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Knee Exoskeleton

Team 102

November 12, 2024

Introduction

Joseph Liberato
Biomedical Engineer

Nikolya Cadavid
Mechanical Engineer

Andrew Baumert
Biomedical Engineer

Arianna Escalona
Biomedical Engineer

Kyle Giddes
Mechanical Engineer

Aaron Gonzalez
Biomedical Engineer

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Sponsors and Advisors

Academic Advisor
Shayne McConomy
Professor

Academic Advisor
Stephen Hugo Arce
Professor and Sponsor

Engineering Mentor
Taylor Higgins
Point of Contact & Advisor

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Objective

The objective of this project is to develop a device that enhances the rehabilitation process for total knee replacement (TKR) patients by providing mechanical resistance and electrical stimulation, intended for supervised use within established recovery protocols.

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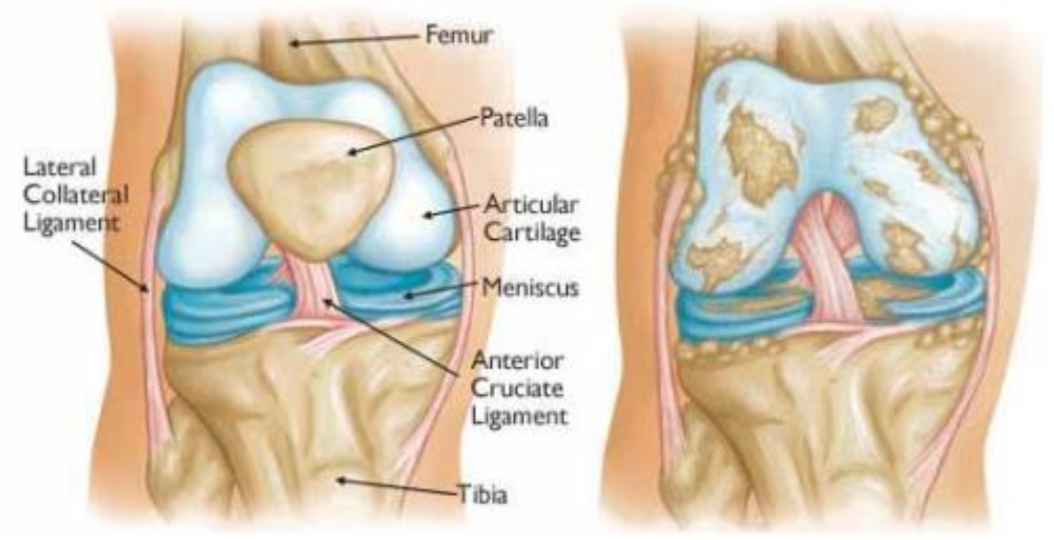
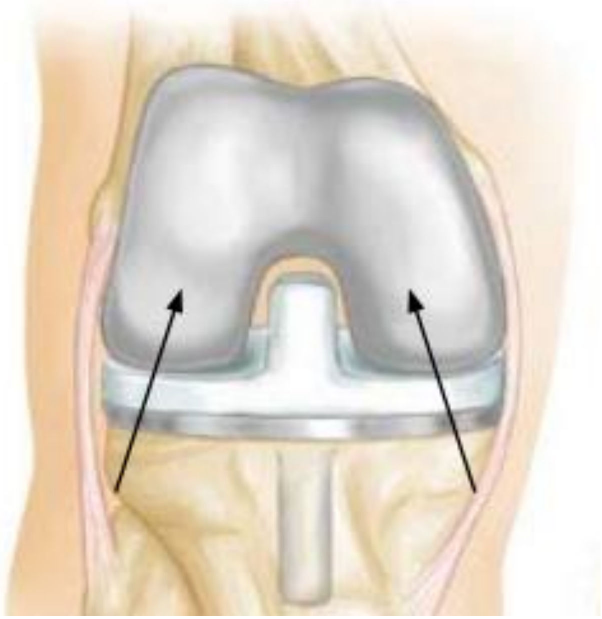
Patient Population and Need for TKR

Knee Joint (of a healthy knee) **Osteoarthritic Knee**



Total Knee Replacement



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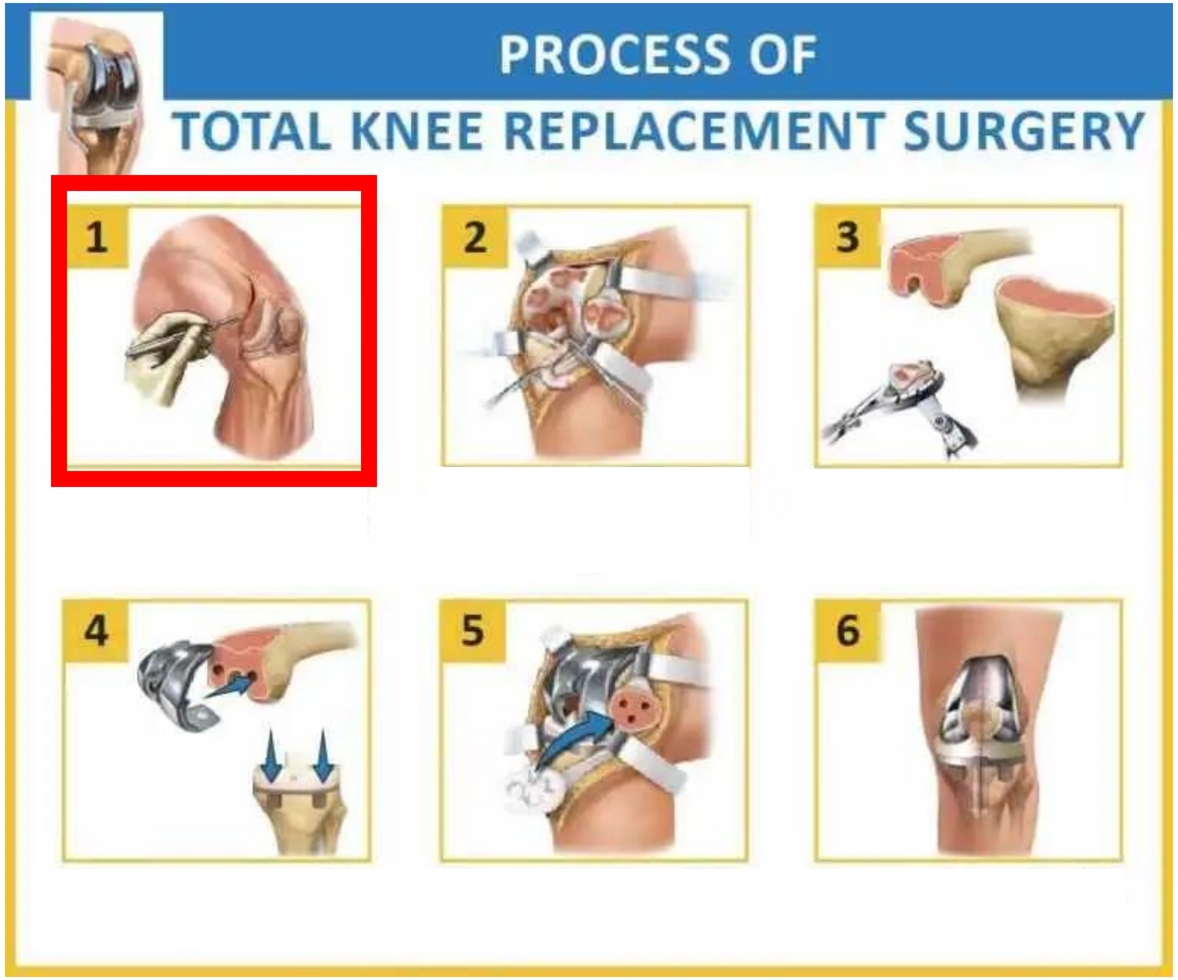
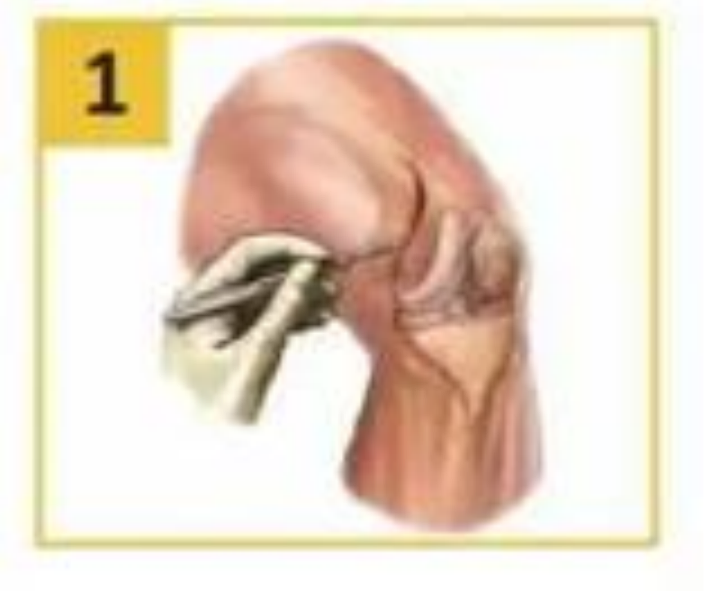
Impact of TKR on the Quadriceps





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Early Recovery – Post-Operative Protocols

Quad Sets

Short Arc Quads

Terminal Knee Extensions

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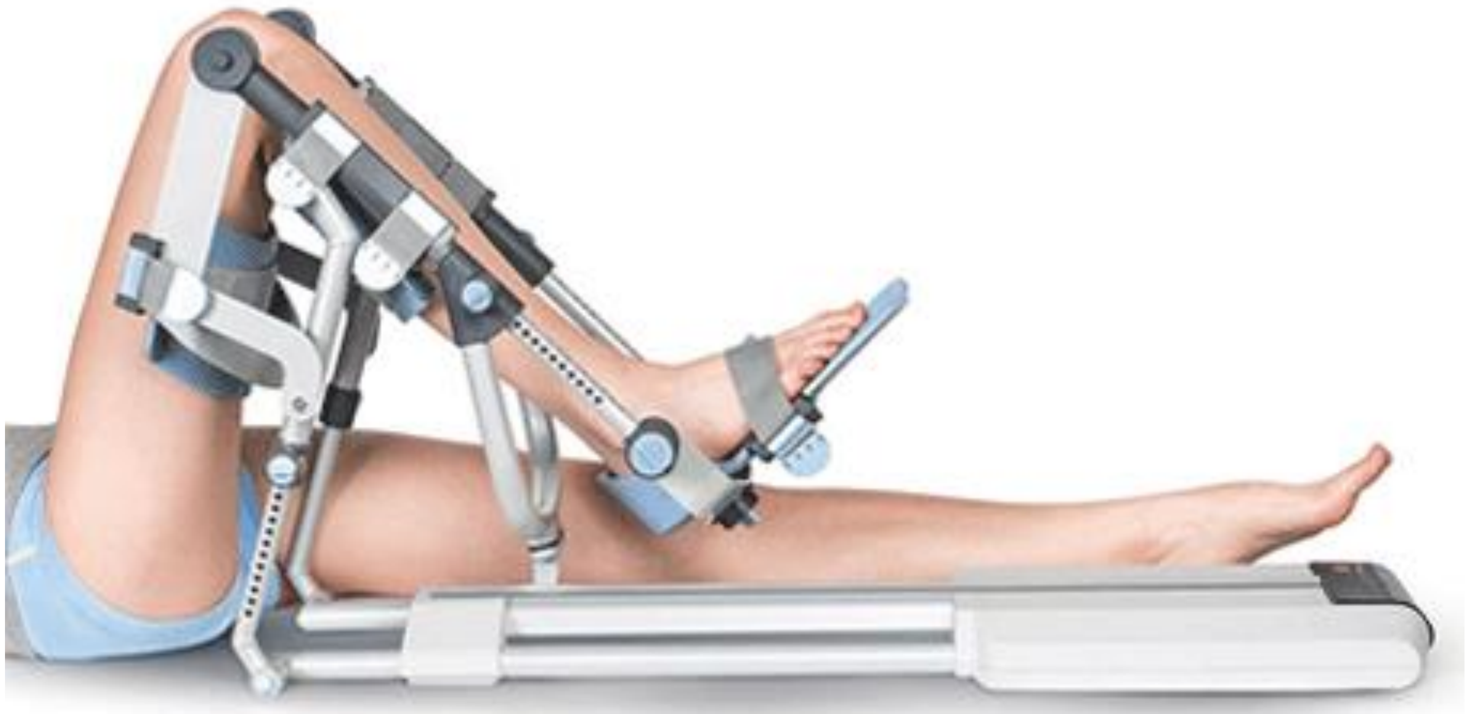
Early Recovery – Limited Effectiveness of CPM Machines



Continuous Passive Motion (CPM) Machine

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Early Recovery – Limited Range of Motion Progress with CPM

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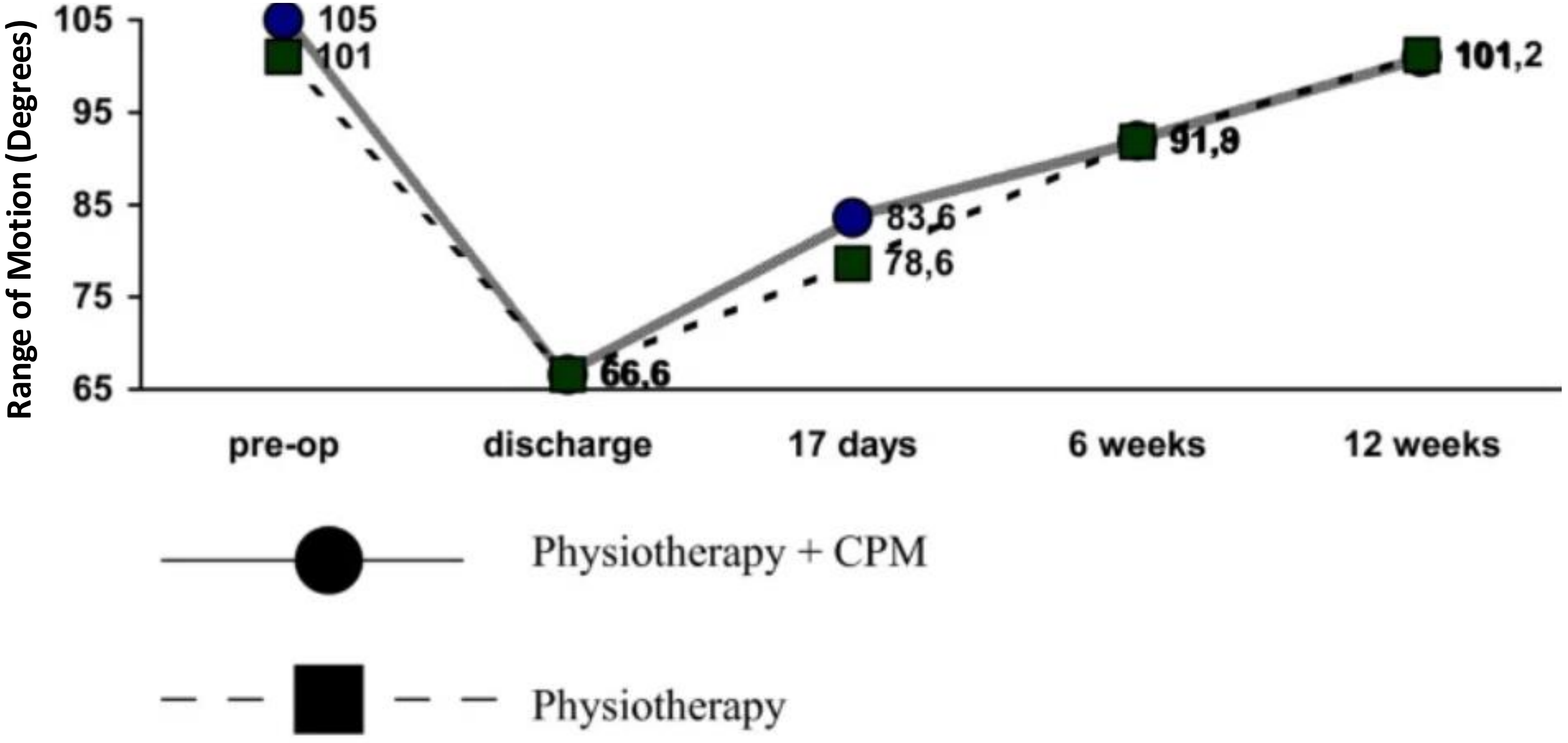
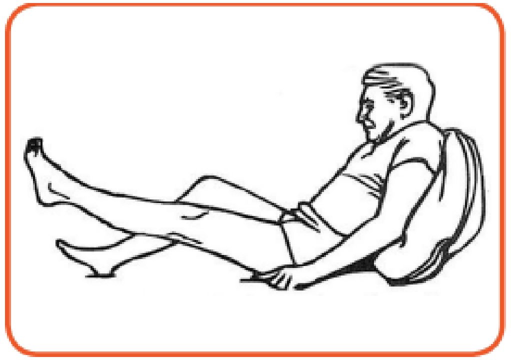
Progress of active RoM through the trial period.



T. A. Lenssen, M. J. van Steyn, Y. H. Crijns, et al., "Effectiveness of prolonged use of continuous passive motion (CPM), as an adjunct to physiotherapy, after total knee arthroplasty," BMC Musculoskelet. Disord., vol. 9, no. 60, 2008. Available: https://doi.org/10.1186/1471-2474-9-60

At-Home Recovery – Challenges and Exercises



Straight Leg Raises

Sitting Knee Flexion

Patient getting into a shower post-TKR

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Existing Rehab Devices – Gaps

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X10 Knee Machine

HAL Single Joint

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Key Goals


Safety
Data Acquisition
SUCCESS
Adjustable Design
Convenience
Integrated Electircal Stimulation

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Customers

Primary Market:

Hospitals & Clinics

Secondary Market:

Physical Therapy Clinics

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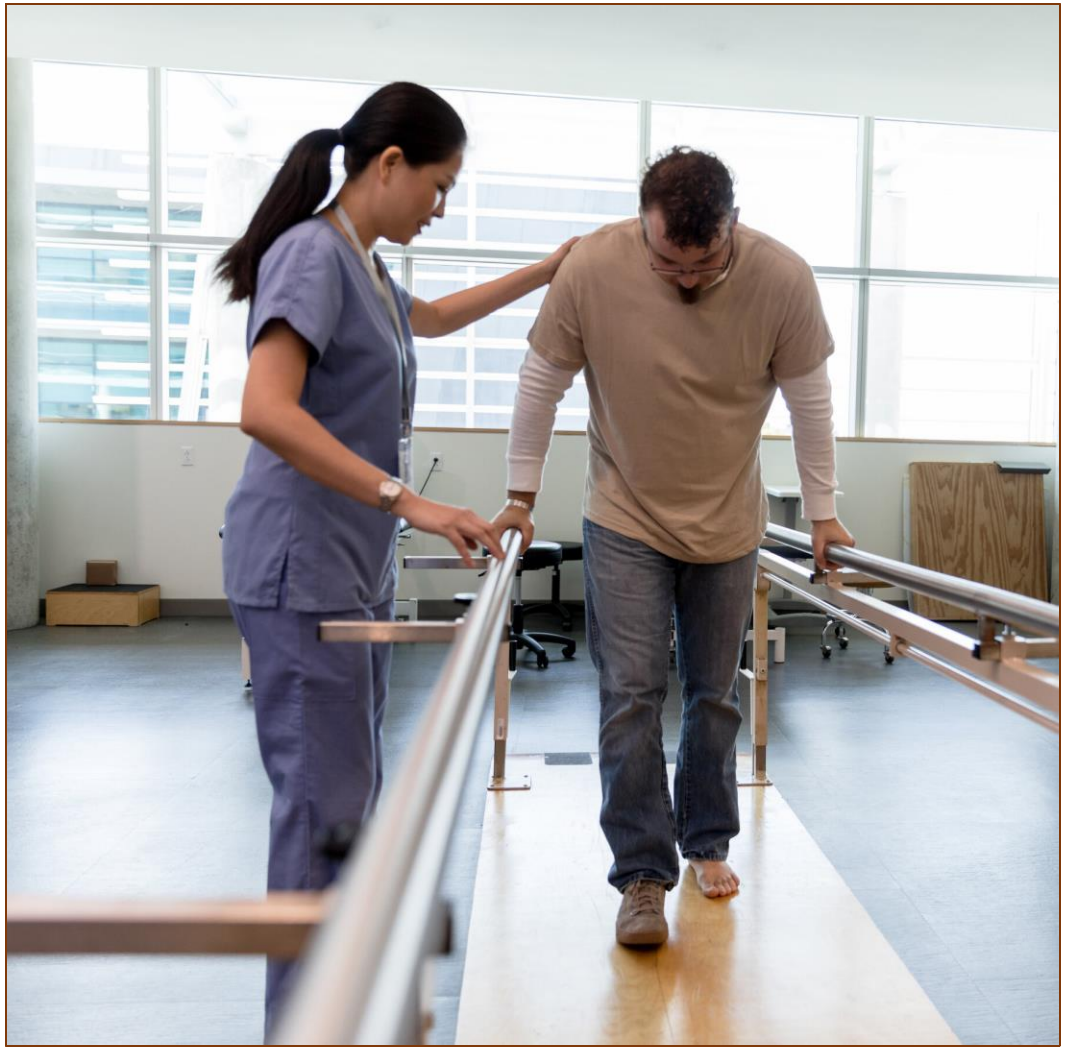
What is Most Important?

Ranking:	Key Design Criteria	Weight
1	Biomechanically Precise	10
2	Mechanical Resistance	9
3	Electrical Stimulation	8
4	Data Tracking	7
5	Adjustable Fit	6
6	User-Friendly Design	5
7	Comfort & Padding	4
8	Affordability	3
9	Durability	2
10	E-Stim On/Off Option	1
11	Compact Design	0



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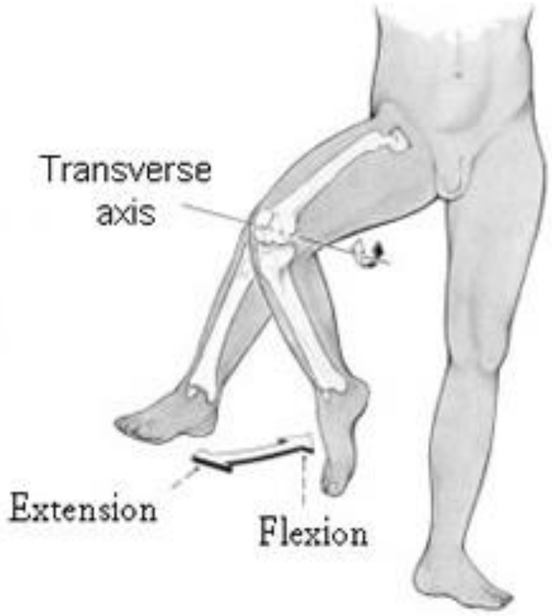
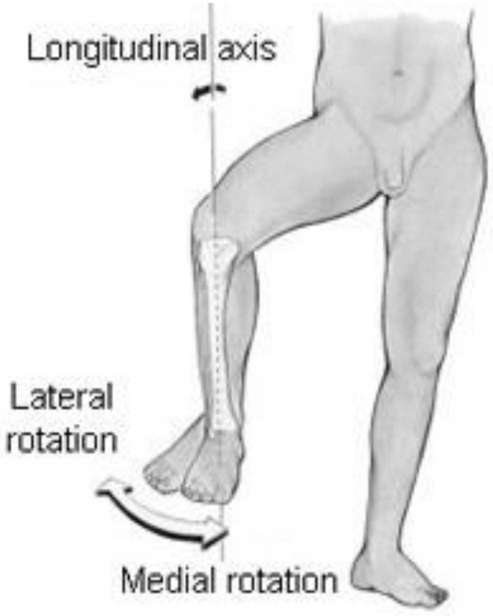
Constraints of the Design

- 10 Nm of Torque at Joint
- Natural Motion 0° to 120°
- Lateral Motion from 0 ± 2° will be restricted





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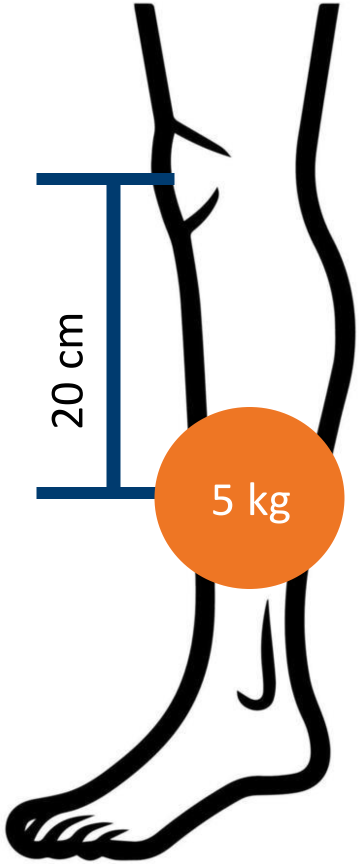
What is the Goal of the Design?

- Torque = F * d *sin(θ) = 9.81 Nm



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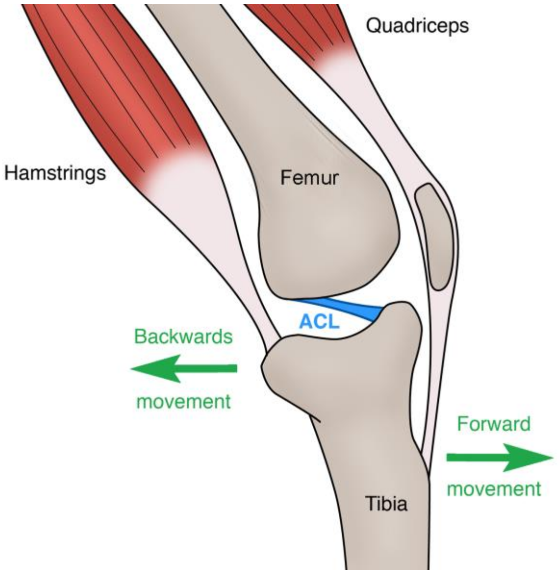
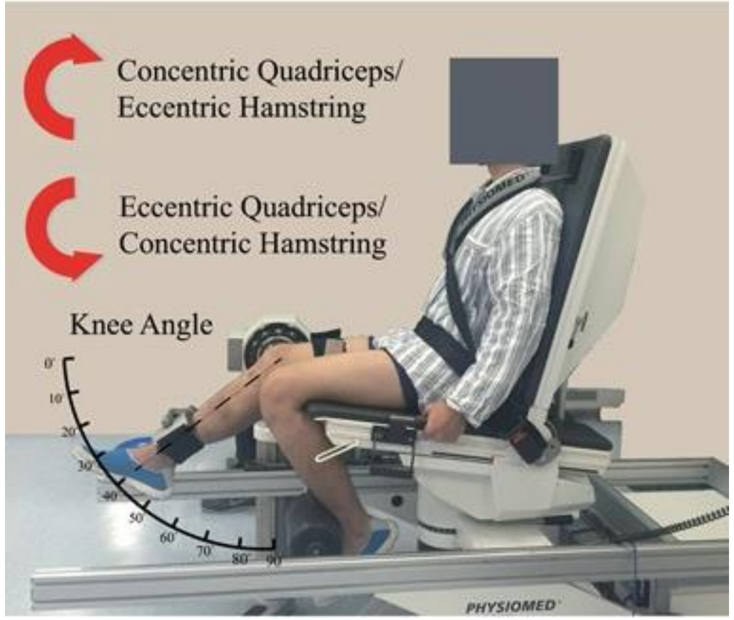
Why is it important?



- Increased Quad Strength
- Better Functional Outcomes
- Faster Recovery time
- Key Stabilizer for Joint



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How will it work?

- Active Actuator System
- Versatile Usage
  - Isometric
  - Eccentric
  - Concentric
- Rated Torque: 10Nm
- Stall Torque: 25Nm

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		Concepts						
Engineering Characteristics	Datum	1	2	3	4	5	6	7
Time to 90% Recovery		S	S	S	S	S	S	+
Resistive Strength		+	+	S	-	+	-	+
Prevents excessive flexion		S	S	S	-	S	S	+
Tracks rehab progress		+	+	+	+	+	+	+
Time to setup and remove		-	-	+	+	-	+	-
Resists lateral movement		+	+	-	S	+	-	S
Enables electrical rehab		S	S	S	S	S	S	S
Fits large range of heights		-	-	+	-	-	+	-
System lifecycle		-	-	+	-	-	-	-
Material Cost		-	-	+	S	-	S	-
# of pluses		3	3	5	2	3	3	4
# of minuses		4	4	1	4	4	3	4

1	Gas Springs w/ Dual Legs
2	Servo Motor w/ Dual Legs
3	Servo Motor w/ Single Leg
4	Coiled Spring (Passive)
5	Geartrain w/ Dual Legs
6	Dual Pivot Point Design
7	Hip-to-Ankle Design

Datum: HAL-SJ

Selected Concept

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What does the assembled prototype look like?

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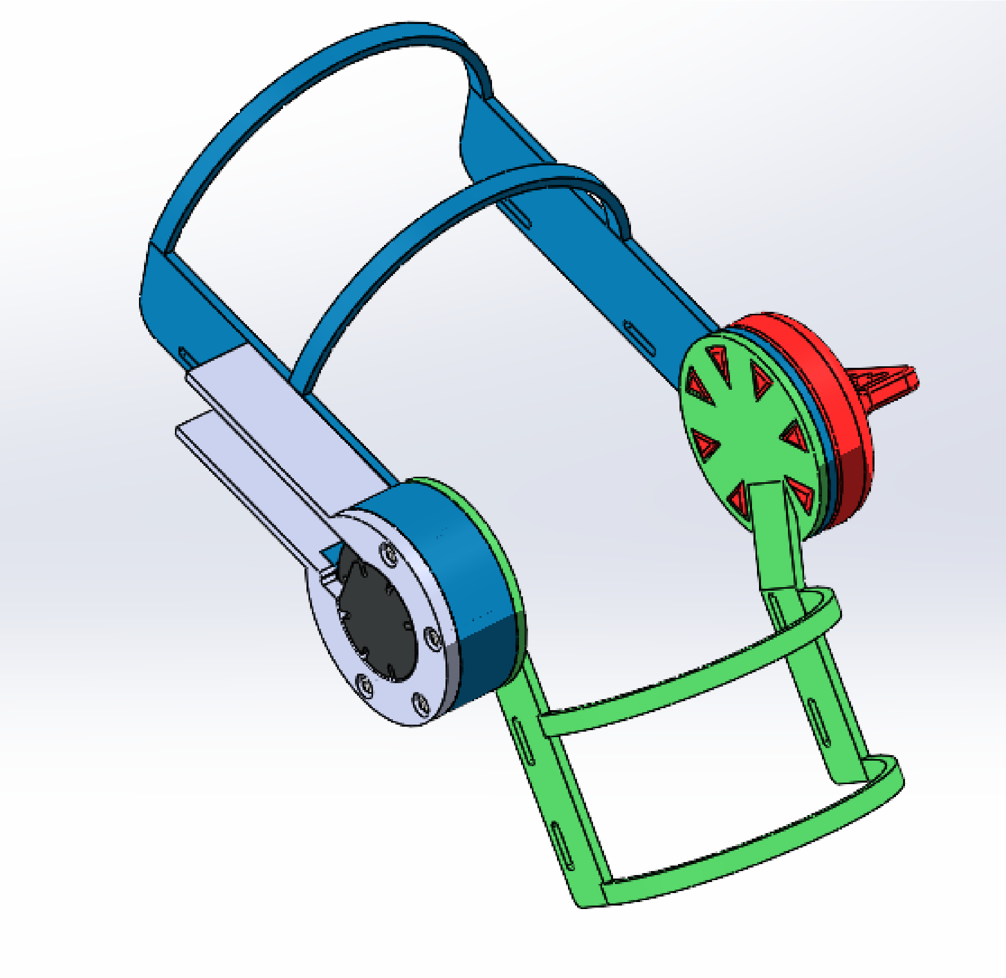

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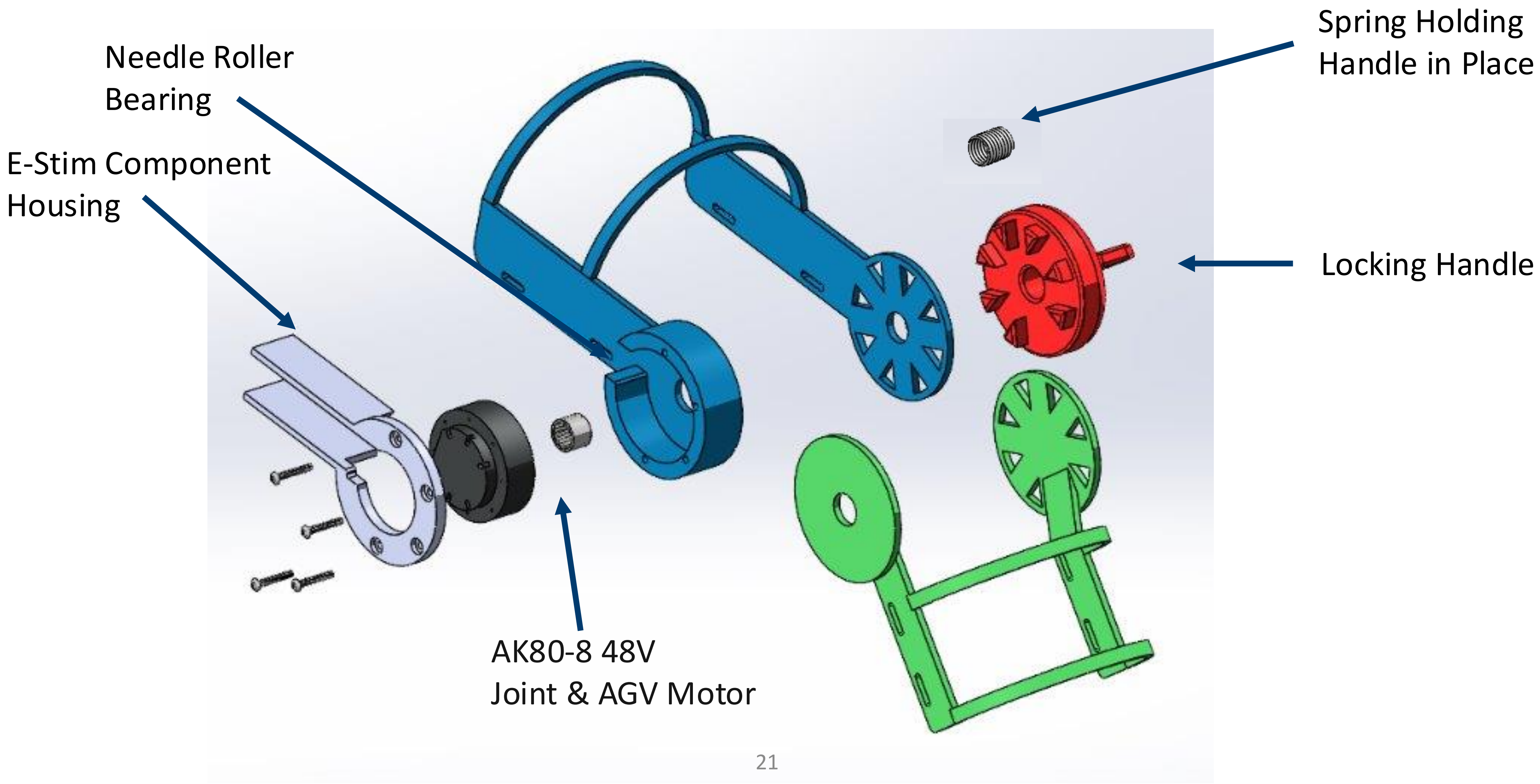
What does the exploded prototype look like?



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What is the purpose of the first prototype?

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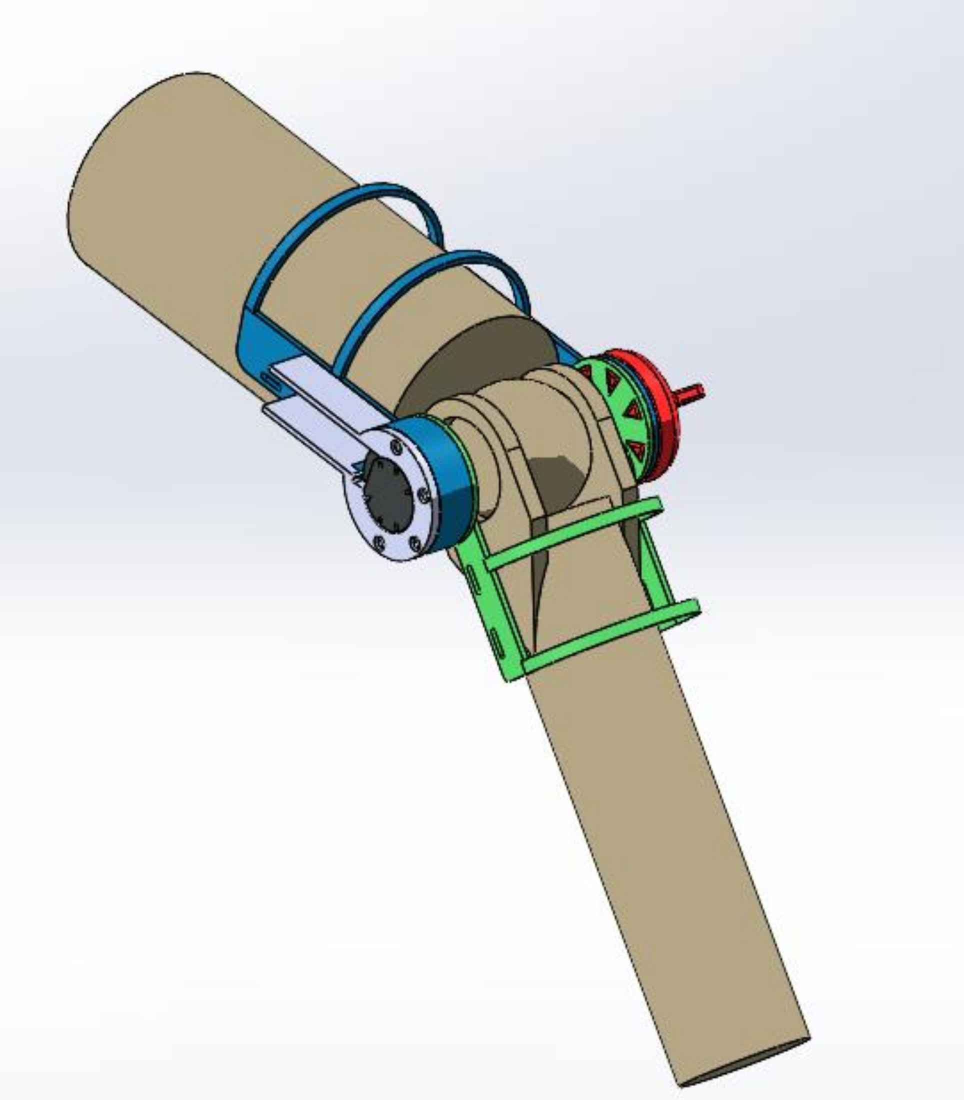
- To test the Safety Features
- Test Biomechanical accuracy
- Ensure target torque is sufficient
- Make sure fitment is correct



How Have we Envisioned Safety?

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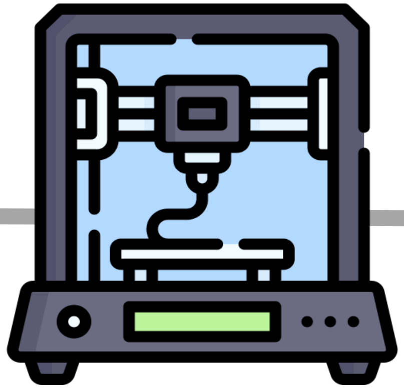
What's Next?

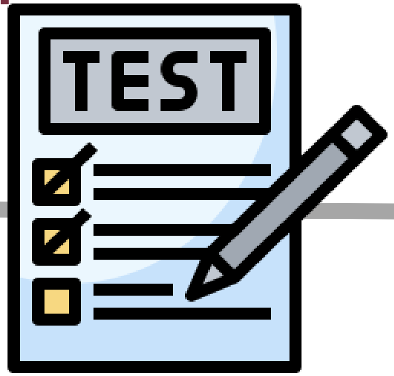


3D Printing

Bring the CAD into reality

Mechanical Testing

Test Safety Features



Implement Battery

Decide on battery/power system

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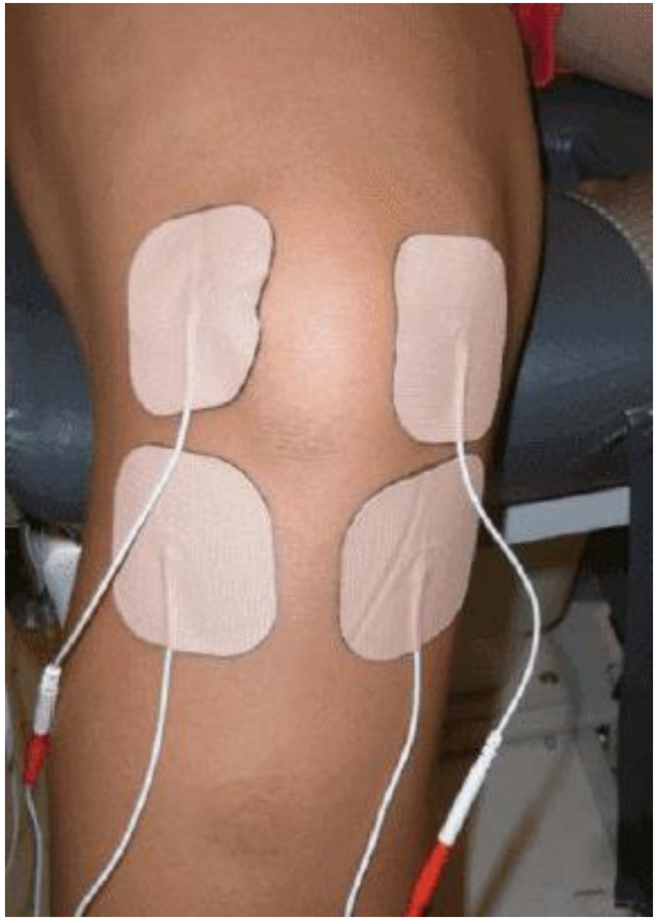
The Targets of E-stim

- Enhance Passive Rehab
  - Activate Quad (NMES)
  - Pain Relief (TENS)
- Build Patient Confidence



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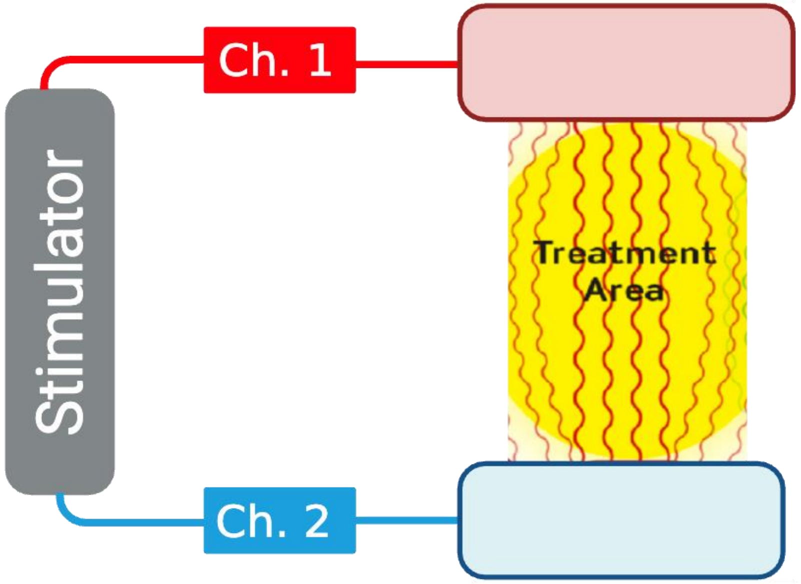
Neuromuscular Electrical Stimulation (NMES)



- For Quadriceps Activation
- Target Motor Nerves
- High Amplitude
- Pulse Frequency: 30 – 80 Hz
- Pulse Duration: 200-400 µs

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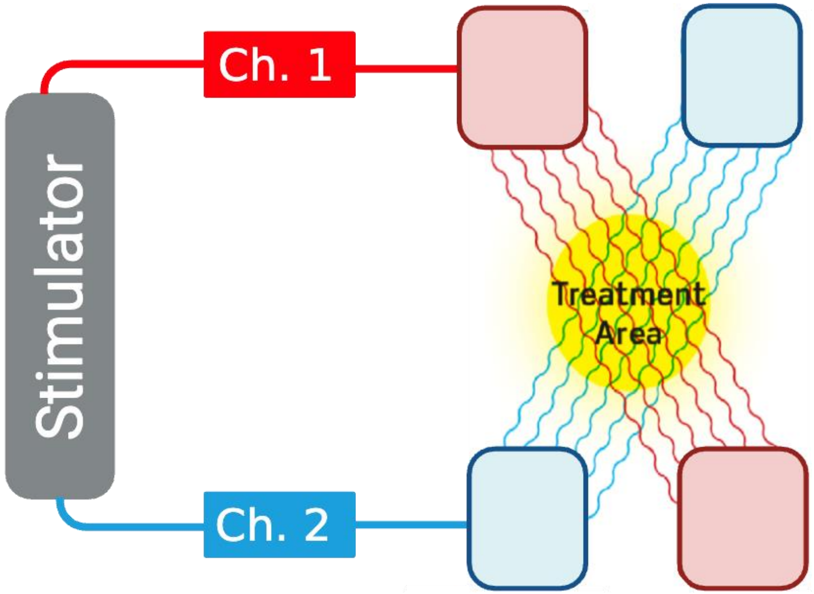
Transcutaneous Electrical Nerve Stimulation (TENS)



- For Pain Relief
- Target Sensory Nerves
- Low to Moderate Amplitude
- Pulse Frequency: 50 – 100 Hz
- Pulse Duration: 50-100 µs

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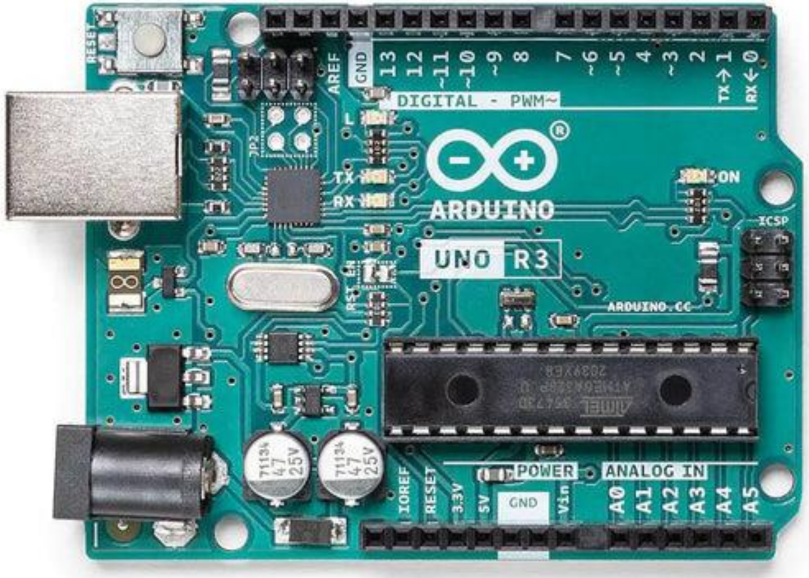
Methodology



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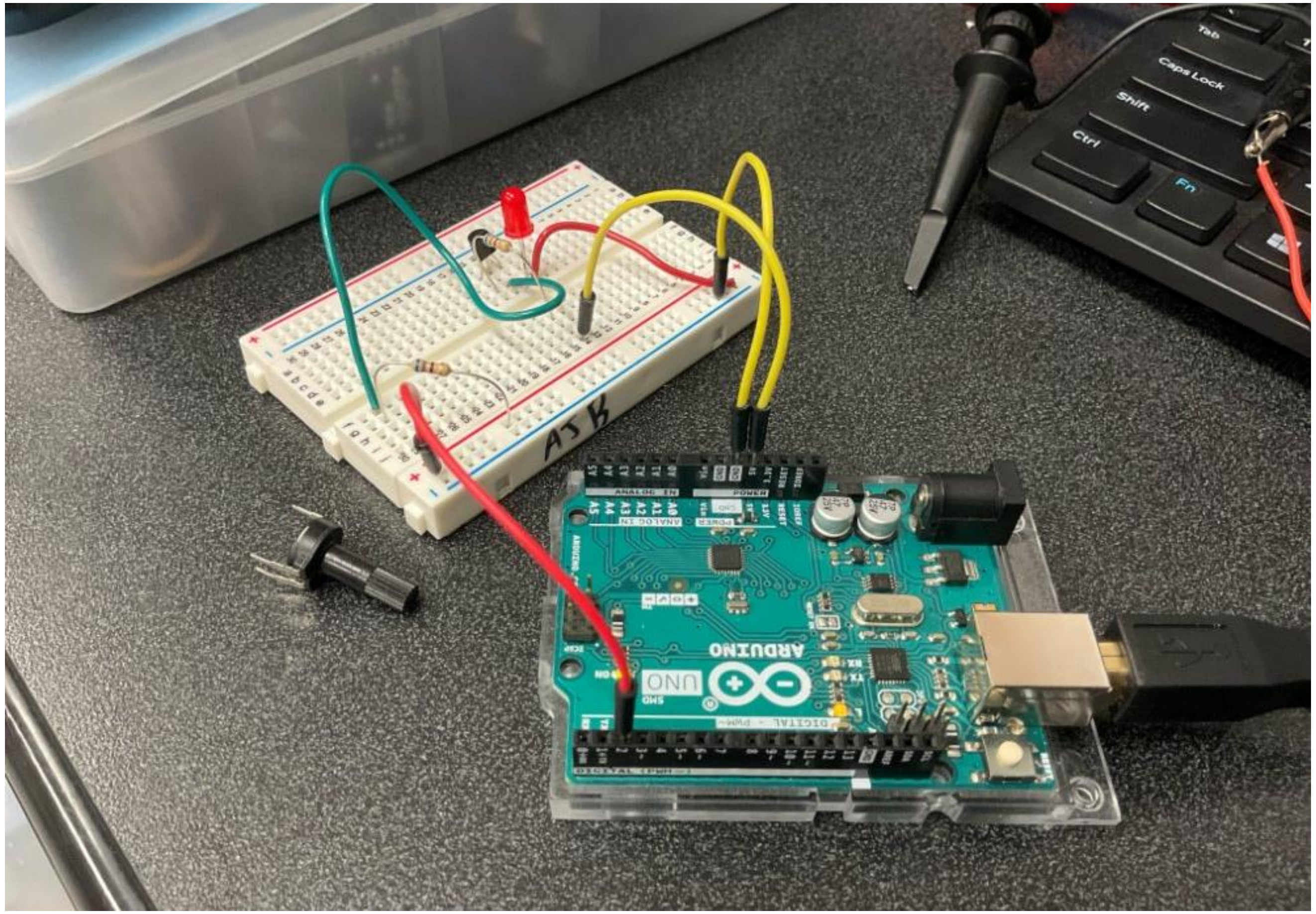
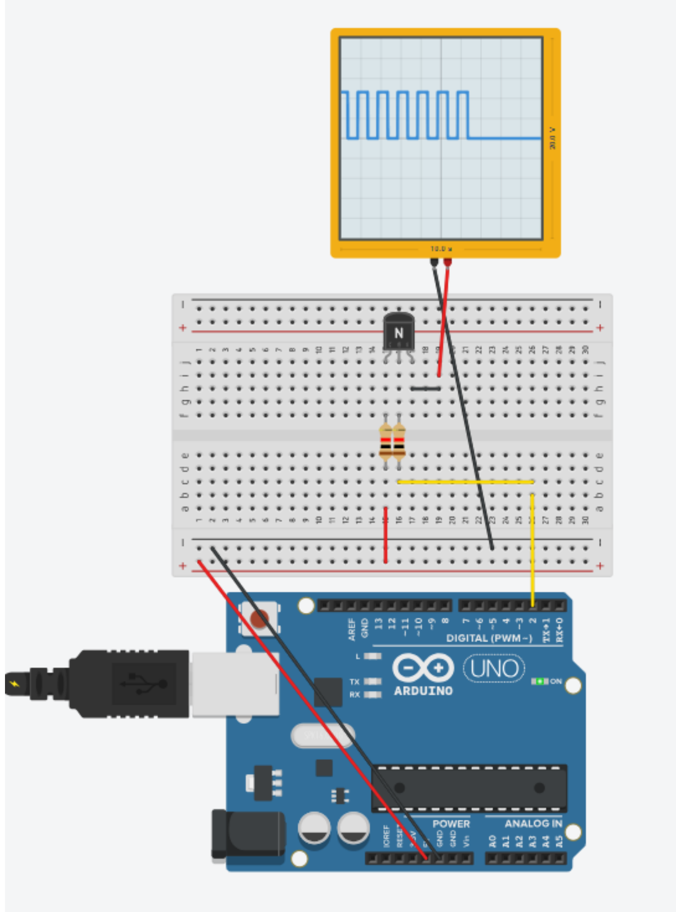
Circuit Diagram





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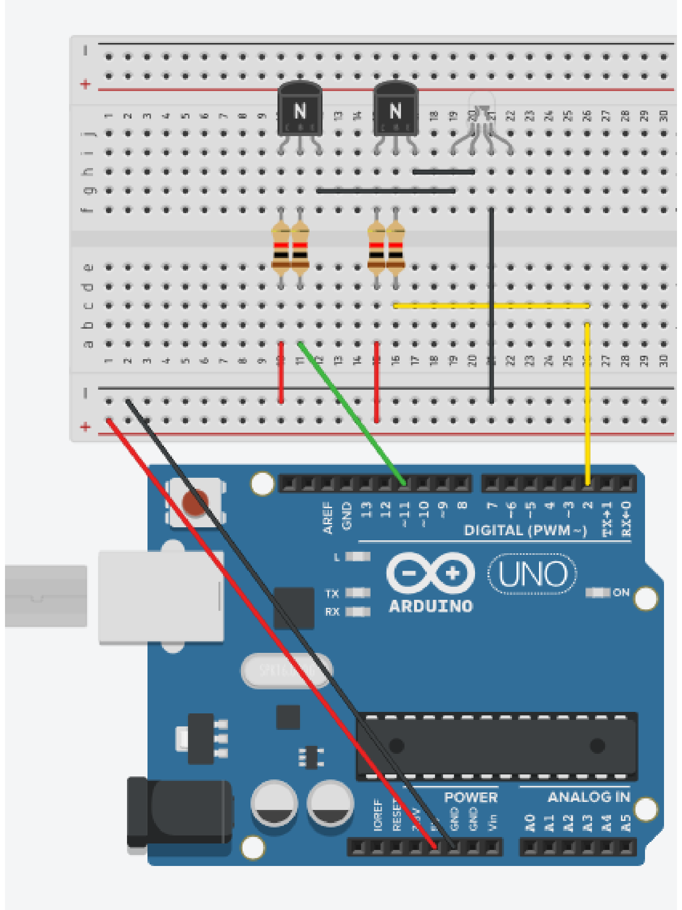
Circuit Diagram

```
int pulsePin = 2;      // Set the pin you want to use for pulsing (e.g.,
int pulseWidth = 10;   // Time in milliseconds for HIGH (5V) signal
int pulseRate = 200;   // Time in milliseconds for LOW (0V) signal
int otherPin = 11;     // Another pin (if needed)
int NMES = 1;

void setup() {
  pinMode(pulsePin, OUTPUT); // Set pulsePin as an output
  pinMode(otherPin, OUTPUT);
}

void loop() {
  if (NMES == 1) {
    digitalWrite(pulsePin, HIGH); // Set the pin HIGH (5V)
    delay(pulseWidth);            // Wait for the pulse width duration

    digitalWrite(pulsePin, LOW);  // Set the pin LOW (0V)
    delay(pulseRate);             // Wait for the pulse rate duration
  } else {
    digitalWrite(otherPin, HIGH); // Set the pin HIGH (5V)
    delay(pulseWidth);            // Wait for the pulse width duration

    digitalWrite(otherPin, LOW);  // Set the pin LOW (0V)
    delay(pulseRate);             // Wait for the pulse rate duration
  }
}

```



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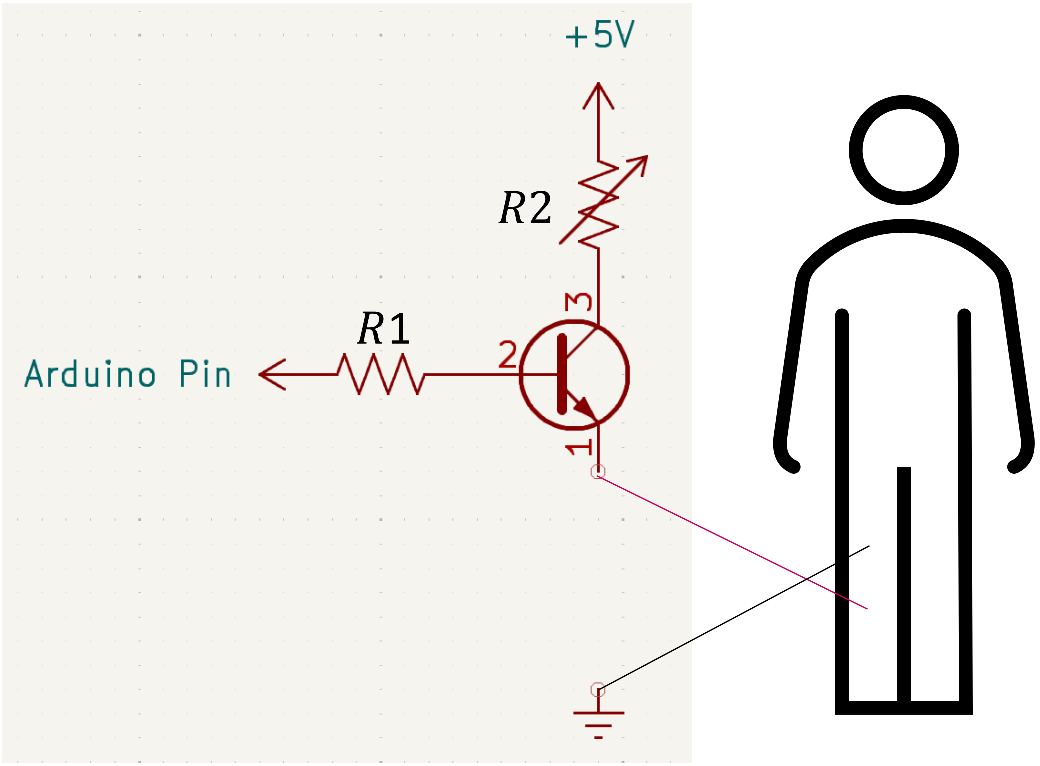
Circuit Diagram

- Ohms Law: $V = iR$
- Arduino Operates at 5V
- Target Current $0 < i < 80mA$
- R2 = 5/0.08 = 62.5Ω → 62 Ω
- R1 = 5/0.008 = 625Ω → 620 Ω



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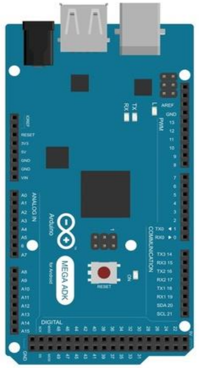
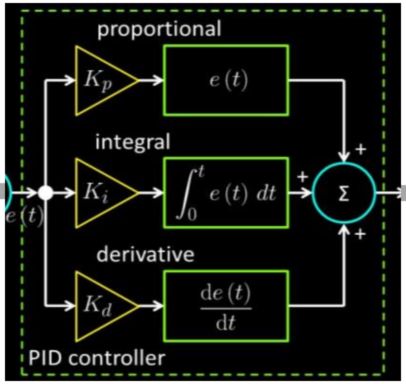
Next Steps for E-Stim Development





Ensure Safety

Meet with medical and technical professionals

Component Identification

Decide on analog/digital components.

Implement into Exoskeleton

Decide how to attach to suit and power

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“We can only see a short distance ahead, but we can see plenty there that needs to be done.”

- Alan Turing

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