International Journal of Advance Research in Science and Engineering
Volume No.08, Issue No.08, August 2019
www.ijarse.com
IJARSE
ISSN: 2319-8354

# Application of Reverse Engineering for design of orthosis for lower extremities - A review

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**Abstract:**

*Orthosis for the lower extremities condition is a very convenient tool to support feet.The term for this abnormal neuromuscular disorder where a patient's ability to raise his foot and the ankle is defined by Drop foot(DF) or Foot Drop.Ankle-Foot Orthosis (AFOs) are devices deliberated to aid or to reinstate the motions of the ankle-foot complex. MRE input is the most vital step as it agrees on the techniques used for data acquirement, it's processing, and analysis as well as medical application and research.3D models are also developed accurately with the help of MRE input.In this paper review of the possibilities for reconstructing more reliable and efficient method to design and develop an AFO by reverse engineering with the help of accurate 3D models of the ankle-foot. This will study probe into the fields related to 3D scanning, 3D printing and CAD designing for the manufacturing of orthosis for lower extremities and customized AFO.*

***Keywords:CT scan,Reverse engineering, CAD/CAM, Orthosis, Rapid Prototyping, Ankle foot Orthosis, MRE***

## 1.Introduction

Orthosis a very unique term used for assistive devices that helps people with disabilities.Orthosis i.e braces, support and modify the structural and functional of human neuromuscular and musculoskeletal systems.Orthosis provide the force to the body to overcome the functional limitations and improve biomechanical needs of patient with impairment.The effectiveness of orthosis depends upon the amount of force, the site of application, and the means of controlling force.The purpose of orthosis is to:

- Keep up or correct the alignment of a body segment,
- Assist or resist joint motion during key phases of patient's gait,
- Relieve or distribute distal weight-bearing forces
- Protect from external stimuli,
- Restore mobility.
- Minimize risk of deformities.

There are many types of Lower limb Orthotics are named according to the joint and the limb involved.The nomenclature for most common orthotics is listed in Table 1

Table 1 Nomenclature of Lower limb orthotics

| **Lower-Limb Orthotics** | | | |
|---|---|---|---|
| FO | Foot orthoses | KO | Knee orthoses |
| AFO | Ankle-foot orthoses | HpO | Hip orthoses |
| KAFO | Knee-ankle-foot orthoses | HKAFO | Hip-knee-ankle-foot orthoses |
| | | KAFO | Knee-ankle-foot orthoses |

Lower leg Foot Orthoses (AFO's) are the orthoses of lower leg joint, and the foot or part of the foot. The capacity of AFO is to have power over movement, rectify any distortion and give compensation to shortcomings.Foot drop can be characterized as a critical shortcoming of lower leg and toe dorsiflexion.To study the functioning of AFO, It is requisite to first understand two standard movements that take place at the lower leg joint as "dorsiflexion" and "plantarflexion" Plantarflexion is the movement of the lower leg joint occurs when the toes point downhill. Dorsiflexion is the movement of the lower leg joint when the footgoes to upward position. This movement is necessary when the foot falls off the ground so that the patient does not draw their toes. Patients with dropfoot for the most part have a halfway or finish shortcoming of the muscles that dorsiflex the foot at the lower leg joint [3]. Clinicians perceive that quantifiable, target information about treatment results advice clinical practice and substantiate recommended mediations (American Orthotic and Prosthetic Association [4] The points of lower leg foot orthosis utilize is to help in strolling. This exploration analyzed the impacts that lower leg foot orthoses have on the vitality recuperation and the mechanical work performed by kids with cerebral paralysis amid strolling [5].Foot drop is a kind of walk deformity which may arise because of inadequacy of lower leg and toe dorsiflexion. There is critical contrast in spatiotemporal parameter of walk of patients with foot drop and normal person. Clinical stride analysis evaluate the impact of Ankle foot orthosis in the patients [12]. The mechanical aspect of lower leg foot orthoses (AFOs, for example, the solidness and unbiased point around the lower leg and metatarsal-phalangeal (MTP) joints, are occasionally measured. Unintelligibly, it is common that these qualities choose the capacity of the AFO in compulsivepace. By this method a tool to decide these AFO attributes named BRUCE was outlined in view of multidisciplinary agreement[6]. Development of digital models of freeform surface anatomy of human body parts through three-dimensional (3D) scanning allows incorporation of computer-aided design and computer-aided manufacturing (CAD/CAM) in orthotic industry,which assist fabrication of AFO with predetermined properties. Several researchers explored the feasibility of CAD/CAM in the manufacturing of AFOs based on external modeling.[7,8,9]. Darling and Sun first demonstrated a method of designing simple AFO through 3D reconstruction that involves both skeletal and exterior geometry of lower limb [10].Reverse engineering is a process of analysis of an existing system or object such that it identifies the component and their interrelationships and evaluate the working of the system in order to redesign or produce a copy without access to the design from which it was originally produced.Reverse Engineering is used for reconstruction of different 3D objects of in various geometrical formats. In this paper, diversemethods for 3D modeling of the Ankle Foot complex based on Reverse Engineering data are probed and accentuated.

## 2. Methods

Reverse Engineering data acquisition is done by Reverse Engineering hardware. The data in the case of3D modeling is the collection of geometrical data that represent a physical object.The data acquisition is done by three main technologies for ReverseEngineering acquisition: Contact,Non-Contact and Destructive. Outputs of the ReverseEngineering data acquisition process are 2D cross-sectional images and point clouds that describe the geometry of an object.For ReverseEngineering systems a large series of 2D cross-sectional images of an object are maintained by the CT and MRI techniques. ReverseEngineering techniques such as Laser Triangulation, Time-Of-Flight (TOF), and Structured Light present point cloud data.CT and laser scanner were used as RE data acquisition hardware for 3D AF modeling for the study.Various softwares MIMICS and Magic R.P. (Materialize NV) were used for triangle mesh data manipulations. CopyCAD & PowerShape (Delcam Inc.),Pro Engineer (PTC) for points and trianglemesh data manipulations as well as geometricalmodelling processes are used. AFO prototypes were fabricated by Selective Laser Sintering (SLS) was used as the Rapid Prototyping (RP) technique.There are four main steps to planpersonalized AFOs as follows:

(i) Data acquisition;

(ii) Dataregistration, processing and region growing;

(iii)Construction of3D NURB AF complex model; and

(iv)AFO’s development.

International Journal of Advance Research in Science and Engineering
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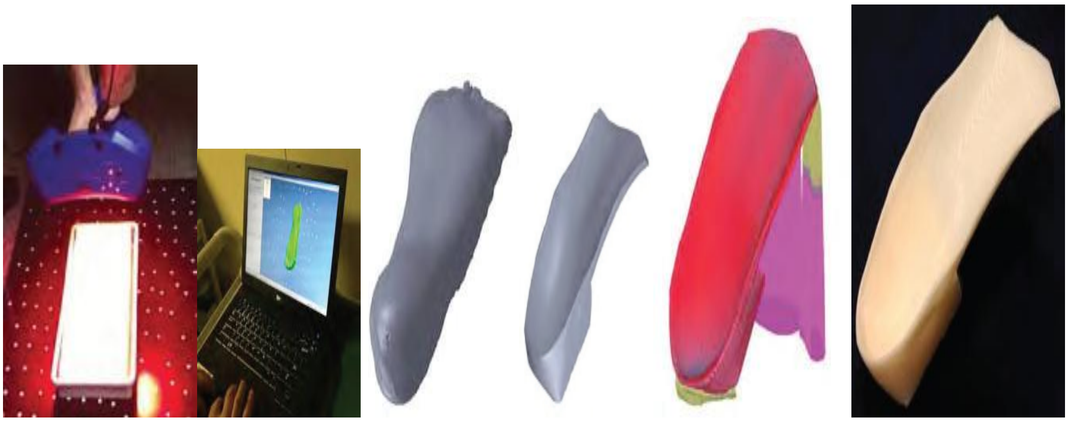
www.ijarse.com
IJARSE
ISSN: 2319-8354

### 2.1. Ankle Foot modeling from laser scanning data

The steps of fabricating the Foot Orthosis using reverse engineering.

A 3D laser scanner captures the 3D geometry by either scanning the impression of the foam box (Fig. 2(a)) or by directly scanning the patient's foot. The surface profile is processed using software; for example, the Tracer® CAD by Ohio Willow Wood. This surface profile is fitted to the 3D geometry of foot plantar surface, as shown in Fig. 2(b).Orthotists makes modifications to the geometry by using Tracer® CAD (Fig. 2(c)). The modified geometry is exported as a stereolithography (STL) file and transferred to another software MagicsTM (Materialize, Leuven, Belgium).In MagicsTM, the "offset" function generates a given thickness of a surface representation to make a solid model. A heal block is generated in SolidWorks™ (Dassault System, Waltham,MA) and exported as another STL file.

These two STL files were merged in MagicsTM and a single STL file is created to fabricate the FO (Figs. 2(d) and (e). Finally, as shown in Fig. 2(f), the FO is fabricated using the fused deposition modeling (FDM) method. It is estimated that, with the advanced FDM technique and sparse structure, the printing time can be reduced to less than 60 min. The time for AM of FO could further be feasible if material use is optimized with topology and sparse structure, and by implementing advanced FDM with higher material deposition rate.



(a) (b) (c) (d) (e) (f)

Fig. 2 Procedure of AM for FO: (a) 3D scanning of the foam box, (b) geometry modification in Tracer® CAD, (c) modified STL file of a positive foot model, (d) merged FO (insole and heel block), (e) FO setup for AM, and (f) FO made by FDM and ABS material.(Courtesy Yu-an Jin, Jeff Plott, Roland Chen, Jeffrey Wensman, Albert Shih)

### 3. Orthosis Designs

Prediction of the stiffness with a certain degree of confidence will define the customized AFO design.Polypropylene and Polyethylene AFO's have state-of-the-art wellrenowned advantages over the conventional designs, but their mechanical behavior under service conditions is not easily predicted. The orthosis has to make sure of mechanical behavior during the complete life cycle of the product while promoting the best function and quality of life to the consumer with the necessary safety. In order to prevent the failure condition we need to better recognize the effect of geometry, material and production process on the arising of fracture and product malfunction. To design a ankle foot orthosis there requires a need to understand the biomechanics in association with a pathological foot and it becomes tricky to develop the models of veins ligaments,muscles due to its complexity. Thus the model generally focus on examining the isolated elements, or specific elements and these helps to build up knowledge of foot by means of self-determining analysis. The stiffness of tissues and position of bones determines the difference between club and normal foot.The lack of data & literature in mechanical properties of ankle foot leads to the limitation and challenges on the analysis that is performed

The model geometry is very composite, a simplified geometry has been constructed on thebasis of measured parameters like:

(1) foot support length (2) width (3) leg height (4) back curvature (5) ankle lateral (6) medial (7) curvatures and medial plantar arch

| CRITERIA | |
|---|---|
| Mechanical Structure | Alignment with users joint |
| | Adaptability to different users |
| | Light weight and strong |
| | Stops to inhibit to go beyond the physiological ranges of motion |
| | Easy to wear and ergonomic |
| Actuator | Powerful( joint torques comparable to healthy individuals) |
| | Low Mechanical impedance |
| | Light weight & safety |
| | Highly Compliant and Zero Backlash |
| | Compact design and efficient |
| | Positioning accuracy and repeatability |

Table 2. Design criteria for Active OrthosisCourtesy (S. Hussain, S. Q. Xie, G. Liu, K. A. Shorter, J. Xia, E. T. Hsiao-Wecksler, W. K.Durfee, G. F. Kogler, U. Onen, F. M. Botsali, M. Kalyoncu, M. Tinkir, N.Yilmaz, Y. Sahin)

At present the AFO designs are used worldwide and are classified into three major categories i.e.passive AFOs, semi-active AFOs and Active AFOs.Active and semi-active AFOs contain onboard power source, sensors,control systems, and actuators. Among these AFOs, passive devices are the most popular daily-wear device due to its durability, and simplicity of the design. Passive devices are of two types: articulated and non-articulated.Non-articulated AFOs are usually single piece, made of lightweight thermoplastic or thermoformable materials, and encompass the dorsal part of the leg and bottom of the foot. These non-articulated AFOs include: posterior leaf spring AFO (PLS AFO), carbon fiber AFO (CAFO), rigid AFO (RAFO), anterior AFO (AAFO), and dynamic supramalleolar AFO. Passive articulated AFOs have different designs of articulated joints with a variety of hinges, flexion stops, and stiffness control elements such as spring and oil damper. These AFOs include: plastic or metal AFO with plantar flexion stop and dorsiflexion free (AFO-PS), chignon AFO and oil-damper AFO (AFO-OD) [8].

3.1. Normal Gait

The responsibilities of the lower extremities are to present a stable base of support instance, allow forward progression of the body mass over the distal limb segments, keep energy expenditure costs to a bare minimum, employ suitable mechanisms for shock absorption and dissipation of forces, and produce sufficient moments for swing. The energy cost is further minimized by the Synchronous interactions of both lower extremities as it limits excessive displacement of the center of mass. Metabolic efficiency is sustained in the normal model when momentum is replaced to muscle action (whenever possible), and displacement of the center of mass from the line of progression is reduced to least

## 4. Results andDiscussions

This study reviewed different designs of orthosis for lower extremitieswhich are currently in fashion for the correction of ankle foot and their compliance**.**

Banga H.K et al[11]. proposed the advantages of an AFO with respect to walk speed, the effect of this kind of orthoses on rhythm stays uncertain. Thusly, there is a prerequisite for further all around laid out randomized, controlled, clinical trials to amassing better techniques for the effects of AFO usage on walk parameters of foot drop patients .

Banga H.K, Belokar R.M, Dhole S, Kalra Parveen, Kumar R et. al[12] reported that Foot drop is a kind of walk deformity which may arise because of inadequacy of lower leg and toe dorsiflexion. There is critical contrast in spatiotemporal parameter of walk of patients with foot drop and normal person. Clinical stride anaylsis evaluate the impact of Ankle foot orthosis in the patients.

Brehm, M.-A., Harlaar, J. and Schwartz, M.et.al[13]. proposed that vitality cost lessening was identified with both a quicker and more effective strolling design, this exploration manages the dynamic demonstrating of human strolling.

Jamshidi, N. et.al. [14] investigated that the primary concentration of this exploration was to advance the capacity of the orthosis in patients with neuropathic feet, in light of the kinematics information from various classes of neuropathic patients.

Nowak MD, et al [15] hasreported the vibrant demonstrating of human strolling. The primary concentration of this exploration was to progress the capacity of the orthosis in patients with neuropathic feet, in light of the kinematics information from various classes of neuropathic patients.

Alexander, M. A et. al[16]. Proposed that the Lower leg foot orthoses are orthotic gadgets that strengthen the lower leg joint. In the proposed work, a planar multi body model of the human body in the sagittal plane was formed. For this motive, the MOBILE computational program was used. The model reenacts the lower appendages and is made of 9 unbending bodies. It has 12 DOFs and is set up for replicating kinematic information gained in a step lab. Kinematic estimations were taken in a stride lab through a solid subject, with and without plastic lower leg foot orthoses worn on both feet.

Jain et al. [17] proposed a novel mechanism for an ankle-foot orthosis (AFO) based on a passivefour-barlinkage for non-surgical treatment of clubfoot disorder and reported six-bar linkagemechanism to house in an ankle foot orthosis, the linkage device is passive and couples the jointmotion of the ankle so that the DF of ankle is assisted during the correction.

N. Berger et al. [18] proposed use of lower leg orthosis (LLO) as an alternative treatment device.Problems associated with disturbance in sleep, skin irritation, pressure sores are low in case ofuse with LLO in 9% of treated children as compared to 54% in case of FAO.

Robert Rizza et al. [19] proposed new method utilizing computer aided design and the finiteelement method can be used to develop a customized weight-bearing dynamic orthotic, so thatRP technologies can be used to produce a custom orthotic within a 24 h time frame.

A dynamic version of the FAO has been proposed by Ruiten, A.G.P. van et al. [20] as an alternative to the static FAO.The dynamic component will positively influence the neuromotor development of the child. It provides more balanced natural growth by repair of soft tissues using dynamic loading that restricts the motion of deformed foot in dorsiflexion, eversion and abduction.

Albert Shih et al.[21] Proposed new method for Design and manufacturing of Custom AFO at the university of Michigan Orthotics and Prosthetics center. Custom orthoses are design on the basis of four parameter i.e. The digital scanning of foot and leg geometry using a stand with transparent foot plate and ergonomics procedure for 3D optical scanning, A cloud based design software that enables clinicians to access scanned points cloud data on the geometry of patients feet , A cloud based Manufacturing software that generates tool path and process parameters for additive manufacturing to fabricate the AFO, Evaluation using Inertia Measurement unit(IMU) for measurement of AFO Motion for Gait analysis.

J. H. P. Pallari et.al.[22] proposed orthoses can be engineered to a very high degree of user specific customization through the incorporation of gait and surface pressure measurement analysis into the design process, this is not done in current clinical practice and this is due to time, cost and manufacturing constraints.

Villa-Parra A.C Et. al.[23] have developed a mechanical design of AO for the knee and ankle ,weight of the orthosis is an important aspect of the design.The weight of AKO is 4.1 kg,then FEM analysisdemonstrates that the mechanical system can beemployed to assist the (F-E) of the knee jointrequired during gait. The total weight of the AAFO is 1.01 kg The AAFO is only able to workand maintenance the ankle joint angle in 90ºduring the swing phase. The KAO and AAFO actuators are provided hightorques while operating in high speeds.

Morshed Alam et. al.[24] proposed a CAD/CAM approach in manufacturing custom articulated AFO , which includes skeletal structure of the lower limb to ensure alignment of anatomical axis and mechanical axis of the AFO. This technique reduces about 50% production time compared to traditional approach as it discards manual techniques e.g., casting, molding etc

Norazam Aliman[25]have previous designs and developments with regard to multiple joint LLEs for augmentation, muscular weakness or gait recovery and rehabilitation.

Yue Wei Ai[26] have proposed an innovative method replace traditionally dedicated moulds with reconfigurable moulds utilizing screw-pins that are directly transferred to the vacuum forming of thermoplastic material at low cost for the fabrication of orthose.

Harish Kumar Banga et. al.[27] proposed new improved design of ankle foot orthosis, problems associated with facing excessive heating and sweating problem during long term usage. After discussing with Patients and Orthotist (Which prescribed AFO to patients), it has been attempted to solve the problem with new improved design of ankle foot orthosis using finite element modelling and stress anaylsis.

Liberty Deberg[28] proposed use of distinguished superelastic behavior of these materials is utilized to develop a passive ankle foot orthosis to address the drop foot disability.

Manak Lal Jain et. al[29] have developed the virtual model of ankle foot orthosis through computer-aided design for non-surgical correction of this challenging clubfoot deformity.

Yu-an Jin et. al.[30] have demonstrated , the AM technology,use of AM technology are capable to fabricating custom FOs, AFOs and prosthetic sockets with good fit and adequate strength.

Kanwaljit S. Khas et. al.[31] was developed a simple orthosis based on the rotation of three mutually perpendicular planes. The device successfully corrected clubfoot deformities in five cases of newborn babies, so that the desired incremental correction to the clubfoot was achieved through the one week intervention with the orthosis. No form of rash, dehydration, ulcers, and so on were observed on the skin of any baby involved in the study during or following application of the orthosis.

Hung-Jen Lai et. al.[32] have developed the ankle–foot simulator with cyclic walking and cyclic stepping conditions with certain limitations. and can be an applicable apparatus for testing AFOs (AAFO). The typical failure progression of low-temperature thermoplastic AAFO was observed under cyclic stepping test with the simulation of flaccid foot,the junction of anterior tarsal bar and lateral (or medial) bar of AAFO is believed as the key location which should be reinforced or prevented the stress concentration to improve the endurance of AAFO.

JianHuiLiu et.al.[33] proposes the orthoses manufacturing method based on digital technology including Computer Aided Design (CAD), Comupter Aided Manufacture (CAM) and Reverse Engineering (RE). use of the digital manufacturing technology can significantly reduce the lead time and cost

Natalia Wierzbicka et. al. [34] proposed Light and strong orthosis of the ankle joint was manufactured using a 3D printing process (FDM), ensuring proper joint stabilization. The orthosis can be worn together with regular shoes and is perfectly fit for the patient.

Muhammad Iftekharul Rakib et. al. [35] have developed a prefabricated SCO with suitable material and design. Prefabricated SCO is 45% lighter than commercially available prefabricated device. Prefabricated SCO have adjustable features to make it competent for wide range of patients in terms of height (153–183 cm) and weight and the Finite element analysis (FEA) was used for selecting the best material and optimizing weight of different components of this device. A brief summary of currently available different designs of orthosis for lower extremities on the treatment outcomes is shown in table 3.

TABLE -3 Summary of Orthosis study and its effect on treatment outcomes.

| **Author(s)/Title** | **Type of Orthosis Used** | **Methodology** | **Outcomes** |
|---|---|---|---|
| Albert Shih et. al "Cloud based Design & Additive Manufacturing of Custom Orthoses "(2017) | -Nylon filled with short carbon fibre AFO | - Cloud Based Design<br>- Scanning(CT/MRI)<br>- Design AFO<br>- Manufacturing(3D Printing)<br>- CAD/FEA | - Evaluation using Inertia Measurement unit(IMU) for measurement of AFO Motion for Gait analysis<br>- CDAM System can enhances the clinical services of custom AFO<br>-improve the patient experience by enabling one day visit |
| J. H. P. Pallari et. al, "Design and Additive fabrication of Foot and | - Custom-Made polypropylene AFO | -Additive fabrication Technology | - shape of the orthotic device can be altered to save weight |

| | | | |
|---|---|---|---|
| Ankle"(2009) | | Scanning(CT/MRI)<br>- Design AFO<br>- Manufacturing-<br>-FEA<br>- Optimization | - AFO have more functional properties, can be fitted with external sensors<br>- user specific customisation through the incorporation of gait and surface pressure measurement analysis into the design process. |
| Villa-Parra et. al., "Mechanical Design of an Active Orthos: Knee and Ankle"(2014) | - Polypropylene plastic AFO | Design<br>Solid work<br>FEM<br>-Robodrive Servomotor<br>-Actuators | - Weight is an important parameter in design.<br>- mechanical system can beemployed to assist the (F-E) of the knee joint<br>required during gait.<br>- Development of a<br>mechanical design of AO using electric actuators for<br>users with knee flexion disability and foot drop.<br>-To assist gait disorder<br>- Physiological ranges of motion |
| ManakLal Jain et al. "A biomechanical control<br>mechanism for correction of<br>clubfoot deformity in babies"<br>(2009) | - linkage mechanism used in AFO | - Design<br>- Analysis | -A six-bar linkage mechanism used in AFO has been designed.<br>-The linkage device is passive and couples the joint motion of the ankle so that DF of the ankle is assisted during the correction |
| M. Alam et. al, "Mechanism and design analysis of articulated ankle foot orthoses for drop-foot"(2015) | -Articulated Plastic AFO | -Computer integrated Design & Manufacturing<br>-CAD Model<br>-Rapid Protyping<br>-CNC Machining | - AFO was very light in weight and strength of the components were marked<br>as good.<br>- The ankle plantar flexion/dorsiflexion trajectory in three conditions<br>reveal that both AFOs have significant influence on gait during pre-swing as both<br>AFOs restricted the plantar flexion<br>- it allows the clinicians<br>to observe external and skeletal patient specific geometry simultaneously<br>- The placement of ankle joint matches the platerflexion/dorsiflexion axis of ankle<br>and fitting dimensions were exact |
| Norazam Aliman et. al., "Design and Development of Lower Limb Exoskeletons: A Survey" (2017) | -Lower Limb Exoskelton | | -Current study includes the application of LLEs for augmentation, muscle weakness<br>or gait recovery and rehabilitation.<br>- survey includes Details of aspects |

| | | | |
|---|---|---|---|
| | | | such as the control strategy, actuator, safety and design, including compactness, noise, heavy structural weight, cost, mimicking of natural walking, and power sources. |
| Yue Wei Ai et. al, A new method of digital manufacturing of orthoses " (2014) | -AFO with Screw Pins | -Digital Scanning<br>-Reverse Engineering (RE),<br>-Computer Aided Design and Manufacture (CAD/CAM) | -An innovative method is proposed to replace traditionally dedicated moulds with reconfigurable moulds utilizing screw-pins that is directly transferred to the vacuum forming of thermoplastic material at low cost for the digital manufacturing of orthosis, and an associated support system is developed<br>- The cost and cycle of orthoses manufacturing and environmental pollution are also minimized to realize the digital manufacturing. |
| Harish Kumar Banga, et. al, "Fabrication and stress analysis of ankle foot orthosis with additive manufacturing"(2016) | Polypropylene and Polyethylene AFO | - 3D Scanning<br>- CAD<br>- CATIA Design Software<br>- 3D Printing<br>- -FEM | They Recommend the the solution of excessive sweating and heating of Ankle foot orthosis to patients having age group three five years during weather changing conditions for long usage<br>-The AFO gave extra medial lateral stability and comparable dorsi/plantar flexion. -There was no effect on the temporal properties of normal gait. |
| Liberty Deberg et. al." An SMA Passive Ankle Foot Orthosis: Design, Modeling,and Experimental Evaluation"(2014) | Passive Shape Memory Alloy (SMA) AFO | -Design<br>-Modelling<br>-Evaluation<br>-Optimization | This AFO demonstrated the ability to meet the torque-angle requirements of an ankle assistive device much better than a typical brace or a conventional passive AFO<br>- motion analysis is performed on a drop foot patient |
| Manak Lal Jain et. al." Virtual modeling of an ankle foot orthosis for correction of foot abnormality"(2011) | Virtual Model Of AFO | -Scanning<br>- CAD Software<br>-3 D Model | - This research demonstrated the development of a customized, user-friendly dynamic AFO having provision of providing ana- tomic motion for correction of clubfoot deformity in newborn babies.<br><br>Virtual Design of AFO realize the evolution of a nonsurgical corrective procedure for the challenging clubfoot abnormalities in babies. |
| Yu-an Jin et.al, | Custom Foot Orthose | - Scanning(CT/MRI) | - The Current study demonstrated |

| | | | |
|---|---|---|---|
| "Additive Manufacturing of Custom Orthoses and Prostheses – A Review"(2015) | AFO | - Design AFO<br>- Manufacturing(3D Printing)<br>- CAD/FEA<br>- Additive Manufacturing | that AM Technology are capable to fabricating custom FOs, FOs and prosthetic sockets with good fit and adequate strength |
| Kanwaljit S. Khasa et al ," Development of an orthosis for simultaneous three-dimensional correction of clubfoot deformity"(2018) | Simple Orthosis | -Cad Software<br>-3D Model<br>-CAD Design Software. | - A simple orthosis was developed based on the rotation of three mutually perpendicular planes.<br>- Patients treated with simple orthosis successfully corrected clubfoot deformities in five cases of newborn babies. |
| Hung-Jen Lai et. al., " Ankle–foot simulator development for testing ankle–foot orthoses"(2010) | Thermoplastic Ankle Foot Orthose | -3D CAD Modeling<br>- 3D CAD Design<br>- Simulator | -The anklefoot simulator has been developed for testing AFOs<br>-To investigate the failure mechanism of anterior ankle–foot orthosis (AAFO).<br>-The accuracy and repeatability of the AFS during cyclic walking, cyclic stepping and cyclic stepping with the AAFO in sagittal plane were measured. |
| S.M. Milusheva Et.al, "Personalised Ankle-Foot Orthoses design based on Reverse Engineering"(2006) | Personalized AFO | -Reverse engineering,<br>-CAD/CAM,<br>- Rapid Prototyping<br>- Fabrication (SLS ) | They have developed personalized AFO based on 3D models of the AF complex that is constructed by RE techniques.<br>-It was designed into two components that are connected by elastic elements to help lift the foot.<br>-Virtual simulation in dynamics and kinematics as well as Finite Element Analysis method were applied to optimize the design |
| Natalia Wierzbicka et. al." Prototyping of Individual Ankle Orthosis using additive manufacturing technologies" (2017) | polyurethane foam AFO | - 3D Scanning<br>- Reverse Engineering.<br>-Additive Manufacturing, | -The patient treated with the orthosis with regular shoes as comfortable and adjusted but rigid and fully stabilizing the joint.<br>- practical tests were performed to further verify comfort of use, strength and functionality of orthosis. |
| Muhammad Iftekharul Rakib et.al. "Design and biomechanical performance analysis of a user-friendly orthotic device"(2015) | Polypropylene Stance control Orthosis | -CT Scan<br>-3D Modeling<br>-Design<br>-Stance control orthosis<br>-Finite element analysis<br>-Weight optimization | -The New walking assistive device(SCO) have been developed ,all of its components are structurally stable.<br>-This new device is 45% lighter than the commercially available prefabricated SCO.<br>- The yield and fatigue tests of |

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|---|---|---|---|
| | | | composite cuffs revealed higher yield point, and greater longevity than the onventional cuffs.<br>-The compressive load test of the knee side bar demonstrated an improved structural rigidity for regular use for a 100 kg patient.<br>-The hardness and impact test results of foot part safeguarded the user comfort and sustainability.<br>-It allowed higher knee flexion (40 ± 1.3°) during swing phase and lower hip hiking compared to commercially available prefabricated SCO. |

## CONCLUSION

The paper presented the technique of constructing 3D models of the AF for AFO development in which RE techniques using direct and indirect as well as CT scanning were examined.These techniques were successfully utilized not only for AFO development,but also used for modeling 3D internal and external anatomical structures.Personalized design is an optimal solution to meet technical, clinical, and cosmetic requirements in AFO development.This allows obtaining absolute fitting to patient anatomy and optimization in the design and material selection.The time,cost and manufacturing constraints while engineeringorthosis to a very high degree of user specific customization. The lack of designer familiar with finite element analysis goes with this industry. Here the design is done on the case to case basis which actually results in long time to design which in turn increases the price per product considerably.Thus, the potential of the CAD 3D, reverse engineering and additive manufacturing technologies have a significant potential in manufacturing medical products, individualized for the particular patients and injuries, in less time and price. Based on literature review following aspects to improve the patient comfort and treatment outcomes.

- The patient himself manufactures an orthosis on a 3D printer the design process can be partly or completely automated, thus, the development of a 3D model for ankle footorthosis is obtained clinically based on the use of CT scan images.
- The computer assisted representation of ankle foot by assimilating MRI and image processing tools which focus on new insights belonging to the thorough look of talus bone based on patient-specific image data. The approach provides a good perspective of normal and clubfoot & helps in understanding the ankle joint anatomy of ankle foot.
- Thecreation ofportable active orthotic devices will likely center around the enabling' technologies such as power supplies, actuators, and transmissions that are lightweight and efficient.
- Kinetics and Kinematic analysis of Mechanism including Yield stress, weight and easy to wear regarding type of loads the orthosis will endure.
- A proper orthotic prescription requires a thorough biomechanical analysis of gait and knowledge of the available orthotic components obtainable to treat specific conditions.
- Cost effective design of AFO with advantages of decreased dependence on access to skilled clinicians , improve acceptance of parents ,decrease need for weekly treatment , decreased dependence on access to centralized clinical facilities.
- Advance Scanning tools may be used for data acquirement and digital technologies including CAD/CAM/RE which can be utilized for the rebuilding of geometry within a virtual computer platform for the design and manufacture of orthosis,Rapid prototyping and CNC machining may be functional for the manufacture of the molds for orthosis to eradicate the need for plasters. Information among data acquirement geometry rebuilding and manufacturing can be induced to trim down human intervention and advance manufacturing efficiency.

- A Mechanism that can be used to with dynamic AFO have to control the six degree of freedom in three mutually perpendicular plane.
- Further research should be carried out to introduce newer biodegradable material in prosthetic and orthotic with improved mechanical properties and load bearing
  Capability.
- To develop specific software packages to enable the full potential of AF to be utilised in orthotic and prosthetic product design and in creating completely new kinds of products, changing the industry currently restricted by old and inefficient manufacturing methods.
- By introducing electronics sensors in the design of AFO it can be used used for movement therapy of foot under telerehabilitation.
- Continuation of research in the field of kinetics & Kinematics analysis of mechanism will enable targeting of design parameters towards biomechanical variables, and may lead to advancements in clinical efficacy

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