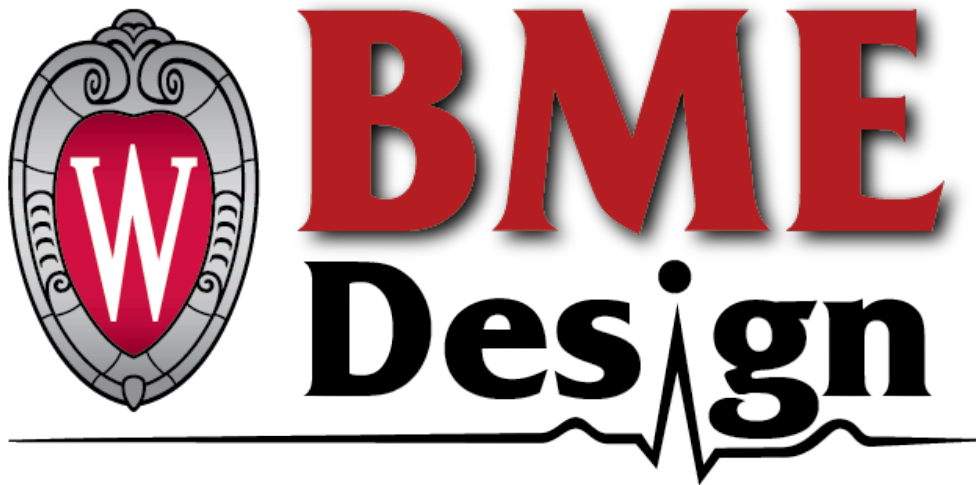




Functional Model of Reduction of Pediatric Radial Head Subluxation

Biomedical Engineering 200/300 - Preliminary Report, October 9th, 2026

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Abstract

Pediatric radial head subluxation, commonly known as nursemaid's elbow, is an injury that frequently occurs in young children and requires proper reduction techniques to return the radial head to its normal position. Healthcare providers currently have limited opportunities to practice these techniques before performing them on pediatric patients. Current training may involve practicing the motions on an adult arm, which does not provide the correct pediatric proportions or the tactile and audible feedback associated with a successful reduction. Existing training models have attempted to address this problem using magnetic mechanisms, but limitations remain in anatomical accuracy and realistic feedback. This project aims to develop a reusable pediatric arm model that allows healthcare providers to practice both hyperpronation and supination-flexion reduction techniques. The proposed design uses 3D printed pediatric arm bones with a spring loaded ball detent mechanism near the radial head that produces a tactile and audible click when a successful reduction is performed. The design also includes elbow and wrist movement, a reusable resetting mechanism, and easily replaceable components to support repeated training. The prototype will be evaluated for clinical accuracy, ease of use, and durability. These results will determine whether the model provides a realistic, repeatable, and practical method for training healthcare providers before performing nursemaid's elbow reductions on pediatric patients.

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Introduction

Motivation and Global Impact

When a child's arm experiences a sudden axial tensile force, whether due to someone pulling it or just playing, the radial head can slightly slip below the annular ligament [1]. This subtle dislocation, or subluxation, can cause discomfort and make it difficult for the child to move their arm away from their body. Although the procedure to fix this injury is simple and relatively painless, there is no accurate model to teach it. Therefore, physicians simply learn this procedure through verbal description and by performing it on patients. If the physician is not confident in their ability to perform the procedure, this may raise concerns with parents or even the patient.

Existing Devices and Current Methods

The current process for teaching the two reduction techniques is to practice on an adult, then try it on an actual patient. Testing the technique on an adult does not offer any tactile or audible feedback, such as the "click" that comes from the radial head sliding back into place. In addition, adult arm proportions are much different from that of a child. The typical size of a child's forearm with this injury ranges from 11-15 cm, while an adult forearm is much larger [2]. This project aims to address the issues that arise from only being able to practice on an adult arm before the real procedure.

There are two existing competing designs. The first model "The Michigan Elbow" was created at the University of Michigan. It features a magnetic internal mechanism that provides the tactile feedback that one would feel during the reduction. During the testing phase, the students had practitioners rate different aspects of the elbow on a scale from 1-5. The elbow received relatively high ratings within training value, but received low ratings for accuracy and feel [3]. It was reported that the model could be improved in the areas of the haptic and tactile feedback and the overall size.

The second competing design is from the University of South Florida. This design was able to be patented and also included a magnetic internal mechanism for tactile feedback. In this design, two magnets repelled during the reduction, and once the elbow was successfully reduced, two magnets would attract to make the "click" feel and sound [4]. The inner workings of the device were not anatomically accurate and instead were made entirely of mechanical components. This device also did not feature any hand portion, the reduction would have to be done by holding the wrist.

Problem Statement

The aim of this project is to create a functional model that would let physicians practice the reduction technique. Currently, the main way physicians learn this technique is by performing the procedure on a child. However, some parents might be concerned if a physician is performing this procedure on their child for the first time. Creating a model that provides similar tactile and resistance feedback would help teach the physician how to perform the reduction before performing it on a child, addressing parents' concerns.

Background

Anatomy & Physiology

Pediatric radial head subluxation, more commonly known as nursemaid's elbow, is caused by a child being picked up by the hand or wrist. It can also be caused by typical daily activities such as playing. When the wrist is pulled, the radius slides down, causing the annular ligament to slide partially off of the radial head [5]. This injury is common to children ages 1 - 4 due to a shallow concave radial head and immature annular ligament [6].

There are two current main techniques for treating pediatric radial head subluxation. The first technique is hyperpronation. The patient stays on the parent's lap facing the examiner; grabbing the elbow with one hand, the examiner's opposite hand firmly grabs the distal forearm, hyperpronating the forearm [5]. The second technique is supination flexion. The practitioner grabs the elbow with one hand, their opposite hand firmly grabs the distal forearm and applies the supination of the forearm followed by flexion [6]. Hyperpronation is more commonly tried first and in a few studies has been shown to be more effective.

Client Information

The client for this project is Dr. Carey Wagoner from the University of Wisconsin-Madison Department of Pediatrics. The model is being developed for University of Wisconsin (UW) Health to help pediatric residents practice nursemaid's elbow reduction techniques before performing the procedure on pediatric patients.

Product Design Specification

Nursemaid's elbow reduction requires controlled manipulation of the pediatric elbow and forearm, with successful reduction commonly associated with a noticeable "click" as the radial head returns to position [7]. The design should represent a toddler-sized arm focusing on the bicep through the wrist and requiring stabilization of both the elbow and wrist during reduction. Additionally, it should have a repeatable tactile and audible "click" at the reduction point. The

range of motion of this model is approximately 140° flexion, 0° to -10° hyperextension, 85° supination, and 60° to 70° pronation [8]. Combined with these factors, durability is important considering over 1,000 complete reduction cycles, with replaceable components. A final big design consideration is a total weight of less than 3 lb for portability during seminars, residency programs, and “just-in-time” hospital training. The model will use rigid artificial bones for the humerus, radius, and ulna, a detent mechanism for the sound, and a silicone outer layer to provide a toddler-like feel while preventing exposure of internal components [9]. Function and accurate reduction training are prioritized over cosmetic realism, consistent with UW Health’s stated requirements. The model should have a minimum two-year shelf life under normal indoor storage conditions, use materials suitable for skin contact, and remain serviceable through replacement of worn ligament, joint, and skin components [10, 11, 12]. The team is targeting a prototype and fabrication cost of approximately \$300.

Preliminary Designs

Design 1: Detent Arm

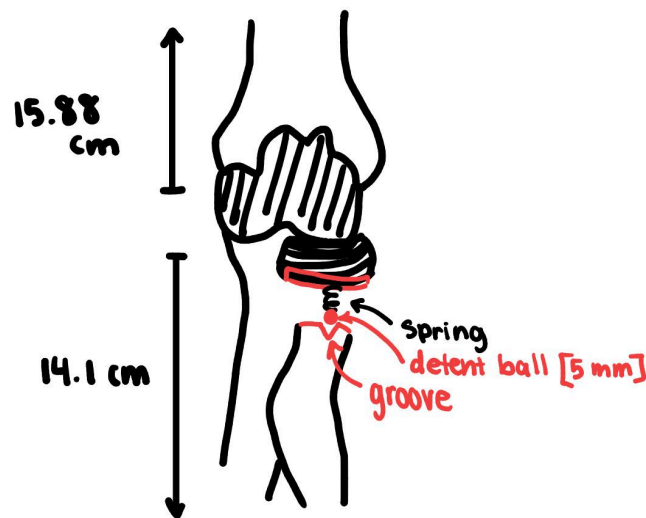


Fig. 1. Detent Arm Design

Design 1, the Detent Arm Design, uses a detent mechanism to simulate the reduction technique of a radial head subluxation. A spring-loaded ball detent or snap-fit mechanism located near the radial head and attached to the radius will provide feedback of a “click” indicating a successful procedure. In an “affected” state, the model will have the annular ligament popped out which will have the detent out of its initial position. Once the procedure is performed and the radial head reaches the desired position, the detent will snap into a groove, producing a “click”. Furthermore, in this design the humerus, radius, and ulna will be 3D printed to represent the major bones of a pediatric arm. Additionally, flexible material, such as silicone tubing, TPU, or elastic cord, will surround the radial head to represent the annular ligament.

After each trial, the mechanism can be manually returned to the subluxated position so the model can be reused. The elbow mechanism will be detachable using screws, allowing worn components or the annular ligament piece to be replaced without replacing the entire model. To get an accurate anatomical feel, a thin foam or silicone sleeve will cover the bones to simulate soft tissue as well as wrist movement to practice proper stabilization.

Design 2: Wind-Up Arm

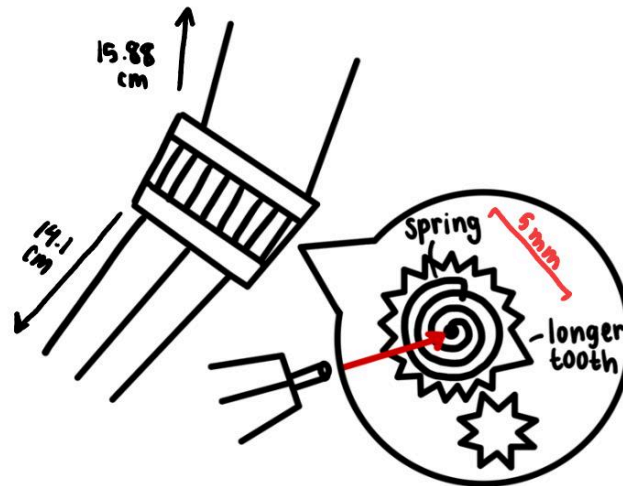


Fig. 2. Wind-Up Arm Design

Design 2, the Wind-Up Arm Design, uses a spring loaded mechanism for the elbow joint. This mechanism would allow the user to rotate the forearm until a “click” is felt, then rotate the arm back to reset the mechanism. The radius and ulna would act as a key that would rotate a gear and coil the steel strip, until hitting a steep, asymmetrical tooth that would click, and then lock into place. This design uses 3D printed humerus that is modified on the elbow side to detach and accommodate the gear and spring mechanism, as well as a 3D printed radius and ulna, that acts as the key on the elbow side and are attached to a wrist mechanism allowing the user to practice stabilizing the joint when performing the procedure. For an accurate anatomical feel at the forearm and upper arm, the bones are surrounded in padding and a silicone layer that simulates the feel of skin.

Design 3: Hybrid Arm

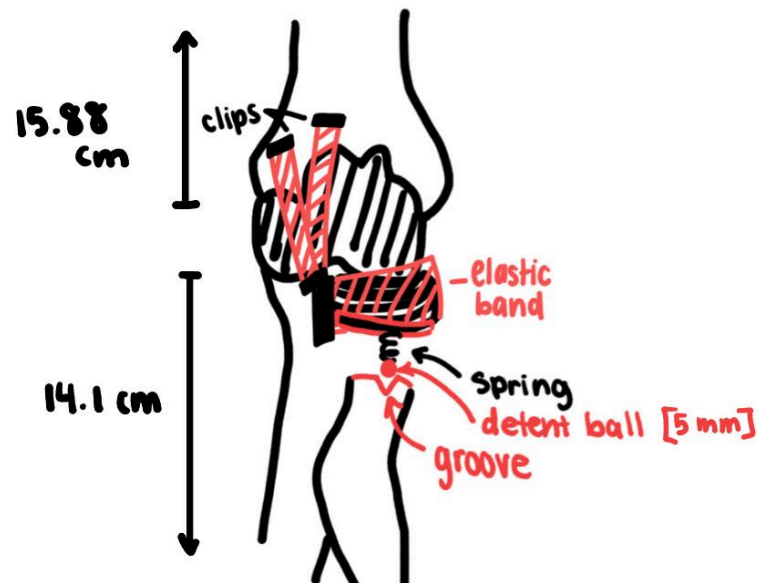
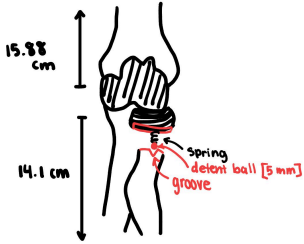
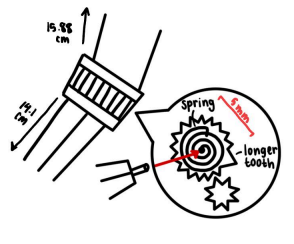
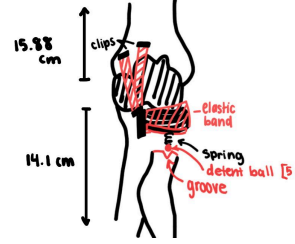


Fig. 3. Hybrid Arm Design

Design 3, the Hybrid Arm Design, incorporates the detent mechanism while creating a visually and mechanically more accurate elbow joint using elastic bands. The spring-loaded, snap-fit detent mechanism, as described in the first design description, will make a “click” noise once the subluxation is corrected. The humerus, radius, and ulna will be 3D printed to represent life-sized versions of the major bones of a pediatric arm. To connect the bones and simulate accurate mechanical forces on the elbow joint, durable elastic woven bands of anatomical size and resistance will be attached to represent the annular, medial collateral, and lateral collateral ligaments. These bands will be attached by secure clips built into the 3D printed bone design, allowing for them to be easily replaced when worn down. Additional coatings or padding will be added at the site of the joint to act as cartilage and reduce wear on the bones.

Table 1. Design Matrix

Criteria	Weight	Design 1: Detent Arm		Design 2: Wind-Up Arm		Design 3: Hybrid	
							
Accuracy	35	4/5	28	3/5	21	5/5	35
Reusability	25	4/5	20	5/5	25	4/5	20
Durability	15	4/5	12	2/5	6	3/5	9
Ease Of Fabrication	10	3/5	6	2/5	4	2/5	4
Cost	10	5/5	10	4/5	8	4/5	8
Portability	5	3/5	3	5/5	5	4/5	4
Total:	100	79		69		80	

Design Matrix Criteria & Discussion

Accuracy: Accuracy receives the highest weight because the primary purpose of the device is to simulate a nursemaid's elbow reduction accurately enough for pediatric residents to practice the procedure. A high score means the model can reproduce the necessary forearm motion, small radial-head displacement, resistance during manipulation, and “click” associated with a successful reduction.

- Design 1: The detent mechanism can create a controlled and repeatable click and can be designed to permit a small amount of radial-head displacement. However, the mechanical detent itself does not closely mimic the function of the annular ligament. This also plays into not enough resistance created to mimic the anatomical functions of ligaments in the arm to get the “twisting” and “cross-over” sensation with the radius and ulna. This is why Design 1 is ranked 4/5.
- Design 2: Design 2 is ranked 3/5. The wind-up mechanism can translate forearm rotation into controlled movement and a “click”, but the gear-based mechanism is less representative of the actual anatomical behavior of the radius and annular ligament.

- Design 3: The hybrid combines the “click” sensation of the detent with elastic elements that can better approximate ligament resistance. This provides both feedback of success with a sound and more anatomically representative resistance. This is why Design 3 rated the highest and received a 5/5.

Reusability: Reusability is also very important to the design, as specified by the client. Given that this device will be used for educational purposes, it must be used over and over again to teach the reduction of radial head subluxation. The inner mechanism of the design should be able to reset to the “affected” state without damaging or causing wear to the product. The process for resetting the device should be simple and quick, as well as intuitive for the user.

- Design 1: The Detent Design is relatively easy to reset, as a small button can be pushed to release the ball and spring mechanism, allowing for the elbow to return to the “affected” state. Given the positioning of the mechanism and the size of the button, resetting the device may not be intuitive to the user. Resetting the device would also require both hands. Therefore, the design received a 4/5 in this category.
- Design 2: The Wind-Up Design is a more simple mechanism for the user, as it just requires you to pull the arm to reset it. The elbow itself acts as a resetting mechanism, so no small button or strange maneuver would be required. The user will be able to feel the device reset without compromising the life-like feel and appearance of the design. For this reason, this design was rated the highest for this category (5/5).
- Design 3: The Hybrid Arm Design received a 4/5 rating in this category because it has an almost identical mechanism to the Detent Design. In addition, the added ligaments and anatomical features could get in the way of the button for resetting the mechanism. The design would have to be consciously made such that this doesn’t impede performance.

Durability: The product must be able to withstand consistent, long-term use. Specifically, the product will be used everyday, and should last at least six months. The product should also remain intact, or relatively unscathed, if faced with an out-of-ordinary situation or accident involving stress on the product, such as falling, being knocked/hit, or being cut. Certain parts of the product that endure the most stress should be easily replaceable, further increasing the design’s longevity.

- Design 1: The Detent Design ranks the highest for durability because it has the least parts that would need to be replaced. Additionally, all of the components are metal or plastic, which is more durable than elastic, giving this design a 4/5 for this criterion.
- Design 2: The Wind-Up Design received a score of 2/5 in durability. This design received the lowest score because the gear component would be very challenging to replace when it wears out, meaning the model could be used for less time.

- Design 3: The Hybrid Design was given a 3/5 rating for the durability category. Although it uses a similar mechanism to the Detent Design, the added elastic bands may get worn out more easily due to constant loading and maneuvering. Although the design allows for these to be easily replaced, it is still less durable overall than the Detent Design.

Ease of Fabrication: This category considers the effort and feasibility of fabrication of the product within one semester. High scores indicate a design that would be difficult to complete within the time frame, while low scores indicate a design that the team considers reasonable to complete within the time frame.

- Design 1: The Detent Design ranks the highest for ease of fabrication because it is the least complex to fabricate. The design received a 3/5 because it would only require modifying the 3D printed bones and adding the detent mechanism.
- Design 2: The Wind-Up Design received a 2/5 for this criteria because the mechanism is more complex than the Detent Design, due to the use of multiple gears and a spring. While it doesn't involve attaching elastic to the bones, it is still much less feasible to fabricate than the detent mechanism.
- Design 3: The Hybrid Design has a 2/5 for ease of fabrication because it involves using elastic to mimic the ligaments. Attaching the ligaments to the 3D printed bones adds an element of complexity, giving this design one of the lowest scores in this category.

Cost: This accounts for the amount of money required to fabricate each design. Lower scores indicate a higher cost, and higher scores indicate a lower cost.

- Design 1: The detent design ranked highest for cost because it uses the least complicated design. This design only requires the use of modifying 3D printed bones with either cheap existing mechanisms. The detent design received a 5/5.
- Design 2: This wind up design only received a 4/5 because it requires a more complex design in which the team will either need to buy or 3D print multiple gears, and buy springs. This requires more than the detent design which is why it is ranked lower. The wind-up design received a 4/5.
- Design 3: The hybrid design also received a 4/5 because it also has a more complex design compared to the detent design. This design also requires an elastic material that could be used to simulate ligaments, which will end up costing more compared to the detent design.

Portability: This category considers the ability to be moved around and stored. The product must be able to be transported between seminars and hospitals without damage. It should also be able to be stored in a cabinet for long periods of time, and able to be easily taken out once needed for teaching.

- Design 1: The detent mechanism within the arm has the possibility of making the arm harder to fold up for storage. If there is a divot for the detent to sit in for the subluxated

position, the arm will be stuck out in an extended position, and therefore less compact. For these reasons, the detent arm received a 3/5.

- Design 2: The wind up arm design received a 5/5 for portability. The detachable humerus allows for the model to separate into two pieces. This would allow for the model to take up half the length of the other designs, which is ideal for storage. The mechanism also does not add bulk that would get in the way of easy storage.
- Design 3: With the hybrid arm design having both rubber bands, the design allows for realistic resistance while still allowing for the arm to be folded into a portable position. The rubber bands do limit the ability to fully fold slightly, but only enough to bring the design score down to a 4/5.

Proposed Final Design

The final design selected utilizes the main mechanism from Designs 1 and 3. Based on recent client feedback, there was a shift to prioritize functional accuracy over exact anatomical representation, and add a reset mechanism. A spring-loaded ball detent or snap-fit mechanism located near the radial head and attached to the radius will provide feedback of a “click” indicating a successful procedure. Once the procedure is performed and the radial head reaches the desired position, the detent will snap into a groove on the humerus, producing a “click”. Furthermore, in this design the humerus, radius, and ulna will be 3D printed out of poly(lactic acid) (PLA) to represent the major bones of a pediatric arm.

After each trial, the mechanism can be manually returned to the subluxated position so the model can be reused. The reset mechanism will have a wedge cam attached to a compression spring to displace the detent ball out of the groove, allowing the procedure to be performed again. A ball and socket joint will also be incorporated for the wrist component, to allow rotation of the forearm. Ensuring correct positioning of the wrist is an important part of performing the reduction techniques, as described in Appendix A. Finally, the upper arm near the bicep will be attached to a base of wood. There will be a hinge mechanism so that the arm can abduct and adduct, giving the model additional movement and creating a more realistic set up.

Fabrication

Materials

The model must represent the arm of a toddler and simulate the mechanism of reduction as accurately as possible. The bone and hand components of the model will be designed in Onshape and 3D-printed. PLA will be used for all 3D-printed components as it meets the needs of the project and is very cost effective. Within the elbow joint, a small spring-loaded ball

plunger will screw into a heat insert within the 3D printed bones. The elbow joint will also include a wedge cam attached to a compression spring which will act as the reset mechanism. The bones will be wrapped with foam to mimic the muscle and fat present on the arm and covered in a layer of silicone to mimic the skin. At the wrist component of the model, a ball and socket joint will allow the 3D-printed hand component to move freely. Lastly, at the shoulder, the model will be attached by a hinge to a wooden stand. The materials that have been purchased can be seen in Appendix B, and any additional materials will be purchased at the Grainger Engineering Design Innovation Lab.

Methods

The first step in fabricating the model is modifying the CAD models of the humerus, radius, and ulna to hold the mechanism in the joint. The radius will need a pilot hole, and the humerus will need two grooves for the detent to “click” into. Additionally, the humerus will need to be adjusted to hold the wedge cam and compression spring in place on the elbow joint. At the wrist, the radius and ulna will need to be modified to accommodate the ball and socket joint. Next, a CAD model will need to be created for the hand component. To connect the ball plunger to the radius bone, a heat inset press will be used to embed a brass insert into the PLA. The ball plunger will then screw into the insert. The wedge cam and compression spring will then attach to the humerus, completing the elbow mechanism. To create the soft tissue component of the model, the foam will be cut to the size of the arm and attached to the bones. Next, the silicone will be wrapped around the foam, creating the outermost layer. Lastly, a stand for the elbow model will be created by cutting two pieces of wood that slot together on the CNC machine, and the elbow will be attached to the stand using a hinge.

Final Prototype

The final prototype will be a toddler-sized arm model consisting of a 3D-printed humerus, radius, and ulna, with a hinge mechanism at the elbow to allow flexion and extension. The radius will also be able to rotate to simulate the pronation and supination movements needed to perform nursemaid’s elbow reduction. A spring-loaded ball detent mechanism will be placed near the radial head to provide a tactile and audible “click” when the reduction is successfully performed. To reset the model, a spring-loaded wedge cam will push the detent ball out of its groove, allowing the radius to return to its starting position. The elbow mechanism will be detachable using screws so that worn or damaged components can be replaced without rebuilding the entire model. The bones and internal mechanisms will be covered with a flexible silicone layer to simulate the soft tissue of an arm while still allowing the radial head to be felt during the procedure. The final model will allow pediatricians to repeatedly practice reduction techniques while receiving tactile feedback similar to that experienced during an actual reduction.

Testing

To determine the accuracy, ease of use, and durability of our design prototypes, a number of tests will be performed, both quantitative and qualitative. Given that the product is meant to be a teaching device for a specific procedure, the expertise of orthopedic surgeons and others who have performed it *in vivo* are needed to determine the accuracy of the device. Ease of use is a more broad category, so the product will be tested on laypeople to determine how intuitive the resetting mechanism is. Durability will likely be the only quantifiable testing area, as it can be measured applied forces on the prototypes.

Accuracy

The accuracy of our product with regard to simulating radial head subluxation reduction will be evaluated by the client, who has performed this procedure on patients in the clinical setting. For this test, the client will perform the reduction procedure on the design as he would on a human patient. He will then rank the following aspects of the experience on a scale of 1-5, with 1 being completely inaccurate to the actual procedure and 5 being completely accurate.

1. Required applied force
2. Resistance
3. Arm movement/range of motion
4. Click feeling
5. Click sound

If possible, other pediatric orthopedic surgeons will be involved in this testing to gather more data and varying perspectives. In an ideal situation, the client should test a variety of prototypes throughout the design process to display progress.

Ease of Use

A major goal for the design is to have a simple and intuitive resetting mechanism such that the device can be easily used over and over in training. To test the ease of use of the resetting mechanism, we will have 15 different individuals attempt to reset the device to its “injured” state. Each individual will be handed the device in its “reduced” state and prompted to reset the device without further instruction. The individual will be timed from when the prompt was delivered to when the device has been successfully reset. Each person will repeat the resetting procedure twice more to ensure the mechanism’s consistency, being timed in the same manner for every trial. The trial times will be recorded to determine the average resetting time and the trend among the three trials.

Durability

The prototype will be subject to conditions of extreme use to determine its durability in the field. Each team member will perform the reduction and resetting sequence 30 times in quick succession before immediately passing it to the next team member. In total, the prototype will have been tested 180 times in a row. The device will then be thoroughly examined for any signs of failure or wear. This procedure should be repeated at least three times to test the longevity of the design and clearly highlight weak points.

Results

Testing has not been conducted yet, but the results of each of these tests will reveal the ability of our design to accurately and reliably replicate the radial head subluxation procedure. By obtaining feedback from experts in the field and testing mechanical limits, it will be clear as to whether or not the design meets the needs of the client and the medical field at large. A combination of qualitative and quantitative results will show which areas meet or exceed expectations and which areas fall short.

Discussion

Successful accuracy testing would be achieved by a client ranking of five in every category, indicating his approval for the design's ability to replicate the feeling of the reduction procedure. If possible, the client should test the device and provide rankings multiple times throughout the design process so that specific areas of improvement as well as positive progress may be identified. Multiple physicians in the pediatric orthopedics fields should also test the device to provide more representative feedback.

To ensure that the device is easy to use and reset, the ease of use testing should have an average time of less than 10 seconds to reset the device for the first trial and less than 5 seconds for the remaining two trials. The resetting mechanism should be simple and intuitive, and the device must be able to be quickly reset between uses to maximize training capacity. By limiting the time required to reset the device, use in the teaching setting will be more effective and time efficient.

The device should be able to withstand at least 180 consecutive uses without signs of wear, as learning the procedure requires repetitions. The performance and feeling of the device should not be impacted by the number of times it is used. By testing extreme use that exceeds actual use expectations, it can be safely assumed that the design will be durable enough in the educational setting.

Given that the product will not be used in an actual clinical or hospital setting, regulations regarding critical medical devices do not necessarily apply. However, the design will come in contact with physicians and physicians in training during work and clinical hours, so it must be easily cleaned to prevent the spread of germs and bacteria. ISO 17664-2 provides guidelines for non-critical medical devices, specifically those that are only intended for contact with intact skin [13]. To ensure that the product abides by ISO guidelines, a detailed cleaning regimen must be devised for safe use and handling.

Conclusion

Currently, there are limited training models available to help physicians learn reduction techniques for nursemaid's elbow, so physicians often learn the procedure through word of mouth and on-the-job experience. Creating a functional model that can accurately simulate a nursemaid's elbow will help the physicians learn and understand the reduction technique before performing it on a child. This will be done by combining a spring-loaded detent mechanism near the radial head that provides a click indicating the procedure is done correctly. To reset the model, a spring-loaded wedge cam will push the detent ball out of its groove, allowing the model to reset and be ready to reuse. This design was chosen because it provides a simple and repeatable mechanism, allowing physicians to practice the reduction procedure.

Next steps include creating the final chosen design. Once constructed, the model will be tested for functionality and accuracy. Testing will focus on the consistency of the tactile click, the range of motion of the elbow and wrist, the reliability of the reset mechanism, and the durability of the model after repeated uses. The prototype will also be evaluated against the design specifications, including weight, cost, and reusability. Dr. Wagoner and, hopefully, other pediatricians will test the model and provide feedback on how accurately it simulates the reduction procedure. Based on their feedback, there will be adjustments and conduct additional testing until the model meets the design requirements and the client's expectations. Once these requirements are met, the final model will be constructed.

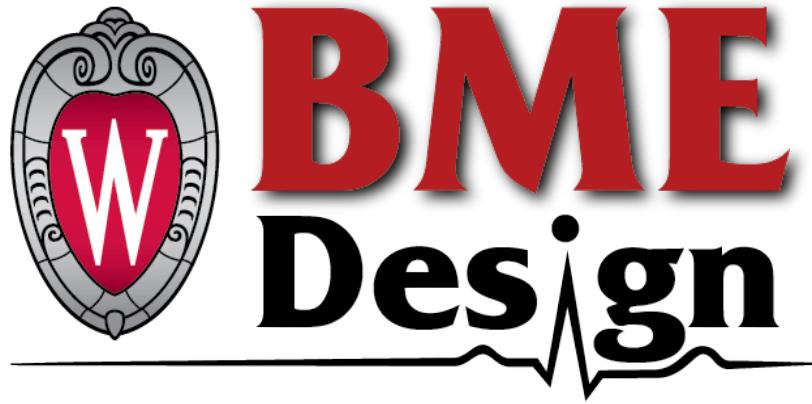
References

- [1] N. M. Nardi and T. J. Schaefer, "Nursemaid Elbow," Nih.gov, Aug. 14, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK430777/> (accessed Sept. 16, 2026).
- [2] T. Edmond, A. Laps, A. L Case, N. O'Hara, and J. M Abzug, "Normal Ranges of Upper Extremity Length, Circumference, and Rate of Growth in the Pediatric Population", Publications of the American Association for Hand Surgery, Feb. 2019, doi: 10.1177/1558944718824706.
- [3] Mohamed Yassin (University of Michigan) et al., "The michigan elbow: Examining the quality of a pulled elbow task trainer by Pediatric Specialists," Michigan Journal of Medicine, <https://journals.publishing.umich.edu/mjm/article/id/8843/> (accessed Sep. 15, 2026).
- [4] K. Kompalli, C. R. Sargent, J. Todaro, T. N. Gore, S. H. Smith, and P. Cecil, "Apparatuses and methods for practicing a reduction procedure for treating radial head subluxation," U.S. Patent Application US20250252870A1, Aug. 7, 2025.
- [5] A. Ulici, A. Herdea, M. Carp, C. Nahoi, and I. Tevanov, "Nursemaid's Elbow Supination-flexion Technique Versus Hyperpronation/forced Pronation: Randomized Clinical Study", Indian Journal of Orthopedics, Jan. 2019, doi: 10.4103/ortho.IJOrtho_442_17.
- [6] M. Miswan, M. Othman, and M. Effendi, "Pulled/nursemaid's elbow", Malays Fam Physician, 2017 April 30, PMID: PMC5420320.
- [7] N. M. Nardi and T. J. Schaefer, "Nursemaid Elbow," Nih.gov, Aug. 14, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK430777/> (accessed Sept. 16, 2026).
- [8] UFO Themes, "Pediatric Elbow and Forearm Conditions," Musculoskeletal Key, Aug. 12, 2021. <https://musculoskeletalkey.com/pediatric-elbow-and-forearm-conditions/> (accessed Sept. 17, 2026).
- [9] Soni J, Gamba LK, Bebbler FS, Kozovits F. DEVELOPMENT OF ORTHOPEDIC SIMULATOR TO PRACTICE CLOSED REDUCTION OF PEDIATRIC FRACTURES OF THE MIDDLE THIRD OF FOREARM. Acta Ortop Bras. 2023 Feb 20;31(1):e252387. doi: 10.1590/1413-785220233101e252387. PMID: 36844128; PMID: PMC9949289.
- [10] ISO, "ISO 10993-10:2021," ISO, 2021. <https://www.iso.org/standard/75279.html> (accessed Sept. 17, 2026).

- [11] “Ecoflex™ 00-20 Product Information,” Smooth-On, Inc.
<https://www.smooth-on.com/products/ecoflex-00-20/> (accessed Sept. 17, 2026).
- [12] S. Life, “Materials Shelf Life Warranty,” Smooth-On, Inc., 2019.
<https://www.smooth-on.com/page/materials-shelf-life-warranty/> (accessed Sept. 17, 2026).
- [13] Center for Devices and Radiological Health, “Use of ISO 10993-1, Biological Evaluation of Medical Devices - Part 1,” U.S. Food and Drug Administration. Accessed: Sep. 16, 2026. [Online]. Available:
<https://www.fda.gov/regulatory-information/search-fda-guidance-documents/use-international-standard-iso-10993-1-biological-evaluation-medical-devices-part-1-evaluation-and>.

Appendices

Appendix A - Product Design Specifications



Functional Model for Reduction of Pediatric Radial Head Subluxation

Team Name: Elbow Enthusiasts

Product Design Specifications | September 17, 2026
BME 200/300 Lab 301

Client: Dr. Carey Wagoner

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Function

Nursemaid's elbow occurs when a child's arm, typically between the ages of one and four, hyperextends, causing the annular ligament to partially slip off the radial head of the elbow [1]. The procedure to fix this is very simple: a physician will perform an elbow reduction by pronating the hand and extending the arm. This technique will almost always work, but if it doesn't, the physician will pronate the hand and flex the arm simultaneously. Most of the time, a popping sensation in the elbow indicates the reduction was done correctly. It is imperative that the physician supports the elbow with their thumb on the radial head with one hand while supporting the wrist with the other, the reduction will not work [2]. This procedure almost never has issues and is very easy to repeat once learned. However, some parents might be concerned if a physician is performing this procedure on their child for the first time. A functional model that can simulate a nursemaid's elbow and perform the reduction would solve this problem. This model would primarily be used during residency for training immediately before a physician performs the reduction. The model also needs tactile feedback indicating that the reduction is performed correctly, so physicians can get a feel for the technique.

Client requirements

The design must simulate a reduction on a toddler's arm as accurately as possible to best support training.

1. The design must provide tactile feedback during the reduction to best convey the feeling of the radial head being reduced.
2. Must look like a toddler's arm, including their wrist; fingers are not needed, all the way up to the bicep.
 - a. Does not need to be an exact replica of the arm; needs bone structure but not accurate skin/muscle
3. Must require stabilization of the elbow and wrist while doing the reduction
4. The design must maximize the number of uses before needing to be repaired
 - a. Although if the model is very accurate, they don't mind more frequent repairs
 - b. Repairs include changing rubber bands that simulate the ligaments
5. It would be ideal if it was portable and around 2-3 lbs or less
6. A budget of around \$300 is given, but can go above if really needed
 - a. Wants to be as cheap as possible
7. Most importantly, the design is a working model that accurately teaches the reduction
 - a. More important than making it look realistic

Design requirements

1. Physical and Operational Characteristics

- a. **Performance requirements:** The pediatric elbow simulation model should withstand repeated use by medical professionals while maintaining the same range of motion with each use. There should be an audible “click” when the arm is rotated, and this click should occur after the same amount of rotation during each use.
- b. **Safety:** The training model should have no exposed sharp metal or plastic parts that could harm a user. Additionally, since the model comes into contact with human skin, the materials should not cause harm. Therefore, per ISO 10993-10, any flexible polymers or rubbers used must be non-irritating and non-sensitizing [3].
- c. **Accuracy and Reliability:** The training model should allow for the range of motion of a healthy pediatric elbow. The model should allow for 140° of flexion, 0° to - 10° of hyperextension, 85° for forearm supination, and 60° -70° for pronation [4].
- d. **Life in Service:** The pediatric elbow simulation model should have a shelf life of at least 2 years under normal indoor storage conditions. The model should be stored in a cool, dry indoor environment around room temperature. Silicone rubber and other soft components should resist drying and cracking [5].
- e. **Shelf Life:** The model should withstand at least 1,000 complete elbow reduction practice cycles before major structural failure. The model should continue to allow normal elbow flexion, extension, pronation, and supination. Parts that experience repeated stretching or wear, especially the artificial annular ligament, joint components, and silicone skin, should be replaceable without replacing the entire model [6].
- f. **Operating Environment:** The model will be used in seminars and residency programs to demonstrate and provide training for reduction techniques. Additionally, models will be used for “Just-In-Time” training within the hospital.
- g. **Ergonomics:** The shape and feel of the model will be as close as possible to a real toddler's arm to replicate real-life conditions.
- h. **Size:** The total length, forearm length, arm circumference, and forearm circumference should be the same as recorded values for a child aged 1-3. For a 2-year-old, the total arm length should be between 13.8 and 14.11cm, forearm length 12.41, arm circumference between 15.59 and 15.64 cm, and forearm circumference between 15.04 and 15.05 cm [7].
- i. **Weight:** The model should weigh no more than 3 pounds. It should be light enough that transporting and storing the model is not difficult. The weight should be similar to the real weight of a toddler-sized arm.
- j. **Materials:** The model should use rigid artificial bones to represent the humerus, radius, and ulna. Silicone rubber should be used for the outer skin and soft tissue.

Flexible materials should be used for the annular ligament and joint to allow realistic movement and resistance [8].

- k. **Aesthetics, Appearance, and Finish:** The model should look and feel similar to the arm of a 1 to 3-year-old. The outside should have a skin-like silicone layer that covers the bones and joint components. The surface should have a smooth finish with no sharp edges or exposed internal parts.

2. Production Characteristics

- a. **Quantity:** The client would like us to provide one unit of the final product, along with the necessary information to produce bulk quantities later on.
- b. **Target Product Cost:** The product should be designed to be produced and purchased affordably. The client did not specify a budget but indicated that roughly \$300 should be sufficient for prototyping and fabrication.

3. Miscellaneous

- a. **Standards and Specifications:** The proposed model will not require FDA approval, as it will be used solely for training purposes. Given the model's intended use in the medical field, perhaps even in clinical settings, it may be deemed a medical device. Medical devices of this nature must be designed and used in compliance with ISO 10993-1, "Biological evaluation of medical devices - Part 1: Evaluation and testing within a risk management process," which outlines safe and unsafe materials for contact with intact skin [9]. The functional model does not need to be sterilized before or after use, classifying it as a "non-critical medical device" under ISO 17664-2:2021 [10].
- b. **Customer:** The customer is the University of Wisconsin (UW) Health. This is specifically made to target pediatric residents who need to practice radial head subluxation techniques for nursemaid's elbows. The model should provide residents with a repeatable training opportunity to develop proper technique and confidence before performing reductions on pediatric patients.
- c. **Patient-related concerns:** Patient comfort and satisfaction should be considered in the design, as pediatric patients will ultimately receive treatment from physicians who have practiced with the model. The training model should help residents learn proper hand placement, stabilization, and reduction techniques while minimizing unnecessary manipulation that could cause discomfort during the actual procedure. It should be mentioned that the model itself will not come in contact with the patients.
- d. **Competition:** Currently, there are few commercial materials available for practicing radial head subluxation reduction techniques. The training methods currently available at UW Health are word-of-mouth; however, the client mentioned that he has seen improvised models using skeletal sketches and elastic materials. One model was developed and produced by the University of Michigan. Their approach used two models representing the supination and

pronation reduction techniques. The models incorporated a 3D-printed plastic mechanism embedded within a silicone-based, child-sized arm form [11]. This existing design provides a useful reference for simulating pediatric anatomy and reduction mechanics.

References

- [1] N. M. Nardi and T. J. Schaefer, "Nursemaid Elbow," Nih.gov, Aug. 14, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK430777/> (accessed Sept. 16, 2026).
- [2] D. F. Huelke, "An Overview of Anatomical Considerations of Infants and Children in the Adult World of Automobile Safety Design," Annual Proceedings / Association for the Advancement of Automotive Medicine, vol. 42, p. 93, 2024, Accessed: Sept. 16, 2026. [Online]. Available: <https://pmc.ncbi.nlm.nih.gov/articles/PMC3400202/>.
- [3] ISO, "ISO 10993-10:2021," ISO, 2021. <https://www.iso.org/standard/75279.html> (accessed Sept. 17, 2026).
- [4] UFO Themes, "Pediatric Elbow and Forearm Conditions," Musculoskeletal Key, Aug. 12, 2021. <https://musculoskeletalkey.com/pediatric-elbow-and-forearm-conditions/> (accessed Sept. 17, 2026).
- [5] "Ecoflex™ 00-20 Product Information," Smooth-On, Inc. <https://www.smooth-on.com/products/ecoflex-00-20/> (accessed Sept. 17, 2026).
- [6] S. Life, "Materials Shelf Life Warranty," Smooth-On, Inc., 2019. <https://www.smooth-on.com/page/materials-shelf-life-warranty/> (accessed Sept. 17, 2026).
- [7] T. Edmond, A. Laps, A. L Case, N. O'Hara, and J. M Abzug, "Normal Ranges of Upper Extremity Length, Circumference, and Rate of Growth in the Pediatric Population", Publications of the American Association for Hand Surgery, Feb. 2019, doi: 10.1177/1558944718824706.
- [8] Soni J, Gamba LK, Bebbler FS, Kozovits F. DEVELOPMENT OF ORTHOPEDIC SIMULATOR TO PRACTICE CLOSED REDUCTION OF PEDIATRIC FRACTURES OF THE MIDDLE THIRD OF FOREARM. Acta Ortop Bras. 2023 Feb 20;31(1):e252387. doi: 10.1590/1413-785220233101e252387. PMID: 36844128; PMCID: PMC9949289.
- [9] Center for Devices and Radiological Health, "Use of ISO 10993-1, Biological Evaluation of Medical Devices - Part 1," U.S. Food and Drug Administration. Accessed: Sep. 16, 2026. [Online]. Available: <https://www.fda.gov/regulatory-information/search-fda-guidance-documents/use-international-standard-iso-10993-1-biological-evaluation-medical-devices-part-1-evaluation-and>.
- [10] ISO/TC 198, "ISO 17664-2:2021," ISO. Accessed: Sep. 17, 2026. [Online]. Available: <https://www.iso.org/standard/74152.html>.
- [11] Mohamed Yassin (University of Michigan) et al., "The michigan elbow: Examining the quality of a pulled elbow task trainer by Pediatric Specialists," Michigan Journal of Medicine, <https://journals.publishing.umich.edu/mjm/article/id/8843/> (accessed Sep. 15, 2026).

Appendix B - Materials

Item	Description	Manufacturer	Mft Pt#	Vendor	Vendor Cat#	Date	QTY	Cost Each	Total	Link
Mechanism										
Reset Mechanism	A detent pin reset mechanism	WHLLING	B0CWR9RSDC	Amazon	B0CWR9RSDC	10/2/2026	1	\$9.99	\$9.99	Link
Detent Ball	Spring-loaded detent ball	Harfington	B0FRGDVB1M	Amazon	B0FRGDVB1M	10/2/2026	1	\$7.19	\$7.19	Link
Ball and Socket	Self-lubricating ball joint + rod-end fitting	uxcell	B0CT2GFR1D	Amazon	B0CT2GFR1D	10/2/2026	1	8.79	\$8.79	Link
Skin/Muscles										
Platinum Cure Silicone	20 oz translucent silicone mold-making kit	Let's Resin	B07V5FFPWC	Amazon	B07V5FFPWC	10/2/2026	1	\$17.69	\$17.69	Link
Foam	Customizable foam sheet	Amgo	B0FFLGC TFK	Amazon	B0FFLGCCTFK	10/2/2026	1	\$14.00	\$14.00	Link
								TOTAL:	\$57.66	