MR COMPATIBLE

WRIST LOADING DEVICE

JOINT EFFORT

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4B MECHANICAL ENGINEERING

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UNIVERSITY OF WATERLOO

March 31, 2021

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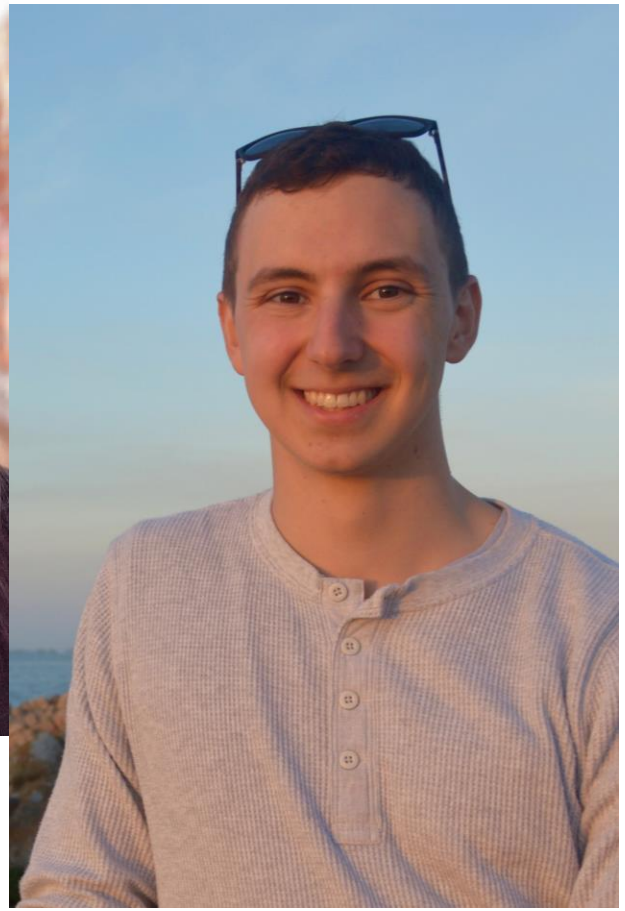
THE TEAM

Kelly Hao
(and Milo)

Catherine Tsang



Michael Beals

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AGENDA

Motivation/Introduction

Design

Manufacturing

Verification

Recommendations

Project Management

Future Plans

Q&A

MOTIVATION

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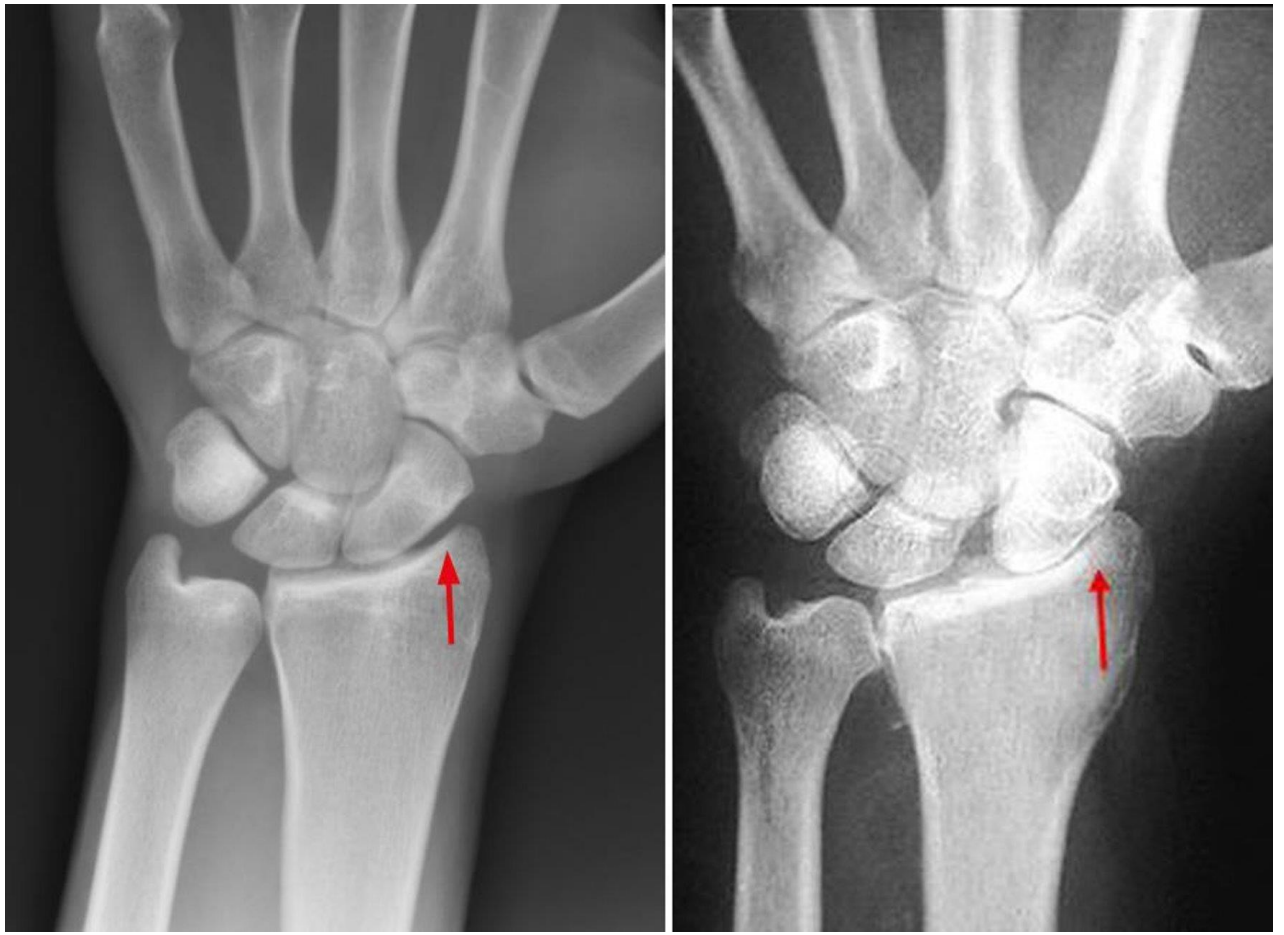

BACKGROUND

MRI

Accessory coil for limbs

BACKGROUND

Weight-bearing MRI (axial loading)

- Reproduce loading due to gravity
- Proven on spine and knee
- **Potential to detect pathology of degenerative diseases**
  - **Osteoarthritis (OA)**

Imaging of Spine (non-weight bearing)

Imaging of Spine (weight-bearing)

NEEDS STATEMENT

There is a need to detect wrist degenerative diseases earlier.

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OBJECTIVE

The objective of this project is to design an MR-compatible wrist loading device that can fit within a typical accessory coil for high quality imaging results

Patient positioned in accessory coil

Accessory Coil by ScanMed

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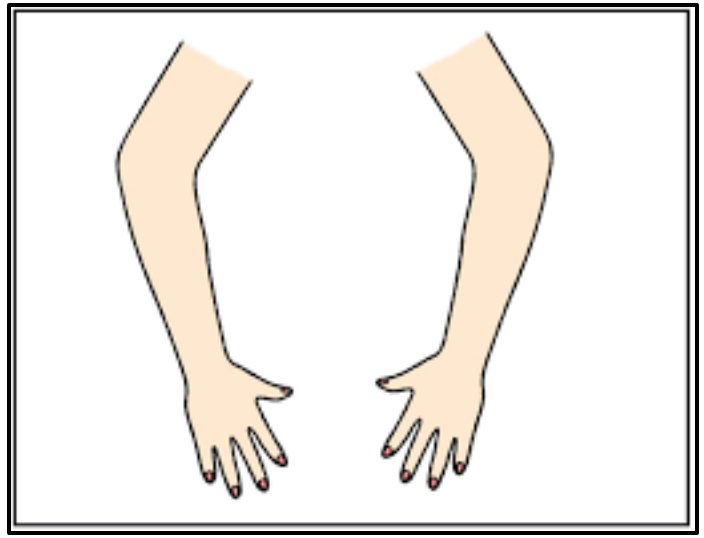
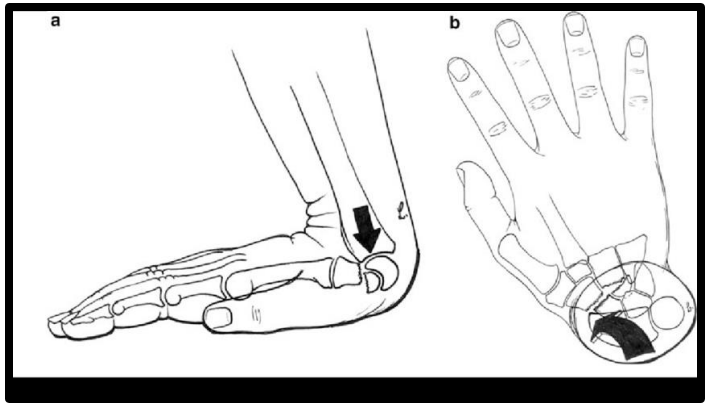
FUNCTIONAL REQUIREMENTS

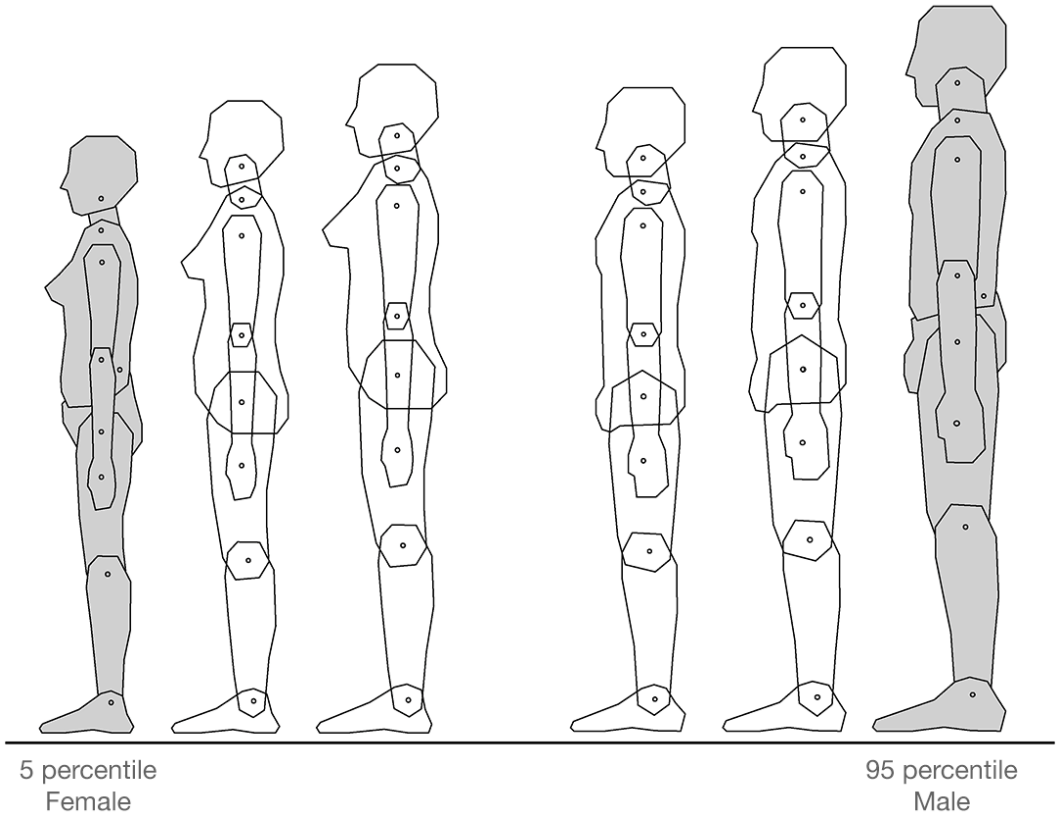
- Bilateral design
- Limit wrist & forearm range of motion
- Compressive wrist loading (2-5 lbs)





NON-FUNCTIONAL REQUIREMENTS

- Adjustable sizing
  - Healthy adults (15 – 59 y/o)
  - 5% - 95% percentile males and females
- Comfort
  - No significant pain after 15 minutes with device on



CONSTRAINTS

- **Total MRI scan time < 45 min**
- **MR compatible materials < non-ferromagnetic**
- **Device size arm < device < accessory coil**
- **Medical grade materials**

QUESTIONS SO FAR?

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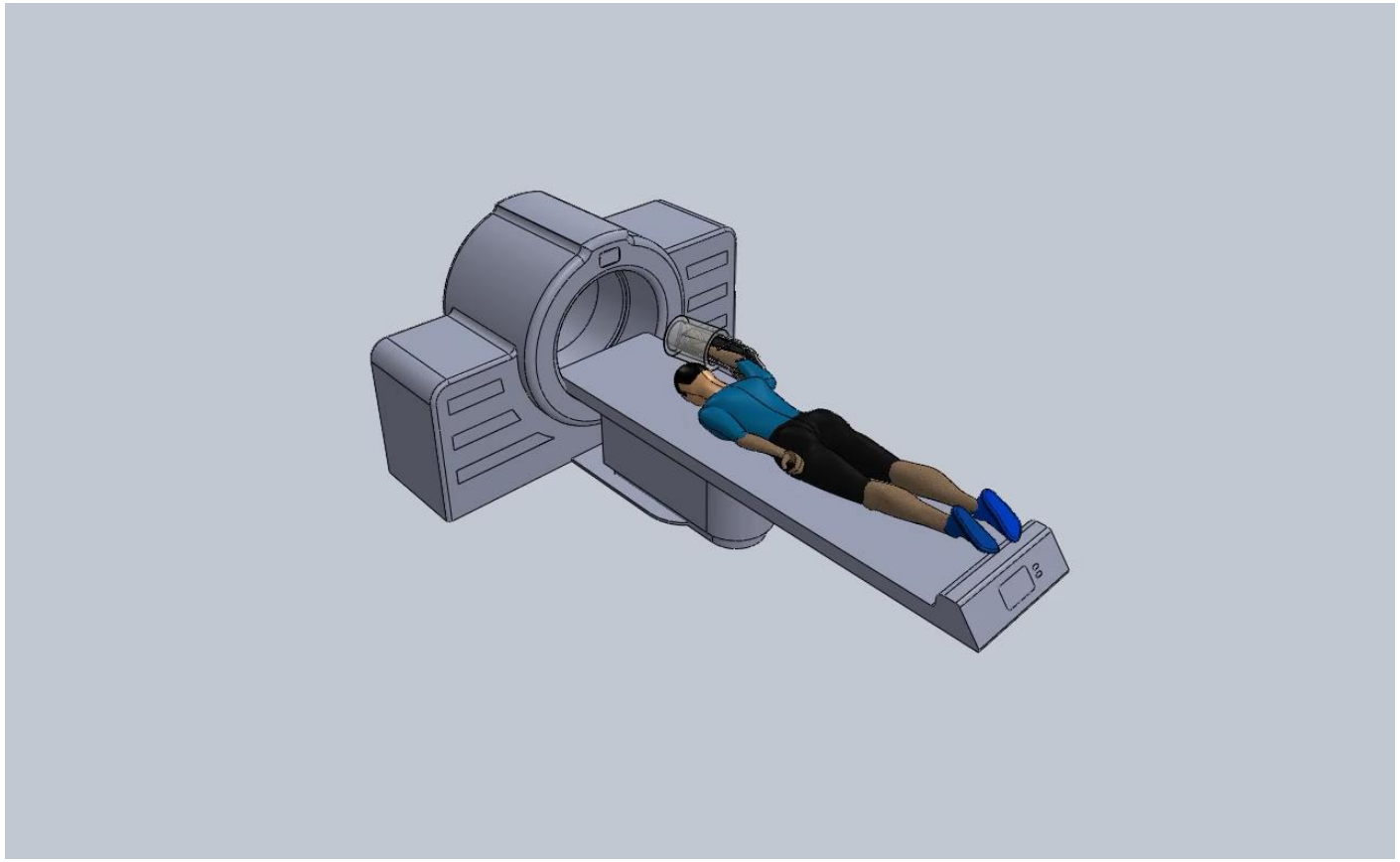
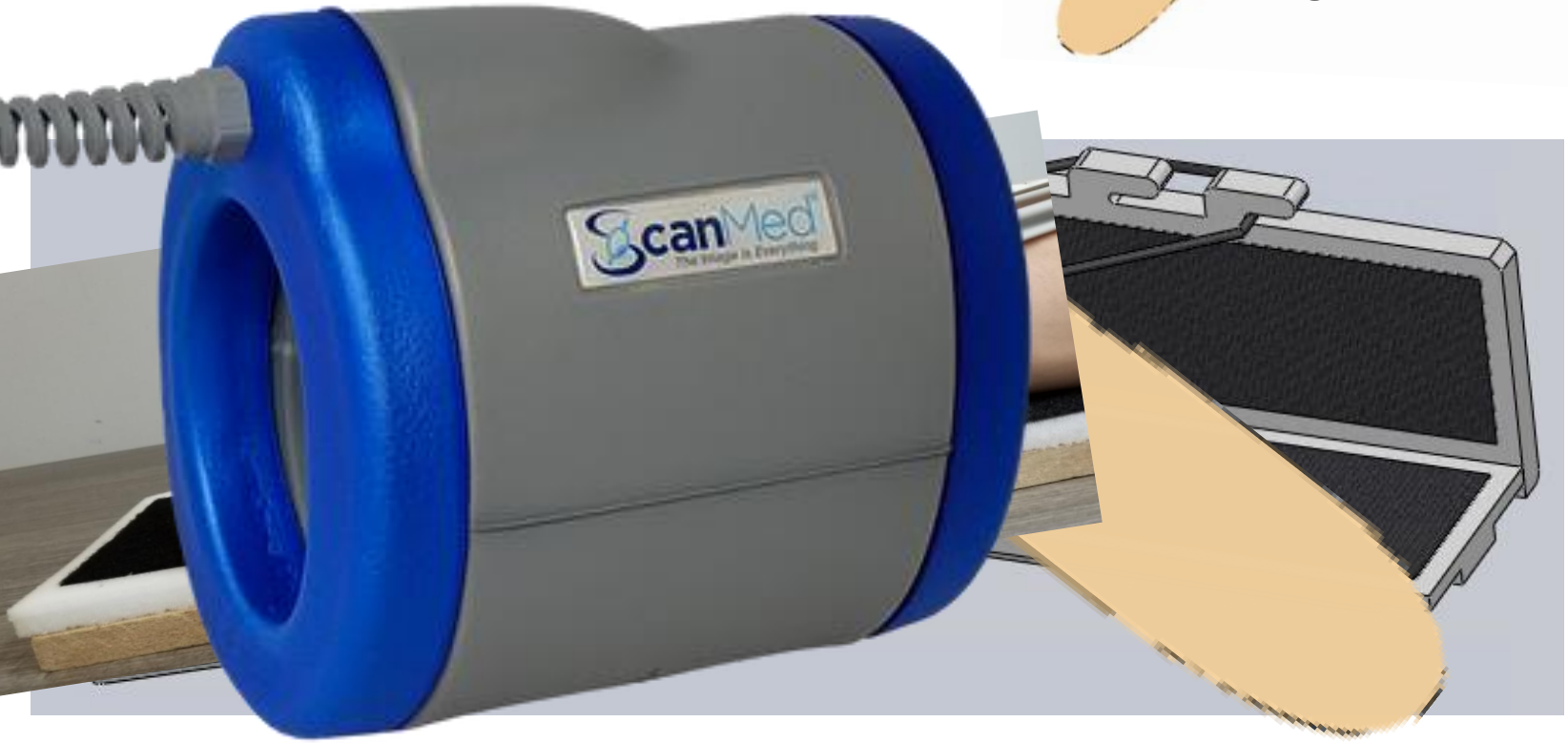
ENVIRONMENT & EQUIPMENT

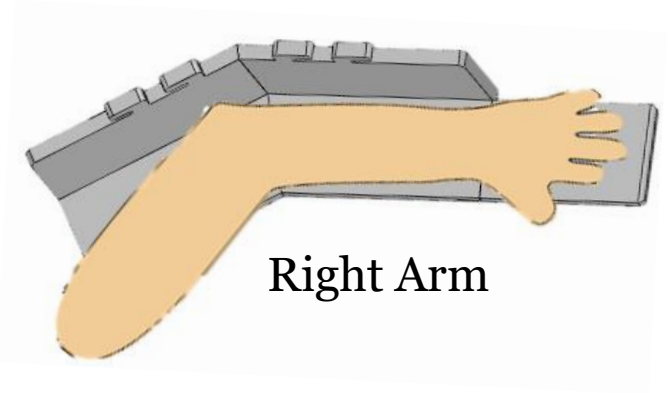


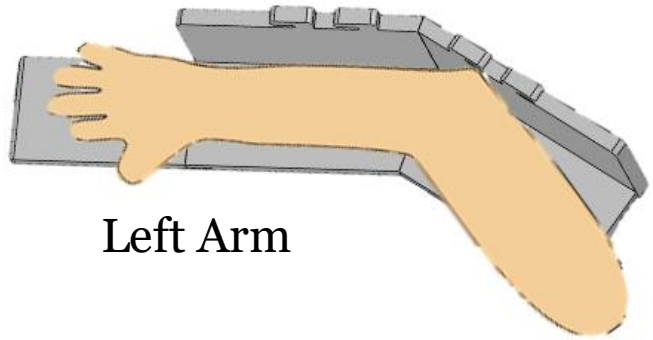
Set up

1. Patient lies on MRI bed, face down
2. Patient wears our MRI device
3. Patient's arm with MRI device enters the MRI accessory coil (superior imaging)
4. MRI technologist applies appropriate padding for comfort
5. Patient enters MRI bore for scanning

OVERVIEW OF DESIGN



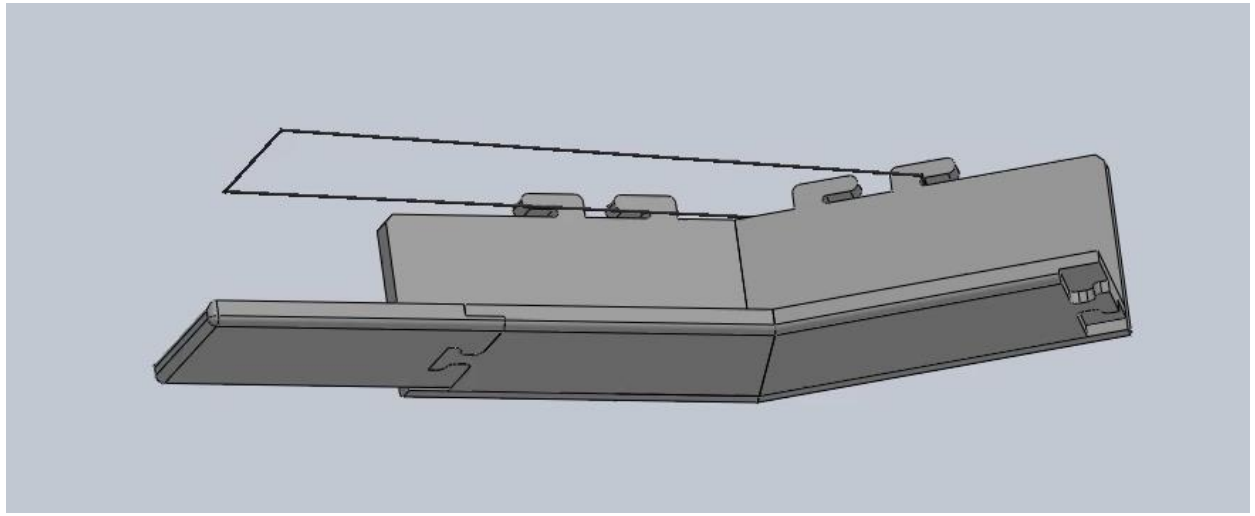


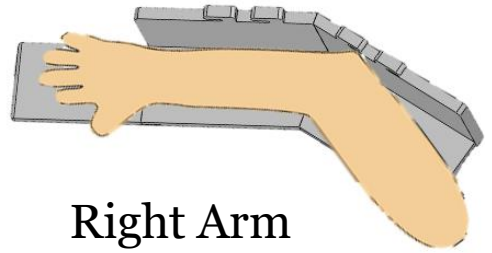


- **Functional Requirements**
  - Bilateral design
  - Variable sizing (healthy adults circumferential upper extremity size)
  - Apply compressive load to wrist
  - MRI compatible
- **Key Constraints**
  - Internal and external dimensions of device size

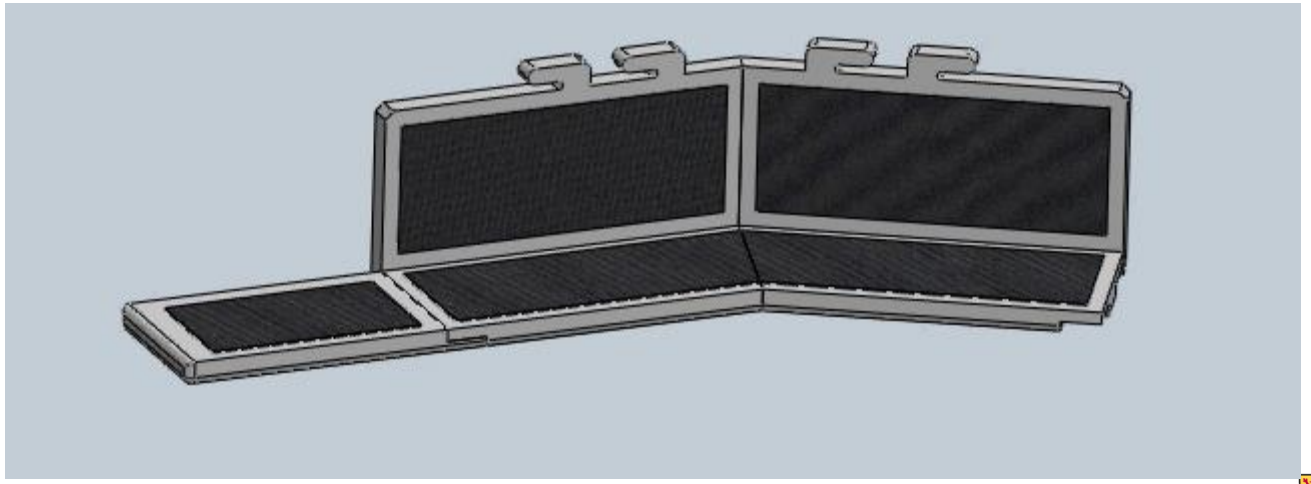
OVERVIEW OF DESIGN

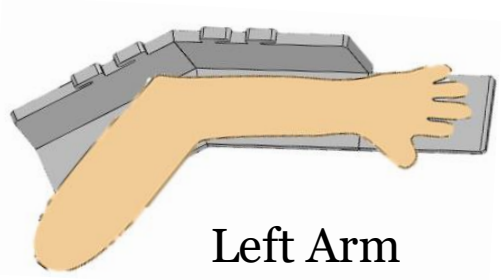
- Removable piece
  - Enables bilaterality





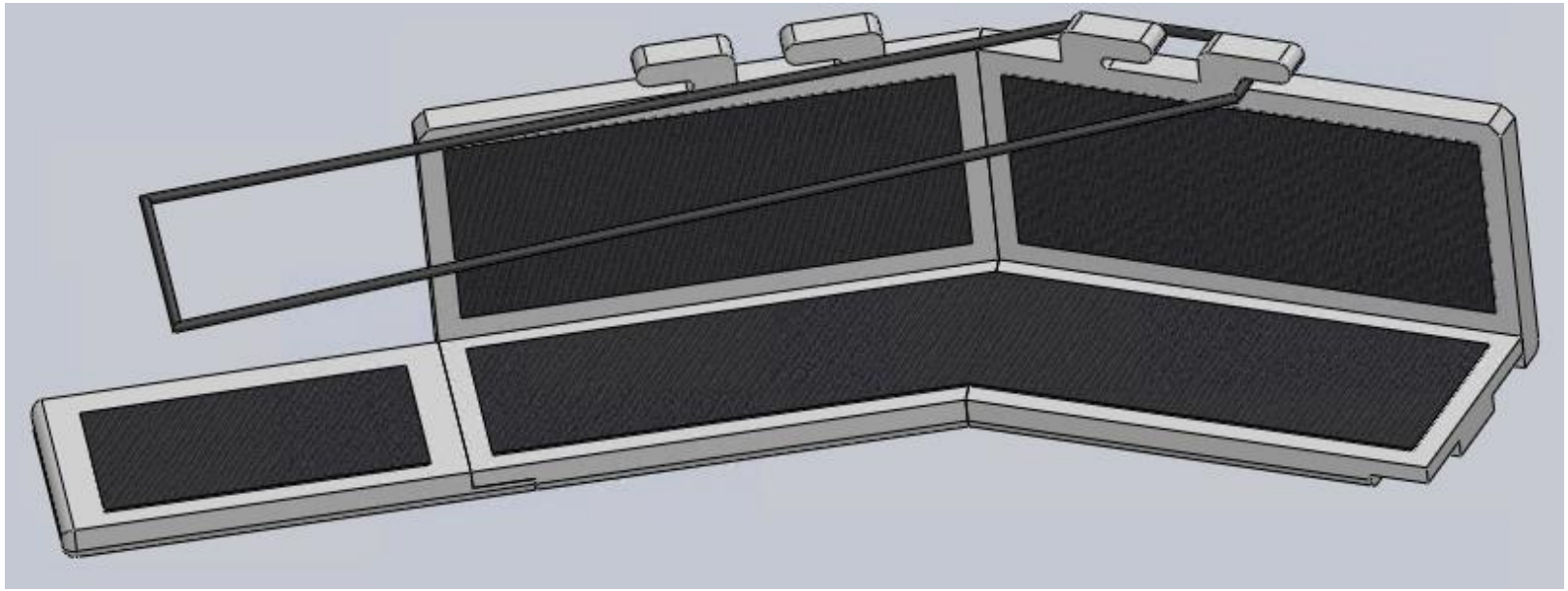
Right Arm



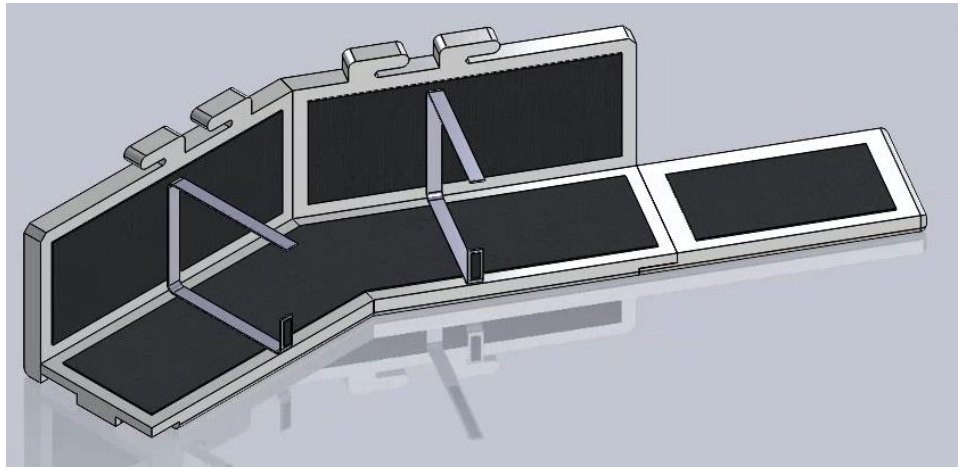


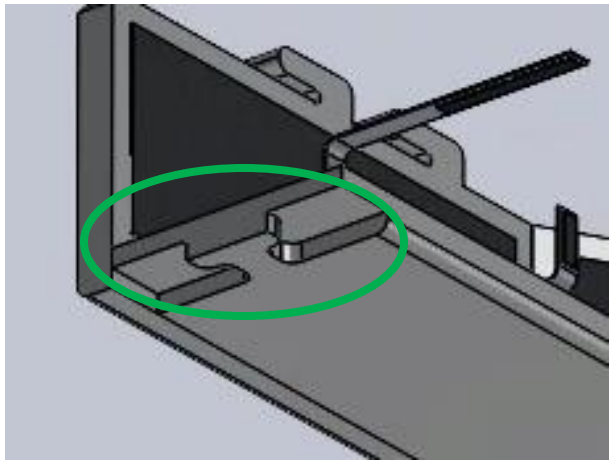
Left Arm

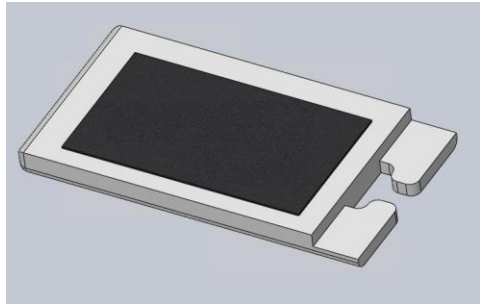
KEY DESIGN FEATURES



- J-Hooks
  - Attachment point for resistance band
- Puzzle Joint
  - Restrain movement in all directions
- Angle at Elbow
  - Reactionary backing force for resistance band

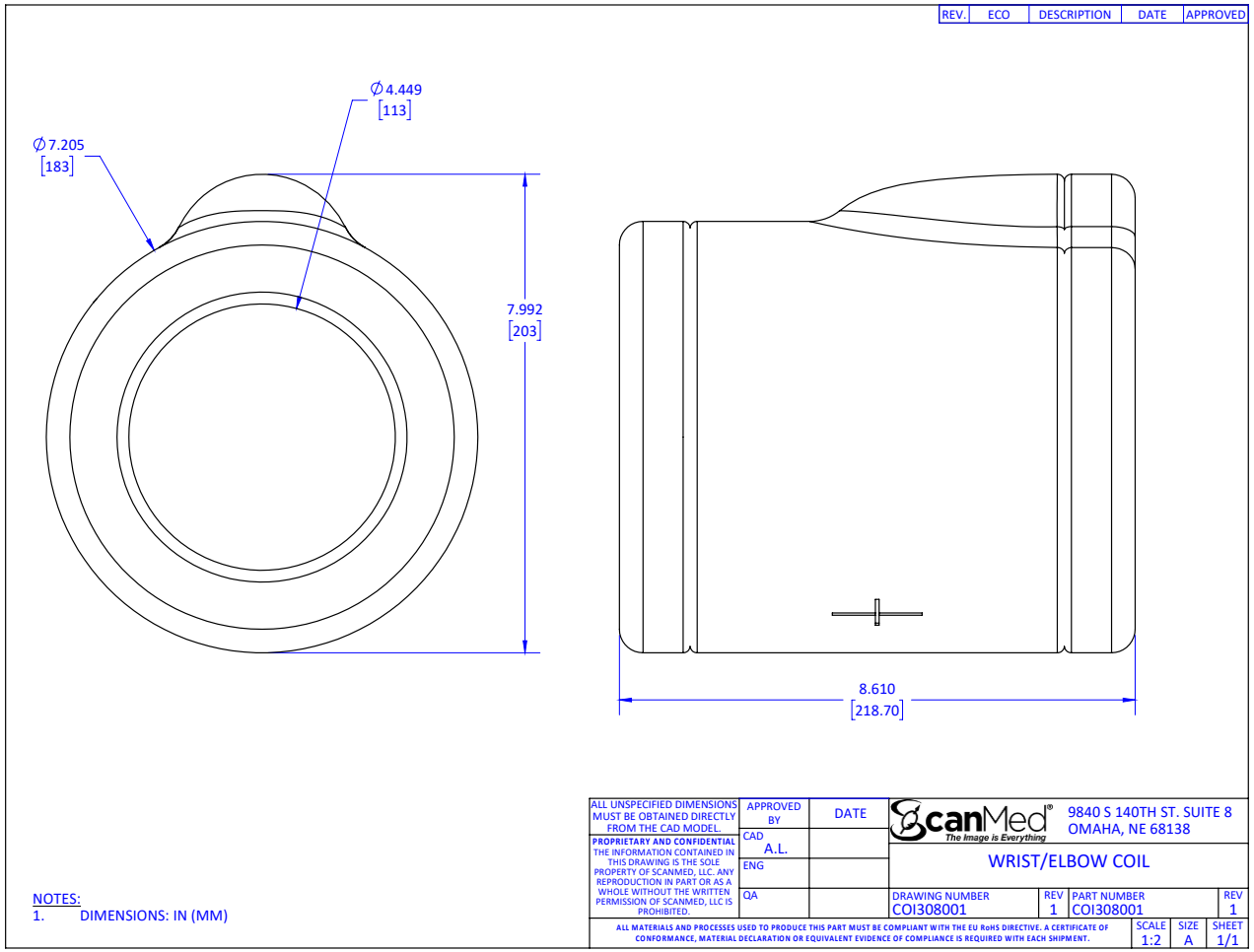






ACCESSORY COIL

- Contact with ScanMed (medical equipment manufacturer)
- Wrist/elbow coil dimensions too small.
  - 4” ID – does not fit most people!
- Knee coil dimensions.
  - 7” ID – fits!



FORCE ANALYSIS

Q: Is there a solution within our design space?

Figure 8-1: Side profile view of device

Figure 8-2: Top view of device

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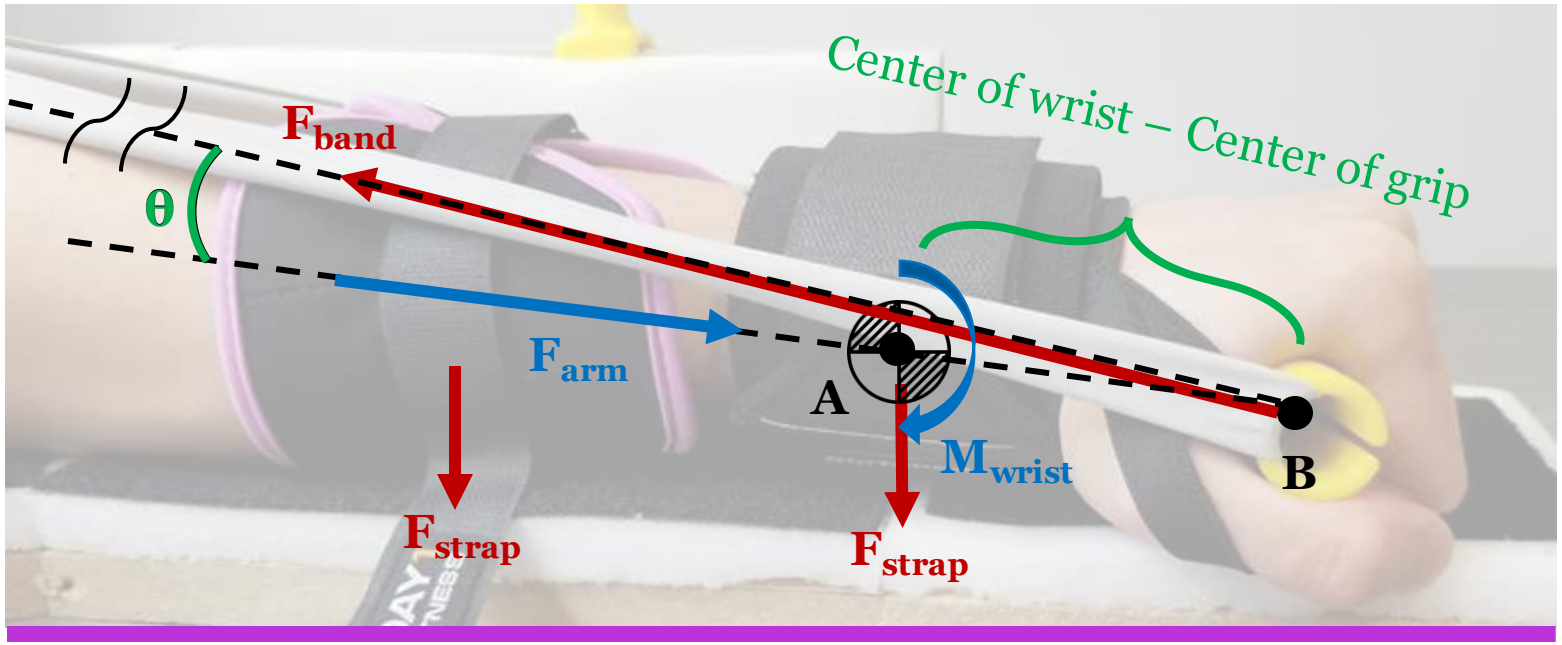

Figure 8-1: Side profile view of device

External forces on arm

Internal forces + torques

Coil boundary

Values change with arm size

Constraints:

$$10° < \theta < 30°$$

$$M_{wrist} < 2 \text{ Nm}$$

$$2 \text{ lbs} < F_{arm} < 5 \text{ lbs}$$

Work for 5% female, 95% male

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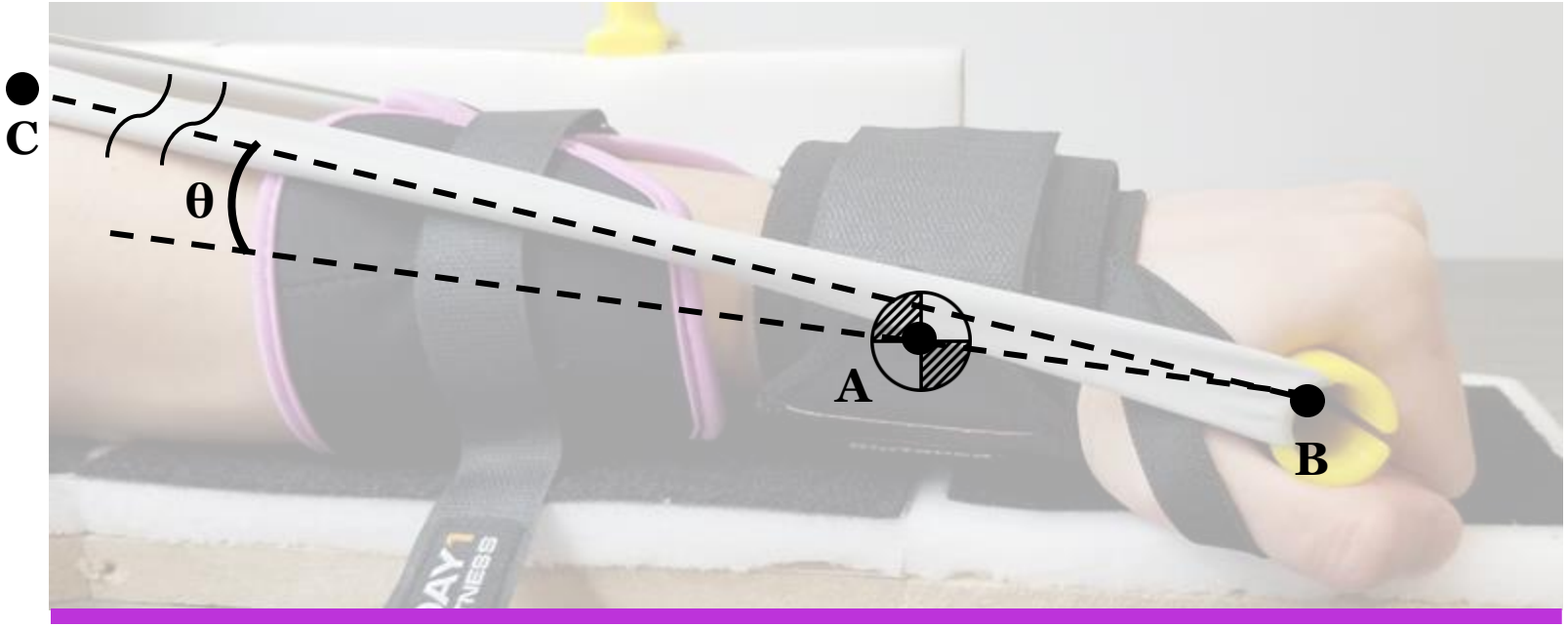

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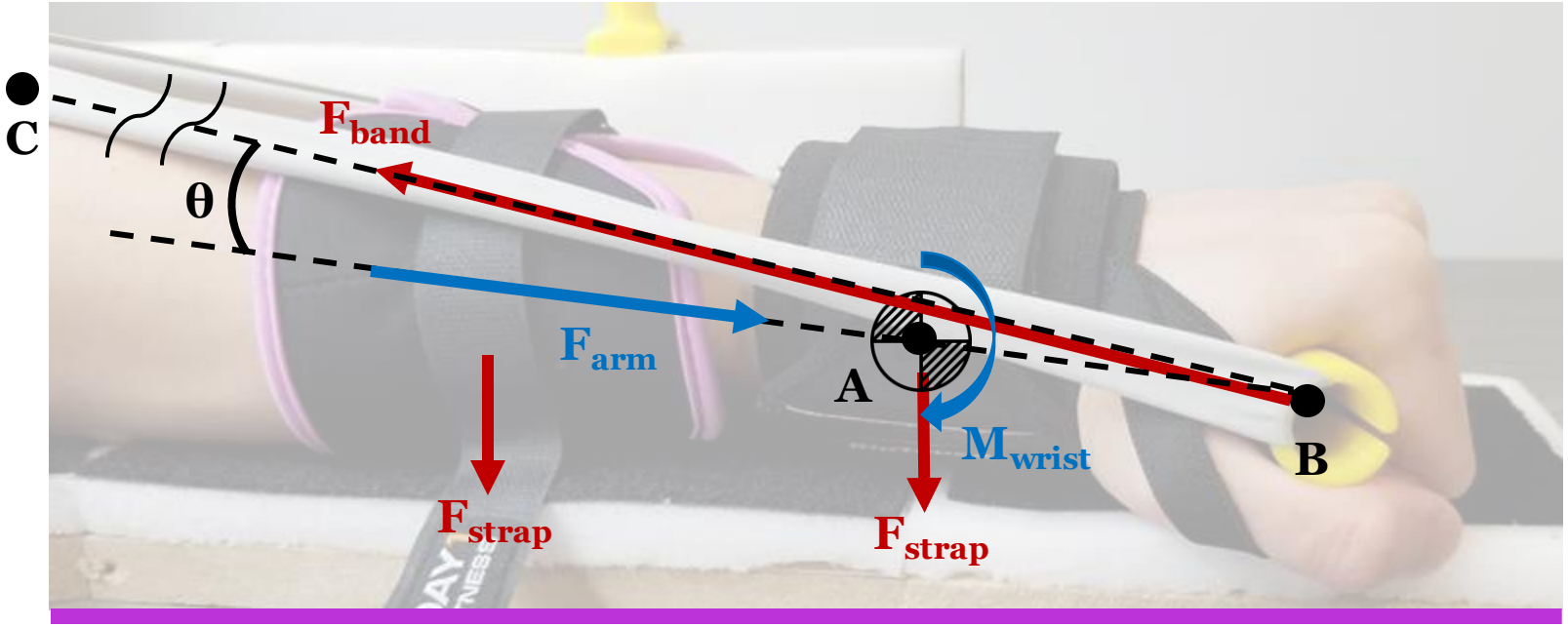

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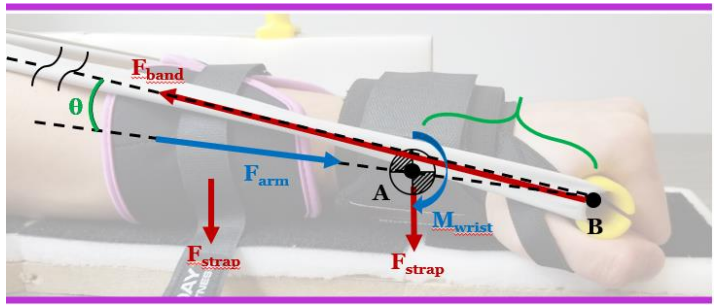
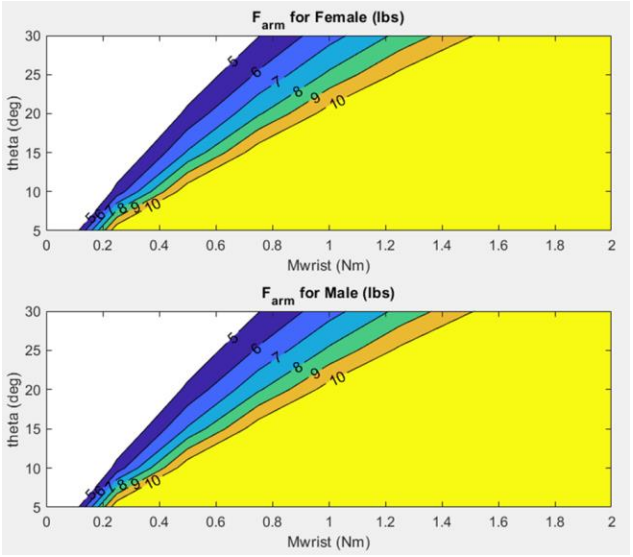


Lay out design space + constraints

$$2F_{band}\cos\theta = F_{arm}$$

$$2F_{band}\sin\theta * \overline{AC} = M_{wrist}$$

System of Equations



Visualize solution space using contour plots

A: Yes, there exist solutions for both 5% female and 95% male, using different values of F_{band}

SAFETY, SUSTAINABILITY, REGULATION

SAFETY

- Hypoallergenic materials
- Patient comfort
- Designed to avoid pinch points, sharp edges, etc.

SUSTAINABILITY

- Device is at least 75% recyclable by mass
- Iterative prototype made from wood (MDF)

REGULATION

- Class 1 Medical Device
  - marketability
- Medical grade materials
  - USP Class VI/ISO 10993-1
  - Standards for plastic healthcare devices in contact with human body

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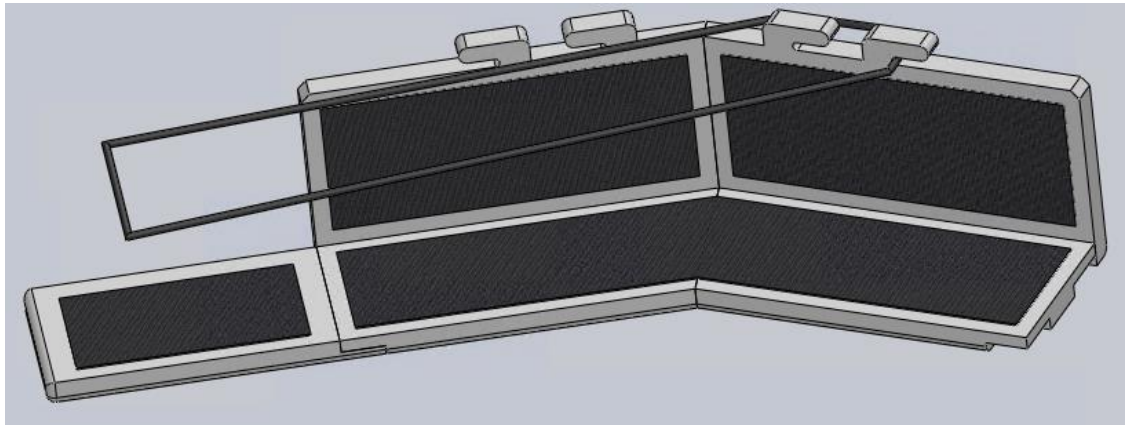
MANUFACTURING

Design

- Stiff member material: Polypropylene
  - ✅ Common plastic used in MR equipment
  - ❌ Not ideal for prototyping



Polypropylene MR Cart

MDF

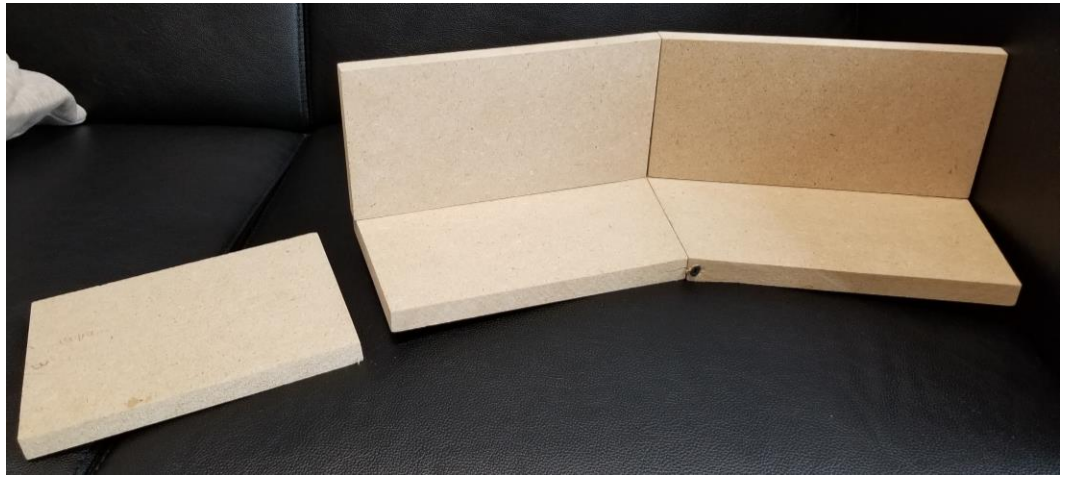
Prototyping

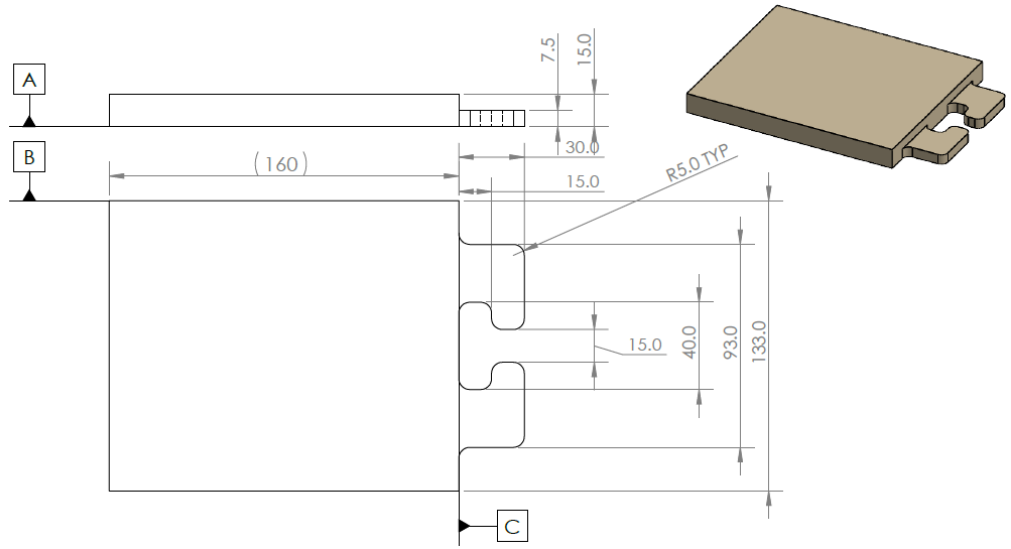
- Stiff member material: MDF
  - ✅ Free source
  - ✅ Rigid
  - ✅ Easy to work with

MANUFACTURING

Stiff Member

- Cut shape out of MDF
- CNC Routing for puzzle joint





MANUFACTURING

Additional Layers

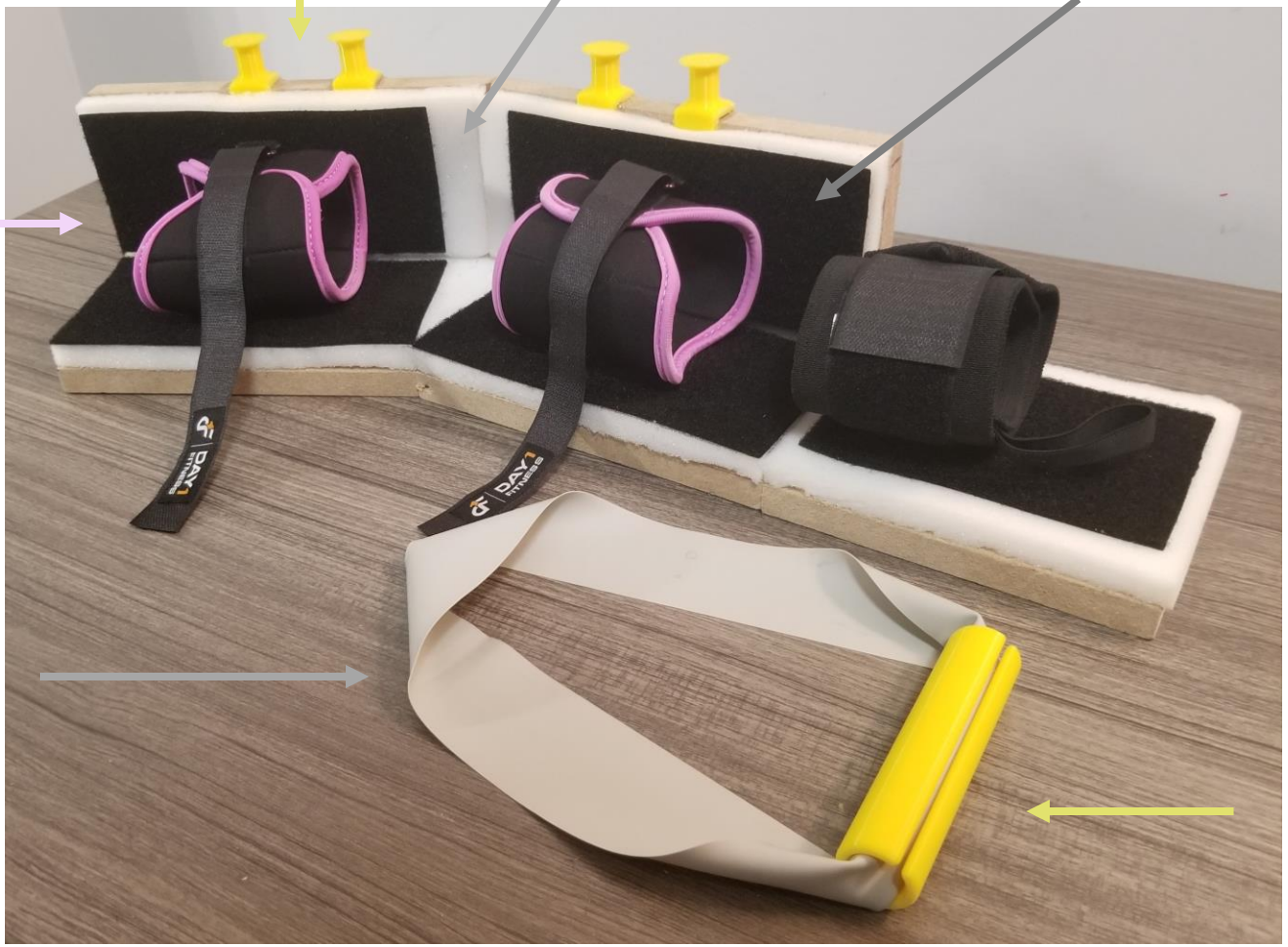
- Polyurethane foam for comfort
- Velcro + arm straps for attachment
- 3D printed hooks and bar

J Hooks

Cushioning Foam

Velcro

Straps



Resistance Band

Handle

MANUFACTURING

Final Prototype

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VERIFICATION

- Modified to not overload the one member with the physical prototype
- Previously: 11 verification tests, some requiring 41 volunteers each
- Key verifications:
  - Variable sizing: fit 5th percentile female, 95th percentile male
  - Size constraint: fit within accessory coil
  - Force applied: within 2-5 lbs
  - Comfort: can be worn for 15 minutes loaded without pain

VERIFICATION: VARIABLE SIZING

Requirement: Device must fit 5th percentile female to 95th percentile male

Approach: Create dummy limbs with appropriate anatomical sizing, check fit within device

Result: Both sizes fit within device as intended

VERIFICATION: SIZE CONSTRAINT

Requirement: Device must fit within typical accessory coil

Approach: Create dummy coil with dimensions provided by ScanMed, make sure device fits with 95th percentile male arm

Result: Device fits within coil with the largest arm

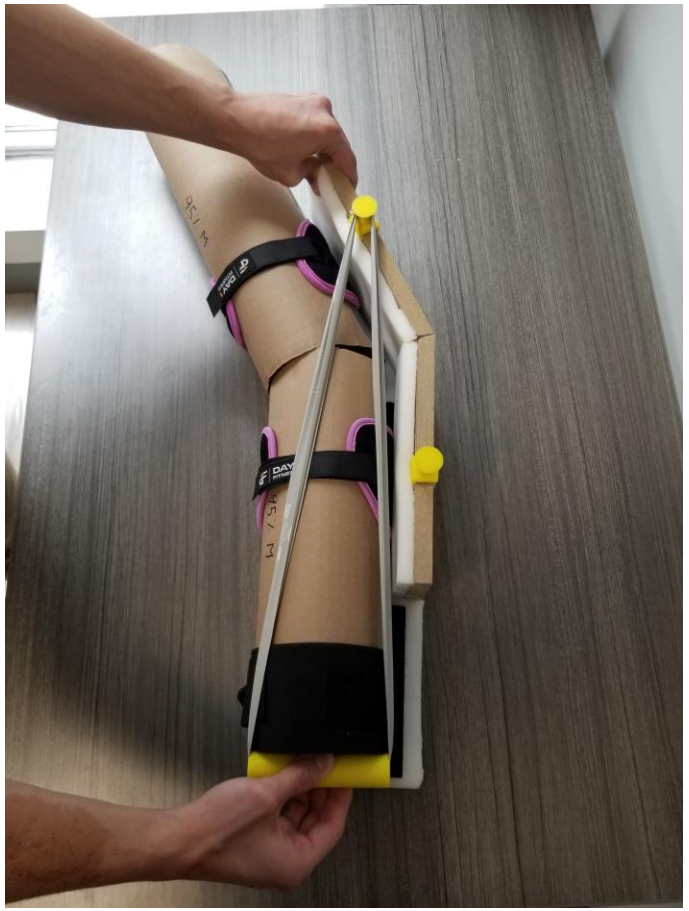
VERIFICATION: FORCE APPLIED

Requirement: Device must apply between 2-5 lbs of force

Approach: Calculate band stiffness, k, using dead weight test. Calculate Δx for smallest and largest arms. Using $F_{elastic} = k\Delta x$, calculate force. Ensure range is within 2-5 lbs

Result: Device applies 2.3 lbs to smallest arm, 4.5 lbs to largest arm

Future Refinement: Use force gauge for better accuracy



VERIFICATION: COMFORT

Requirement: Can be worn for 15 minutes without pain (time recommended by research expert)

Approach: Load volunteer (me) into device in correct position. Hold position for 15 minutes. Record and rate any discomforts

Result: Slight numbness (arm fell asleep), but no pain

Future Refinement: More volunteers (avoid designer bias)

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RECOMMENDATIONS TO IMPROVE DEVICE

Design improvements

- Ensure consistency of wrist position in between scans
- Reconsider arm position to have accessory coil in line with MR coil
- Develop simple table that tells MR technologist force based on wrist position and band being used
- Replace wrist strap with a slot design to avoid any resistance in X direction

Verifications (post-COVID)

- Clinical testing with MRI equipment
- Greater volunteer sample size

MDR FEEDBACK

Concern/Comment	Our actions
The introduction and need for the device was not clearly presented	Rewrote introduction. Dedicated slides to background, needs statement, & objective ✓
Force Analysis explanation could use refinement	Rewrote force analysis section, focused on key takeaways ✓
Is there a way to measure force on the fly?	Not with the current design, but We have brainstormed a potential solution (lookup table) ✓
Does the arm coil need to be parallel to the MR bore?	While it's not necessary, it could affect image quality. This is a desired refinement for future designs ✓
What is the rationale for a puzzle joint?	Previous design required a locking pin. Puzzle joint removes need for locking pin easy to work with ✓
Application of ScanMed	Prevalence of knee coils over wrist coils were confirmed. ✓

Table MDR Feedback

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EXPENSES

Table 1: Expense Breakdown

No.	Category	($) MDR	($) FDR
1	Materials	$70	
2	Shipping	$21	
3	Equipment	~~$96~~	$133
4	Manufacturing Services	$0	
	Budget	**$375**	
	Expenses	**~~$237~~**	**$274**
	Budget Remaining	**~~$138~~**	**$101**

$101 remaining

RISKS ENCOUNTERED

- **Finding volunteers to perform validation tests !!!**
  - Problem: COVID19 guidelines prevented us from running trials on volunteers
  - Solution: Adjusted verification plan to focus on key requirements for 1 member ✅

- **Validating CAD Design !!**
  - Problem: CAD measurements were sized too small for arms after manufacturing
    - Change CAD dimensions, iterate
  - Solution:
    - Proactively budgeted extra time for manufacturing ✅
    - Opted for quick prototyping methods (MDF, cardboard, personal 3D printer) ✅

- **Remote collaboration!**
  - Problem: Remotely collaborating in 2 different time zones, 3 different cities
  - Solution: Proactively setup: Teams, OneDrive, OneNote, PowerPoint, Excel & GrabCAD ✅

WORK BREAKDOWN

* Total Hours:

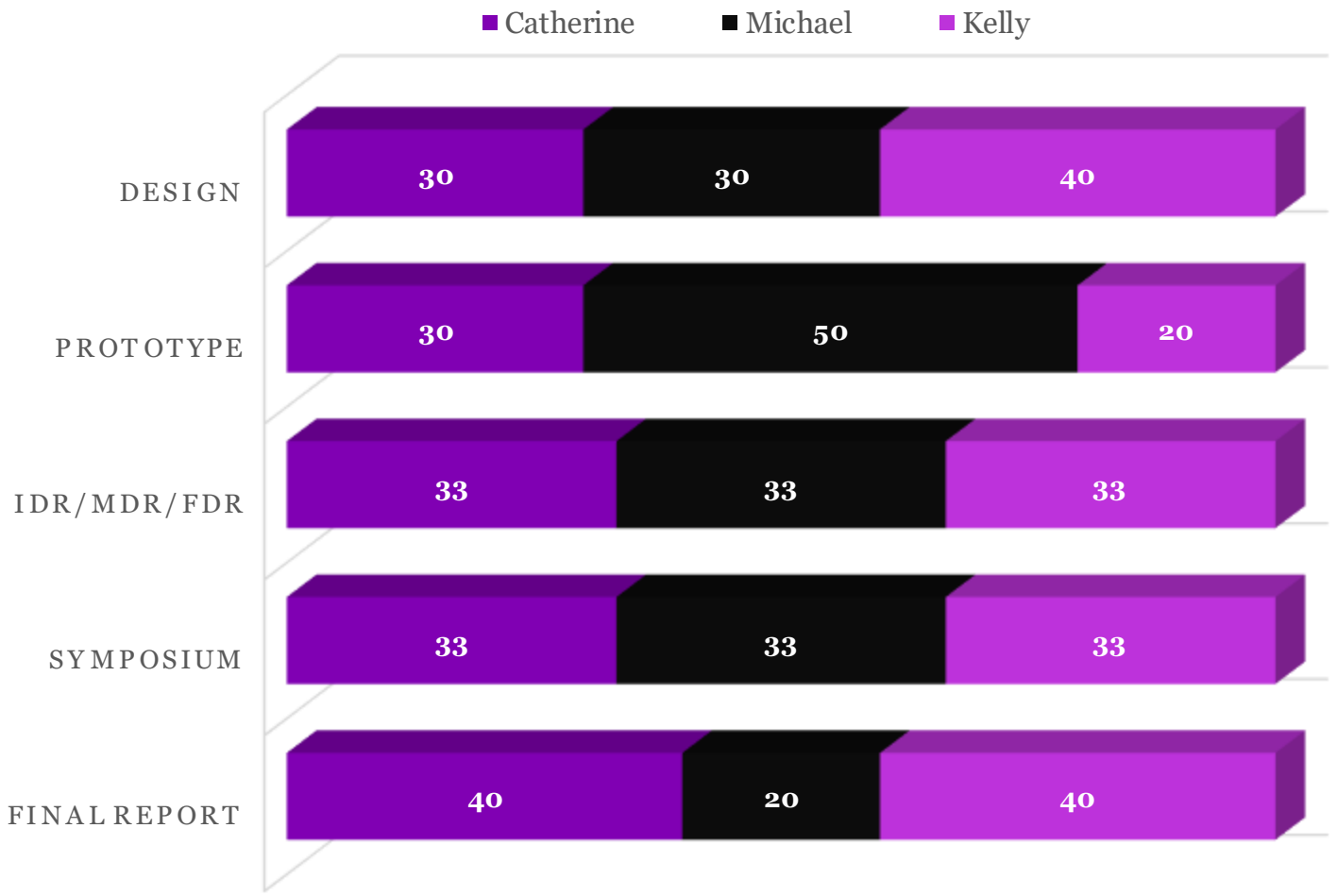
198

* Avg. hours spent/ member:

66

Estimated hours left:

45



Work distribution by task per member

*Up until FDR

Timeline (thus far)

- Improve design ✓
- Source all parts ✓
- Manufacture first prototype ✓
- Iterative redesign ✓
- Prepare verification plan ✓

- Finish final prototype ✓
- Complete verifications ✓
- Work on FDR and DPR ✓

- Finish Symposium Video
- Complete Design Project Report (DPR)

Timeline: Next Steps

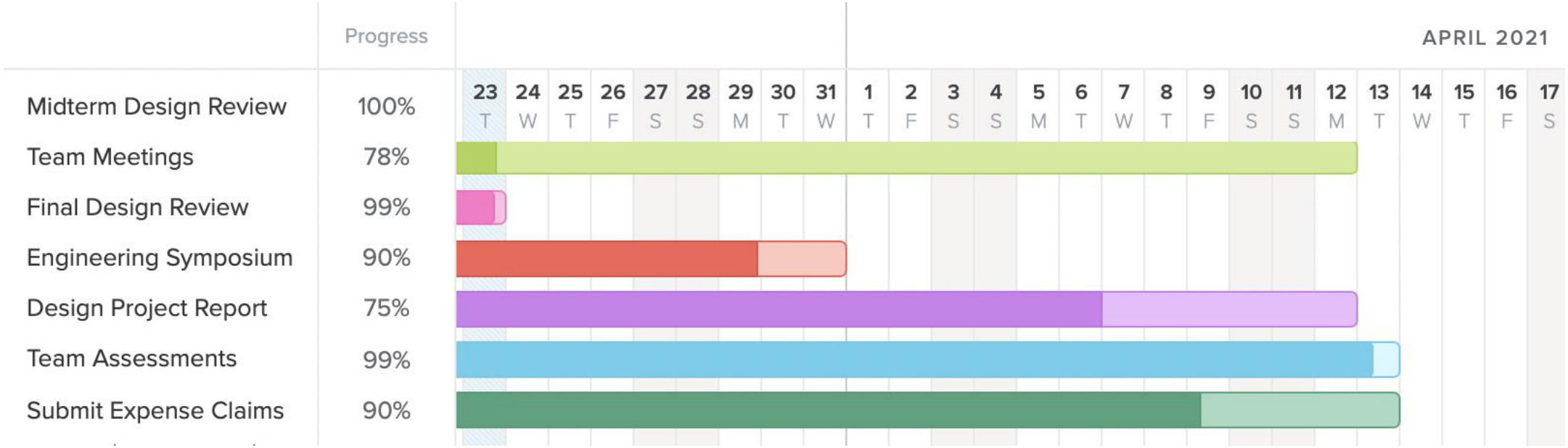


Figure: Gantt chart section of FDR to last deliverable

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FUTURE OF THE DEVICE

- Proven industry interest via communications with expert researchers
  - Compressive MRI loading is a highly pursued topic at the moment
- Open source design, BOM, CAD, and all other relevant files for future researchers to pursue further

Western

ROTH | McFARLANE
HAND & UPPER LIMB CENTRE
ST. JOSEPH'S HEALTH CARE LONDON

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Thank you for listening!

Any questions?


DAY1
FITNESS
DAY1
FITNESS