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A NOVEL VERSATILE MOVEMENT ASSISTANCE ORTHOTIC ANKLE JOINT: A Prototype

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ABSTRACT

There are more than 10 million physically handicapped people in India. A majority of them needing ankle foot orthoses to preserve the ability of anatomical ankle joint function. In the present condition orthotic ankle joint options are not sufficient to deal with such large orthoses needing population. Most of the mechanical orthotic ankle joint are single axis which control motion in the sagittal plane. The ankle is controlled in the form of free, fixed, stops and assists. There is need for a universal mechanical orthotic joint with minimal modifications for every individual with pathological conditions around ankle joint. We conduct this study to develop an universal design of a mechanical orthotic ankle joint, which will help the patient to give multifunctional adjustment facilities.

Keywords:

Mechanical orthotic ankle joint, Versatile movement, Universal design.

INTRODUCTION

Most of the mechanical orthotic ankle joint are single axis which control motion in the sagittal plane (dorsiflexion and plantar flexion). The ankle is controlled in the form of free, fixed, stops and assists.[1] Free ankle joint: It is indicated for Medio-lateral instability around the ankle (sub-talar joint). This joint allows full range of plantar flexion & dorsiflexion and prevent Medio-lateral instability. Fixed ankle joint: It gives no movement around the ankle joint. Indicated in case of fractures with weight relieving orthoses. Stops ankle joint: Ankle joint stops may be set to allow for any predetermined degree of motion. A plantar flexion (posterior) stops, which is often used in the case of a drop foot, allows full dorsiflexion, but restricts plantar flexion. A dorsiflexion (anterior) stop provides the reverse function, allowing plantar flexion and restricting dorsiflexion. Indicated for patients with strong dorsiflexors and weak plantar flexors. Restricted motion in both directions is accomplished by a limited motion stop, which is often indicated when there is involvement of a number of muscles around the ankle joint. Assists ankle joint: Ankle joint assist may be utilized as an aid for weakened muscles. Motion at the ankle may be provided by the action of a spring, elastic strap or the spring characteristics of the material of which the orthosis is fabricated. A dorsiflexion assist function with a spring which helps in dorsiflexion of the foot during swing phase and allows controlled plantar flexion at heel strike. Double action ankle assist provides assistance to both plantar flexion and dorsiflexion group of muscles.[2]

In current scenario, there is need for a universal mechanical orthotic ankle joint with minimal modifications for individual with pathological conditions around ankle joint. In this research article we have design & develop a versatile movement assistance mechanical orthotic ankle joint, which can help the patient to lock the ankle motions in a particular position of dorsiflexion or plantar flexion but allowing the opposite motion at full range & also provide assistance by manual adjustment for dorsiflexion and plantarflexion.

METHODOLOGY

This new and simple design generally needs a proper design blueprint along with an empirical thought process. A proper blueprint led to a better device with less error. This design was fabricated from the following components such as:

1. UPPER PART – Calf Part
2. LOWER PART – Foot Part
3. Two Spring
4. Two Piston
5. Locks – to adjust the spring resistance

A manually drawn design blueprint with appropriate dimensions of the parts of the ankle joint model was designed. A 2D model was drawn in AUTOCAD software as shown in Figure: 1.

In AUTOCAD Software, the 3D structure for both upper and lower components were designed separately. Selected the parts or region of the 2D drawing that was needed to ‘Extrude’ into 3D to turn a 3D object from a flat shape. The ‘Extrude’ command pulls the object in the specified direction or along a selected path. To analyze the 3D object on all the sides, 'Revolve' command was used which rotate the object around an axis. (Figure: 2)

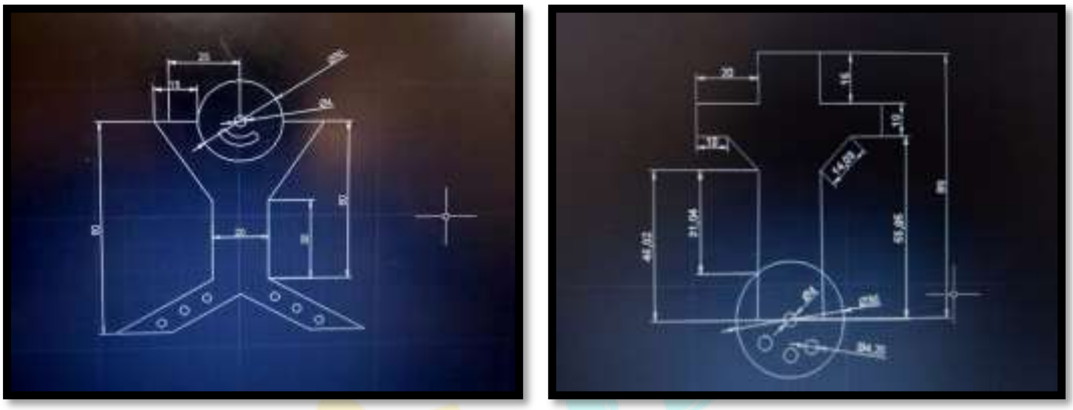

FIGURE:1 (2D Design)

Key in the precise measurements or angles to achieve the desired 3D structure and specified the heights and profile for the extrusions and revolutions. This design involved multiple parts, so used different Auto CAD'S tools such as Fillets, chamfers, and some other features to combine or assemble them in a 3D space. Assigned the materials and textures to the 3D model to make it visually realistic. Also have used the AutoCAD options such as color, transparency, etc. to create a lifelike representation of the design.

FIGURE: 2 (3D Design)

Once the design was complete, it was exported in the format such as .stl or .obj for use in 3D printing. This allows for efficient and organized design work, especially when dealing with complex projects that involve multiple components. After exporting, it was imported into GRAB CAD 3D PRINT Software for slicing operation, after which we directly gave print command and printed the part in 3D printer.

The process of 3D printing was carried out by using the Stratasys F370, a series F123 printer, which is a fascinating blend of technology and materials. Operating on the principles of FDM (Fused Deposition Modeling) technology, this printer utilizes model material-ABSCF10 and supportive material-QSR, to create 3D objects. The entire process, from design to completion, typically took around 4 hours.

The 3D printing marvel lies in its extrusion mechanism. As the desired 3D design file are uploaded onto a pen drive and the drive was inserted into the printer. It efficiently feeds the model and supportive materials into the nozzle by the help of dual extruder, where heat is applied at the tip of nozzle. This controlled extrusion and heating process helps in printing the model on to the build tray. Layer by layer, the printer constructs the desired 3D object, moving along the XYZ axis on the print bed within its chamber. This additive manufacturing process results in the creation of precise 3D model. (Figure.3)

FIGURE: 3 (3D Printing of joint in Stratasys F370 printer)

Once the printing was completed, the model was carefully removed from the build tray. This operation typically requires the use of a spatula tool to gently separate the model from the tray. Subsequently, the model was placed into a dissolving tank filled with a water-soluble solution. The purpose of this step was to dissolve and eliminate any support material that was used during the printing process. Taken out the model design from the tank then cooled it on the normal water. Assembled the upper and lower parts with the help of screws and nuts (Figure.4).

FIGURE: 4 (Assembled the prototype model)

The development of this ankle joint mechanism presents a solution for individuals with varying degrees of dorsiflexion and plantar flexion weaknesses. This mechanism comprises of an upper part with strategically positioned holes and cylinder shapes, and a lower part with corresponding slots for fixation. The key component is a specialized spring designed to assist and regulate ankle movement.

MECHANISM OF VERSATILE ANKLE JOINT

The function of ankle joint maintained on the slots:

1. Dorsiflexion stops – up to 40 degrees
2. Plantar flexion stops - up to 50 degrees
3. Limited motion- neutral
4. Fixed ankle

In cases of dorsiflexion weakness, the mechanism is configured to provide enhanced plantar flexion assistance. This is achieved by positioning the screw on the plantar flexion side, allowing for a plantar flexion stop. Conversely, for patients with plantar flexion weakness, the mechanism is adjusted to facilitate dorsiflexion by placing the screw on the dorsiflexion side, enabling a dorsiflexion stop.

For individuals who require only limited ankle motion, the mechanism is set to a neutral position. In this mode, the system offers controlled, restricted movement, catering to the unique needs of each patient.

The core element of this mechanism is the 2mm-thick spring, which is inserted inside the cylindrical structures on both sides of the upper part. During dorsiflexion, the apex part of the piston compresses the spring superiorly, while during plantar flexion, the spring elongates inferiorly. This dynamic interaction between the piston and the spring allows for customized assist, stop, or limited motion, depending on the patient's specific condition and requirements.

By offering adaptable support for dorsiflexion and plantar flexion, as well as the option for limited motion, this innovative ankle joint mechanism represents a significant advancement in addressing the unique need of patient with ankle weakness.

FIGURE: 5 (Final Prototype Model)

ALIGNMENT OF PROTOTYPE MODEL ON AFO:

The process of fabrication of an Ankle-Foot Orthosis (AFO) for a patient involved measurements to ensure a precise fit, and a cast was taken according to the patient's anatomy. Once the casting was complete, necessary modifications were made to optimize comfort and functionality (Figure.6). These modifications often include flattening both malleoli, which are the bony protrusions on either side of the ankle.

The next step involved placing the lower part of the designed ankle joint was aligned at the lateral side of the AFO mould in the ankle region and fixed it temporarily with nails. 5mm polypropylene sheet draping was done for the foot portion over the designed ankle joint. This ensured that the AFO offers proper support and alignment for the patient's foot and ankle. The moulded foot shell was removed from the mould and trimmed according to the trimline. This was followed by the moulding of the calf shell by aligning the upper part of the ankle joint on the mould and then draping it with 5mm polypropylene sheet to providing comprehensive coverage on the foot shell. Trimline was cut and smoothing was done to create a finished, comfortable product that won't cause any discomfort.

Finally, the ankle joint was attached to the calf shell and the foot shell, allowing for natural movement and adaptability. This process ensured that the custom AFO provides optimal support and mobility for the patient, promoting their overall comfort and well-being. (Figure. 7)

FIGURE: 6 (Modification Procedure of AFO)

FIGURE: 7 (Alignment of Orthotic ankle joint in upper part and lower part)

FIGURE: 8 (Allen key alignment to maintain joint position)

RESULT

The intention of the study was to design an ankle joint which will work for any of the patients with ankle joint instability. It can control both plantar flexion & dorsiflexion by altering the resistances of the respective spring. Also, it prevents excessive plantar flexion and dorsiflexion by the stops designed on the ankle joint.

While many studies focus on the prescription of different orthotic ankle joint in different condition often by means of free, fix, stop and assist type of joint, the current study focuses on a universal joint configuring with different mechanism. More over the design takes multiple ankle motion control into consideration. Articulated AFO uses experience difficulties in multiple ankle motion control in a single mechanical ankle joint. This study aims are to validate a new prototype on multiple ankle motion control in a single universal ankle joint.

In this prototype design it is expected that by use of this newly design universal orthotic ankle joint will improve ankle joint control the prototype will improve orthotic walking also it is expected that the prototype will reduce the repeated orthosis changes due to individual mechanical ankle joint. We have checked the working function of the joint and its consequence when locked in neutral position. It was found that the joint was capable to provide resistance during motion & allow efficient movement in opposite direction in respective locking position and works as fixed ankle when locked in neutral position. Finally, this study will provide valuable new insight into orthotic ankle selection and ankle joint control during orthotic walking.

DISCUSSION

S. Yamamoto et.al. (1999) conducted a study about DACS AFO, that orthosis consisted of two plastic parts, the foot and shank connected at the ankle joint. An assist device that generates the dorsiflexion assist moment is set at the rear of the shank. Dorsiflexion correction is achieved via the compression force of a spring within the assist device. When the ankle joint rotates into plantar flexion, a piston compresses the spring and the assist device generates the assist moment proportion to the plantar flexion angle. The dorsiflexion assist moment can be changed easily by using 4 springs with different spring coefficients.[3]

In relation to the above literature, this design does not have a single assist device which is only based on the length changes within it for dorsiflexion & plantar flexion control. Instead, our design is an ankle joint designed with two springs with same spring coefficient placed anteriorly for dorsiflexion control and posteriorly for plantar flexion control which are also adjustable and assist the patient in the respective motions.

T. Kobayashi et.al. (2017) conducted a pilot study an articulated ankle foot orthosis with adjustable planter flexion and dorsi flexion resistance and alignment in subjects with stroke hemiparetic gait. On mechanical properties and effects on stroke hemiparetic by application of an articulated AFO, used the Becker triple action ankle joint on an AFO and tested. The orthotic joint permitted the independent adjustment and moulding of AFO Plantar flexion resistance, dorsiflexion resistance and null torque alignment. Plantar flexion resistance adjusted by screw and dorsiflexion resistance has two types for low torque and high torque adjustment. The null torque angle is for the neutral angle.[4]

This design also consists most of the points placed on the Becker joint. These are the dorsiflexion and plantar flexion resistance in anterior and posterior respectively and also adjustment of the resistance by spring by the set screw above the spring. Also, our joint consists of a neutral position which can set the AFO in neutral alignment and also resist excessive plantar flexion and dorsiflexion.

CONCLUSION

The mechanical ankle joint is commonly used as a complement to the ankle joint motion in orthosis. There are numbers of mechanical ankle joint available in orthotic field and are used for various purpose, not only for the unidirectional movements but for almost mimic of mechanical ankle joint. The newly designed multifunctional orthotic ankle joint prototype meets certain biomechanical objectives, such as dorsiflexion assist, plantarflexion assist, dorsiflexion stops, plantarflexion stop, limited motion and free ankle motion. Further to get an appropriate and conclusive statement it needs an extensive study with the movement assistance Orthotic Ankle joint. A novel prototype multifunctional orthotic ankle joint was designed to more accurately reflect and adjust required ankle movement. This versatile of performance of this ankle joint offers adjustment according to the user requirement.

AUTHORS' CONTRIBUTIONS:

The entire clinical course of "A Novel Versatile Movement Assistance Orthotic Ankle Joint: A Prototype" service delivery was done by Miss. B. Sabaritha towards the fulfilment of a bachelor's degree research project under the guidance of Mr. Parthasarathi Swain & Miss. Ashmita Milan. The manuscript preparation is done by Mr. Parthasarathi Swain and Miss. B. Sabaritha. All the clinical service delivery to patients and research study was carried out in the premises of NIEPMD, Chennai.

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