Amphibious Ankle Foot Orthosis

Stephanie Ku | Daniel Meza | Sarah Van Belleghem | Morris Vanegas

Team


Morris Vanegas


Stephanie Ku


Daniel Meza


Sarah Van Belleghem


Brandy Baker


Subarna Basnet

The Context

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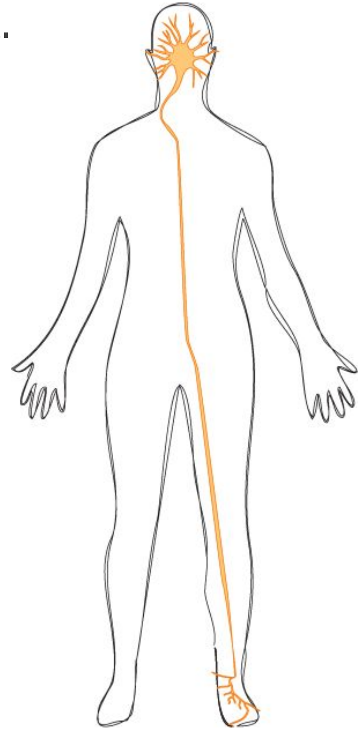
Ankle Foot Orthoses (AFOs) comprise **26%** of the US orthosis market.

720,000 people suffer from Peripheral Nerve Disorders

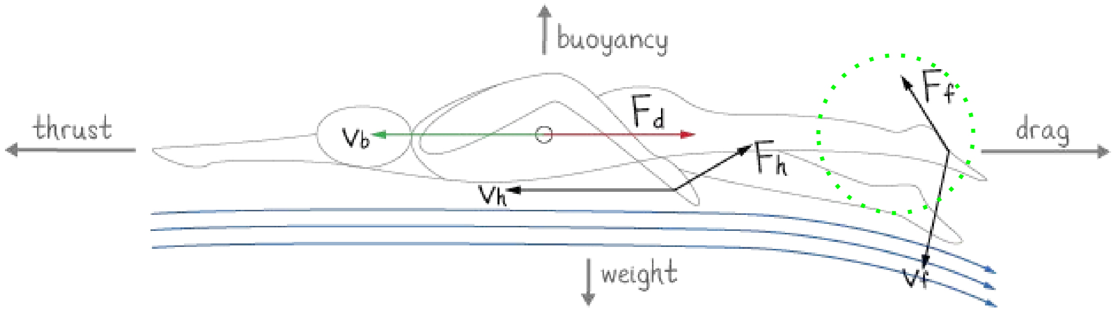
- Diabetic Sensorimotor Polyneuropathy
- Charcot-Marie-Tooth

Reduced ankle control **prevents active lifestyle**.

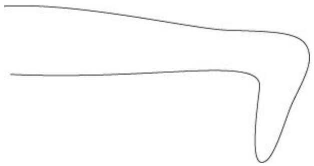
Swimming is both a great form of exercise and muscle rehabilitation.



Physics of Swimming

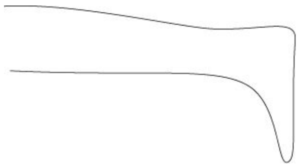


Dorsiflexion
"Walking Position"

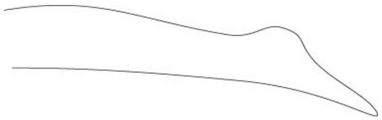


Normal: 20º
CMT: 8º

Neutral
"Neutral"



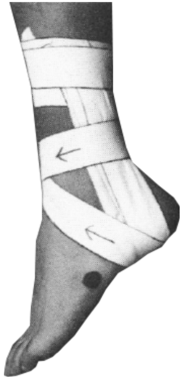
Plantarflexion
"Swimming Position"



Normal: 50º
CMT: 15º

Hyperextension
"Painful"

Prior Art



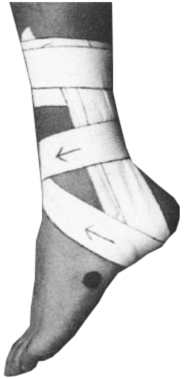
Athletic Taping

Everyday Swimming Gear

Prostheses

Standard AFO

Prior Art



Athletic Taping

Everyday Swimming Gear

Prostheses

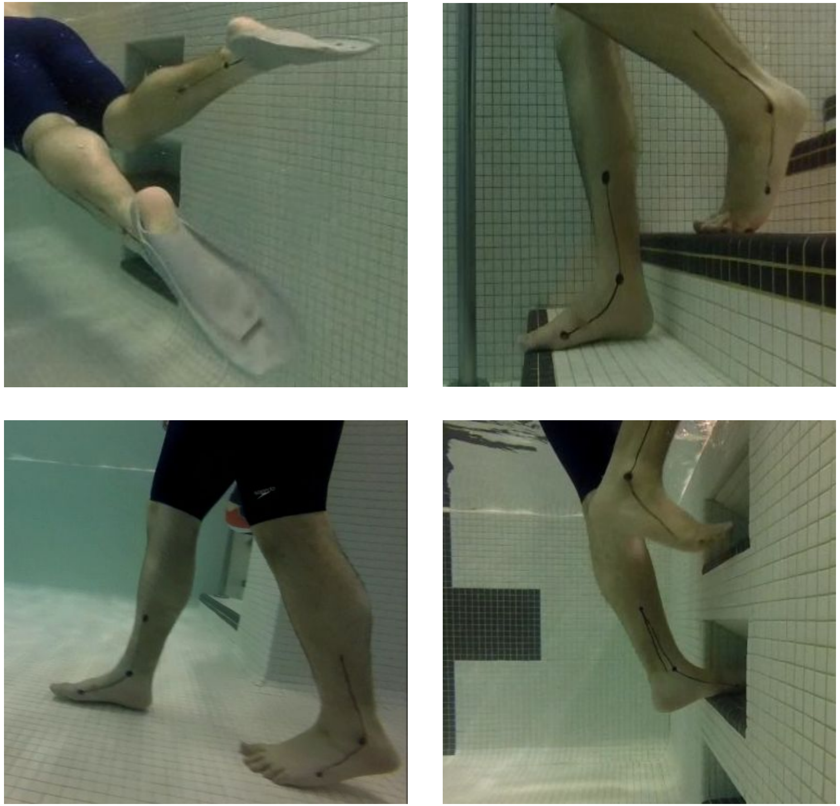
Standard AFO

No swimming-specific articulating orthosis currently available!

Mission

"To design a specialty **foot brace** that enables adults with gait abnormality to both **access and swim** in a standard pool environment."

Explore



In-context user studies and observations

Visualized changes of angles occurring at ankle and ball of foot by drawing rods and pin joints

Dorsiflexion is necessary for climbing ladders and walking, and plantarflexion is necessary for swimming

Empathize

Functional Requirements

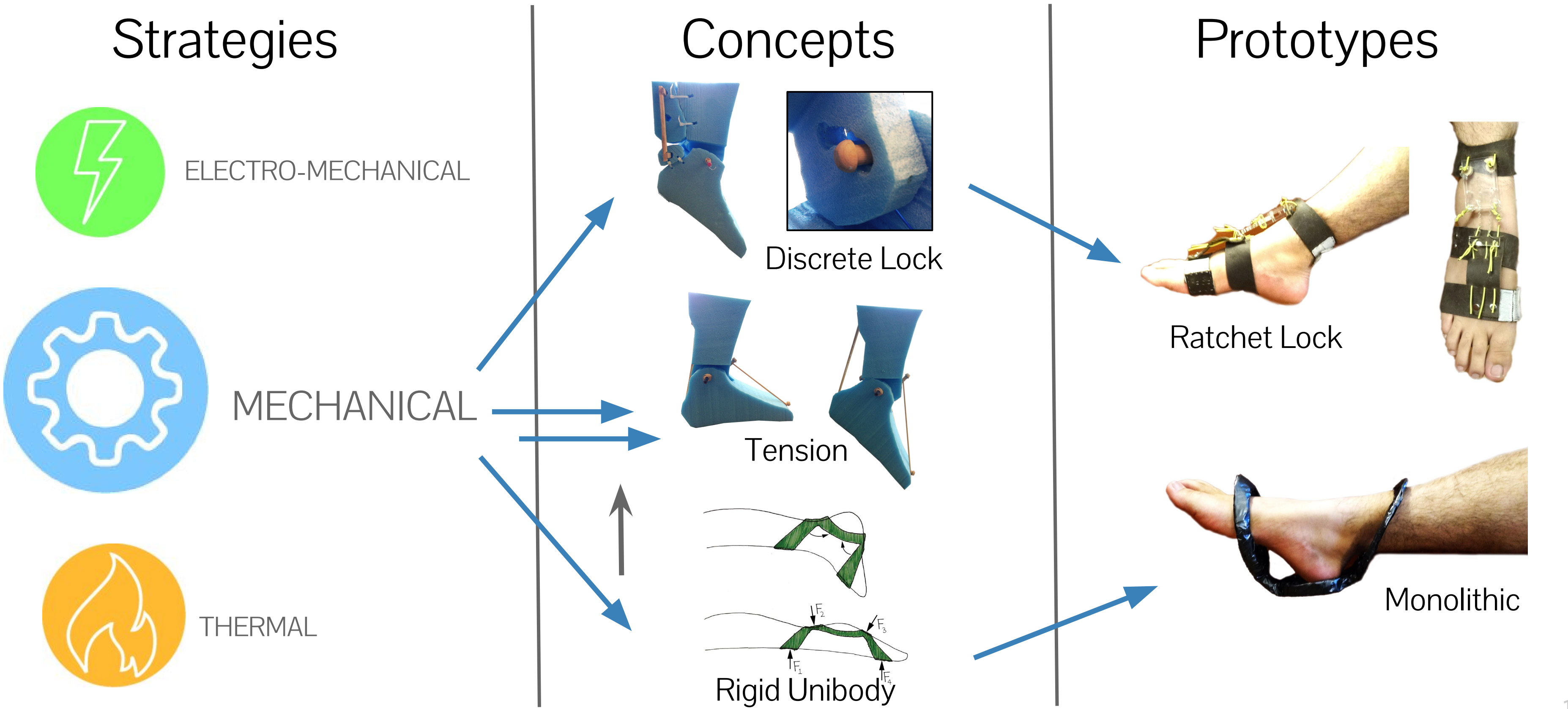
STRUCTURE

Ankle Support (turning, standing, lift, etc.)
Angle States (walk up ladder and swim)
Withstand pool environment
Does not fall off feet
Minimal Drag

USABILITY

Easy transition between angle states
Easy to take on and off
Comfortable
Durable

Design Process



Bistable Mechanism

6-Bar

4-Bar

Lateral Actuation

Anterior Actuation

Designing for Comfort

Summary of Merits

4-Bar Mechanism

Two angle states

Self-locking in each state

Easy state transitions

Lateral Actuation

Low profile

Minimal strapping

Anterior Actuation

Accessible switch

Compact mechanism

Few components

Minimal drag

User Comfort

Incredibly comfortable

Easy to take on/off

Robust ankle support

Does not fall off feet

Final Design

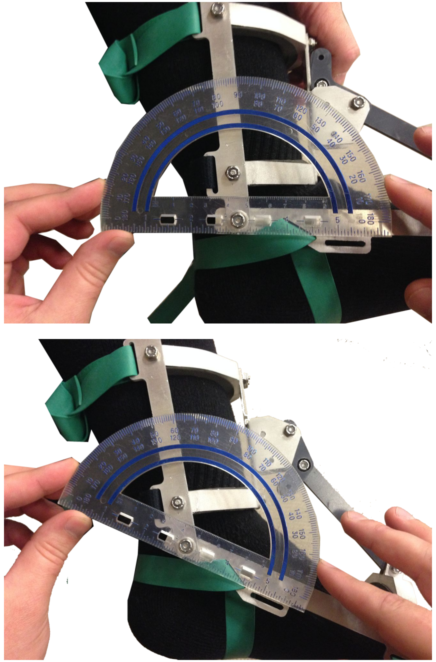
+

+

+

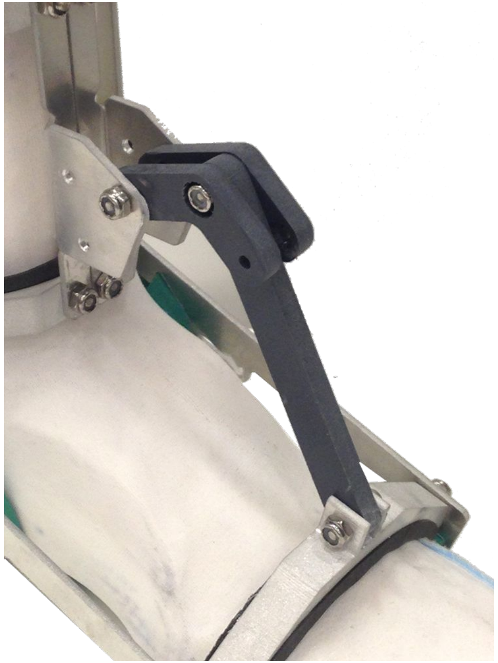
Results

95º - 125º Angle Range



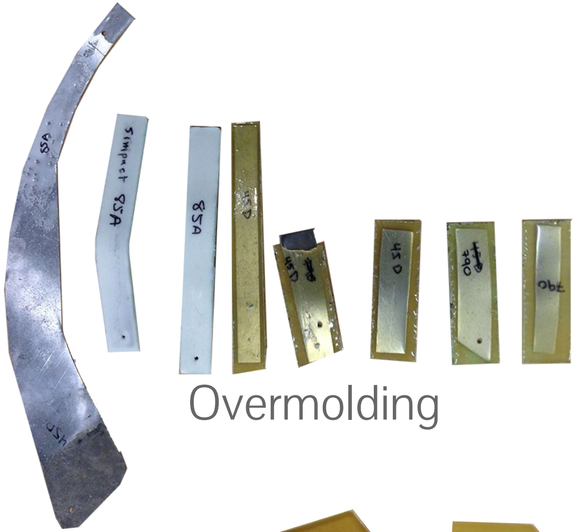
Perfect Fit

Easy Mechanism



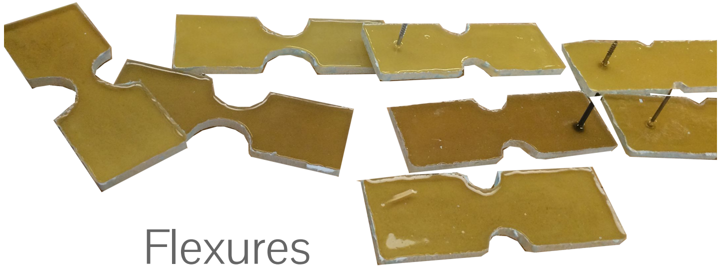
Future Work

Aesthetics



Overmolding

Strap Integration



Flexures

Special Thanks

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2.75 students & staff

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Spaulding Rehab Hospital
Robert Drillio
Aaron Norel

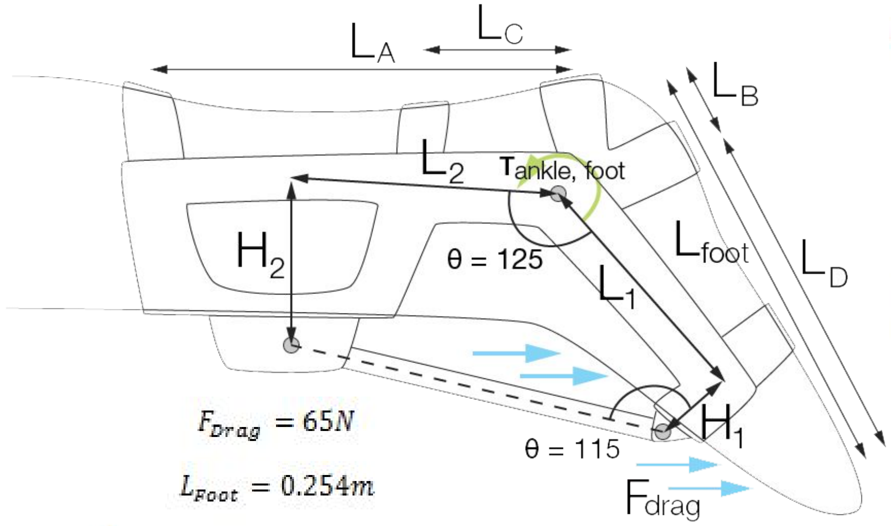
Fin

(not for swimming, but like “the end”)

Additional Slides

Concepts (more in depth descriptions)
Analysis (physics of swimming below)

FBDs



$$F_{Drag} = 65N$$

$$L_{Foot} = 0.254m$$

$$T_{A,F} = \frac{1}{2} F_{Drag} L_{Foot} \cos(10°) = 6.76N * m$$

$$T_{A,F} = T_{Foot,Brace} + T_{Shin,Brace}$$

$$T_{F,B} = F_{Drag} \sqrt{(L_1^2 + H_1^2)} \cos(10°) = 8.32N * m$$

$$T_{S,B} = F_{Drag} H_2 = 7.15N * m$$

Worst Case scenario (only closest straps to ankle):

$$F_{Strap,C} = \frac{T_{S,B}}{L_C} = 255.4N = F_{max}$$

$$F_{Strap,D} = \frac{T_{F,B}}{L_D} = 133.12N$$

Best Case scenario (only furthest straps to ankle):

$$F_{Strap,A} = \frac{T_{S,B}}{L_A} = 55N$$

$$F_{Strap,B} = \frac{T_{F,B}}{L_B} = 52N$$

$$A_{Strap} = 4.71 * 10^{-6}\ m^2$$

$$Max\ Tension = \frac{\frac{F_{max}}{2}}{A_{Strap}} = \frac{27.1MN}{m^2}$$

Tension → Shear is 1:0.6 ratio, therefore

$$Shear_{max} = 16.3 \frac{MN}{m^2}$$

$$Shear\ Strength\ of\ Skin = 3GN/m^2$$

Safety Analysis

SKIN SHEAR

Tensile Strength of Skin: 5 - 30 N/mm^2 [Evaluation of Biomechanical Properties of Human Skin (Edwards, Marks)]

Tensile Strength → Shear Strength conversion: 1:0.6x
Therefore, shear strength range is [3, 18] N/mm^2

Converting to N/m^2:
[3, 18] GN/m^2

Max Shear from brace: 16.3MN/m^2

CONCEPT 1

Variable Tension

MERITS

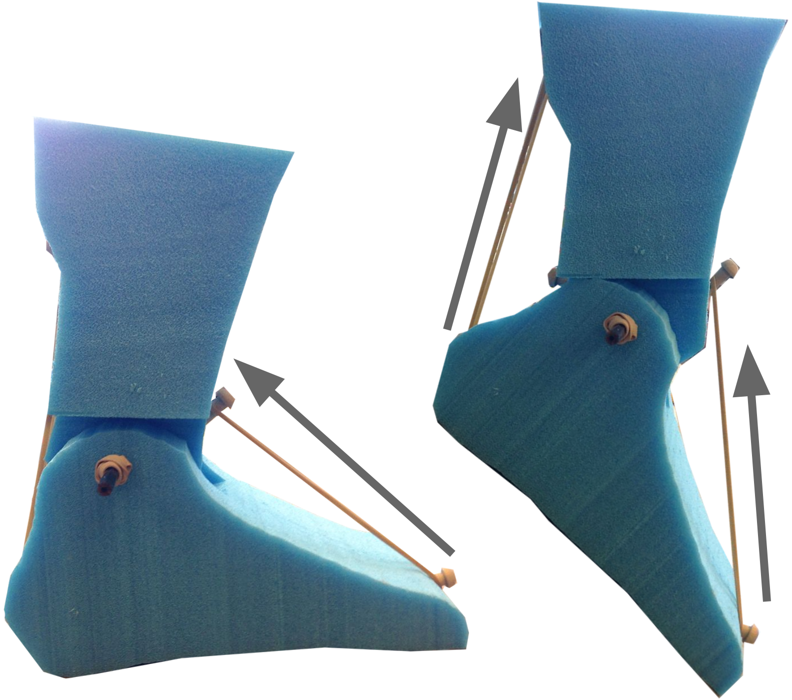
Compliance allows foot flexion while swimming

Potential for continuously variable angles

CHALLENGES

Elastic material failure or weakening

Reduced ankle stiffness/stability



CONCEPT

Rigid Unibody

MERITS

Complete stability of the ankle

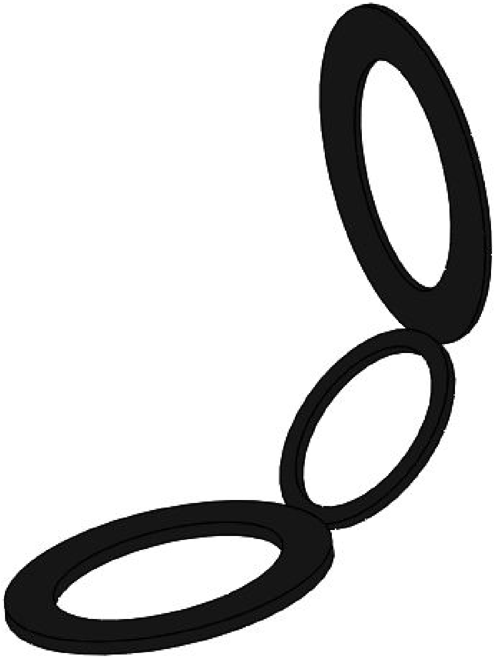
Simplicity means fewer failure modes

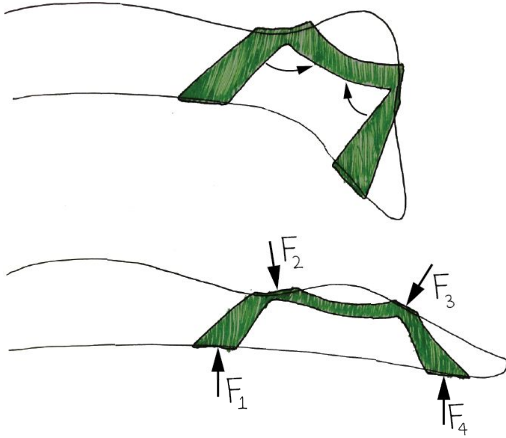
CHALLENGES

No (current) adjustable angle of ankle

Prevent slipping off of foot

Should we transition from walking to swimming given new feedback

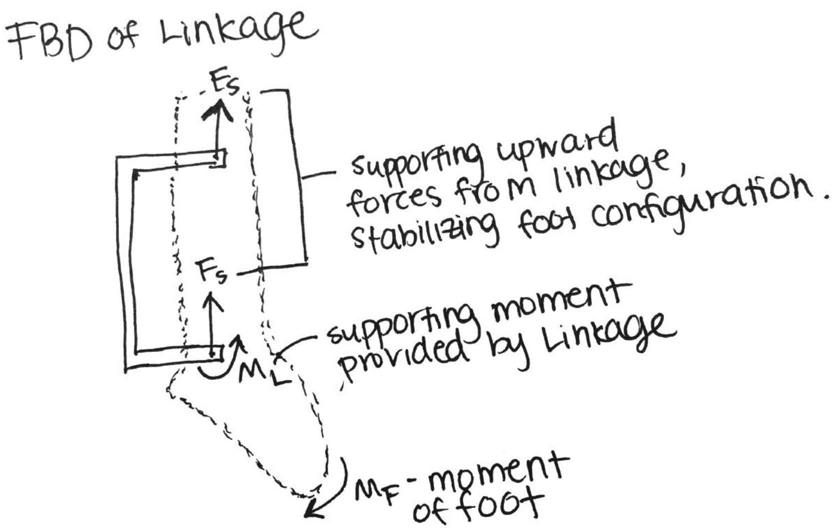




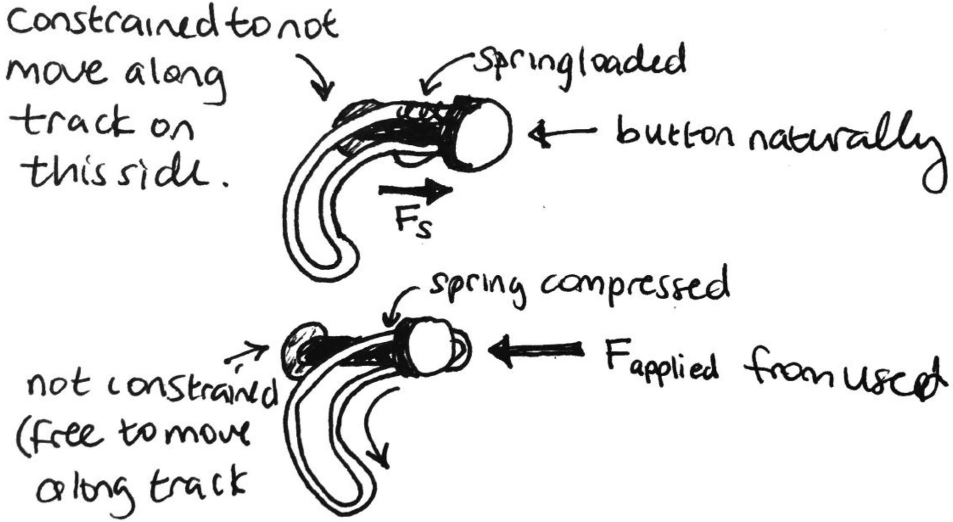
CONCEPT 2

Discrete Locking

Allows ankle to be statically locked into to a number of predetermined angle configurations.



Rigid handle is removed and inserted into preset pin holes.



Pins slide along a curved track at the ankle, and lock into preset stops.

CONCEPT 2

Discrete Locking

MERITS

Simple mechanism

Potential for multiple angles

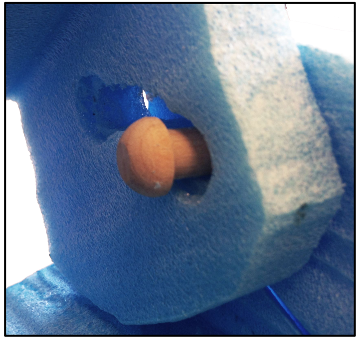
One-handed operation

CHALLENGES

Usability - alignment of pins underwater

Pin/rod durability

More separate parts can break or get lost



Ratchet

MERITS

Hands free transition

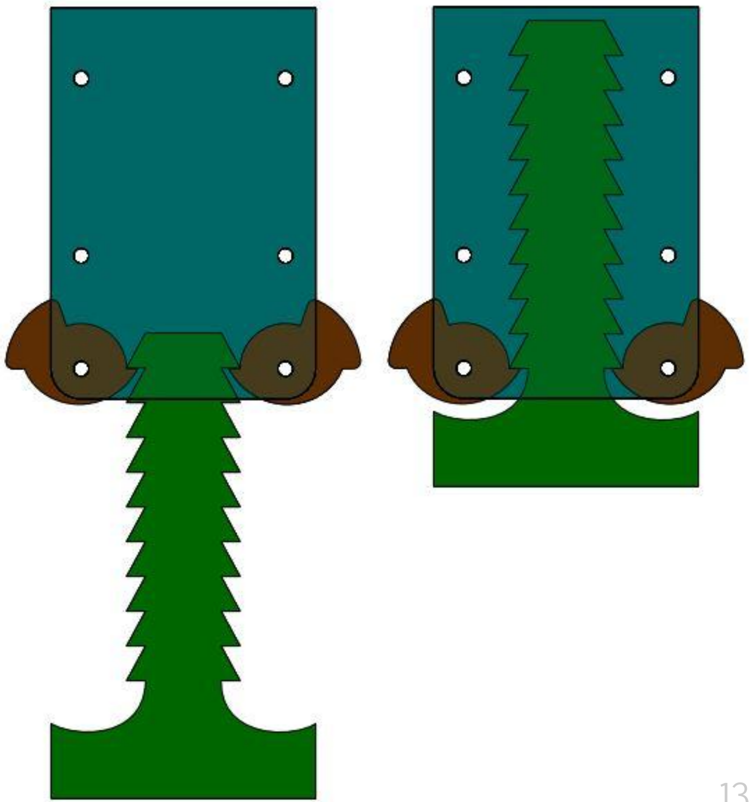
Multiple angle adjustments

Prior art of ratchet

CHALLENGES

Requires exploration/redesign of pinching mechanism

Potential for point loads



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