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Manufacture, Design and Structural Analysis of a Custom Ankle Foot Orthoses on Foot Drop Patients Using 3D Scanning

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Abstract—The Custom ankle foot orthoses (AFO) is an externally applied device used to support and improve the function of lower limb during walking and modify the structural or functional characteristics of the neuro- muscular system. AFOs can be divided into three groups: passive, semi active, and active. There are two types of orthoses: custom and off-the-shelf. Custom orthoses give fit the patient's body and better of perform than off-the-shelf orthoses. The stringent design requirements such as light weight, small size, high efficiency, and these challenges are subject to produce this device. The purpose of this study is to simulate a better functional Custom ankle foot orthoses by measured force with deflection (θ) for three different types of force that applied on the Custom AFOs. Computational and experimental analyses of AFO structure by finite element method to find out the optimal force that permits on the case study of droop foot.

Index Terms—Ankle Foot Orthosis (AFO), Design of a Custom Ankle Foot Orthosis, Analysis of structure, FEM

1 INTRODUCTION

THE Ankle foot orthesis (AFO) technologies include passive devices with fixed and articulated joints, semi active devices that adjust damping at the joint, and active devices that make use of a set of technologies to produce power to move patients' foot. Passive devices do not contain any control or electronics, but can have mechanical elements such as springs or dampers to control the motion of the ankle joint through gait. Semiactive devices use computer control for damping joint movement in real time. Fully active devices have tethered source of power and a computer control for sensors and actuators for torque requirements in gait applications [1]. The proportion of foot drop patient's people is rising in India and now represents two billionpeople (10% of theglobal population), that leads to increasingly demand for orthotic device [2]. Compared to traditional technique for orthoses manufacturing, Additive manufacturing is becoming popular to reduce the long lead time, lack of flexibility, material wastage, environmental pollutionand also the cost [3]. AFOs are produced in various forms, consist of different materials, and utilized with a wide variety of aims. Prior AFOs were made from leather and steel, but nowadays most AFOs aremade from thermoplastics, such as polypropylene. It has recently become possible to construct AFOs out ofcarbon composites. The construction of a custom made AFO starts with molding a plaster cast of lower leg, which is subsequently covered with flexible sheets of polypropylene or layers of carbon fibers. Thiscover isthen hardened chemically, or cooling by air, after which it is extracted from the plastercast and finalized by the prosthetist. In the process of finalization, the prosthetist trimmed off AFO to the dimension for fitting the patient [4]. It is important to study the stress-strain analytics of the developed AFO both experimentally and computationally [5].

Drop foot it is an abnormal neuromuscular disorder characterized by a steppage gait that affects the patient's ability to raise their foot at the ankle, it is further characterized by an excessive and uncontrolled plantarflexion, an inability to point the toes towards the body (dorsiflexion) or move the foot at the ankle inwards or outwards (Fig 1). Foot drop or (drop foot) can affect either one (unilateral) or both (bilateral) the feet [6].

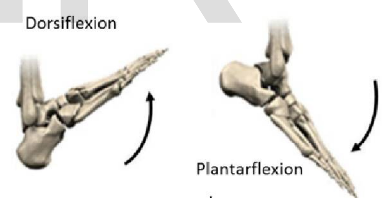

Fig 1: Ankle foot movement [8].

Patients with foot drop can not raise the front of their foot because of weakness or paralysis of the muscles in lower limb. Through walking, their toes scuff along the ground and the patient may raise their thighs to lift their foot higher than usual to avoid scuffing. This results in a form of gait abnormality, called "steppage gait", which is associated with the loss of dorsiflexion [7]. In some patients the lack of function is so severe that they are not able to walk without treatment, while others have a steppagegait. The surgery is necessary while some patients can not be treated by wearing an ankle foot orthosis— a brace that stabilizes the foot and lifts it in an upright position while the foot swings [8].

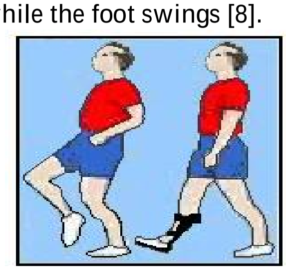

Fig 2:Drop foot with and without AFO [9].

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The main objectives of AFO is to provide patients with a comfortable orthosis that will give them the most normal gait as possible as shown in Fig 2 [9]. Fig 3 shows the steps involved in AFO manufacturing.

In the current study design philosophy for the manufacturing of AFO was proceed with the aim to digital prototype the AFO and conducting FEA analysis on it.

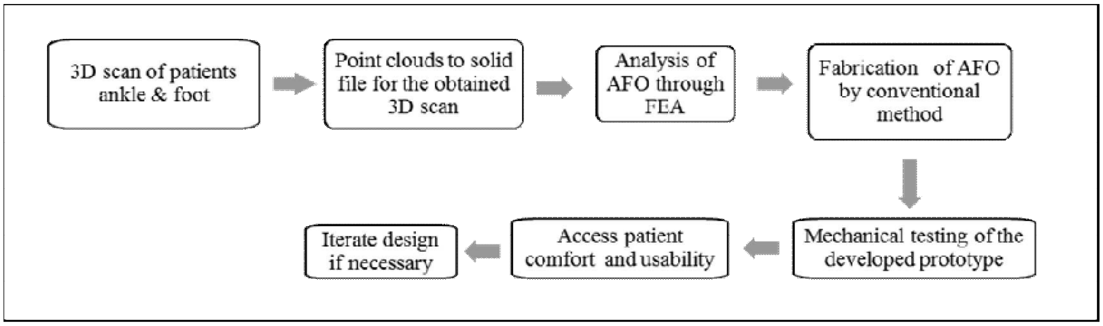

Fig3: Flow chart of ankle-foot orthoses prototype manufacturing.

2 METHODS

In this study a virtual prototype for the AFO was developed from full scale model of Human leg. Firstly, a point cloud for the human leg was obtained using 3D scanner(RangeVision Smart). The point was later imported in Autodesk Meshmixer for surfacing and developing the solid model from the point cloud (Fig 4).

Fig 4: Three dimensional scan of patient s leg.

The solid model (STL) file was then worked for the development of AFO model in Autodesk Inventor (Fig 5).After that the model was imported in Autodesk Simulation Mechanical FEA environment for the stress analysis.

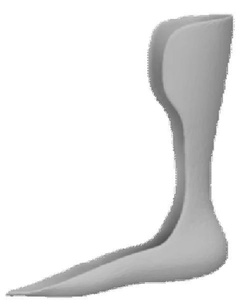

Fig 5: Custom Ankle Foot Orthoses AFO.

2.1Material

Polypropylene is extensively used material for the fabrication of AFO. In the present analysis polypropylene AFO with 4mm thickness was analyzed for the developed stresses. Table 1 shows the mechanical properties of polypropylene.

TABLE 1
MECHANICAL PROPERTIES OF POLYPROPYLENE

Properties	Value
Elastic Modulus	1.2 GPa
Passions ratio	0.4
Mass density	946 kg/m3
Tensile strength	35 MPa

2.2 Boundary conditions

During the operation AFO, it has to support axial forces from the foot. Digital prototype of the AFO was evaluated for three force conditions viz. 50N, 250N and 500N, normally distributed at the calf element of AFO.Foot plate of the AFO was given the fixed constrains (Fig 6).

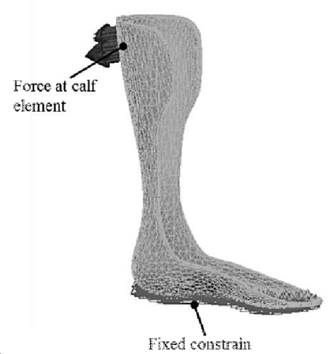

Fig 6: Boundary conditions for FEA.

3 RESULTS AND DISCUSSIONS

Fig 7 shows the FEA results for Von Mises stresses and displacements for the tested axial forces on the AFO. The maximum stress was confined at the edges of calf section. The result of analysis are summarized for peak values of stress and displacement for simulated conditions in Table 2.

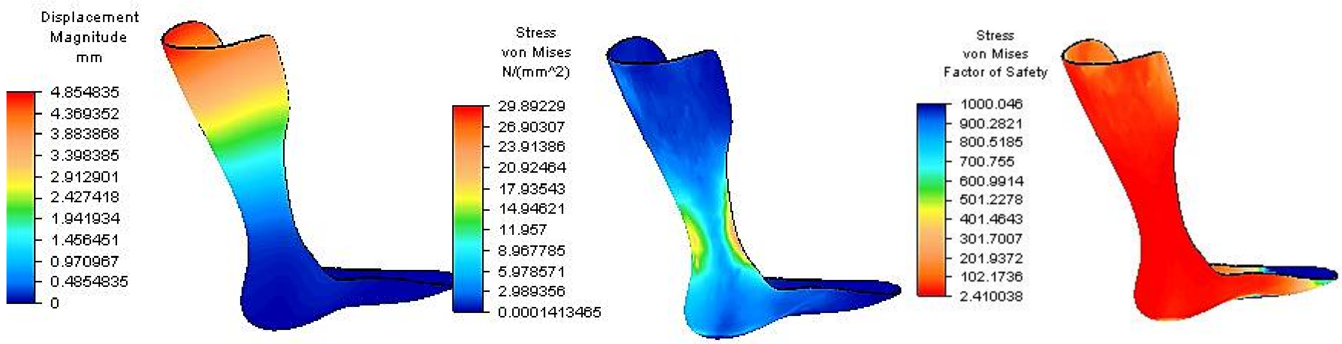

FIG 7: FEM RESULTS FOR THE AFO FOR 250 N AXIAL FORCE.

TABLE 2
FEA RESULTS FOR THE AFO SUBJECTED TO AXIAL FORCE

Force (N)	von Mises stress (MPa)	Factor of safety	Displacement (mm)	Deflection (θ) (degrees)
50	5.43	13.27	0.87	0.15
250	29.89	2.41	4.85	0.92
500	62.08	1.161	10.13	1.95

The results indicate that polypropylene design is suitable to withstand the axial load upto 250N. However for much lager loads the factor of safety is compromised and may not be suitable to be deployed in service. For higher loads it would be appropriate to use thicker sheet of polypropylene or even change in the material could be viable option. Carbon fiber being light in weight provides higher strength to weight ratio and is preferred material for AFO now a days. For the tested design, the optimization for material may be done to reduce the weight of the AFO. The material reduction could be done at the foot and calf element.

4 CONCLUSION

Polypropylene being cheap is a suitable material for the manufacturing of a custom AFO. A reasonable factor of safety for the studied AFO design was obtained for axial force of 250 N. Strength to weight ratio for the AFO can be improved by material optimization at the calf and foot elements of the AFO. However, the design needs to be revised for sustaining axial loads as high as 500N. One way of increasing the strength is to add more material by increasing thickness in regions of excessive stresses.Alternatively, use of composite materials like carbon fiber can be used for improving the strength and reduce the weight of AFO.

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