

Designing and Testing a Novel Custom 3D-Modeled Post-Operative Knee Brace

(Technical Paper)

Supporting Knee Joint Health to Promote Longevity and Wellbeing

(STS Paper)

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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

Introduction

Health experts and physicians often highlight cancer, anxiety, obesity, and, more recently, pandemics as the leading health issues faced by the world today. While all certainly warrant discussion and research, some physicians surmise that another issue plagues the health of all populations: deterioration to knee health and mobility. Poor knee joint health lowers a patient's activity levels, leading to a host of other health problems. Most obvious, perhaps, is the vulnerability of such patients to obesity, but reductions in physical activity have even been shown to negatively impact mental health (Sharma et al., 2006). Current medical procedures and surgeries can promote good knee health, but the knee braces used for recovery introduce risks that limit the success of the surgeries themselves. My technical work will be designing a post-operation knee brace that minimizes these risks and allows for a more effective and physiologically mindful recovery.

Designing a Novel Post-Operative Knee Brace

Throughout the world there are 654 million individuals over the age of 40 who currently suffer from knee osteoarthritis (Cui et al., 2020). Many of these individuals will undergo knee replacement surgeries to alleviate some of their pain, but simply replacing the knee joint does not always work. Perhaps nearly as important as the surgery itself is the recovery and rehabilitation process after the completion of a successful surgical procedure. And the importance of the rehabilitation process holds for all intrusive knee surgeries, such as ACL reconstruction and meniscus repair surgeries. With total knee arthroplasty (TKA) and ACL reconstruction surgeries constituting nearly one million surgeries performed annually in the U.S. alone, the need to properly rehabilitate patients after their operation is of high importance (Hewett et al., 2010).

Typical rehabilitation protocol works in stages, beginning by completely restricting the joint's movement, then progressing to movement within a constrained range. Eventually, the patient will continue to full movement with weight unloading on the joint. Along with physical therapy, rehabilitation efforts involve multiple knee braces for each stage of recovery, which often perpetuates the occurrence of post-operative complications. Patients who have undergone TKA can lose up to 62% of their quadriceps strength due to the atrophy, and some patients have permanent physiological limitations to their knee's range of motion, a condition known as knee flexion contracture, as a result of the long-term immobilization of the joint (Anania et al., 2013; Mizner et al., 2005).

Current post-operative knee braces act only to immobilize or restrict the range of motion of the joint only, and subsequent braces need to be purchased during recovery. My team and I plan to design an adaptable post-operative brace that addresses all stages of the recovery process. The brace will be custom fit to the patient, will initially immobilize the joint completely, and for later stages of the recovery, will have an adjustable range of motion and adaptable force redistribution intensity at the joint to unload forces on the tibia. Our brace hopes to address the shortcomings of current technology by allowing the patient to exercise their mobility at all stages with assistance from the brace and foster better recovery of the knee joint following all intrusive knee operations.

We will achieve these aims by the end of the academic year, starting with extensive research on the current market, including relevant intellectual property, standard recovery protocol post-operation, post-operative patient needs, and insurance information. This will ensure that we are designing a product that meets the needs of the patient population we are targeting and that it has a viable space in the market. Next, we will conduct a testing protocol and

collect data to validate the device in a clinical setting. Our final objective is to construct a marketing strategy for the brace. After bringing the product to market, we will continue to evaluate its efficacy and ensure that it continues to meet patients' needs throughout the span of the recovery process.

Supporting Knee Stability and Mobility to Promote Long-term Health

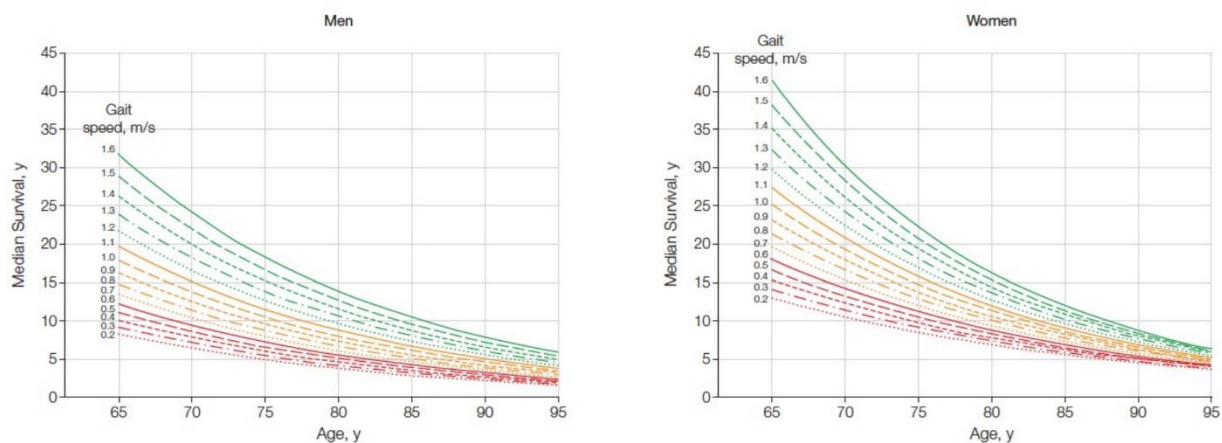
The current state of the health world is challenging to navigate. New diets touted to stimulate extreme weight loss, new drugs promised to permanently cure a formerly incurable disease, and new recommendations for daily activities explained to increase longevity fill the pages of news articles and tv screens. Determining the greatest threats to individuals' long-term health proves a difficult task. Still, as older populations grow rapidly in many developed countries across the world, investigating the chief causes of poor health will become increasingly important.

According to CDC data, the leading causes of death in the United States are chronic conditions, including heart diseases, cancer, and stroke. Additionally, the prevalence of obesity has grown at an alarming rate over the past few decades – by 16.5 percent among all U.S. adults from 1988 to 2018 (*FastStats*, 2022). Pharmaceutical companies spend large sums of money to develop treatments for each of these diseases and conditions, but they often neglect the root issues that lead to their development. As a result, the burden falls on patients to pay for drugs that treat their symptoms – often a costly and repetitive cycle. For example, in 2017, adults in the United States spend an estimated \$108.7 billion to treat heart disease (Muhuri, 2020). This figure could be significantly reduced if upstream factors that lead to heart disease were properly researched and controlled.

Knee pain is one such factor. As a person ages, the knee joint accumulates natural wear-and-tear from everyday activities. Most significantly, the cartilage in the knee joint – which is responsible for the cushioning and facilitation of smooth contact between bones in the joint – can degrade. Without a proper layer of cartilage, the bones of the joint rub directly against one another, often causing pain that hampers one’s ability to lead an active and healthy lifestyle (Clynes et al., 2019). This condition is known as knee osteoarthritis (OA), and it affects 19 percent of adults in the United States over the age of 45 years old (Wallace et al., 2017).

The reduction in physical activity caused by OA leads to hypertension, depression, heart disease, diabetes, and a host of other aforementioned health issues, many of which are leading causes of death in the United States (Marshall et al., 2019). The progression that ultimately leads to the exhibition of these diseases shouldn’t be surprising, but it certainly warrants serious thought when considering how to best promote health and longevity.

The discovery of the link between physical activity and general health is not new. Extensive research into the benefits an active lifestyle has proved what common sense held to be true: active individuals are happier, healthier, and live longer than their more sedentary counterparts. Take walking speed, for example. A simple measurement that accounts for a wide variety of physical factors, including balance, strength, and coordination, walking speed unsurprisingly acts as one of the best indicators of longevity. In a study that looked at the walking speed, also known as gait speed, of over 34,000 individuals, gait speed was found to have a positive correlation to life expectancy in older adults (Studenski et al., 2011). In other words, an individual with a faster gait speed is predicted to live significantly longer than an individual with a slower walking speed (Figure 1).

Figure 1*Gait Speed and Median Survival from 65 to 95 Years Old*

Millions of individuals suffer from general knee pain and instability, and the demand for total knee replacement surgeries projects to grow by 673 percent to nearly 3.5 million yearly operations by 2030 (Kurtz et al., 2007). If this projection is any indication, the burden of knee OA on public health will grow exponentially. Although only a single facet of a larger collection of health challenges, the medical world should prioritize the development of medical devices and drugs that promote knee health and stability and thereby reduce the incidence of chronic illnesses that lead to a degradation in overall health.

Research Question and Methods

The goal of my research will be to investigate the burden that knee pain and instability places on the healthcare industry by increasing the prevalence of other diseases. I seek to understand the comorbidities associated with knee osteoarthritis and to draw preliminary conclusions that outline how significantly knee pain can influence longevity and long-term health. A successful study should give a better and more complete understanding of the relationship between knee instability and immobility and life-threatening conditions such as heart disease and obesity.

Much research has been conducted surrounding osteoarthritis and related diseases, and since collecting personal health data from patients poses a substantial challenge with HIPAA regulations, I will collect information by conducting a thorough literature search through previously collected data, and I will analyze trends between the occurrences of different diseases. Using these data, a correlation will be established and modeled that will give clues about the importance of investing in new ways to promote knee joint health as a preventative measure.

Conclusion

Knee pain and osteoarthritis affect millions of individuals across the world, and as life-expectancy rises, the prevalence of these conditions projects to increase too (Clynes et al., 2019). Poor knee health can result in a host of other diseases that affect longevity. Treatment options for knee pain often involve surgery, but current post-operative knee braces fail to adequately prevent complications such as atrophy and knee flexion contracture, prolonging individuals' journey to a full recovery. For my technical work, I hope to design a brace that addresses current complications including range of motion and joint stability, and to provide an industry leading option for post-operative knee joint rehabilitation. I also hope to investigate the impact of knee instability and pain on the development of other medical conditions. With a greater understanding of how knee pain factors into longevity, the healthcare industry could take focused efforts to promote knee health and prevent life-altering conditions.

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