Design of a Pediatric Orthopedic Free-Foot Splint

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Summary

This study presents the design and prototyping of a 3D-printed unilateral clubfoot splint aimed at improving adherence and comfort. Clubfoot is commonly treated with the Ponseti method. Traditional bracing immobilizes both feet using a bar, which can be restrictive and impact compliance. This study proposes an alternative unilateral design using lightweight, 3D-printed materials for durability and prolonged use. The splint was designed in SolidWorks and evaluated with ANSYS finite element analysis (FEA) to ensure structural stability.

Introduction

Clubfoot is an orthopedic condition that affects approximately 1 in 1000 births worldwide [1], characterized by foot abduction, pronounced plantar arch and equinus position. Treatments often rely on the Ponseti method, which comprises a casting process, wherein a manual correction is performed, followed by a splint phase using a splint that connects both feet with a bar.

We focus our research on the splints phase by designing and manufacturing an innovative abduction splint characterized for keeping an abducted position, without relying on the correction bar. These allow free feet movement while ensuring alignment. This unilateral splint was designed using 3D-printed technologies prioritizing durability, lightweight construction, and affordability to contribute to treatment adherence.

Methods

The design was performed based on 4 principal components as shown in Figure 1: 1. Knee flexion to 75°; 2. tibial-length extension mechanism; 3. Abduction component; and 4. Adjustable foot platform.

The biomechanical foundation of the device is predicated upon a tibiofemoral flexion component, which positions the lower extremity at a 75° angle while providing dynamic stabilization of the patellofemoral complex to mitigate external rotational forces. This configuration establishes a mechanical axis that facilitates the generation and maintenance of frontal plane abduction at a controlled, customizable angle (ranging from 30° to 60°, contingent upon individual patient parameters). The telescoping tibial-length adjustment mechanism and the multi-planar foot positioning apparatus accommodate individualized anthropometric variables, enabling precise calibration across diverse morphological presentations.

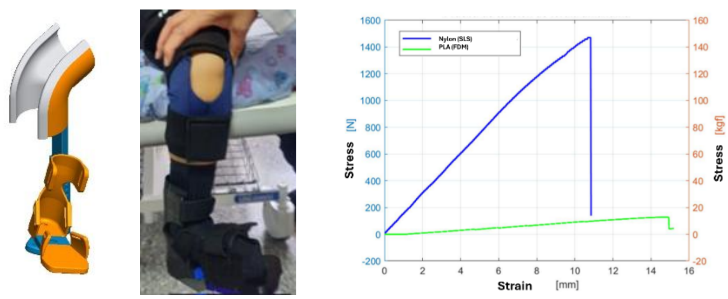
Results and Discussion

To evaluate the mechanical performance of the splint, we compared multiple materials, including PLA and Nylon under simulated plantarflexion conditions for structural stabilizer components.

Inital testing with PLA in Fused Deposition Modeling – FDM revealed a mechanical constraint due to layer separation, causing the splint to fracture at 13kgf. This failure highlighted the printing method's weak interlayer adhesion and its low ability to withstand multidirectional forces.

To overcome this issue, we explored alternative 3D printed methods, such as Selective Laser Sintering (SLS) with Nylon as a promising solution. The same protocol for mechanical testing was done using the SLS printed Nylon, and it demonstrated a significant improvement, withstanding 149 kfg – more than a tenfold increase in strength compared to its predecessor in FDM PLA.

Finally, for the adjustable knee and foot components, TPU fabricated using FDM technology is an ideal choice, as it provides both anatomical adaptability and resistance.



(a) (b) (c)

Figure 1: (a) Splint design; (b) Functional Prototype. (c) stress-strain to fracture results

Conclusions

This unilateral splint achieves abduction stability while allowing free foot movement, enhancing treatment adherence in children. Its design, utilizing SLS 3D printing with durable nylon and TPU materials, ensures a resistant, adaptable, and efficient device.

Acknowledgments

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References

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