Design of an Elbow Joint Reduction Trainer for Dislocation Management

A Technical Report submitted to the Department of Biomedical Engineering

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

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Spring, 2023

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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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Abstract

An elbow reduction trainer is complementary for medical professionals to be able to practice elbow reduction techniques in order to improve preparedness and prevent loss of skills. In this project, an elbow joint reduction trainer was designed, developed, and tested to allow medical students and professionals to learn and practice the reduction of a posterior elbow dislocation. The trainer consisted of a CAD-designed and resin-cast joint mechanism and attached foam cast bicep and forearm components. The tension and forces in an elbow joint were simulated using springs attached to the joint mechanism, and the anatomical landmarks typically used in elbow joint examinations were included in the design. The trainer was tested by orthopedic experts to determine the accuracy the trainer achieved in its force simulation, anatomical landmarks, form simulation, and useability. Overall, the experts found the elbow joint reduction trainer to be successful in achieving its constraints and criteria and allowing users to practice reduction techniques of a posterior elbow dislocation.

Keywords: elbow, joint, dislocation, reduction, trainer, simulation

Introduction

Background

A closed joint dislocation is an injury where a joint is forced out of normal position without breaking the skin, which can be very painful and can temporarily deform and immobilize the joint. Closed joint dislocations are treated with closed reductions which is a procedure to set the dislocated joint back in place without surgery. Despite standard requirements for joint reduction training, the first time a clinician performs a joint reduction is typically on a patient, which can lead to hesitancy or error in the technique. This potentially results in complications such as injury to nerves, blood vessels, and other soft tissues near the bone, formation of blood clots, and new fractures[5]. Eight percent of closed reductions result in complications[6]. The likelihood of a successful reduction is higher with a prompt reduction attempt. Addressing the injury on-site can also limit the cost of healthcare while reducing

psychological trauma for the patient[7]. To address this need for timely, technically accurate joint reductions, an elbow joint reduction trainer was developed to teach medical personnel proper recognition of a dislocation and the procedure necessary to reduce the joint. Creating an elbow joint reduction trainer provides medical professionals the resources to practice joint reduction procedures under more realistic conditions and practice an unlimited number of times.

Significance

This project focused on creating a joint reduction trainer that models a posterior elbow joint dislocation and reduction. As such, the trainer focused on modeling the humeroulnar and the humeroradial joints, which give the elbow its characteristic hinge-like properties and are the joints displaced in a posterior elbow dislocation. This type of joint dislocation was focused on because ninety percent of elbow dislocations are posterior[2]. A proper closed elbow joint reduction requires a practiced medical professional with knowledge and previous experience. In most other areas of medicine, there are methods to learn and practice procedures to ensure a medical professional is able to effectively execute a procedure on a patient. There are standard educational requirements for both athletic trainers and medical students when learning joint reduction techniques. Despite this, the first time a clinician performs a joint reduction is typically on a patient. In a survey of athletic trainers, 42.5 percent of athletic trainers denied receiving training in joint reduction techniques[8]. While students may learn the procedure in books and by completing the motion on a non-dislocated joint, there is no method to practice on a dislocated joint, preventing students from gaining a solid understanding of the forces and exact technique involved in a closed joint reduction. This lack of practical training can lead to hesitancy or technical errors during the procedure, which can cause complications that require surgery. These complications include injury to nerves, blood vessels, and other soft tissues near the bone, the formation of blood clots, and new fractures[4]. Eight percent of closed reductions result in complications, but this can be decreased by reducing the number of improper closed joint reduction procedures performed[6]. Although eight percent is not a very high rate of complication, it is the nature of possible complications that is concerning. In one analysis of closed reductions, there was a case where a fracture was caused during the attempt at reduction[9]. Patients seek medical care in hopes of alleviating their ailments, and they put their trust in medical professionals to do so. They do not expect to have their problems exacerbated by complications due to a lack of effective training and practice. No matter how small the percentage rate of complications is, every patient deserves to have the chance that they will leave a situation worse than before decreased as much as possible. In interviews with physicians, they cited errors in technique and lack of confidence that cause complications. Many physicians also explained that there is a lack of technical practice and the reduction technique is mainly taught through lecture, textbooks, and "walking through the motion and direction of force."

By creating an elbow joint reduction trainer, students will be able to practice the joint reduction procedure in a much more realistic simulation, as the trainer will be functionally and anatomically representative of a human elbow joint. This allows medical professionals to be able to better understand the feel, motions, and forces involved in an elbow joint reduction. It also allows medical professionals to practice an unlimited number of times, ensuring that they perfect a technically accurate procedure and build confidence before performing an elbow joint reduction on a patient. In decreasing the hesitancy in medical professionals and technical errors during the procedure will decrease, the

occurrence of complications caused by the closed joint reduction decreases. Furthermore, professionals who have not performed a reduction for a significant amount of time can refresh their technique before executing the procedure on a patient again[2].

A decreased rate of complications has a positive impact on patients, the most important being the lack of need for surgery. If complications arise from a closed reduction procedure such as injury to nerves, blood vessels, and other soft tissues near the bone, formation of blood clots, and new fractures, those complications must be resolved in surgery. This brings about a host of further risks and complications, including hemorrhage, deep vein thrombosis, and infection. It also results in a long and painful recovery for the patient[1]. If no complications arise from a closed joint reduction because the procedure was completed properly due to having well-trained medical professionals, it prevents the patient from these further risks. The need for surgery also increases costs of healthcare for the patient because, as opposed to having one non-invasive procedure completed, a surgery requires several staff and equipment as well as overnight hospital stays before and after the procedure. This can become extremely costly and become an undue burden and stress on the patient. Surgery often causes psychological trauma in a patient due to the fear of having a serious medical problem and having to undergo a dangerous operation, as well as the extremely painful and long recovery. In ensuring that a patient does not need to undergo surgery due to complications caused by an improper joint reduction, the patient will have a shorter recovery time, reduced cost of healthcare, and reduced psychological trauma, which is extremely valuable in patient care[7].

The current lack of training in joint reduction procedures is a barrier in improving patient care. The elbow joint reduction trainer will help to solve this issue, allowing medical professionals in the orthopedic field of medicine to be better prepared to provide patient care that ultimately improves patient outcomes[3]. The elbow joint reduction trainer would be an invaluable teaching tool that would revolutionize the way students learn to complete posterior elbow reductions and allow physicians to continue to practice the skill throughout their careers as often as needed. Additionally, it will lead to the creation of multiple joint reduction trainers for various other joints.

Innovations

The design of an elbow joint reduction trainer offers the potential to change the way athletic trainers and physicians learn and practice reduction techniques prior to the use of their skills on alive patients. This was done by building upon a shoulder joint reduction trainer created by Luna Labs.

The current curriculum and approach for teaching athletic trainers how to perform reduction techniques for dislocated joints is through the use of in-class demonstrations and reading about the techniques in books[8]. Similarly, according to Dr. Matthew Chung, a physician at Virginia Tech, in an interview that was conducted for this project, medical students learn from "walking through the motion and direction of force" on someone who does not have a dislocated joint. These two methods offer no hands-on experience for the students, and they are limited to watching demonstrations or going through the motions of a technique on an already healthy human. This lack of hands-on experience prior to performing a joint reduction in a real-life situation can lead to medical complications due to hesitancy and errors. By designing an elbow joint reduction trainer, this current method of teaching reduction techniques will be completely transformed. Students will no longer have to guess or imagine what it would be like to put these techniques into practice. Once they learn the techniques, they can apply them using the

elbow joint reduction trainer in a low-stress environment. This repetitive practice refines skills, builds confidence, allows students to determine which reduction techniques work best for them, and offers the ability for students to make mistakes and correct them before working on patients.

Another downside to the current method of learning and practicing joint reduction techniques is that once the skills are learned and the student is done with their training, they reduce a very small number of dislocations. This can lead to a loss of the skills that they learned during training. In a survey of approximately 800 athletic trainers, it was found that, on average, athletic trainers perform less than one joint reduction per year after completing training and certification[7]. Likewise, in speaking with multiple emergency medicine residents, almost all of them said that they have performed two or less joint reductions in their career thus far. Despite the low occurrence of this type of injury, it is still imperative that medical professionals are knowledgeable and well practiced with the procedure in order to be able to perform it accurately when the time comes. Because the current method of practicing reduction techniques does not offer a way in which to repetitively use the skills learned besides a few times per year, athletic trainers and physicians can forget or become unpracticed with the techniques. If the techniques are forgotten and a situation arises where they need to reduce a joint, this can cause medical complications due to hesitancy and errors. In an interview, Dr. Greg Beato, a physician at Virginia Tech, stated that the most common mistake inexperienced individuals make during a reduction is being "too timid in their technique." This timid demeanor arises when medical professionals lose confidence in their skills. The elbow joint reduction trainer will offer a way in which athletic trainers can repeatedly practice reduction techniques throughout the span of their career to prevent extinction of skills and to build confidence that they can effectively perform the technique.

Overall, the design of the trainer was focused on simulating realistic conditions of an elbow joint dislocation, how to reduce the dislocation properly, and being durable enough for repetitive use. This will transform the way in which joint reductions are currently taught to and practiced by athletic trainers and physicians. A current technology in the field of joint reduction trainers is the shoulder joint reduction trainer created by Luna Labs. This current trainer accomplishes the goal of transforming reduction curriculum and solves the problems stated above, but it can only be used for shoulder dislocations. The elbow joint reduction trainer built upon how the shoulder joint reduction trainer was created in terms of design process and materials. The shoulder joint reduction trainer used springs to simulate forces within the shoulder. Springs were used in the elbow joint reduction trainer, but it was built upon by finding the correct springs to simulate the forces in the elbow instead of the shoulder. The elbow joint reduction trainer will also be the start of a collection of reduction trainers for various joints including, but not limited to, finger joints and knee joints. Once all of these joint reduction trainers are designed and functional, they can be transformed into a full-body reduction trainer with multiple joint dislocation points. Medical professionals and students will be able to learn and practice any joint reduction technique they desire on multiple joints within the body using just one full body reduction trainer. With the use of the shoulder joint reduction trainer as a baseline idea of how to simulate dislocations, the elbow joint reduction trainer built upon this to transform current reduction technique curriculum and practice.

Problem Statement & Hypothesis

To address the need for timely, technically accurate joint reductions, an elbow

joint reduction trainer was developed to teach medical personnel proper recognition of a dislocation and the procedure necessary to reduce the joint. Creating an elbow joint reduction trainer provides medical professionals the resources to practice joint reduction procedures under more realistic conditions and practice an unlimited number of times. The goal was to create an elbow joint reduction trainer that is anatomically and functionally representative of a human elbow joint, allowing medical practitioners to be better prepared to complete the procedure on patients.

Materials and Methods

Specific Aims

In order to accomplish the project goal, three overarching aims for the design process were set out. Aim 1 was to collect data pertaining to joint reductions to apply to trainer design. Aim 2 was to design the elbow joint reduction trainer to be biomechanically representative of human joint functionality. Aim 3 was to evaluate functionality characteristics of rough prototypes to develop a polished demonstrator prototype for clinical evaluation.

Preliminary Data Collection

For aim 1, athletic trainers and orthopedic specialists were interviewed to obtain qualitative data on joint reduction procedures and preferences in a trainer, using questions developed by Luna Labs in previous expert interviews. The deliverable for aim 1 was to compile collected qualitative information to form a selection matrix in order to visualize the most important aspects to focus on in the design process. Outreach was conducted with orthopedic specialists and athletic trainers residing at various academic institutions to obtain input on which dislocations are common in their experience, how the reduction technique is typically taught, key anatomical landmarks of said joints, what reduction trainers are the most needed, what features should be included, etc. Once interviews were conducted, the responses were reviewed, and common response elements were identified. These were compiled for consideration when initially designing prototypes. Dr. Matthew Chung, a sports medicine physician at Virginia Tech, concluded that an elbow trainer "would be good practice as the positioning of this can be an issue." Additionally, Hisham Ziyout, an athletic trainer and sports medicine director at Virginia Tech, stated in an interview that elbow dislocations were "complicated" and that he makes sure the physicians handle it. Thus, an elbow trainer will be focused on.

A selection matrix was generated using the input from the interviews and taking into consideration how Luna Labs wanted to manufacture the final product. This matrix was created to decide on the following design criteria and constraints, listed in order of importance as shown in Table 1.

Criteria/Constraint	Description
Criteria 1	Reflects human forces
Criteria 2	Contains anatomical landmarks
Criteria 3	Durable
Constraint 1	Designed for manufacturing
Constraint 2	Human form and aesthetics
Constraint 3	Usable with one person

Table 1. Selection matrix. Selection matrix created to outline design criteria and constraints to incorporate into the final design.

Criteria 1, reflects human forces, means that the trainer must replicate the feel of the amount of force that medical professionals need to perform a reduction. The trainer also needed to encourage the techniques that are most effective

for joint reductions. Criteria 2 contains anatomical landmarks, means that the trainer must include anatomical landmarks that are typically used in a physical examination of the elbow - the humerus, ulna, radius, olecranon process, and medial and lateral epicondyles. These landmarks will serve to help the user determine where the joint is actually sitting and can be used to "diagnose" the dislocation. Criteria 3, durability, means that the trainer must be able to withstand several thousand uses over its lifetime to make it cost effective for the buyer. Constraint 1, designed for manufacturing, means the trainer must be designed with a low part count and simpler parts to ensure that the final product is easier and quicker to produce. Constraint 2, human form and aesthetics, means that the overall design of the trainer must look like a human arm, shoulder, and elbow in order to best simulate the reduction experience for the user. Constraint 3, usable with one person, means that even though reductions are performed by multiple people, the trainer must be constrainable so that a single user can practice with it.

Designing the Joint Mechanism

For aim 2, the joint mechanism was designed using SolidWorks. CAD designs were 3D printed for physical assessment of functionality and improved upon in following iterations. Specific components were focused on when designing and going through iterations. These include integration of anatomical landmarks, audio cue after reduction, limited range of motion when in the dislocated position, full range of motion when in the reduced position, slight forearm rotation, and a "down and forward" motion that mimics the motion of an elbow reduction. The anatomical landmarks we focused on were the ulna, radius, humerus, olecranon, and medial/lateral epicondyles. Later iterations also allowed for a simulated humerus to be attached to the upper joint, which made it possible to attach the elbow to Luna Labs' existing shoulder reduction trainer. The initial designs are shown in Figure 1. The chosen design is shown in Figure 2.
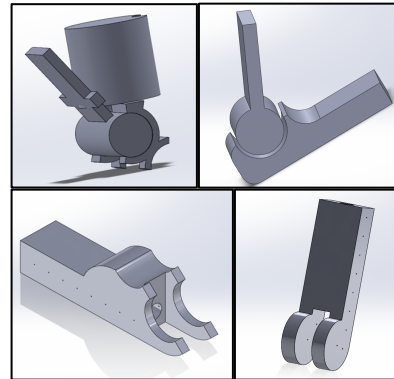

Fig. 1. Initial joint mechanism designs. Initial iterations of the joint mechanism design created independently by each team member.
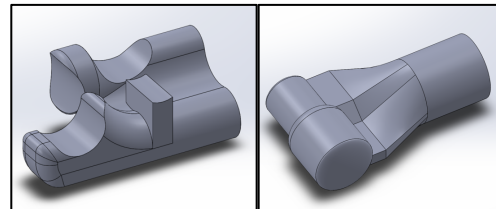

Fig. 2. Chosen initial joint mechanism design. Initial design of the joint mechanism that was chosen to modify into the final design.

Assembling the Prototypes

The finalized designs were 3D printed using an SLA printer. The parts were tested to make sure that they fit together correctly. The upper component of the mechanism was packed with modeling clay to fill in the empty spaces in the humeral component so that a viable mold could be created. A section of the print was removed using a dremel to fit a resin cast humerus that was attached to the shoulder. The upper joint mechanism was then cast using Smooth-on SmoothCast 300 resin. Holes were drilled in the upper mechanism and screws were fitted into them. A dremel was then used to remove some of the excess material to clear a channel for the springs and to provide enough space for the loops of the springs to fit around the screws. The first

cast was too pliable after having set, and the piece became deformed when the upper joint was grabbed during reduction. Subsequent casts were heat cured overnight to provide a more rigid final product. A bicep was cast using FlexFoam-iT VIII and was fitted over the humerus. At that point, the humerus was connected to the upper joint mechanism and glued together. The bicep and the joint mechanism were also glued together to prevent the bicep from sliding up and down the humerus. The screws were then put back in place, securing the springs. The completed upper section of the trainer was then attached to the torso at the shoulder using a cable to keep the shoulder stationary. The printed lower joint mechanism was suspended over the mold for the forearm and hand. To help the joint mechanism attach better to the foam, holes were integrated into the design to allow the foam to fill in these channels as it expanded, making the attachment more integrated. Once the foam cast was finished, excess foam was removed. Holes were drilled into the flat portions of the mechanism closest to the joint. The springs were then looped around the screws.

Results

Final Design

The final design of the joint mechanism is shown in Figure 3 and an assembly of the final design is shown in Figure 4. The radial component was designed so that the grooves for the dislocated position were higher than the grooves for the reduced position. This choice was made to accurately replicate the position of the bones in a dislocated elbow, where the forearm is shifted downward. The bicep was foam-cast to simulate the feeling of a human bicep while making it easier to grip. The humeral component was resin-cast because it was faster to make changes than 3D printing a brand new version while reducing cost. The resin material is also easier to remove with a dremel than the SLA printer material. The indentation incorporated into the radial/ulnar component made it so that the reduction technique being practiced required the same motion needed as a real reduction. The distance between the reduced and dislocated grooves make it so that when the trainer is in the dislocated position, the range of motion is constrained by the olecranon making contact with the back of the humeral portion. The locations for the screw placement on the humeral portion were determined based on how much the springs would be stretched when the trainer was in the dislocated position. The optimal locations were determined based on where the springs would be under enough tension that the joint would stay together but not so much that it was difficult to move the trainer to the reduced position. It was originally planned to hide the heads of the screws in the channels between the cylinders that make contact with the radial/ulnar portion and the outside of the humeral section, but this was abandoned when it was determine that leaving the screws outside simulated the medial and lateral epicondyles fairly well. The radial/ulnar section was left as a 3D print because the holes through the design made it difficult to create a mold for that component. When in the dislocated position, the radial/ulnar portion protrudes behind the humeral section to visually and tactilely simulate the olecranon in a posterior elbow dislocation.
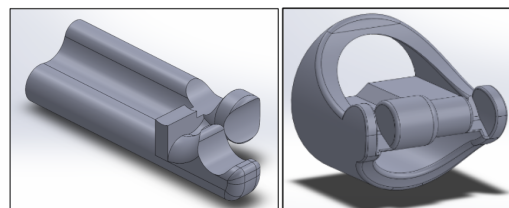

Fig. 3. Final joint mechanism design. Final joint mechanism design with simulated radial/ulnar component (left) and simulated humeral component with bicep attachment (right).
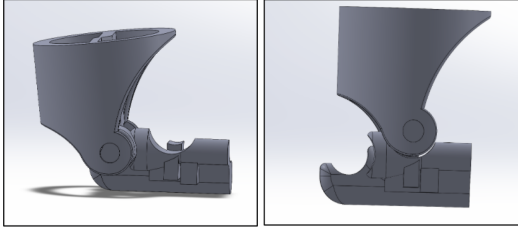
Fig. 4. Final joint mechanism design assembly. Assembly of the final joint mechanism design in the reduced position (left) and the dislocated position (right).

Fig. 5. Final prototype of joint reduction trainer. Final printed and cast elbow joint mechanism mounted to the shoulder and torso on a stand.

Expert Evaluations

The elbow joint reduction trainer prototype was showcased to six experts including five orthopedic surgeons and one athletic trainer. The experts tested the trainer by moving it into a dislocated position and performing a reduction. They then were asked to rate the trainer numerically on a scale of one to five (five being the highest) based on the accuracy of its force simulation, anatomical landmarks, form simulation, and useability. These categories were chosen to assess whether the trainer accomplished its original criteria and constraints. Force simulation was rated based on the accuracy of the trainer to the "feel" of a true posterior elbow joint reduction in terms of the difficulty and forces/tensions involved in the joint. Anatomical landmarks was rated based on the accuracy of the trainer in modeling anatomical

landmarks that are typically used in physical examinations of the elbow joint, such as the olecranon process and the medial and lateral epicondyles. Form simulation was rated on the accuracy of the trainer in terms of its human shape, such as the form of the chest and attached arm, "feel" of the materials used for the bicep and forearm, and the range of motion the elbow joint in the trainer is capable of. The useability was rated based on the applicability of the trainer in an educational or professional setting. Along with the ratings for these categories, the experts provided general feedback. The numerical ratings were summarized in Figures 6 and 7.
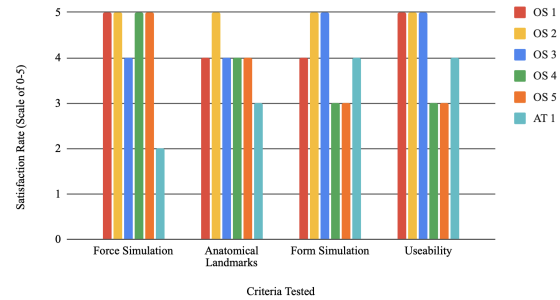

Fig. 6. Expert prototype evaluation scores. Prototype evaluation scores given by each expert in four categories (force simulation, anatomical landmarks, form simulation, and usability) on a scale from one (lowest satisfaction rate) to five (highest satisfaction rate).
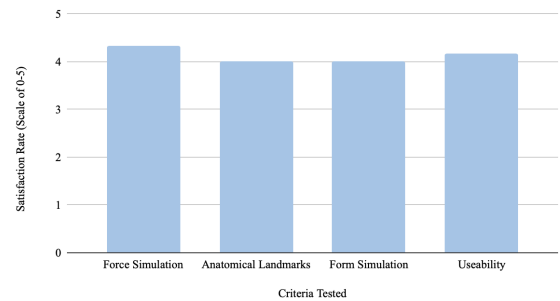

Fig. 7. Average expert prototype evaluation scores. Average of the prototype evaluation scores in four categories (force simulation, anatomical landmarks, form simulation, and usability) on a scale from one (lowest satisfaction rate) to five (highest satisfaction rate).

Force Simulation Results

Most experts agreed that the trainer is a good representation of how much force is required to reduce an elbow dislocation "in the field." Some stated that once a patient arrives at the emergency department, it takes more force to reduce a joint without sedation. This is because patients tend to contract their muscles more under distress. Experts suggested increasing the amount of force needed to reduce the trainer, so it is more representative of the most difficult scenario. Some experts recommended adding tendon and ligament features to increase the total force.

Anatomical Landmarks Results

All experts agreed that two important anatomical landmarks were integrated, the olecranon and the epicondyles. The olecranon process was included in the design of the ulna. The epicondyles were simulated by the rounded tops of the screws used to hold the springs in place. Some experts expressed desire for the epicondyles to be more prominent.

Form Simulation Results

Most experts agreed that the trainer simulates the physique of an athlete, more specifically a football player. When presented with both a hard foam bicep and a soft foam bicep, experts preferred the hard foam. They specified that the hard foam feels more muscular than the soft foam. Experts also mentioned decreasing the circumference of the bicep to increase the realism of the trainer as well as make it easier for medical professionals with a smaller grip.

All experts expressed the desire for the elbow joint to be more organic and less mechanical. They thought it was too easy to feel the resin, hardware, and other components within the elbow joint. Experts suggested covering the elbow joint with a skin-like material. This would reduce the mechanical feel of the trainer. It would also allow medical professionals to practice

diagnosing an elbow dislocation during a physical exam of the trainer.

Experts appreciated how the forearm was able to slightly rotate, and some suggested that the amount of rotation could be increased. They also noted the "clunk" sound after reduction added to the realism of the trainer.

Useability Results

All experts agreed that this trainer would be most valuable to medical students, orthopedic residents, emergency medicine residents, athletic training students, and athletic trainers. They noted the trainer would be implemented mainly in skills/simulation labs.

Experts noted that elbow dislocations are not the most common dislocations. They pointed out the design is limited to only simulating simple posterior dislocations. Experts concluded that the trainer would be a more valuable educational tool if it could simulate posterolateral and posteromedial dislocations as well. Experts expressed desire for the trainer to be less straightforward and obvious. They wanted the trainer to provide less guidance with the reduction in order to increase the difficulty.

Experts also brought attention to the fact that the design has no false success state, so there is no way to tell if the reduction was done properly or not. Because of the variability of the patient population, they suggest providing interchangeable springs and bicep pieces to simulate a variety of scenarios with the trainer. Experts appreciated that they were able to put the trainer in a supine position because some reductions are performed while the patient is lying down.

Conclusion

The elbow joint reduction trainer was successful in simulating a posterior elbow dislocation and reduction. The trainer was also successful in accomplishing most of its original design constraints and criteria. According to the

expert evaluations, the trainer realistically simulated human forces and the human form, encouraged accurate reduction techniques, and the anatomical landmarks incorporated were accurate. Durability testing was not completed due to time constraints. However, based on the durability and performance of the Luna Labs shoulder reduction trainer, which was created with the same materials and general design concepts, the elbow joint reduction trainer should exhibit a similar durability. Lastly, the expert evaluations reflected that as little as one person is able to use the trainer to perform the reduction technique.

Impacts

According to the expert testing, the trainer would be a useful application in medical schools and hospital simulation labs. The trainer was also lauded for its applicability in a variety of educational settings, such as in emergency medical technician (EMT) and paramedic training, medical school emergency medicine and orthopedic rotations, and orthopedic resident training programs. Many experts reflected that the trainer is a large step forward in meeting the need for better reduction training and concluded that the trainer would improve patient outcomes by improving reduction education.

Future Work

Based on the feedback from the expert evaluations, there are several changes that could be made in future iterations of the trainer. The most important change to make is to cover the joint mechanism with a skin-like material to cover the mechanical parts. This would improve the human form simulation by increasing the original feel of the trainer. Another helpful aspect to incorporate would be interchangeable parts for the trainer, such as bicep pieces and springs. For example, switching the foam bicep piece to ones of greater stiffness and increased circumference would better simulate the arm of an athlete, which

would be more applicable to athletic training education. Another change would be to increase the stiffness of the springs to make reduction require more force. This change would better simulate a reduction performed in the Emergency Department where the physicians would encounter more resistance due to increased muscle contraction. Luna Labs has expressed interest in mounting the elbow joint reduction trainer on their shoulder joint reduction trainer to create a trainer with a variety of joint dislocations. Based on the expert evaluations, they recommended using these design principles to create finger and hip joint reduction trainers. The rationale for focusing on these two joints are that fingers are fairly common dislocations and can dislocate in a variety of ways, and hips are one of the more complicated joints to reduce, which would require more practice. Some experts also recommended that the trainer model tendons and ligaments around the joints. These could serve as additional anatomical landmarks and add a realistic challenge to the reductions. Another feature to add would be embedded metal markers to allow for practice X-rays of a dislocated elbow, which helps to simulate another aspect of the diagnostic process in the elbow joint reduction. Overall, this elbow joint reduction trainer has a large potential to change the landscape of joint reduction education in the orthopedic field.

End Matter

Author Contributions and Notes

N.E.P., L.A.B., P.J.T., and L.B.A. conducted initial research. Berk, L. created the final joint mechanism design. N.E.P., L.A.B., P.J.T., and L.B.A. created and assembled the final elbow joint reduction trainer and its prior iterations. N.E.P led expert evaluation meetings. N.E.P., L.A.B., P.J.T., and L.B.A. wrote the final report. M.P. advised the entire project and aided in the creation of the elbow joint reduction

trainer. The authors declare no conflict of interest.

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