INCONSPICUOUS ANKLE FOOT ORTHOSIS (AFO) DEVICE FOR TEEN

Team Members: Alex Conover, Avery Lyons, Claire Matthai, Sean Carey, Aditi Singhdeo, Celia Oslakovic
Client: Debbie Eggleston, **Advisor:** Dr. Justin Williams
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College of Engineering
University of Wisconsin–Madison

Problem Statement

Ankle-foot orthoses (AFOs) help support dorsiflexion during walking. For adolescents with **Facioscapulohumeral Dystrophy (FSHD)**, weakened ankle control can increase fall risk. Our project aims to design a brace that improves safety by assisting dorsiflexion, while staying lightweight, discrete, and flexible to allow natural movement.

The primary goals of the device are to **enable dorsiflexion to combat foot-drop**, to minimize mediolateral movement to stabilize the foot, and to ensure the device is **sleek and inconspicuous**.

Condition & Impact

Client: Debbie Eggleston, a physical therapist and activist for FSHD.

Patient: A high school student with FSHD.

FSHD:
- Progressive muscle weakness.
- Many patients develop foot drop due to weakened dorsiflexion

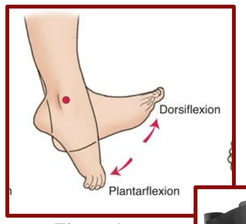

Figure 1: Dorsiflexion Diagram [4]

Global Impact: Could be made custom to other patients. Increases research on FSHD.

Existing AFOs:
- Passive-Dynamic AFO
  - Flexible energy-absorbing design
  - Extremely visible and bulky
- Supramalleolar Orthosis (SMO)
  - Made from thin plastic
  - Can be worn in shoes
  - Does not support dorsiflexion
- Jointed AFO
  - Hinge joint supports full range of motion
  - Extremely bulky

Figure 2: Supramalleolar Orthosis [2]

Figure 3: Passive-Dynamic AFO [1]

Figure 4: Jointed AFO [3]

Design Specifications

- Eliminate excess plantarflexion by assisting in dorsiflexion
  - Deliver approximately 5–10 Nm of counteracting torque for every 10° of plantarflexion [5]
- Must provide an observable heel-strike stage of gait.
- Minimize pressure points, prevent skin irritation, and distribute forces evenly across the foot and ankle.
- Needs to be easy to assemble to ensure they can use it independently without relying on others.

References

1. J. Feng, J. Weiss, A. Thompson, and J. E. Meeker, "Passive Dynamic Ankle Foot Orthoses Use in Civilian Patients with Arthritic Conditions of the Foot and Ankle," Foot Ankle Orthop, vol. 8, no. 1, p. 24730114231157734, Mar. 2023, doi: 10.1177/24730114231157734.
2. F. M. Medical, "What is an SMO Brace?," Forward Motion. Accessed: Oct. 02, 2025. [Online]. Available: https://www.fdmotion.com/blog/what-is-an-smo-brace
3. "Jointed AFOs," Orthotics Plus Melbourne. Accessed: Oct. 02, 2025. [Online]. Available: https://orthoticsplus.com.au/orthotics/ankle-foot-orthoses-afo/jointed/
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5. M. Alam, I. A. Choudhury, and A. B. Mamat, "Mechanism and Design Analysis of Articulated Ankle Foot Orthoses for Drop-Foot," Sci. World J., vol. 2014, no. 1, p. 867869, 2014, doi: 10.1155/2014/867869

Previous Work

Figure 5: Fall 2024 Final Design

Iteration 1 (Fall 2024)
- Focused on dorsiflexion support
- Nylon straps and PLA supports were utilized
- Patient testing did not occur
- Minimal success seen with bungee supports

Figure 6: Spring 2025 Final Design

Iteration 2 (Spring 2025)
- Focused on inversion prevention
- PLA with 50% carbon fiber infill used
- Prototype sent to client, not tested in person
- Effective in inversion, but one support broke near the malleolus

Final Design

Figure 7: OnShape model of AFO on 3D modeled foot

Fabrication Process:
- 3D-printed medial and lateral sides of brace with slits for straps
- 2 layers of mesh padding were sewn together and super-glued to sides of brace
- Ballistic nylon strap was sewn into lateral side, threaded through medial side, then reconnected to the lateral side via velcro
- Elastic polyester dorsiflexion strap was cut and sewn to the slits on the top of the brace

Design Features:
- Prevents ankle **inversion** and **eversion**
- Supports **dorsiflexion** while walking using static front polyester strap
- Double padded for maximum **comfort**
- Ballistic nylon straps for attachment and **adjustability**

Figure 8: View of final prototype from the front

Figure 9: View of final prototype from lateral side

Client Testing and Results

Force Plate & Balance Testing Summary

Gait Results
- Without a brace, the patient showed a large imbalance between heel-strike and toe-off forces.
- Both braces reduced this difference, bringing the patient closer to a typical gait pattern.
  - **Red brace:** ~80 N improvement
  - **Black brace:** ~50 N improvement (best performance)
- After normalizing for weight:
  - The brace condition showed **reduced loading** (9.546 N/kg vs. 10.719 N/kg without brace)
  - Impact loading became **more controlled and consistent**
- Effect size analysis indicated **moderate–large positive improvements**, despite small sample size. Cohen's d value of .837 indicates effectiveness, despite a higher p value of .263 between the control data and the best data.

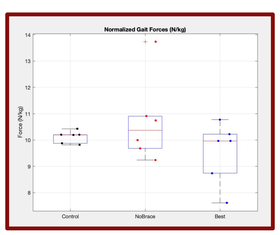

Figure 10: Normalized Gait Analysis of the Patient

Balance Results
- Stabilograms confirmed **greater sway** on the affected right side.
- With the black brace, sway **decreased**, indicating improved postural stability.
- Cohen's d values suggested **meaningful practical improvements**, especially in right-leg performance.

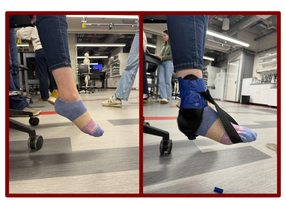

Figure 11: Degree of Dorsiflexion Assistance

Dorsiflexion Assistance
- Without any assistance, the ankle sits at 145 degrees. With assistance of the elastic polyester strap, the degree of foot drop decreases to 106 degrees, providing adequate support for the foot.

Materials Testing

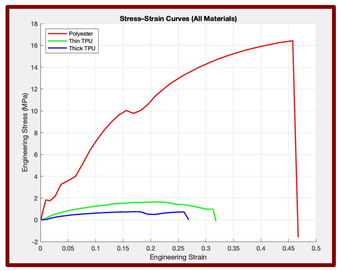

Figure 12: Stress vs. Strain curve

MTS Analysis
- Performed MTS tensile testing on polyester and TPU straps
- Neither strap failed under test load
- TPU slipped out of the MTS grips before failure
- Polyester strap showed greater stiffness compared to TPU

Elastic Modulus
- Polyester: 64.8 MPa
- Thin TPU: 20.7 MPa
- Thick TPU: 9.09 MPa

Costs

Item	Description	Manufacturer	Vendor	Date	QTY	Cost Each	Total
CF-PLA	3D printing for testing	Design Innovation Lab	Makerspace	10/27/2025	2	$2.25	$4.50
CF-PLA	3D printed for testing of mediolateral support	Design Innovation Lab	Makerspace	10/27/2025	2	$2.25	$4.50
CF-PLA	3D printing for final product	Design Innovation Lab	Makerspace	11/17/2025	1	$1.90	$1.90
CF-PLA	3D printing for final product	Design Innovation Lab	Makerspace	11/17/2025	1	$2.18	$2.18
CF-PLA	3D printing to send to client	Design Innovation Lab	Makerspace	11/19/2025	1	$2.17	$2.17
CF-PLA	3D printing to send to client	Design Innovation Lab	Makerspace	11/19/2025	1	$2.50	$2.50
Elastic Strap	1 inch wide Polyester and Rubber blend. 10 yd in length	Cisone	Amazon	10/10/2025	1	$7.99	$7.99
TPU	TPU Test Strip for testing apparatus	Makerspace	Makerspace	10/22/2025	1	$0.39	$0.39
Padding	Air Sponge Mesh Fabric	Tong Gu	Amazon	10/24/2025	1	$16.99	$16.99
Superglue	Superglue for fabrication	Makerspace	Makerspace	11/4/2025	1	$1.15	$1.15
Superglue	Superglue for fabrication	Makerspace	Makerspace	11/5/2025	1	$1.15	$1.15
Nylon Fabric	Fabric used for straps and padding	Xtreme Sight Line	Amazon	11/20/2025	1	$0.00	$0.00
Velcro	Velcro pieces	Myuren	Amazon	11/20/2024	1	$0.00	$0.00
						TOTAL:	$0.00

Table 1: Costs of all spending throughout the semester

- This project was funded through BME Design.
- Total spending was $45.42, with $37.43 covered through the Grainger Design Lab.

Discussion

- **Limitations**
  - Only one weekend to perform testing with the patient
    - Could not test comfort with the altered design
  - Limited materials available
    - Only 3D printing can be done to match the organic shape of the brace
    - Changes made to the design but still concerns about strength
- **Did it work?**
  - Testing showed noticeable improvement in dorsiflexion
  - Foot drop during gait also decreased
  - Testing showed increased stability while standing
  - The design is noticeably more sleek and concealable than it was previously

Future Work

- Extend mediolateral supports to the floor to reduce downward slippage.
- Test TPU strip integration to improve dorsiflexion support.
- Evaluate performance of multiple strap lengths to optimize effectiveness.
- Potentially connect with the University of Michigan to collaborate with them and keep the prototype up to date, fix any damages to the brace, and overall, make it easier to collect testing data, as the patient and client are in Michigan, 15 minutes from Ann Arbor.

Acknowledgements

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