KAIROS

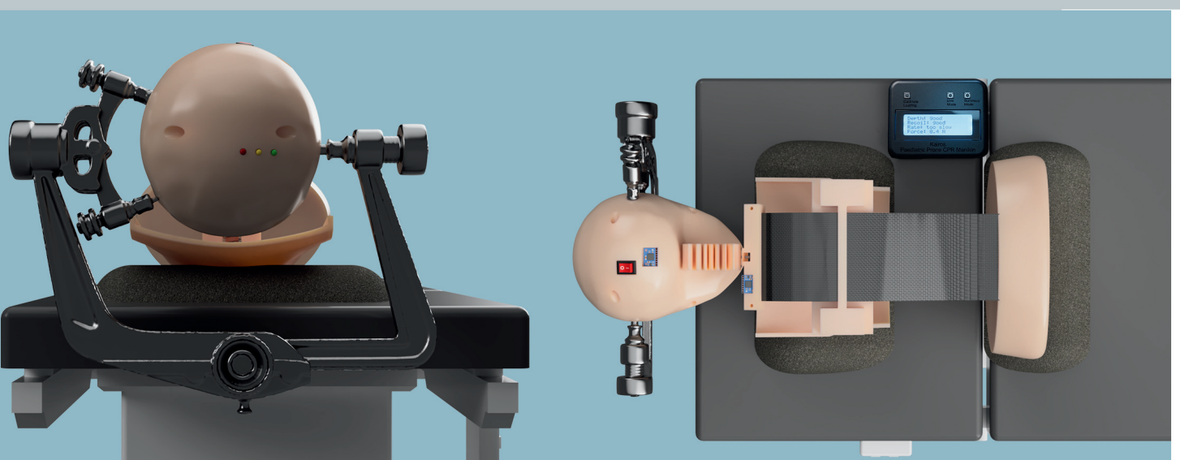
Preparing clinicians for the critical moment

Medical Devices Unit

Paediatric Prone CPR Manikin

Real-time Feedback
CPR quality monitoring
LED injury-risk indication
Engineered paediatric spine model
Mechanical Spring System

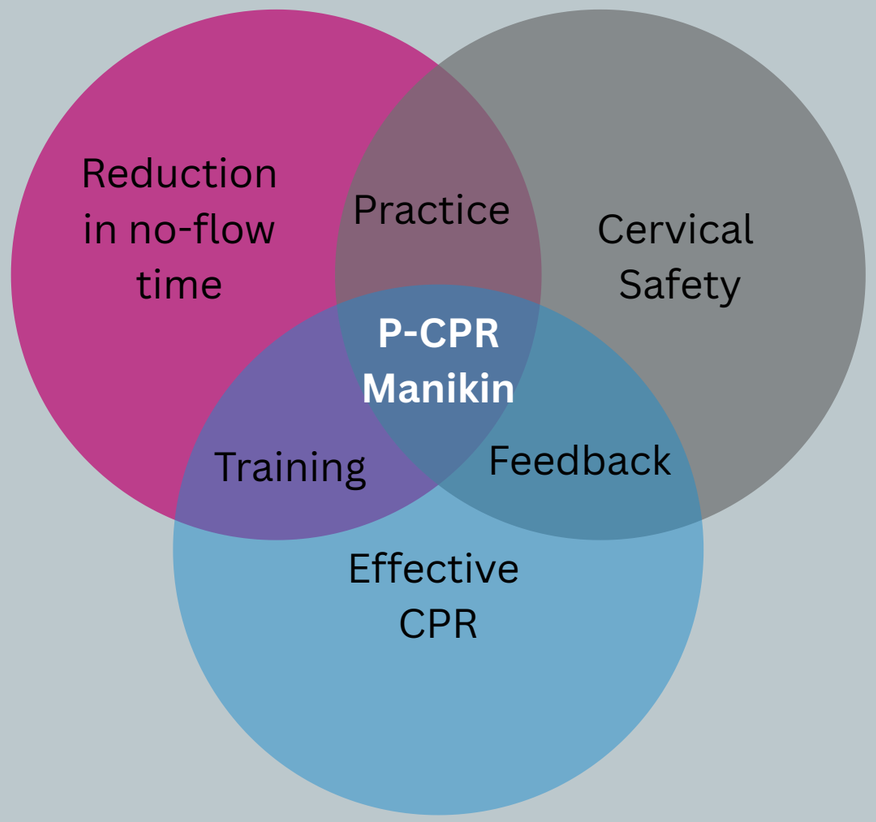






DESIGN BRIEF

There are **NO Prone CPR Manikins**, which leaves clinicians no realistic way to practice prone CPR or assess where it is safe for paediatric patients. There is also worry surrounding **injury** to the cervical spine for paediatric prone CPR which is not present in traditional CPR, due to their differing anatomy, the fact they can sustain spinal cord injury without bony injury and compressions being applied to the spine in Prone CPR.



Potential Paediatric Prone CPR Injuries

- C1-Skull Dislocation
- C1-C2 Rotary Subluxation
- Anterior/Posterior Subluxation at C1-C2
- C1/C2 vertebral Fracture
- Wedge compression Fractures
- C3-C7 compression fractures
- Ligamentous injury
- Facet joint capsule injury or gapping
- Spinal cord Injury

Objective

- Design a paediactric prone-CPR ‘smart’ manikin
- Provide realistic training scenarios for clinicians performing CPR on prone patients
- Simulate anatomical and physiological characteristics of a prone paediactric body
- Enable training in technics that maximise CPR effectiveness while minising CPR-induce trauma
- Support future research into prone CPR safety and effectiveness

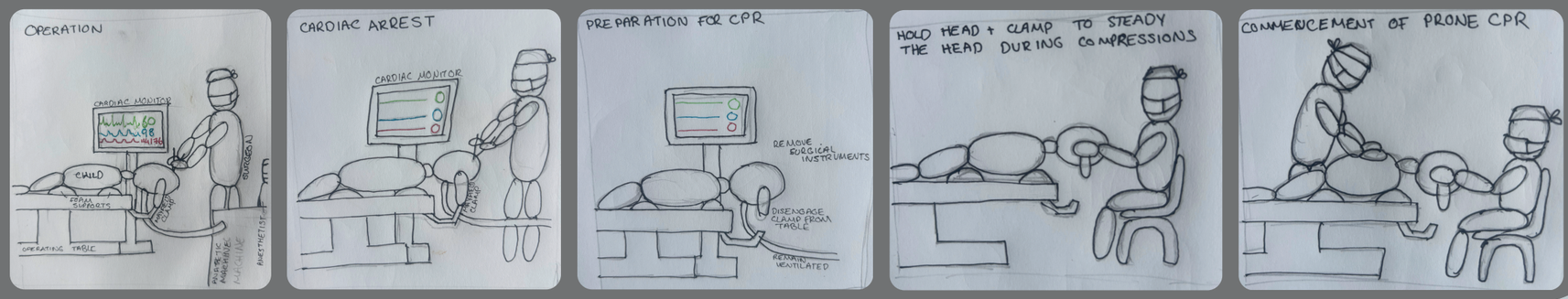
Design Requirements

- *Safety and Effectiveness Feedback* to indicate injury risk and compression quality
- *Paediatric Realism* with appropriate protions and mechanical behaviour
- *In-house manufacturability* for the NHS Greater Glasgow and Clyde Medical Devices Unit
- *Durability* to last repeated training sessions
- *Future-proofing* to allow for later development

Medical Devices Unit

THE PROBLEM AND THE USER

Scenario

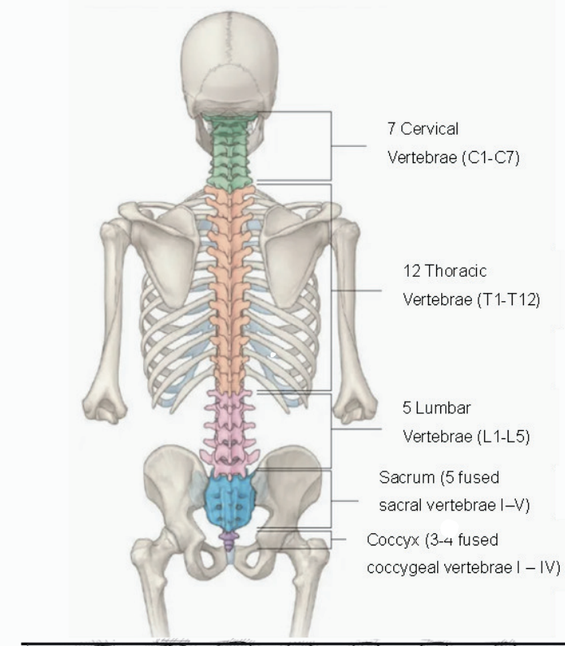


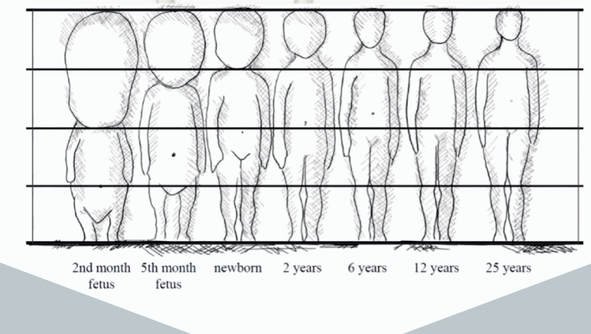
In Glasgow, ~1 intraoperative paediatric cardiac arrest during prone spine or neurosurgery occurs each year. These rare, critical events demand immediate intervention, with **every minute without circulation reduces the likelihood favourable neurological outcomes by 13%**.

When the patient is in the prone position, clinicians face 2 options

1. Turn the patient **supine** for traditional CPR (**Not always possible**, longer no-flow time due to requirement of wound closures, need more staff to help turn the patient but tried and true)
2. Perform **prone** CPR (**Faster** as it avoids repositioning but no paediatric scientific backing and **risk is unknown**)

As **no training** is provided for prone CPR due to the lack of a prone specific CPR manikin, clinicians are more likely to hesitate when they need to preform prone CPR. Add to this the fact that there are **no standardised clinical guidelines** for paediatric P-CPR.



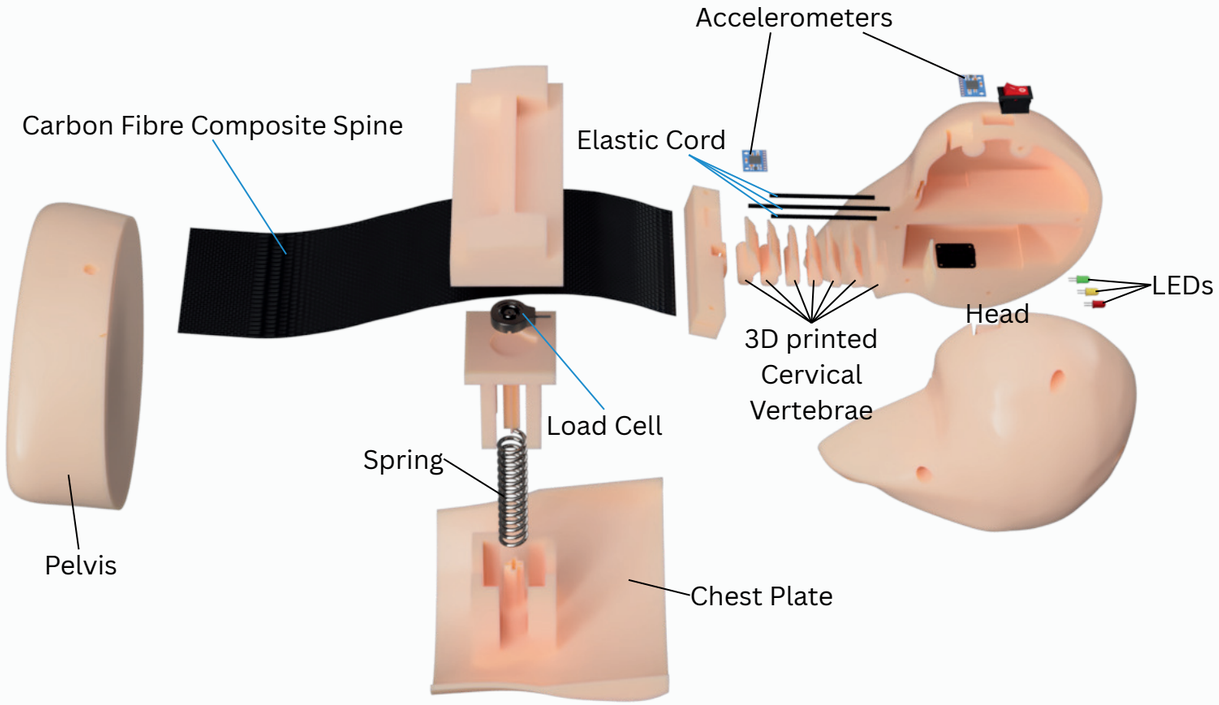


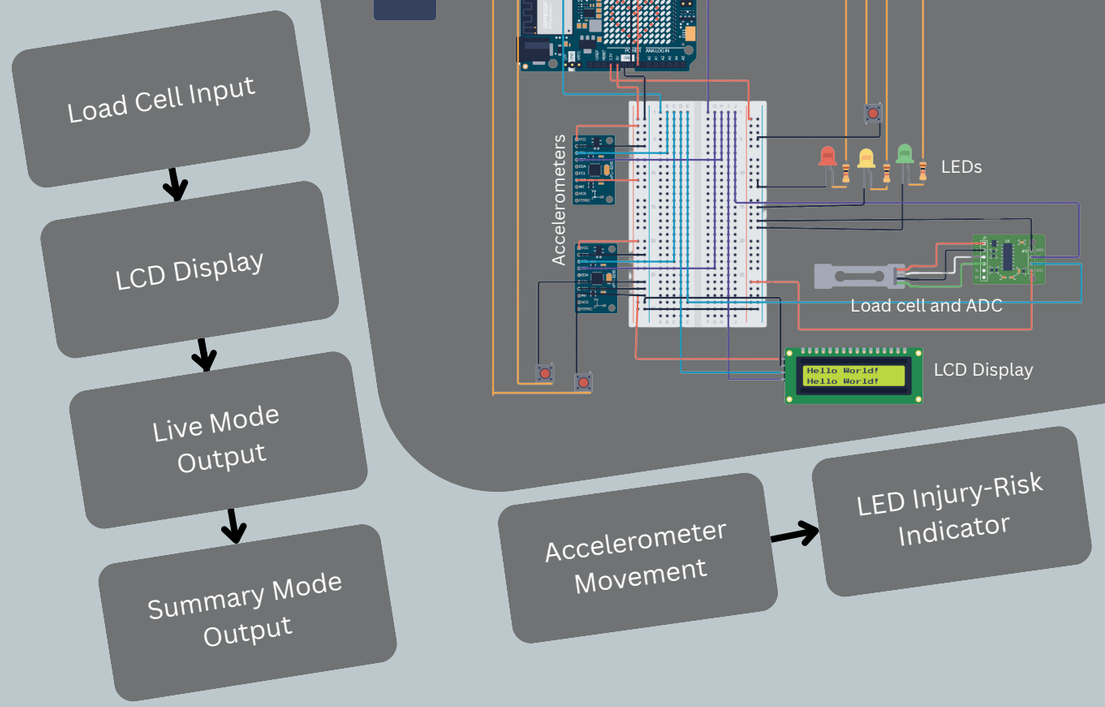
Paediatrics are higher risk of injury due to larger head to body ratios, more elastic ligaments, more flexible vertebrae due to lack of ossification.

The User



WHAT THE PROJECT DELIVERED





- Thoracic/Lumbar spine composite which simulates spinal behaviour under loading
- Elastic cord and printed vertebrae mimic cervical spine movement
- 3D printable head, pelvis, and chest to spine loading subsystems
- Modular architecture for easy assembly, repair and further development
- Electronic system to monitor compression quality (depth, recoil and rate) and cervical spine injury risk (displacement of C7-T1 Junction and relative displacement between Skull and C7-T1 junction)

Modelled on a 3-Year-Old

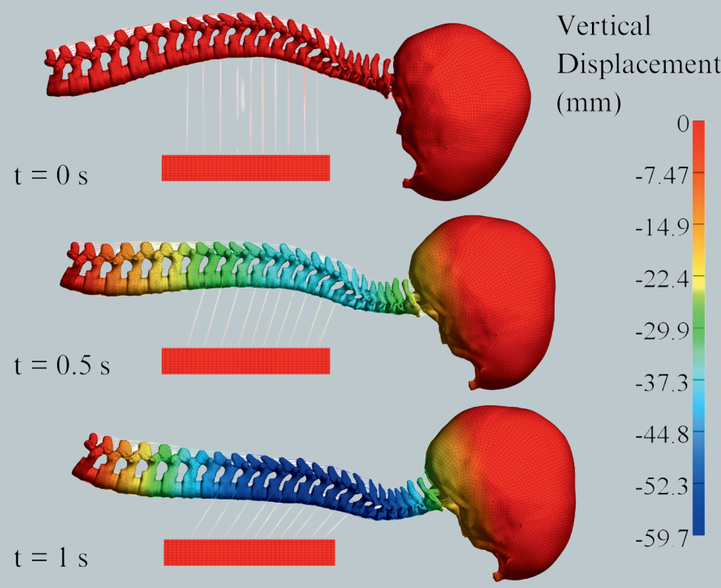
Only age group with CPR cervical spine displacement data

Highest risk group for CPR related cervical spine injury

Most clinically relevent



ANTHROPOMETRIC DATA AND HUMAN FACTORS CONSIDERATIONS



Known paediatric spine displacement under loading

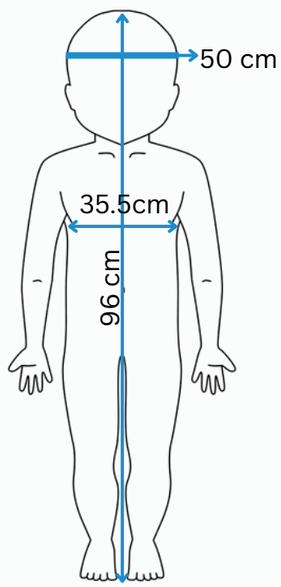
Cervical Spine → Smallest region → Most flexible

Thoracic Spine → Reinforced by Ribcage → Reduced flexibility

Lumbar Spine → Supports the upper body → Least flexible

Measurements from 50th percentile 3 year old male

Height: 96cm
Weight: ~14kg
Head Circumference: 50cm
Chest width: ~35.5cm
Chest Depth: 15cm
Compression Depth: 5cm
Spine Segment Lengths
Cervical: 4.40 - 6.80cm
Thoracic: 18.66 - 29.90cm
Lumbar: 5.16 - 8.58cm



Human Factors

- Realistic proportions to improve clinician trust and allow easier training transfer to real life scenarios
- Manikin Size and weight to be balanced with child anthropometric data to allow for easy manoeuvring
- Clear hapic/tacile feedback to support skill acquiation
- Placement of warnings and feedback so easily accessed by particpating parties
- Surface geometry to support correct hand placement

CONCEPT DEVELOPMENT

With so many parts to the is project, each had to be considered separately befor they could be consided together

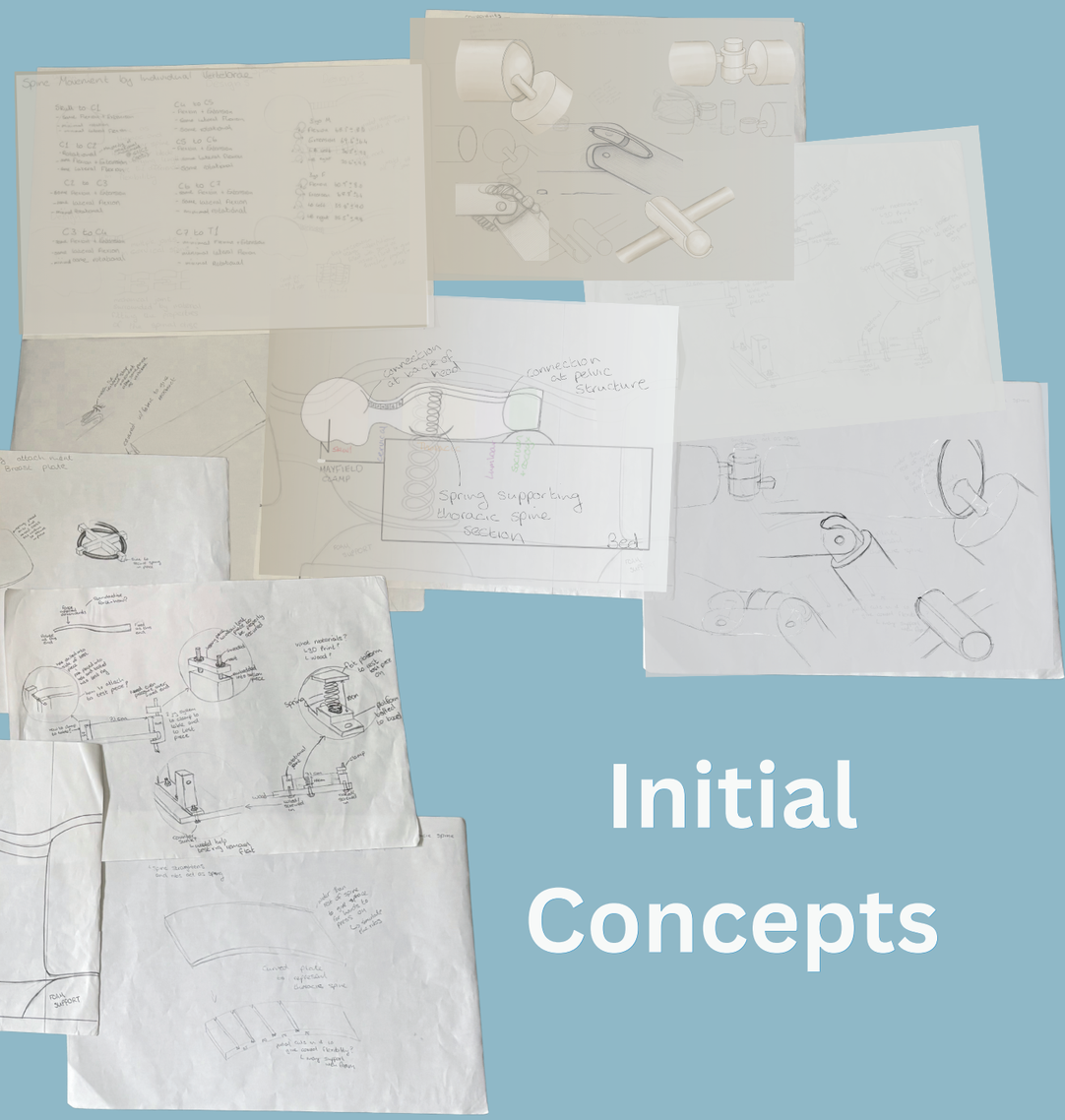
Cervical Spine - Thoracic Spine - Mechanical Mechanism - Electronics - Connections

Concepts were evaluated on feasibility, ability to mimic spine displacement, ease of manufacture for the Medical Devices Unit and Feedback from the MDU and Clinicians. Some of the designs were prototped at this stage to give an idea of how well they simulated cervical spine movement.



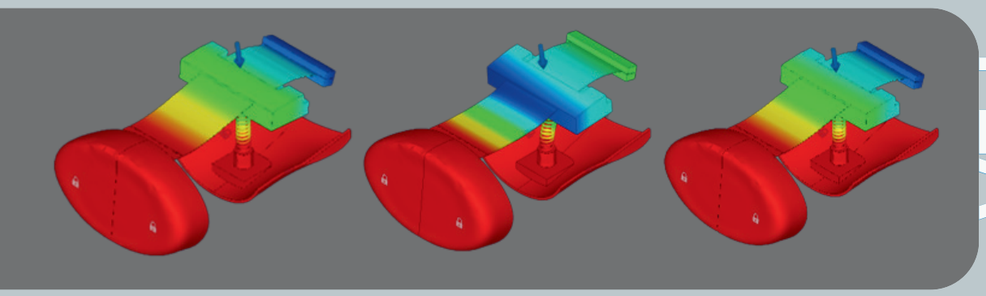
Inspirations

All initial concepts were presented to the MDU and straight away some where shelved due to lack of feasibility, either due to complexity of the design or they were unlikely to reproduct spinal behaviour.



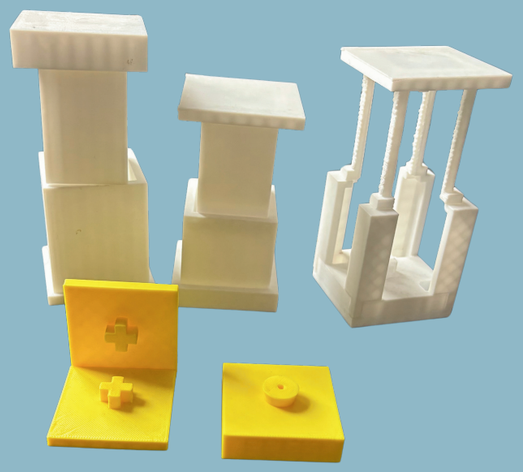
Initial Concepts

DESIGN DEVELOPMENT

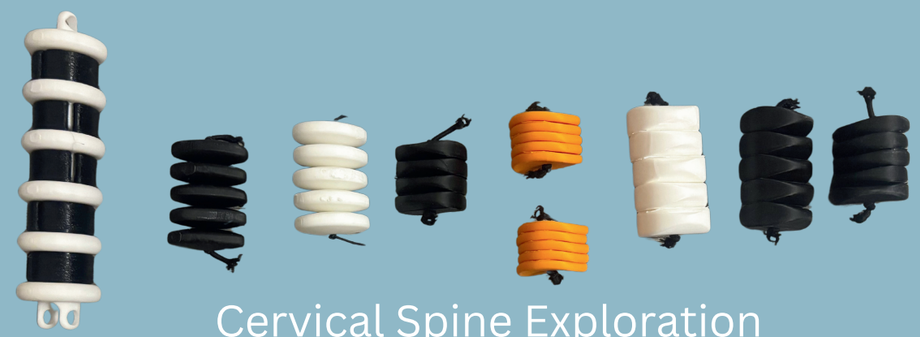


Design development **focused on** refining the **mechanical realism**, **structural durability**, and **sensor stability** of the manikin. FEA was used to select an appropriate material for the thoracic/lumbar spinal segment.
Multiple carbon fibre composite configurations where then explored and tested by building a rig and perform CPR. Several iterations of the cervical spine were also created to explore and refine the movement.
Euler's buckling proved to be an issue so designs were made and tested to prevent this.
Each configuartion of the spine and spring mechanisms was tested for appropriate movement.

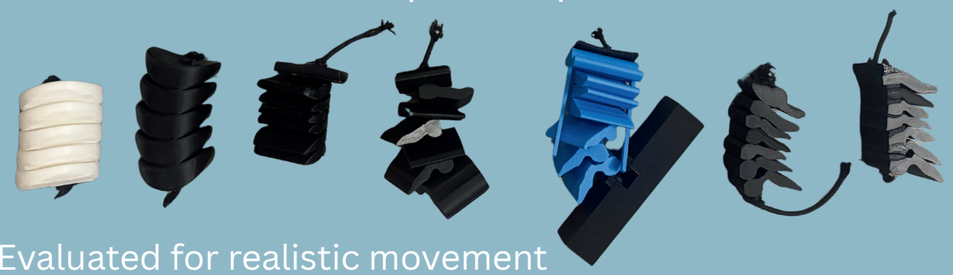
Prototypes



Euler's bucking prevention and Spring attachment exploration



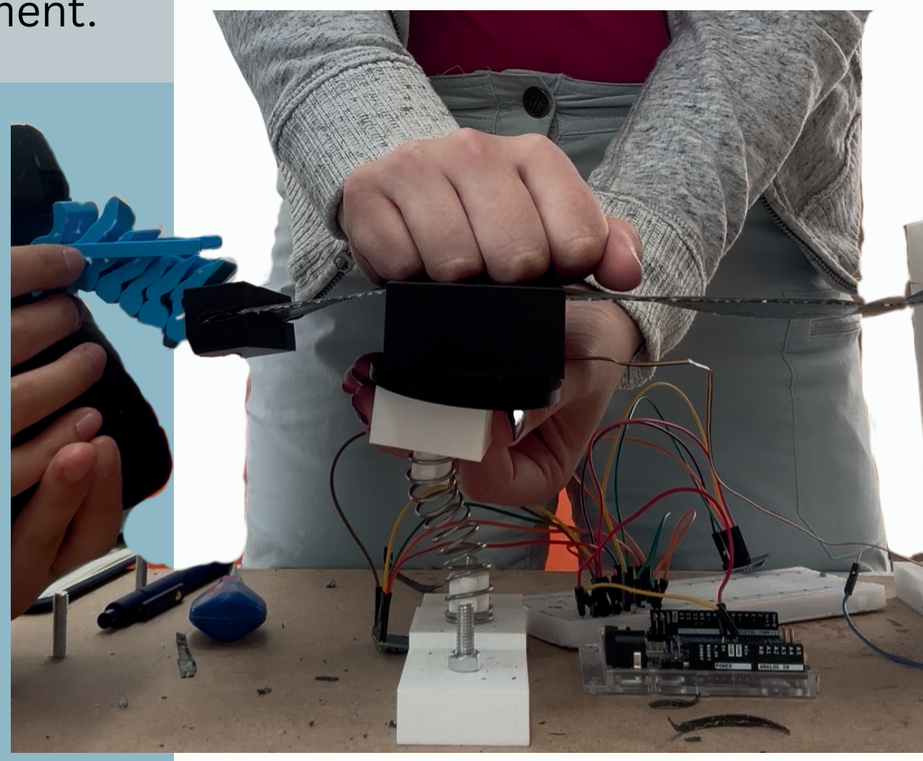
Cervical Spine Exploration



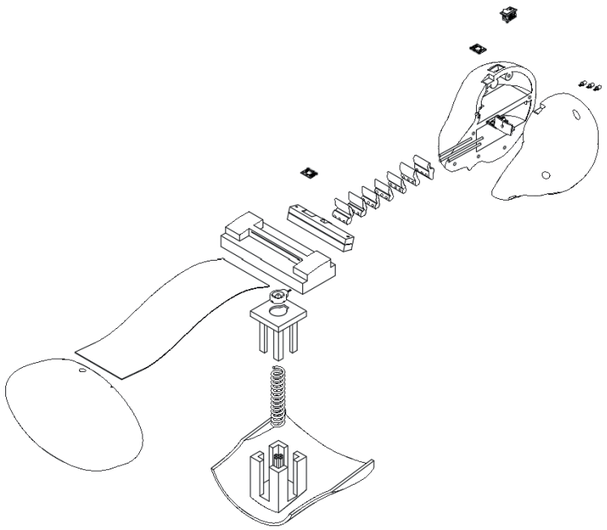
Evaluated for realistic movement

Composites and Testing

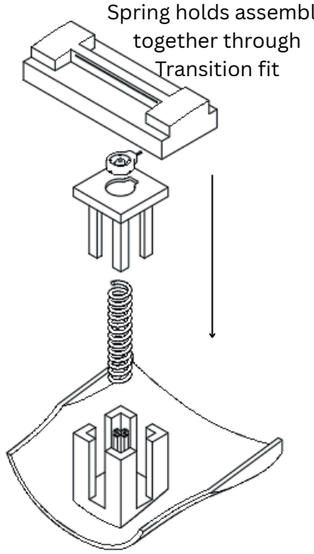




COMPONENTS AND ASSEMBLY

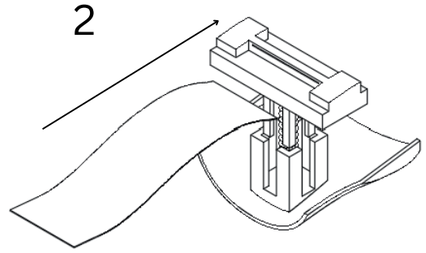


1



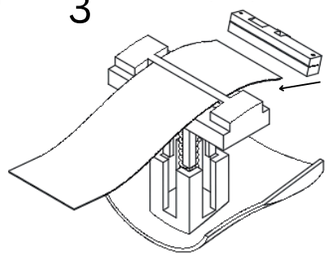
Spring holds assembly together through Transition fit

2



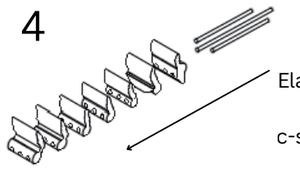
Carbon fibre slides through gap and held in position with transition fit

3

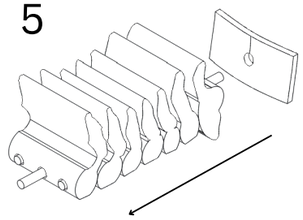


Bolted either side of the composite to keep in place

4

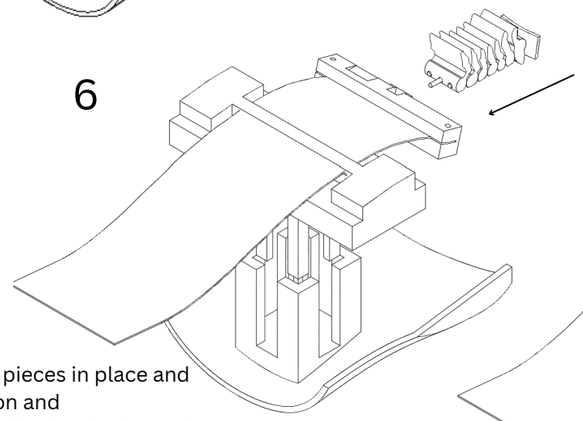


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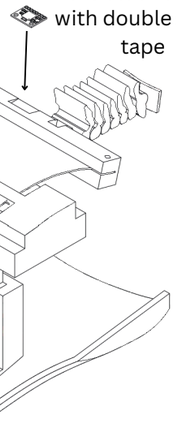


Elastic cord in knotted to keep the pieces in place and provide correct tension and
c-sine pieces have a clearance fit with the elastic cord

6

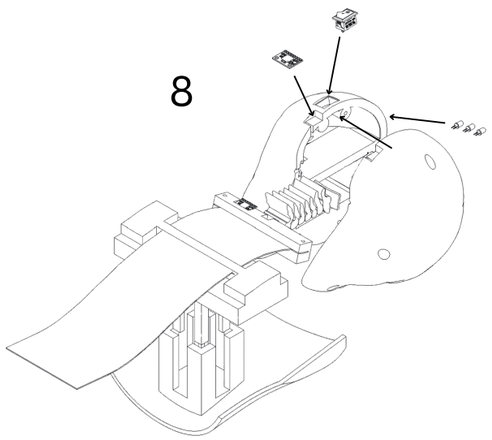


7



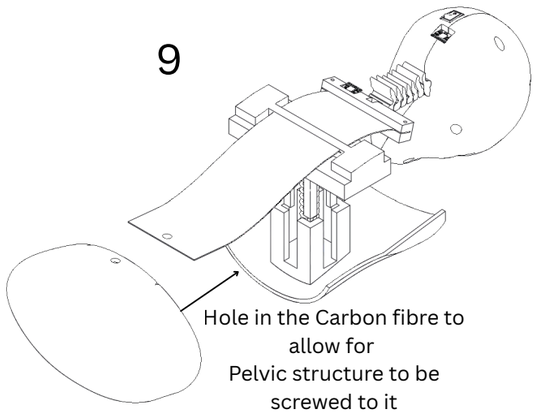
Accelerometers are stuck down with double sided tape

8



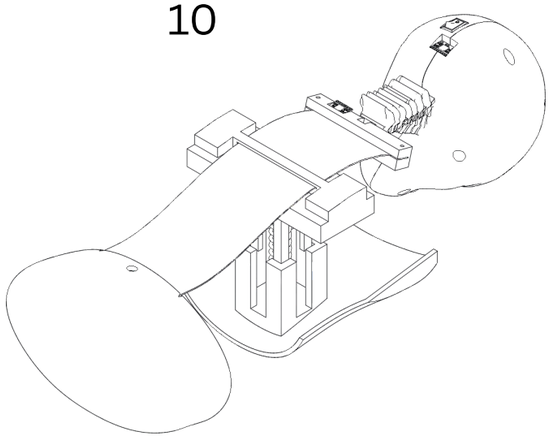
Head screwed together in 5 places with interferance fit

9



Hole in the Carbon fibre to allow for
Pelvic structure to be screwed to it

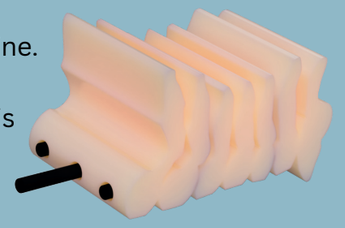
10



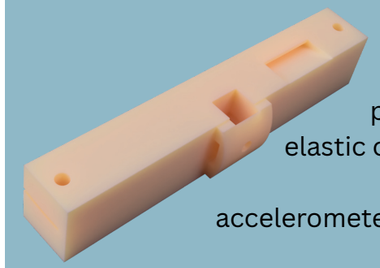
*Screws not shown in diagrams but all screws are M4 with interferance fit

C-Spine

Modelled off the paediatric C-Spine. It produces the same range of movement and each connection is rounded so it curves over each other during movement. Started as a design of convex discs.



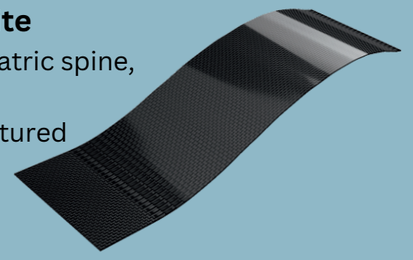
C7-T1 connector



The composite is bolted onto place with this connector and the elastic cord goes through the hole at the front and is tied off. One of the accelerometers is positioned in this connector

T-Spine/L-Spine Composite

Shape modelled from a paediatric spine, made from a Unirdirectional-Bidirectional layout. Manufactured using wet layup and vacuum bagging techniques.

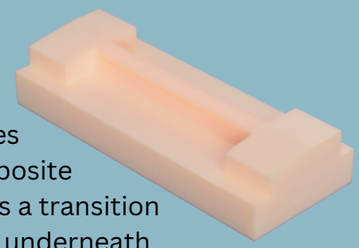


Pelvis



Largest piece which has a slot to screw the composite into place. This is one of 2 contact points with the bed/table.

Composite-Load Cell Connector

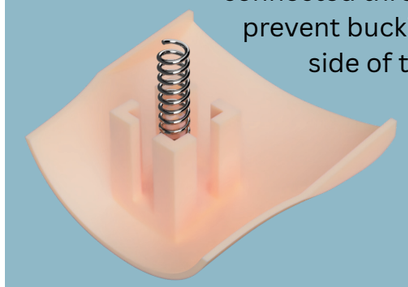


This part is where the user applies the compressive force. The composite slides through the game and uses a transition fit to hold in place. Load cell sits underneath.

Chest and Spring Connectors



There are 2 parts which connect to the spring, the chest plate and the part which connects the spring to the Composite-Load Cell connector They are connected through the centre of the spring to prevent bucking and also have guides at the side of the spring. This ensuressmooth downward motion during compressions while the spring minics the compression/recoil mechanism of the ribs.

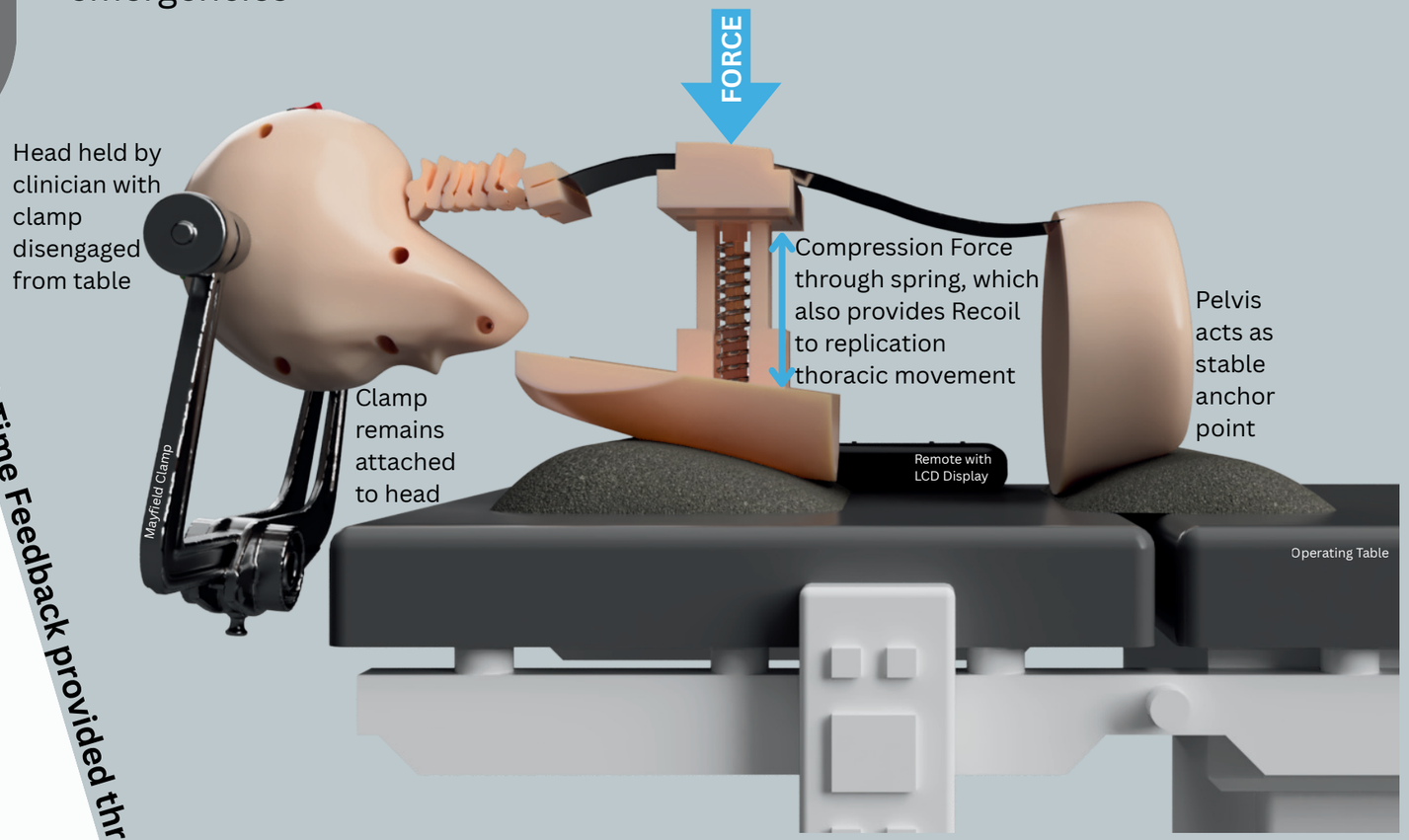


HOW THE MANIKIN WORKS

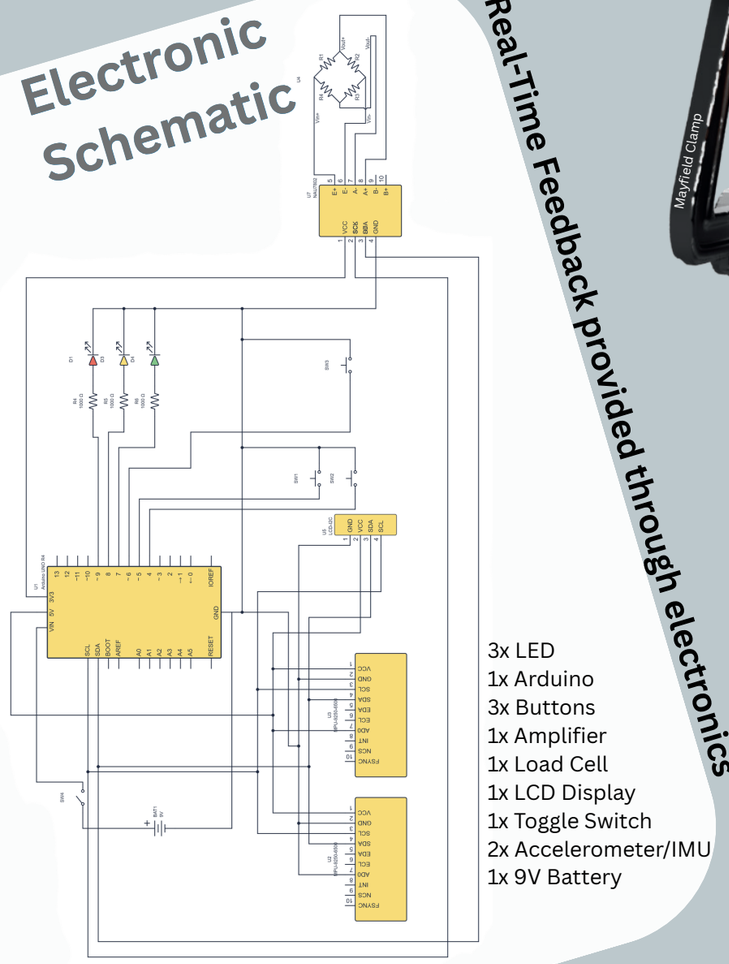
Correct Pressure Application
- **Depth** (Load Cell)
- **Recoil** (Load Cell)
- **Cervical displacement** (IMUs)
- **Compression Rate** (Load Cell)
- **Force Applied** (Load Cell)
- **Hand Position**
  - Compressions will be harder if not over spring

Measurements

Through the use of this product clinicians learn the correct pressure forpaediatric compression depth, how to maintain full recoil and appropriate compression rate, how to stabilise the head to reduce injury to the cervical spine, allowing them to confidently perform prone CPR in emergencies



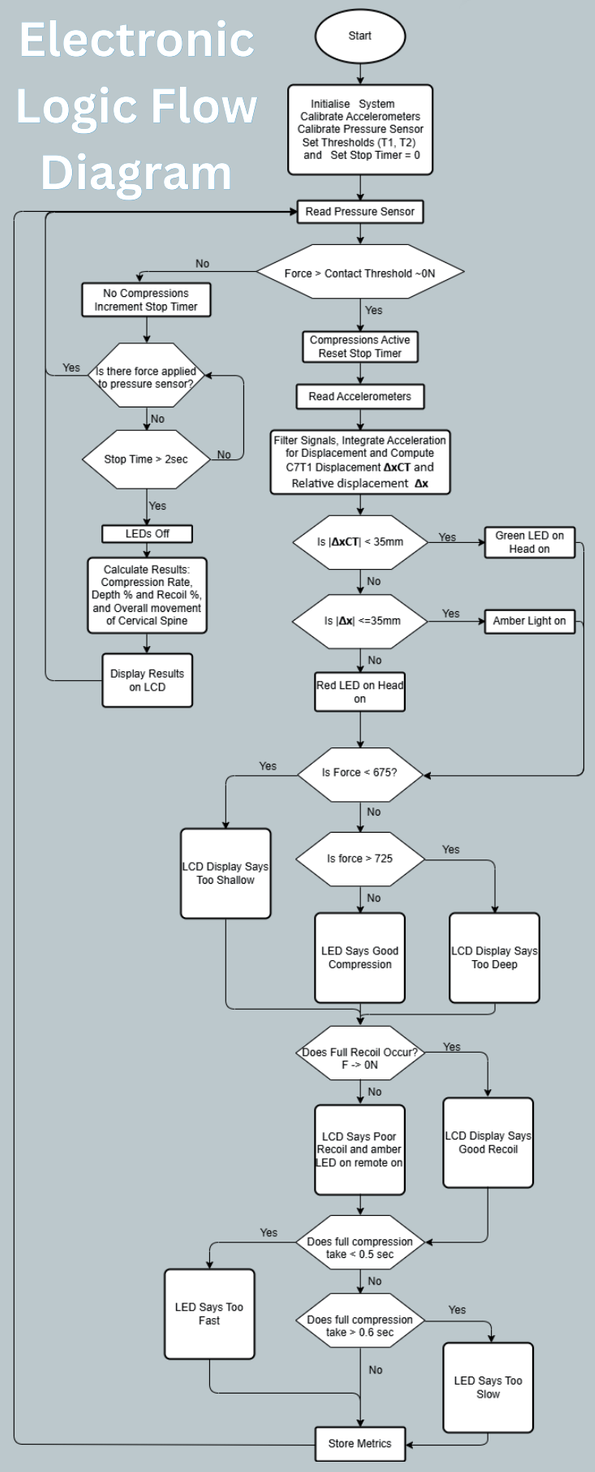
Electronic Schematic



Real-Time Feedback provided through electronics

3x LED
1x Arduino
3x Buttons
1x Amplifier
1x Load Cell
1x LCD Display
1x Toggle Switch
2x Accelerometer/IMU
1x 9V Battery

Electronic Logic Flow Diagram



CPR Compression Logic

Take Baseline - Compression Start - Compression Peak - Recoil - Rate - Quality

Compression depth, recoil, rate and force are calculated directly from the load cell using calibrated force-displacement equations. With Displacement measured as a force (~700N for 50 mm compression), Recoil is the evaluation from how close the force approaches to the Baseline, Rate measured as time taken from Baseline force to reapproaching Baseline force to capture full compression cycles and C-spine displacement computed from IMU acceleration via double integration. Thresholds selected from FEA.

Allows for real-time CPR quality monitoring with summary when training completed.

CPR Logic Equations

$$\text{Depth (mm)} = kF_{\text{Load Cell}}$$

$$\text{Recoil} = \begin{cases} 100\% \text{ if } F_{End} \approx F_{Baseline} \\ <100\% \text{ if } F_{End} > F_{Baseline} \end{cases}$$

$$\text{Rate (Hz)} = \frac{1}{t_{\text{Baseline-Baseline}}}$$

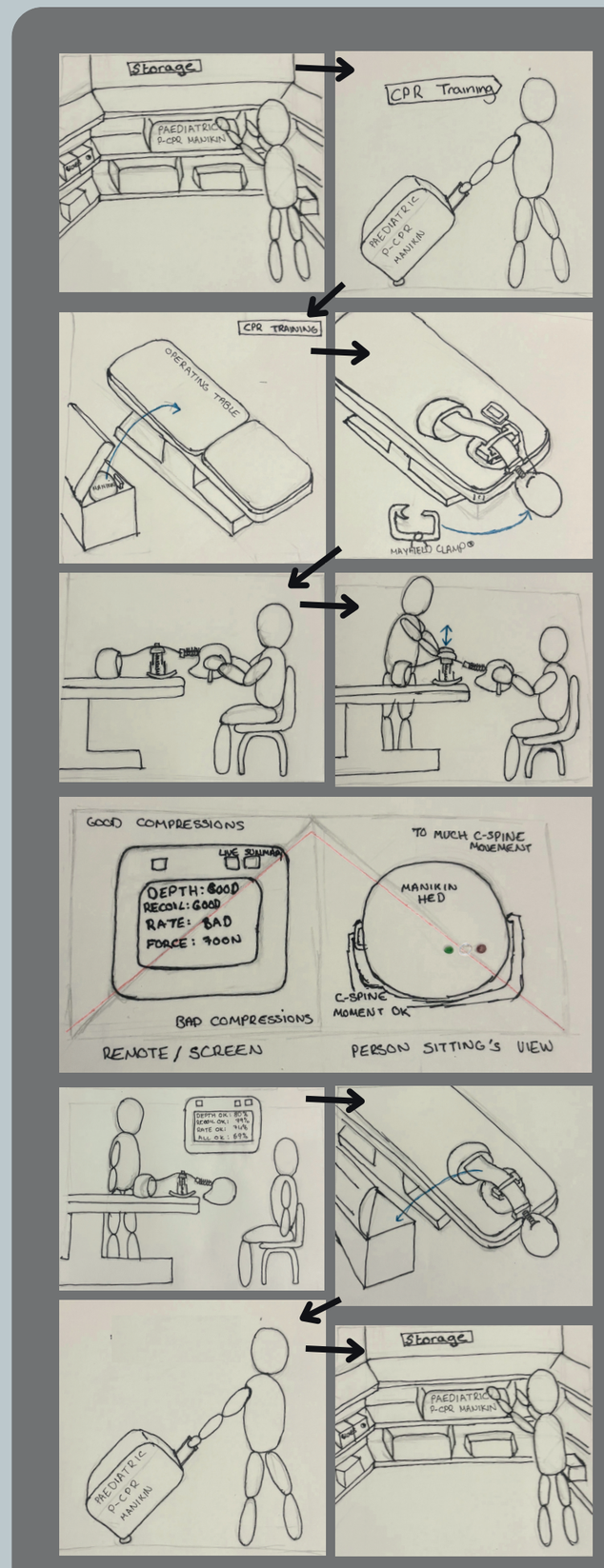
$$x(t) = \iint a(t)\,dt$$

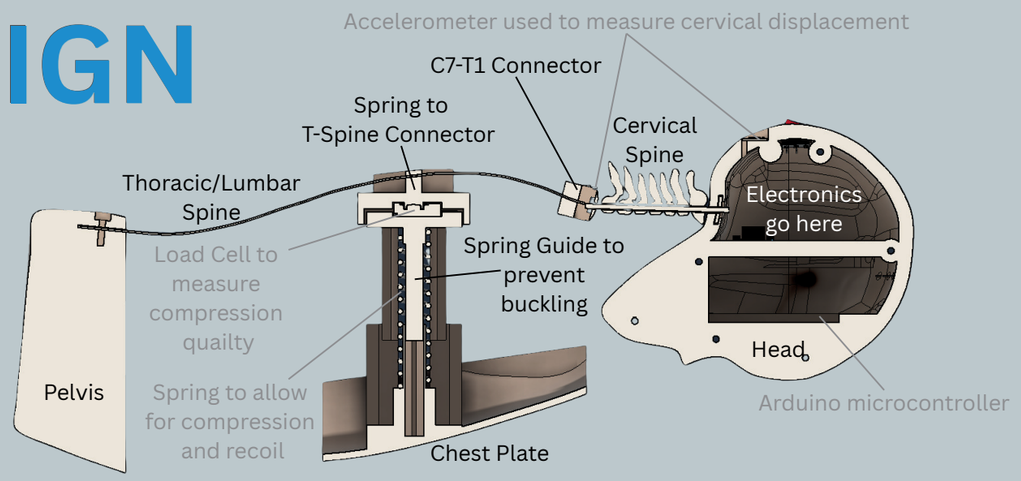
NEXT STEPS AND FINAL DESIGN

Next Steps

1. Add Realistic Paediatric Head Mass
   - Improve Training Realism
2. Validate Cervical Motion Thresholds
   - Define clinically accepted safe displacement limits
3. Optimise Spring Stiffness
   - To prevent Euler's buckling occurring ($P_{cr} = \pi^2 EI/(KL)^2$)
4. Add Silicone Soft-Tissue Layer
   - Improve Realism and for better ingress protection
5. Validate Prone CPR Force Requirements
   - Current threshold based of a FEA model which is stiffer than real life
6. Anatomical Indications for Hand placement such as tip of Scapulae
   - Could be integrated into sodt-tissue layer

User Journey





Paediatric Prone CPR SMART Manikin which measures compression quality and alerts to cervical spine injury



Made from 3D printed PLA, elastic cord, carbon fibre composite and a steel spring