THE DESIGN OF JOINT REDUCTION TRAINERS

HEALTHCARE DISPARITIES IN RURAL AND LOW-INCOME AREAS

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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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Many joint dislocations such as the shoulder, elbow, and knee require immediate reduction to stabilize the joint (Penn Medicine, 2022). Although medical professionals require knowledge of joint reduction techniques, typically first-time reductions are performed on a patient, in turn increasing the likelihood of complications (Luna Labs, 2020). A specific type of joint reduction trainer (JRT) will be chosen, designed, and produced for the technical project in order to help train medical professionals (MP) and athletic trainers (AT) in the technique, with a hands-on, realistic model designed to mimic the dislocated joint (Luna Labs, 2020). The Social Construction of Technology framework will be used to discuss the necessary negotiations between JRTs and its affiliated groups for development (Bijker & Pinch, 1984). Emphasis will be on the specific social groups in rural and low-income communities in order to limit the exacerbation of preexisting healthcare disparities, as JRTs could ultimately reduce complication costs and provide better medical training, creating a tightly coupled analysis (Douthit, 2015 & Claxton et al., 2022).

THE DESIGN OF JOINT REDUCTION TRAINERS

Studies have reported that joint dislocation accounts for 3.6% of emergency department visits for US sports-related injuries only (Meixner & Loder, 2019). A joint is where two or more bones are connected, joint dislocation occurs when the ends of bones are forced from their normal positions, usually resulting from a fall, auto accident, or collision from sports (Mayo, 2022). This causes the joint to typically become deformed and immobilized, giving the recipient intense pain, numbness in the joint, and limited ability to move (Wright et al., 2020). Common types include glenohumeral (shoulder), patellofemoral (knee), interphalangeal (finger), and elbow joint dislocations (Skelley et al., 2013). Following a joint dislocation, medical professionals (MP) are required to perform a dislocation reduction that refers to “reducing” the gap between the two bones of a joint, thus relocating it (Yu, n.d.). It is essential for the joint to be put back in place as soon as possible to avoid complications such as damage to soft tissue, articular surface injury, and neurovascular compromise (DeBerardino, 2022). Figure 1 represents an x-ray of a left posterior elbow dislocation for understanding, as they are classified by the position of the radio-ulnar joint relative to the humerus (Oppenheim, 2018).

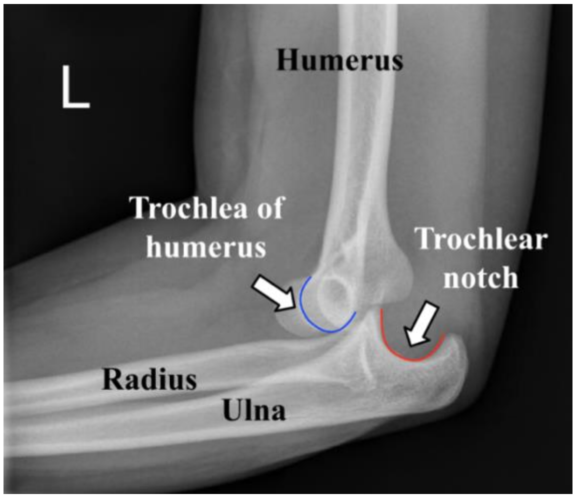

Figure 1: Posterior Elbow Dislocation. This shows an x-ray of a left posterior elbow dislocation of a 15-year-old girl following a wrestling match. The concerned bones are labeled in black and the displaced joint is labeled in white prior to reduction (Oppenheim, 2018).

The figure shows the radius and ulna displaced posteriorly with respect to the distal humerus, and the empty trochlear notch of the ulna displaced posteriorly relative to the trochlea (Oppenheim, 2018). Many dislocations such as this can be repositioned without surgery through a closed reduction procedure, by applying various physical forces and ranges of motions on the patient for stabilization of the joint (What is, 2019).

It has been shown that a successful relocation rate is higher with prompt reduction, as it additionally improves patient comfort, joint integrity, and functional prognosis (Wright, 2020). Typically, medical professionals perform first-time joint reductions on the patient, therefore increasing the likelihood of complications from error in technique or hesitancy (Luna Labs, 2020). Luna Labs developed a model of a glenohumeral (shoulder joint) in 2019 that imitates a shoulder dislocation to alleviate this issue (Luna Labs, 2020). The Shoulder Joint Reduction Trainer (SJRT) allows users to practice the joint reduction technique an unlimited number of times, without practicing on a patient. Figure 2 shows the biofidelic, table-top shoulder JRT that allows a realistic, hands-on experience, and encompasses a variety of reduction techniques, as well as efficient portability (Luna Labs, 2020).

Figure 2: Luna Lab’s Shoulder Reduction Trainer. This shows an image of Luna Lab’s table-top accessible, Shoulder Reduction Trainer being used in the classroom (Luna Labs, 2020)

Another type of joint dislocation trainer (JRT) will be designed, prototyped, and tested, following similar procedures as the shoulder model, and the general process of the report is outlined in Figure 3.

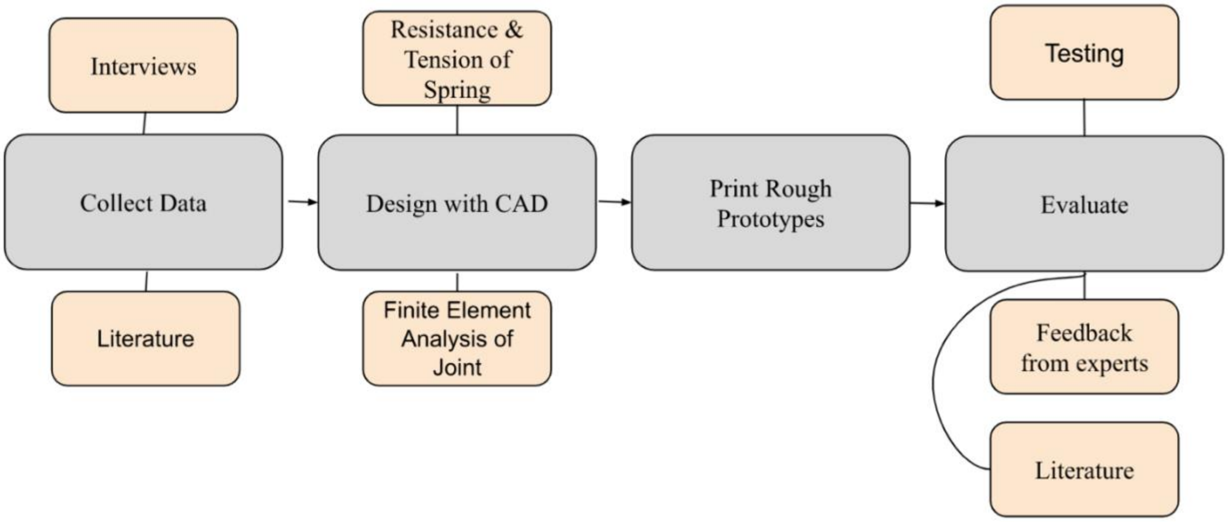

Figure 3: Joint Reduction Trainer Design Process. A visual of the progression of steps when developing a Joint Reduction Trainer (Ambrose, 2022).

Initially, outreach was conducted in order to gain input from orthopedic surgeons, physicians, and athletic trainers residing at the University of Virginia (UVA), Virginia Commonwealth University (VCU), Ohio State University (OSU), Virginia Tech (VT), and UVA-Culpeper Medical. The survey questions include what dislocations are the most common in their experience, key anatomical landmarks of the joints they are the most familiar with, how they determine on-site reductions, how joint reductions are taught in their experience, if there are noticeable differences in gender, etc. Literature will be used to help understand important landmarks, the procedure, and specific force and tension elements. So far, outreach and analysis of literature has led us to start designs for an elbow model. Initial AutoCAD designs are currently being produced, alongside outreach efforts, and conceptualized with the help of Luna Labs' lab space, computer access, and hands-on 3D printed models of critical joints such as hinges. It will be necessary that the amount of force needed to reduce the simulated joint is close to physiological values, as well as proper ranges of motion for the incorporated technique (Luna

Labs, 2020). The final step involves the evaluation process, in which the team will receive feedback from testing, experts, and literature. It will be necessary that the JRT's final material withstands heat produced by friction, in which Smooth Cast 300, a plastic mold-making and casting kit will be used. The synthetic skin additionally should not obstruct the elbow joint during the reduction process. The Instron Machine will be used to test the joint's strength and stress. The JRT will be tested for durability by repeatedly performing the reduction, aiming for an ideal value of 1,000 accurate uses. Following prototype assessment, two advanced prototypes will be produced and distributed to the UVA Athletic Training Department for use and their input will be received for possible improvements. The JRT project is advised by Dr. Kelley Virgilio and Matthew Patterson at Luna Labs over the course of nine months, and clearance by the Institutional Review Board (IRB) was granted. The expected product from this project is a fully functional model of an elbow joint that is able to be dislocated and reduced back in place, mimicking the technique on a live patient. This project will be documented in a technical report.

HEALTHCARE DISPARITIES IN RURAL AND LOW-INCOME AREAS

First-time reductions are typically performed on the patient, which reflects the clinician's lack of mastering the technique, leading to ultimately "training" patients (Luna Labs, 2020). Joint reduction trainers have the capacity to alleviate this issue by training physicians in perfecting the technique for prompt reduction of joint dislocations (Luna Labs, 2020). Along with improving joint integrity and function, prompt and accurate reduction significantly reduces monetary costs from ER visits as well as psychological trauma to the patient (Wright, 2020).

Prompt examination, however, is much more difficult to obtain in rural areas; a study stated that there have been more hospital closures than hospital openings in the US and about two-thirds of them have been in rural areas since 2011 (Kannarkat, 2022). Another study by Douthit et al. discussed these disparities in healthcare access between urban and rural areas, as rural reluctance was often due to financial challenges, scarcity of services, a lack of trained physicians, insufficient public transport, and poor availability of broadband internet services (Douthit, 2015). Figure 4 reflects a significant difference between the number of orthopedic specialists available per 100,000 people compared to urban areas (Fu et al. 2013).

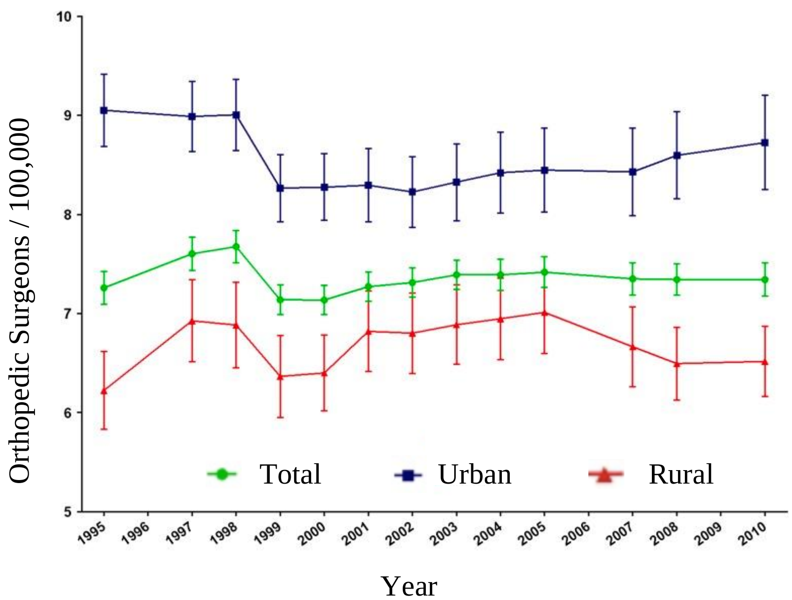

Figure 4: Orthopedic Surgeons in Rural vs. Urban Areas in 1995 - 2010. The graph shows the orthopedic surgeon density, producing significant discrepancies between urban and rural with rural having fewer surgeons (Fu et al. 2013),

Additionally, over 20 million rural Americans live in areas that have a provider-to-patient ratio of 1 to 3,500 or less, where services recommend a ratio of one primary care physician to every 2,000 individuals (Health, 2019). Thus, rural areas have a lack of needed specialists causing these groups to depend on more generalized physicians, such as primary care (Fu et al. 2013). Limited specialists make it more difficult for these groups to get specialized care; this, along with far drives to hospitals, contributes to these residents' poorer health, increased risk of complications, and higher costs (Douthit, 2015).

Low-income groups spend a significantly higher share of their income on healthcare compared to higher-income groups (Claxton et al., 2022). Figure 5 shows the difference in expenditure of groups below and above the Federal Poverty Level; for 2020 a family of four was $26,200 (Claxton et al., 2022).

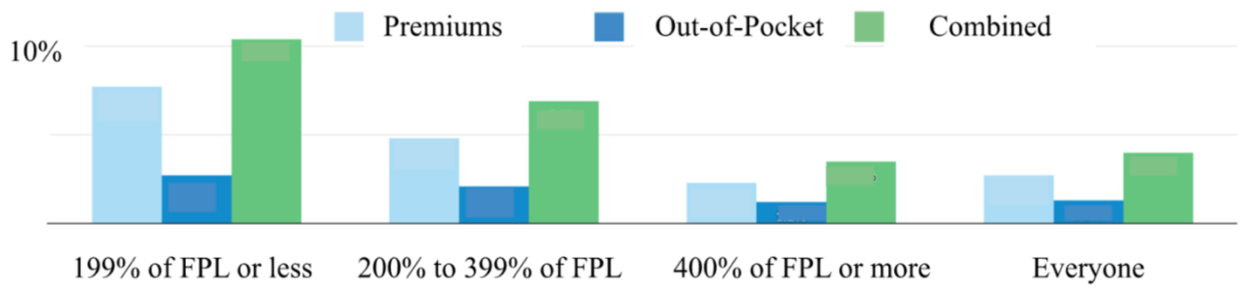

Figure 5: Average Share of Family Income Toward Health Costs at Various Poverty Levels in 2020. This shows an analysis of the Current Population Survey to observe the share of family income people with employer-based coverage pay toward their premiums and out-of-pocket costs, limited to non-elderly people living with one or more family members who are full-time workers and have employer-based coverage. It shows a downward trend as incomes increase, thus reflecting how low-income families spend a larger share (Claxton et al., 2022)

The lowest income group contributes the highest average share of income, thus creating severe financial strain that affects other needs, contributing to an increased risk for health complications and less access to healthcare (Claxton et al., 2022).

The implementation of JRTs could have the potential to help suppress these disparities by training rural physicians at a more uniform level to their urban counterparts, and providing easy portability for professionals to practice at home due to such far distances to the hospital (Lam, 2020 and Luna Labs, 2020). Additionally, JRTs could be beneficial for both rural and low-income groups by decreasing the likelihood of complications, thus decreasing travel and complication costs concerning joint dislocations. The incorporation of these groups within the design process of JRTs is essential in order to account for the health disparities these groups experience to avoid exacerbating the disparities. Proper access to JRTs could have the potential to contribute to lower complication costs in these communities, as well as produce more qualified doctors and athletic trainers, therefore leading to less expenditure and greater health for these groups (Antosova et al., 2019). It will be necessary to explore the societal aspects of this technology, and ensure recognition of these groups' needs.

Recently in 2019, the National Athletic Trainers' Association (NATA) clarified that joint reductions are within athletic trainers' (AT) scope of practice, and provided them with clinical legal recommendations and guidelines (National Athletic Trainer's Association, 2016). This not only highlights the need of JRTs for AT use, but these new guidelines uphold their importance especially for rural and low-income groups, as these communities lack access to sufficient, affordable, and close healthcare (Antosova et al., 2019). The distribution of JRTs to ATs in these communities may reduce disparity in medical resources due to ATs involvement in medical issues in gyms compared to hospitals, as well as their involvement in public school sports.

I plan to use the social construction of technology (SCOT) framework pioneered by Trevor Pinch and Wiebe Bijker to analyze Luna Lab's Shoulder Joint Reduction Trainer (SJRT) that was developed, shown in Figure 6, and use it as a guideline for developing the technical project with emphasis on groups with limited healthcare access (Bijker & Pinch, 1984).

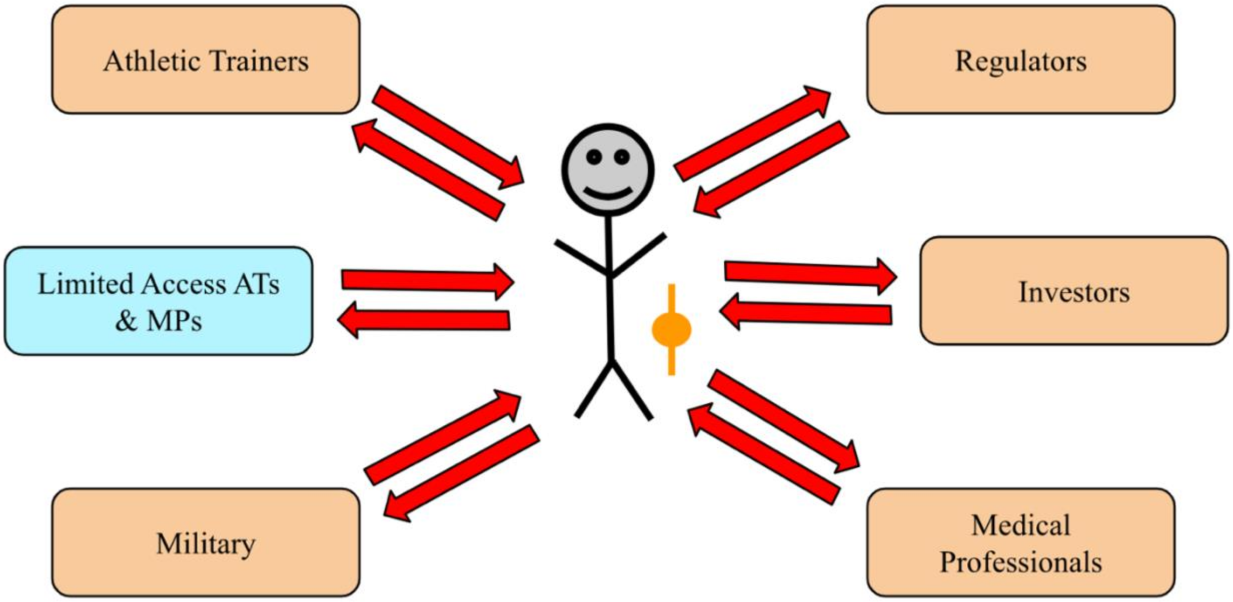

Figure 6: The Social Construction of Technology Model: Joint Reduction Trainers. This chart represents social construction of joint reduction trainers and their affiliated groups. The red arrows represent equal negotiations all around, and back to the engineer. Limited ATs and MPs are represented by the red bubble to be incorporated in this construction in order to limit creating more healthcare disparities (Adapted by Ambrose (2022) from Carlson, 2009).

The framework describes the negotiation between the technology and its affiliated groups in the orange ovals, and the blue oval indicates limited access groups, which will be highlighted throughout the development process (Bijker & Pinch, 1984). "The primary point of focus [of the developmental process] should be the perception of problems and solutions by members of specific social groups," instead of only considering technical functioning (Bijker & Pinch, 1984, p. 41). This is essential to recognize the different groups involved as the JRT can carry various perceptions and different needs in design from various groups such as MPs, ATs, and investors, as well as for differing areas. It is important to separate rural and low-income groups in the model as they carry unique perspectives, due to disparities in healthcare. The transactions between these groups and the engineer are shown by the red arrows, as the groups inform the engineer about the characteristics of their needs concerning the JRT, while the engineer is providing something to each group (Bijker & Pinch, 1984). Thus, this follows social constructivists' claim that technology shapes society *and* society shapes technology (Fuller, 2005).

Medical professionals are of the utmost importance in the process because their input regarding design characteristics is fundamentally necessary, and in return they expect to enhance their skills in the technique. Athletic Trainers were a big motivator for Luna Lab's SJRT, since they have been recently certified and now require joint reduction training. ATs may additionally provide a differing input based on the specific sport they tend to oversee. Both groups are an important influence during outreach when considering anatomical landmarks of the specific joint dislocation, reduction techniques, common dislocations to determine the specific type of JRT, etc. The government may additionally utilize JRTs for military purposes, as they have already done with Luna Lab's SJRT, due to the high prevalence of shoulder dislocations in military activity (Luna Labs, 2020). Additionally, they may request differences in sizes of models, due to having larger patients to assist. Investors play a necessary role as the trainer could not be adopted for hospitals, athletic departments, medical schools, or military facilities, without the interest and funds. In return, the engineer is expected to simplify the parts of the model in order to reduce these costs of production, however constraining the engineer to only focus on major interactions and their respective forces and ranges of motion. Regulators will be important in this process in order to check the accuracy of the model and its overall safety for users and their patients, as it would be bad to teach professionals the wrong technique. In exchange, the engineer will fix any issues regarding regulation.

MPs and ATs from rural and low-income areas with limited access will be included in design discussions as it is important to recognize these groups which have limited specialists in their area and a higher risk for complications. Thus, the engineer may be communicating with more generalized doctors when considering outreach to these areas, rather than orthopedic specialists, gaining insight into their specific training needs. These areas may experience different common dislocations due to participating in different activities than their counterparts. Additionally, there may be less interest by investors in these areas, and thus there will be an increased need for funding or simplified production costs. Further research will use this model to analyze other medical training technology in order to help understand how to be more inclusive of these rural and low-income groups in society.

The JRT has the potential to alleviate issues in healthcare, especially in rural and low-income areas, thus shaping society. It will be essential that those with limited access to sufficient healthcare are included in the design process, and it will be necessary to monitor the ever-changing societal conditions of all conditions, as society also affects the development process of the technology.

This research project will be in the form of a scholarly article outlining the relationship between healthcare disparities in rural and low-income areas, and the JRT's development. This design research will use the Social Construction of Technology Framework (SCOT) to analyze the development of the technical project, and propose implementation throughout the design process for future medical training technology. It is important to understand the necessary, unique societal negotiations involving this technology, as well as to fully recognize groups with healthcare disparities, in order to ensure a positive impact and reflect their unique needs. This will aim to help create a more inclusive joint reduction trainer that may provide needed relief regarding joint dislocation management to these communities.

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