Knee Braces Alleviate Osteoarthritis Disparities

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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

Knee osteoarthritis is the most common orthopedic disorder in the U.S., affecting around 1 in 3 adults over their lifetime. With no known cure, this degenerative disease causes the breakdown of the knee's connective tissue and protective cartilage. The current gold-standard treatment, total knee replacement (TKR), replaces the entire knee with an implant. While TKR has an estimated 90% satisfaction rate, many patients face insurmountable barriers to accessing the procedure (Lespasio et al., 2017). These obstacles have exacerbated healthcare disparities in osteoarthritis outcomes across multiple intersecting power structures, namely race, gender, class, geography, and disability. Since many of these challenges stem from the nature of surgery itself, there is a high demand for more effective non-surgical osteoarthritis treatments.

This paper explores how knee braces are promising non-surgical treatment options that can bypass many of the barriers preventing patients from accessing TKR. I begin by outlining the primary challenges to TKR access and analyzing their underlying causes using the Science-Technology-Society (STS) theory of user configuration, which emphasizes how a designer's assumptions about the intended users affect the resulting technology (Woolgar, 1990). By comparing the design of surgical technology with that of knee braces, I demonstrate how braces can help mitigate the healthcare disparities that TKR fails to address. I conclude with recommendations for engineers and clinicians on optimizing the research and development process of knee braces to enhance their effectiveness in reducing these disparities.

Barriers to Accessing Surgical Treatment for Knee Osteoarthritis

Although TKR is effective, peer-reviewed articles show that many patients face barriers to accessing it. Patients can be barred from TKR due to comorbidities like obesity or diabetes, which disproportionately affect those in low-income or racial minority groups (Ezomo et al.,

2020). Additional obstacles include costs of up to $25,000 (Losina et al., 2015), lack of insurance, lack of accessible high-volume hospitals, biases in referral, distrust of surgeons, lengthy recovery, and physical therapy expenses (Chun et al., 2021; Goodman et al., 2023). Other surgical options exist but are less common and face similar challenges, including high costs and lengthy recovery (McCormack et al., 2021). These surgical barriers have contributed to TKR access disparities for women (Vina et al., 2013), racial minorities, low-income individuals, underserved areas (Hartnett et al., 2022), and those with multiple disabilities (Zhang et al., 2018).

Furthermore, TKR implants last an average of 20 years. This limited implant longevity makes 70 the ideal age for TKR, yet nearly half of TKRs are performed on patients under 65, with 45–55 being the fastest-growing group (Franklin et al., 2020; Perdisa et al., 2023). Additionally, around 25% of TKRs are performed prematurely, meaning that it would have been ideal for the patient to have delayed their TKR further (Ghomrawi et al., 2020). However, since TKR is a major surgery, patients often already wait until the pain and immobility are intolerable, so these patients who received a premature TKR likely had no effective non-surgical alternatives.

For these reasons, we need an effective non-surgical treatment that offers the following: (1) the treatment can delay or even eliminate the need for surgery, (2) patients do not feel pressured to wait until their condition worsens before electing the treatment, and (3) the treatment avoids the access barriers associated with TKR and other surgical options, therefore making the treatment more accessible and alleviating disparities in osteoarthritis outcomes.

Knee braces are non-surgical alternatives for osteoarthritis that meet these three criteria. Braces can delay the need for surgery and have significant cost-effectiveness, meeting the first technical criterion (Lee et al., 2017). To explore the second and third criteria, the STS theory of user configuration can be applied, which emphasizes how a designer’s assumptions about the

user are embedded in the technology's design and accessibility (Woolgar, 1990). To give an example of user configuration, Barla (2023) analyzes how the original designers of the spirometer—a device that measures lung capacity—falsely assumed Black people had inherently lower lung capacity, so the designers added a race correction feature that made it more likely for the spirometer to miss lung diseases in Black patients, thereby perpetuating racial healthcare inequities. In the next section, I will explore the faulty assumptions behind TKR surgery and how they have worsened healthcare disparities. The designers of TKR surgery include the engineers and clinicians who developed and researched TKR implants and surgical procedures.

User Configuration Highlights Faulty TKR Assumptions

In creating TKR surgery, designers make many assumptions about the patient: that the patient is appropriately referred for TKR, trusts their orthopedic surgeon, is comfortable with undergoing TKR, can travel to receive the TKR, can afford the TKR and post-care, has the social support, language services, and health literacy necessary to follow post-care instructions, and is financially stable enough to manage disruptions in work, caregiving, and other daily responsibilities during recovery. As it can be seen, many layers of assumptions are required before it can be stated that TKR is an accessible treatment. Falsely assuming that these assumptions are true has led to exacerbated healthcare inequities that limit surgical access, particularly for racial minorities, gender minorities, and low-income individuals, especially those in underserved areas, those with additional disabilities, and those with limited language or healthcare literacy.

To illustrate how these assumptions are faulty given the aforementioned TKR barriers, consider the following hypothetical case: *Rosa* is a 50-year-old Mexican immigrant and single mother living in rural California. She is experiencing sharp right knee pain that is hindering her

ability to walk for more than 20 minutes straight. Initially, Rosa is reluctant to visit a doctor, which reflects the medical mistrust often felt by marginalized gender and racial groups due to experiences with systemic healthcare discrimination (Antony et al., 2024; Ezomo et al., 2020). Language barriers only add to Rosa's difficulty navigating the healthcare system (Nguyen et al., 2022). For this reason, Rosa waits until the knee pain becomes unbearable and is forced to visit a primary care physician.

Rosa is informed of her knee osteoarthritis diagnosis but is not referred for TKR surgery. The physician may have withheld TKR as an option because Rosa's younger age makes her a suboptimal TKR candidate, as she will likely need costly revision surgery in 20 years (Perdisa et al., 2023). However, studies have shown that women are less likely to be appropriately referred for TKR surgery (Mandl, 2013). Instead, the physician suggests that she should start by taking ibuprofen, eating healthier, and losing more weight.

Women like Rosa may experience unequal assessment due to clinicians' faulty assumptions regarding women's bodies and preferences, leading to delays in surgical referral (Mandl, 2013). Explanations for this unequal assessment include doctors inaccurately processing women's initial symptom reports, doctors not involving women enough in their decision-making, doctors harboring biases that prevent them from recommending surgery to women, and doctors not sharing enough medical information to women, making women less likely to pursue treatment (Borkhoff et al., 2011). Women, especially those from racial minority groups, also have a higher prevalence of multimorbidity than men, which further complicates their TKR candidacy and recovery (Temkin et al., 2023). These barriers cause women to present at more severe stages of osteoarthritis by the time they undergo surgery, which negatively affects their postoperative recovery (Devasenapathy et al., 2020).

Rosa returns after a year, now unable to walk more than 5 minutes without pain. Recognizing the severity of her symptoms, the physician refers her to an orthopedic surgeon. The closest high-volume hospital that performs TKRs is 1.5 hours away and the orthopedic surgeon has a 2-month wait time. Rosa has to buy two bus tickets to get to the hospital. During her consultation, Rosa becomes deeply uncomfortable at the idea of her knee being removed. Rosa also realizes she cannot afford the TKR procedure, let alone the time off work and caregiving duties it would require—barriers disproportionately faced by women (Demiralp et al., 2019), low-income individuals, racial minorities (Goodman et al., 2023), and those in underserved areas (Cyr et al., 2019; Grimes et al., 2011). Rosa's case demonstrates how the aforementioned assumptions regarding TKR are faulty. She had a delayed TKR referral, is hesitant to visit doctors, is uncomfortable with invasive surgery, has transportation barriers, lacks social support from other adults, has limited English and health literacy, and cannot afford TKR or its post-care disruptions in work and caregiving.

Knee Braces Bypass the Faulty Assumptions that Restrict TKR

The design of knee braces allows them to avoid the faulty assumptions and barriers that affect TKR, which makes them an ideal alternative for Rosa. Knee braces offer a non-surgical approach to early osteoarthritis intervention, potentially delaying osteoarthritis progression and therefore TKR surgery (Parween et al., 2019). According to peer-reviewed articles, the average brace costs $365 (Nin et al., 2022), with daily use becoming significantly cost-effective after 4 months (Lee et al., 2017). Braces are far cheaper than the average TKR surgery cost of $12,000–25,000 (Losina et al., 2015) and comparable in cost to other non-surgical options like intra-articular injections (Nin et al., 2022), addressing Rosa's affordability concerns.

Additionally, knee braces do not require doctor visits and reliably last for multiple years. This feature is unique even compared to other non-surgical options like intra-articular injections, which still require professional administration by a healthcare provider and have effects that only last for a few months (Nin et al., 2022). While check-ups at a primary care or physical therapy center are recommended every few months to ensure proper fit and minimize side effects like skin irritation or discomfort, they are not required (Lee et al., 2017). Regardless, it is far easier for Rosa to travel to her primary care center than to a hospital, and she can discontinue check-ups if she finds them unnecessary. If Rosa orders a brace online and it is an ideal fit, she may not need to see a doctor at all. In this case, online purchasing eliminates her geographical barriers, the cost of provider visits, the need for a referral, and concerns related to medical mistrust.

Knee braces require no recovery time, so Rosa will have no disruptions in her job or caregiving responsibilities. Their non-invasive, removable, and self-administered design is a major advantage over TKR, as months of rest, family support, and physical therapy are essential for TKR rehabilitation (Jette et al., 2020). While recovery times vary, only 34% of TKR patients return to work after 3 months, and just 67% return within a year (Hylkema et al., 2021). Given these statistics, Rosa can reasonably expect a year-long recovery. However, even just a month off work can be financially problematic, as 35% of low-income and 20% of high-income U.S. households live paycheck to paycheck according to the Bank of America Institute (Tinsley, 2024). In this context, knee braces help Rosa overcome the barriers posed by the inability to take time off work or caregiving and her lack of social support. In contrast to the intensive post-care instructions for TKR, the simplicity of knee braces also addresses any barriers related to language comprehension or low health literacy.

One could argue that improving TKR surgery to address its barriers would be preferable to developing alternative treatments. However, several fundamental factors limit this endeavor. First, TKR will always require sterile operating rooms and specialized surgical teams, making it inaccessible to many in underserved rural and urban areas—an issue that extends globally to low- and middle-income countries (Cyr et al., 2019; Grimes et al., 2011). Additionally, TKR will always rely on anesthesia, which disqualifies patients with comorbidities or allergies that conflict with anesthesia administration. Lastly, the long recovery period and intensive post-surgical care make TKR unfeasible for those without the personal social support needed to follow post-surgical instructions or take time off work and caregiving. In contrast, knee braces avoid these fundamental barriers entirely.

User Configuration Outlines Improvements for the Knee Brace Design Process

In summary, knee braces avoid the faulty assumptions that limit TKR. Braces do not require referral, trust in an orthopedic surgeon, medical procedures, travel, time off work or caregiving, or access to family support, language services, or health literacy to use effectively. However, there are four concerning assumptions regarding knee brace design: (1) that patients are aware of knee braces as a treatment option, (2) that they can afford one, (3) that the brace fits their knee properly, and (4) that the brace sufficiently alleviates the osteoarthritis symptoms.

Despite the major advantages over other treatments that were discussed, knee braces remain underutilized, with only around 12% of osteoarthritis patients wearing them (Mistry et al., 2018). This low adoption rate, similar to most other non-surgical options, reflects the underdevelopment of non-surgical osteoarthritis treatments (Nin et al., 2022; Testa et al., 2021). Limited clinical trials, a lack of design regulations, and poor user convenience are major causes of low brace adoption rates. To increase the use of knee braces, efforts should focus on

establishing standardized design guidelines and strengthening clinical evidence to optimize brace fitting in healthcare centers. A patient-centered approach in both design and clinical trials will ensure braces are not only effective but also convenient, encouraging long-term use.

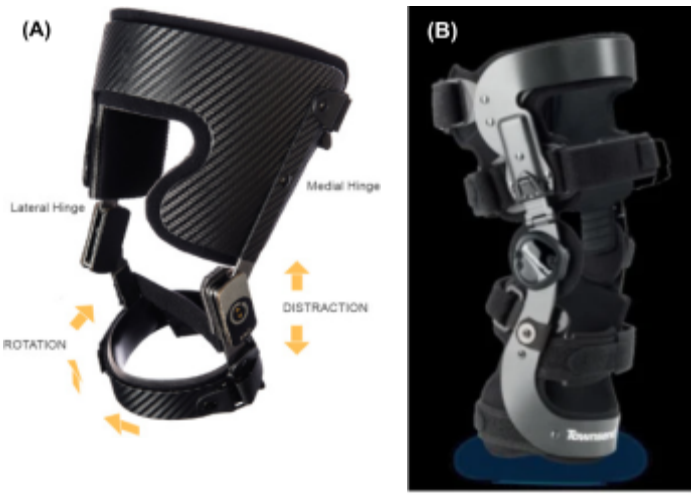

Figure 1: Comparison of (A) the OdrA brace from Gueugnon et al. (2021) with (B) the Rebel Reliever brace from Thoumie et al. (2018).

The primary obstacle to knee brace development is the lack of high-quality and long-term clinical trials (Beaudreuil et al., 2009; Mistry et al., 2018). This issue is further complicated by the absence of standardized brace design guidelines, making it difficult to compare studies that use different brace designs—even for the same type of brace. For instance, Gueugnon et al. (2021) and Thoumie et al. (2018) conducted randomized-controlled trials on distraction-unloader knee braces, but the braces have notably different designs. Should knee braces prioritize minimal surface area like the OdrA brace (Figure 1A), or have four supportive straps like the Rebel Reliever (Figure 2B)? Neither study justifies these design choices, which underscores the need for greater standardization and communication in the knee brace design and development process.

The lack of standardization stems partly from the U.S. Food and Drug Administration (FDA) categorizing knee braces as Class I exempt devices, allowing them to be sold without FDA approval or clinical testing due to their low-risk, external design (Code of Federal Regulations, 2001). While a lack of strict regulations enables design flexibility and faster

development, it also results in an overwhelming variety of brace designs with little guidance on which are best. The absence of clinical evidence further discourages clinicians from confidently recommending braces, limiting patient awareness and access. As such, standardizing knee brace design and conducting high-quality clinical trials will help address the first and fourth faulty design assumptions by increasing awareness among patients and providers while ensuring consistent effectiveness.

Although knee braces are far cheaper than TKR surgery and comparable in cost to other non-surgical options, the average price of $365 (Nin et al., 2022) may still pose a financial burden. According to the Board of Governors of the Federal Reserve System (2023), Americans under 35 have the lowest median savings balance at $3,240. Furthermore, 59% of Americans lack the savings to pay an unexpected $1,000 expense (Gillespie, 2025). While $365 falls well below these thresholds, affordability can be further enhanced by insurance coverage and mass manufacturing. Fortunately, major public and private insurers like Medicare (2025), Anthem Blue Cross Blue Shield (2025), and UnitedHealthcare (2024) cover knee braces for osteoarthritis, though coverage criteria can vary. For example, Medicare and Anthem Blue Cross Blue Shield cover pre-sized and customized braces, whereas UnitedHealthcare covers only customized options. Nevertheless, pre-sized braces are already more affordable and accessible than customized braces due to the efficiency of mass manufacturing. Research also shows that, given a proper fit, pre-sized braces are as effective as customized braces (Paluska & Mckeag, 2000). The streamlining of the knee brace design process will allow mass production to reduce costs even further. These factors support the second design assumption that patients can afford braces.

The customizable nature of knee braces allows them to accommodate a diverse range of lower-limb shapes and sizes, supporting the third design assumption that a brace can be made to

ideally fit a patient's knee. Clearer communication of design considerations between engineers and clinicians will further enhance the development of knee braces based on patient-specific needs and body structure. For example, it would be ideal for the designers of the OdrA and Rebel Reliever braces to incorporate biomechanical testing in their published research to assess the advantages of their respective design choices (Gueugnon et al., 2021; Thoumie et al., 2018). The rigorous testing of contrasting brace designs will enable researchers to determine which designs are best for different patient populations, thereby mitigating possible disparities in brace efficacy. To give a hypothetical example of results, it could be discovered that the OdrA brace, with its minimized surface area, is ideal for patients of average weight but significantly less effective for obese patients, who may require a bulkier brace like the Rebel Reliever.

Furthermore, because knee braces are self-administered and worn continuously, an ideal fit necessitates not only treatment efficacy but also ease of use and comfort. A patient-centered development process is therefore essential, as research shows that convenience and comfort significantly influence patient compliance with knee braces (Bashir et al., 2022; Dzidotor et al., 2024). Gueugnon et al. (2021) is a positive example of a clinical trial that incorporated subjective patient feedback on knee brace design. In addition to standard clinical metrics like pain levels, knee functionality, and side effects, Gueugnon et al. (2021) investigated the OdrA brace's long-term compliance and its impact on quality of life. Their findings were striking—84% of patients continued wearing the OdrA brace after a year, far exceeding the typical compliance rates of around 30% reported in most other studies (Robert-Lachaine et al., 2020; Squyer et al., 2013). These results led Gueugnon et al. (2021) to a valuable insight: the OdrA brace's smaller surface area greatly improved patient comfort and satisfaction, leading to consistent long-term use that enhanced the OdrA brace's effectiveness. This example highlights the importance of

integrating subjective patient feedback and ergonomic considerations into the knee brace design process to improve compliance and therapeutic outcomes.

Although knee braces require several major improvements to become more competitive as alternative osteoarthritis treatments, multiple actions can greatly enhance their efficacy and adoption. Standardized and patient-centered design guidelines, along with high-quality and long-term clinical trials, will make knee braces more appealing to both patients and providers, allowing them to better alleviate the healthcare disparities that TKR cannot.

Knee Braces: A Promising Non-Surgical Alternative

The STS framework of user configuration was applied to juxtapose TKR surgical technology with knee braces, revealing how braces can address disparities in osteoarthritis treatment access that TKR cannot. Braces are mass-manufacturable and shippable, helping to reduce socioeconomic and geographic barriers. Their low-risk nature makes them more accessible to patients with multiple health complications and mitigates medical mistrust. As fully external, non-invasive, and self-administered devices, knee braces promote patient autonomy and eliminate the need for traveling to specialized doctors or hospitals. These advantages help circumvent the access barriers that disproportionately affect women, racial minorities, low-income individuals, those in underserved areas, and those with multiple disabilities.

However, user configuration also exposed several concerning design assumptions regarding knee braces, which are primarily caused by insufficient clinical trials, unclear communication of design considerations, insufficient standardized design guidelines, and a lack of patient-centered development that impacts user convenience and comfort. To maximize the potential of knee braces to mitigate healthcare disparities, future efforts should prioritize establishing clear design criteria and rigorously assessing the specific features of knee braces in

long-term clinical trials. Additionally, better communication methods between knee brace designers, which include engineers and clinicians, should be developed to streamline the brace and clinical trial design processes. Lastly, the best way to incorporate subjective patient feedback in the design process should be established, as keeping the designers in touch with the knee brace users will minimize the risk of faulty assumptions and improve user satisfaction.

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