectively implemented. Maintenance issues can often prevent a technology from being utilized efficiently. (Lawrie et al., 2022) A study that identified common causes of "flow disruptions (FD)" during robot-assisted surgery found that roughly a quarter of FDs were caused by some form of equipment (EQ) malfunction (Jain et al., 2016).

Maintenance issues can be particularly relevant for advanced technologies like surgical robots and exoskeletons as their complex mechanics require more skilled labor. Data from the Baylor College of Medicine found that maintenance of a single surgical robot can cost upwards of

$100,000 annually (Clarice, 2024).

Looking at surgical robots highlights several potential problems for rehabilitative exoskeletons. The average cost for a complete upper-limb exoskeleton with five actuated joints is in the order of $130,000 (Palazzi et al., 2022), which is dwarfed by the $1-2 Million a surgical robot would cost, but it still requires advanced maintenance. Exoskeletons are not widely adopted enough to have specific data, but drawing comparisons between the two technologies shows it is potentially a significant factor.

Another potentially significant barrier to exoskeleton adoption is perceived use by providers. This is an area in which comparison with surgical robots is particularly useful. Like surgical robots, there is barely any research done to validate the technology's usefulness.

From an anecdotal standpoint, a study that surveyed practicing physical therapists with experience with exoskeletons found those who used it found it useful in certain cases but had concerns about the maintenance being an issue. A point several repeatedly stressed is the importance of managing patient expectations. They also reported that many patients turned down the exoskeleton saying, “I’ll wait for the next model”, showing how even a flashy technology such as this still wasn’t perceived as useful by the public (Ehrlich-Jones et al., 2020).

Prosthetics

If surgical robots relate to exoskeletons through their mechanics, prosthetics relate to exoskeletons through their function. A prosthetic is an artificial device designed to replace a missing body part—such as a limb, hand, or joint—restoring function, mobility, or appearance through mechanical, electronic, or biomechanical means.

Similarly, rehabilitative exoskeletons can be used to return function to patients with disabilities, though the disability is different. They are used to allow for movements that would otherwise be impossible for disabled individuals.

Prosthetics are a useful comparison to exoskeletons as they illustrate potential barriers on the availability front. Prosthetics are difficult to acquire, with data from the World Health Organization showing that only 5-15% of people have access to prosthetics in lower-income countries (Abbady et al., 2021). Limited access to advanced healthcare in developing countries is not a new thing, but this issue persists even in developed ones. Amputees in Canada often find that availability and pricing concerns prevent them from accessing even the most bare-bones prostheses (Petlock & DiMario, 2021). The issue is one of funding, as funding agencies, both public and private, often fail to adequately meet the needs of Canadian amputees.

Amputees are often forced to pay thousands of dollars out of pocket. Notably, Canada’s healthcare system often does not offer additional benefits such as ambulance, children’s, geriatric, or rehabilitation services (Ross University School of Medicine, 2025). However, even

in the U.S. with private coverage affordability is a barrier to access for many (Orthotic Prosthetic Center, 2024). This illustrates that adoption of the device is globally hindered by issues of affordability and availability.

This is relevant to exoskeletons as interviewed physicians stated that the burden of purchasing the device fell upon the patient with many patients electing not to adopt it because of cost (Ehrlich-Jones et al., 2020). Exoskeletons are a product intended for the patient to take home and use when they can, and as such each patient must buy their own. Both prosthetics and exoskeletons can cost up to tens of thousands of dollars for patients with insurance, and the cost can be staggering without.

48% of U.S amputees did not get a prosthetic citing cost as a leading reason compared to only 4% of Austrians (Austria fully covers prostheses through publicly funded healthcare) (Salminger et al., 2020).

The issue of availability continues as you look at manufacturing. Both prosthetics and exoskeletons must create a technology molded to the specific user to ensure comfort and user-friendliness. The previously mentioned Austrian study found that in individuals who did adopt the technology, comfort, and weight were critical factors in whether or not the patient went on to abandon the device. Additionally, surveyed physicians stated that if they could say something to the manufacturers of the exoskeleton they would have them make it more adjustable so it was comfortable and usable for patients of all shapes and sizes (Ehrlich-Jones et al., 2020).

Traditional manufacturing methods have a difficult time matching the demand for prosthetics as customized, comfortable prosthetics can not be mass-produced. This is part of the reason they are so expensive. New techniques such as additive manufacturing seek to address these issues but are not ready for mainstream use yet (Kulkarni et al., 2023).

Exoskeletons experience the same issue. Each exoskeleton must be fit to the user which makes mass manufacturing difficult. Most of the current brands require special measurements to custom-fit participants before donning/doffing. This may require special adjustments for persons in case there is leg length discrepancy, pelvic obliquity, severe muscle wasting, or even highly sensitive skin; which may require up to 2-3 sessions to accomplish this task (23).

Another factor that affects the manufacturing difficulties of prosthetics is the high cost of materials and manufacturing processes. Finding a material with enough strength and durability that is also biocompatible and long-lasting has challenged the prosthetics field for many years (Aliyu et al., 2017). Robotic Exoskeletons have similar expenses. In 2022, global industrial robot component prices surged due to supply chain disruptions, chip shortages, raw material price hikes, and inflation (Control Engineering, 2024).

Analysis

Comparisons to surgical robots show how the implementation of a robotic system can be hampered by maintenance and marketing issues. These barriers are created by a mix of socio and technical issues. A lack of quantitative research into the effectiveness of the technology makes adoption less likely. The perceived ease of use and perceived use of a piece of medical equipment play a large role in the decision to implement a device. Once implemented, the effective use of a device is heavily affected by ease of maintenance. Maintenance costs and lack of preventative maintenance lead to large amounts of machine downtime and inefficient utilization.

Based on these factors, the following predictions can be made regarding robotic exoskeletons.

1. Exoskeletons will mirror surgical robots in their extremely slow implementation rate. The current lack of research into the practical benefits of exoskeletons may cause resistance from providers.
2. Maintenance issues will reduce the effectiveness of exoskeletons. Lack of preventative maintenance plagues surgical robots, and these issues will be even worse for exoskeletons. A large portion of exoskeletons are taken home and rely on the patient to apply them. Patients are infamously noncompliant (Kleinsinger, n.d.). If they can't do something as simple as finish their antibacterial treatment course, they will not maintain the exoskeleton the way they need to.
3. While the perceived use will limit its acceptance by providers, its marketing will be effective with patients. While physicians are reluctant to accept the technology without clinical research backing it, patients rely on hearsay, which is much more effective for exoskeletons than surgical robots. Already providers state that they must "temper patient expectations" because patients have seen promotional videos boasting true stories of patients' tremendous recoveries using it (Ehrlich-Jones et al., 2020).

Examination of prosthetics illustrates how manufacturing challenges and high prices are ingrained in the process of acquiring a personally tailored rehabilitative system. Advanced rehabilitative devices are deemed unessential by U.S. insurance and are uncovered by the majority of global healthcare systems. Both exoskeletons and prosthetics are "prohibitively expensive" (Gorgey, 2018) and therefore harder to implement. Manufacturing processes are expensive, time-consuming, and impossible to mechanize.

This demonstrates the socio-technical difficulties related to implementing a new technology. Social systems force patients to pay the cost out of their pocket and technological limitations make the technology expensive to manufacture. The complex manufacturing process is caused by the social requirement for comfortable and personalized technology. Companies cannot lower the cost of the device because it is so expensive to manufacture even if they want to. Using this parable, additional predictions can be made:

1. Insurance will not satisfactorily cover exoskeletons, forcing many patients to pay out of pocket. The prohibitive cost of exoskeletons will lead to a similarly low usage rate, particularly in developing countries. It is worth noting that this may be worsened by the lack of conclusive research into exoskeleton effectiveness. Just as perceived use matters to physicians, it matters in the case of insurance policies.
2. Cost will continue to be a determining factor in exoskeleton adoption until a revolutionary manufacturing technique (such as additive manufacturing for prosthetics) is developed.

Conclusion

Rehabilitative exoskeletons are a developing technology with the potential to offer significant improvements to mobility and strength in patients suffering from Post Stroke Motor Dysfunction or spinal cord injuries. As such it is important for the efficient and timely implementation of this technology into the medical system. Effective implementation of medical technology can often stall out for a variety of reasons, breaking down into two sections, adoption and implementation. Adoption involves the acquiring and acceptance of a technology by a large percentage of the provider population. It can often take decades for a technology to be fully adopted as the medical community is resistant to the technology. This is not always their fault, as research into surgical robots shows that many advanced technologies lack a foundation of conclusive research into their efficacy. The surgical robots also showed the power of marketing and perceived use in convincing physicians to accept technology. TAM principles can be used to understand the importance of perceived use and perceived ease of use in the adoption of any technology in any field. Studying prosthetics examined how the low availability due to prohibitive cost will be another issue for exoskeletons. Complex manufacturing processes due to the individual nature of the technology and the inability to mass manufacture cause prices to rise, and the view of rehabilitative technologies as “non-essential” by insurance companies can make the price even higher. It was noted that the view of insurance companies can also be linked to a lack of research into the subject.

It is equally as important that after the technology is adopted it is efficiently implemented. Many factors affect utilization, but maintenance was identified as one of the most prominent factors concerning rehabilitative exoskeletons. Due to the complexity of the technology and cost associated with maintenance, machines can often be inoperable for long periods of time leading to ineffective utilization and reducing patient outcomes.

This paper recommends a focus on quantitative research proving the effectiveness of the technology as well as efforts to make the technology cheaper through improved manufacturing processes. It was noted that the current marketing of exoskeletons is currently well done, particularly with patients. In all, there is much work to be done in implementing rehabilitative

exoskeletons into the medical system, but the work is progressing well.

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