

# Study and development of an external aid for treating congenital talipes equinovarus (CTEV)

E. Vijayaragavan<sup>1</sup>, T. V. Gopal<sup>2</sup>

<sup>1</sup>Research Scholar, Department of Mechanical Engineering, SRM University, Kattankulathur, India  
vijayaragavan.e@ktr.srmuniv.ac.in

<sup>2</sup>Professor, Department of Mechanical Engineering, SRM University, Kattankulathur, India  
gopal.t@ktr.srmuniv.ac.in

**Abstract**—Clubfoot referred as congenital talipes equinovarus (CTEV) is a congenital deformity that twists the foot, ankle, and toes. Left untreated in the early stage, it may lead to lifetime disability. With no proper treatment, the child born with clubfoot cannot walk, run or play. Clubfoot, the most common congenital physical disabilities worldwide, known to occur between 1 and 3 in every 1,000 live births worldwide with evidence of higher rates in developing nations. In a year, over 220,000 children are born with clubfoot in developing countries. In India, more than 50,000 children are born with Clubfoot every year. The most preferred type of clubfoot treatment is the use of braces or orthosis. This study deals with the design and development of an external aid for treating children with clubfoot. The virtual model of an orthosis and the clubfoot is made using computer aided design. Then the assembly is then analyzed for predicting the growth pattern in the foot.

**Keyword**-Clubfoot, Finite element analysis, orthosis

## I. INTRODUCTION

The human foot contains 26 bones, 33 joints and over 100 muscles, ligaments and tendons [1] as shown in Fig. 1. The foot is a most complex structure that provides support, flexibility, balance and stability during gait and weight bearing [2]. It behaves as an interface between the human body and the ground. The foot is an excellent load bearing structure that during walking, running, jogging, climbing stairs, jumping and other physical activities. The different foot deformities include Hammer Toe, Arch, Flat foot, drop foot, Achilles tendinitis, clubfoot and so on. The type of deformity very much affects the quality of life.

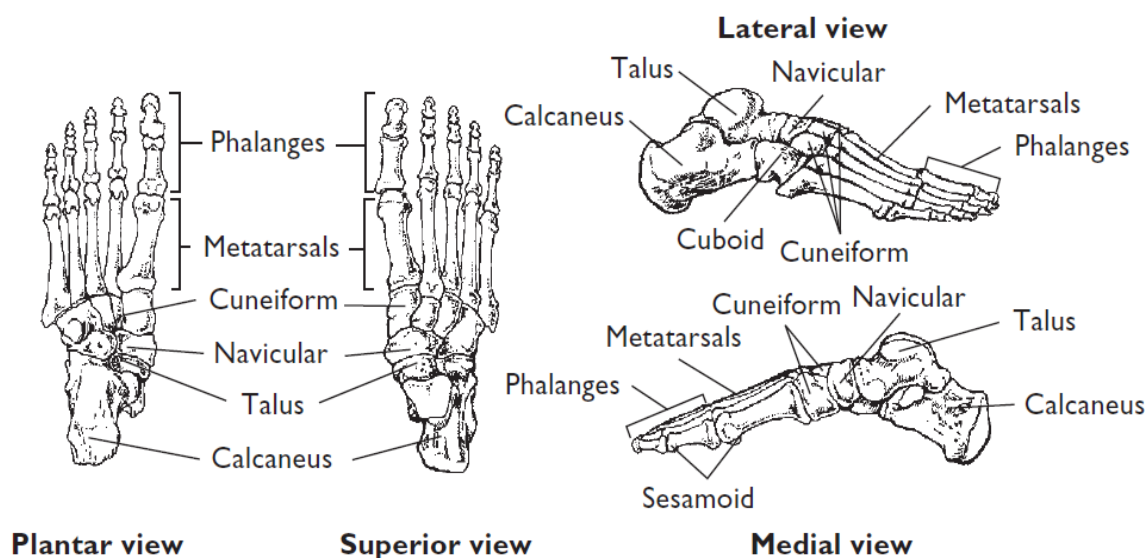


Fig. 1. Anatomy of human foot

This study deals with the congenital talipes equinovarus (CTEV), which is a kind of deformity which combines different ranges of deformity combining a wide range of deformities and disability that affects about 1 to 3 per 1000 live births [3]-[5]. CTEV is the condition where the ankle is twisted inwards with poor bone alignment, the position of the calcaneus, cuboid, and the navicular bone segments are displaced medially and rotated about the talus. The exact reasons for clubfoot remain unclear, but it may be due to genetic and environmental factors including abnormal intrauterine positioning, cerebral palsy, polio, genetic or chromosomal deformity and so on.

Males are more affected by clubfoot rather than females [6]. The risk of this deformity is very high if one of the parent or siblings is affected. The Fig. 2. depicts the child affected with clubfoot and its equivalent structure.

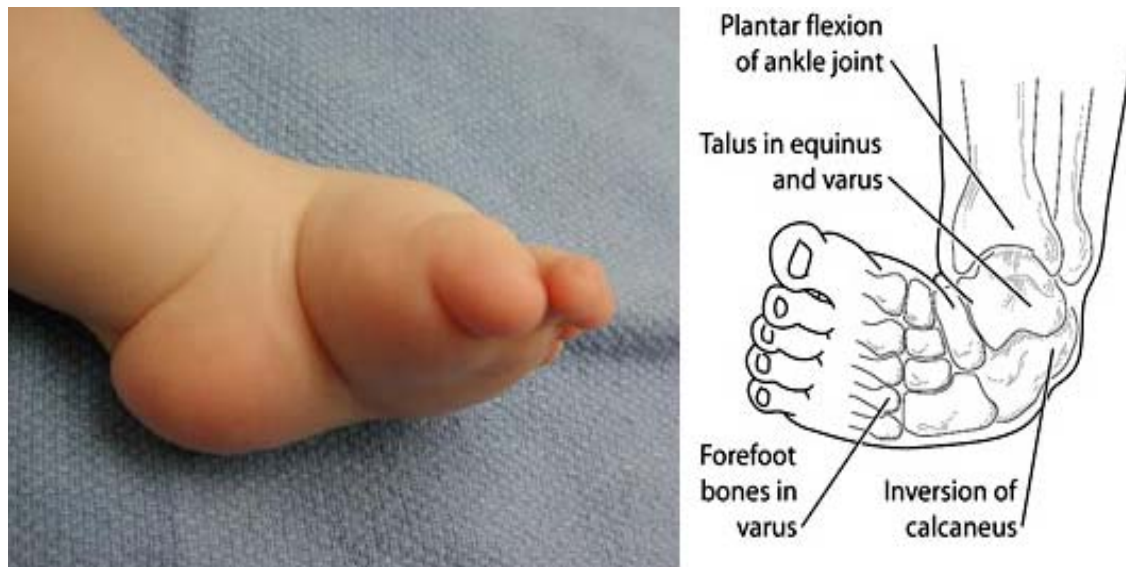


Fig. 2. Child with clubfoot

## II. CLUBFOOT TREATMENT

There are approximately 6 to 8 million adults worldwide who are physically disabled with clubfoot who could have been healed in their childhood. For the vast majority of cases, there is no known cause, although genetic and environmental causes appear to be linked. Clubfoot is considered as a permanent disability in western industrialized countries, with compulsory treatment immediately after the birth, in India, many children are neglected without proper treatment and thus results in a permanent disability. Clubfoot can be easily and inexpensively corrected if treated within the first two years of life. Since there is a lack of awareness, these children in India are forced to walk on their ankles.

Those with neglected clubfoot also suffer social stigma – they are commonly mocked, ignored or isolated from the family and community in which they live. Once the child reaches adulthood, the opportunity to correct the condition without extensive, expensive, and painful surgery is lost. In India, the family also faces the stigma and discrimination for having a child with the disability. These families are not invited for public events, festivals and marriages in the community they live. A majority of these neglected children were denied of education opportunity.

The treatment for clubfoot in the history started with non-operative methods, and it goes back to Hippocrates who suggested manipulation and splinting around 400 BC. During 1575, Ambroise Pare performed manipulation and later in 1743 Nicholas Andry developed the concept of manipulations and bandage and splints. Antonio Scarpa designed the first clubfoot orthosis during 1803. In 1836, Dieffenbach and Guerin used plaster of Paris for clubfoot correction. Thomas during late 1800s used the methods of forceful manipulations. Denis-Browne in 1934 used strapping and corrective bar, which is "Nutcracker" for recalcitrant cases. During the late 1940s, Ponseti has developed the golden method for clubfoot treatment method. It is a technique involving serial manipulations that corrects clubfoot without any invasive procedures [7].

The American Academy of Orthopedic Surgeons, American Academy of Pediatrics, and World Health Organization (WHO) accepts the Ponseti method for clubfoot treatment as the standard for clubfoot treatment. As per the research conducted at the University of Iowa for over 50 years, the success rate for Ponseti method is found to be around 95%. The rate of reoccurrence, when compared to surgical interventions, are very less in Ponseti method [8]. In a recent survey of clubfoot treatment in the USA, parents identified the Ponseti method as their preferred treatment option [9]-[12].

## III. BIOMECHANICS OF CLUBFOOT

The various foot angles under normal conditions are shown in Fig. 3. The dorsiflexion and plantarflexion angles are limited to 20° and 40° respectively. The standard foot angle between the foot axis and bimolar axis must be between 85 to 90°.

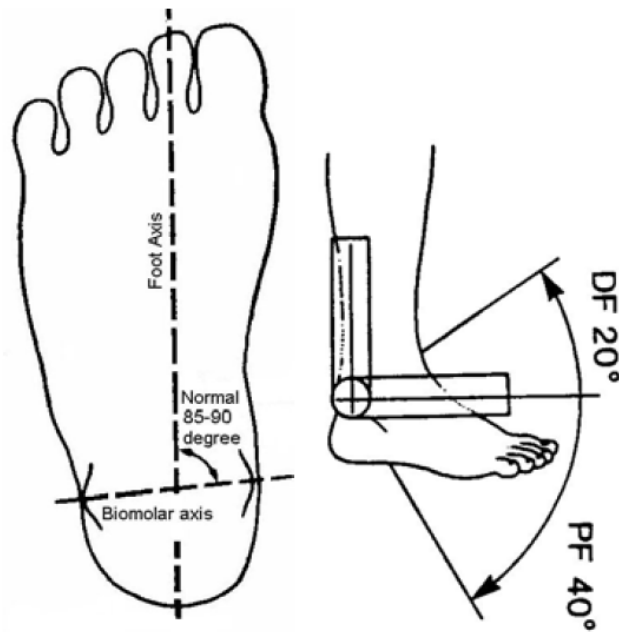


Fig. 3. Angles in a healthy foot

The misalignment of bones in the deformed clubfoot are shown in Fig. 4 [13].

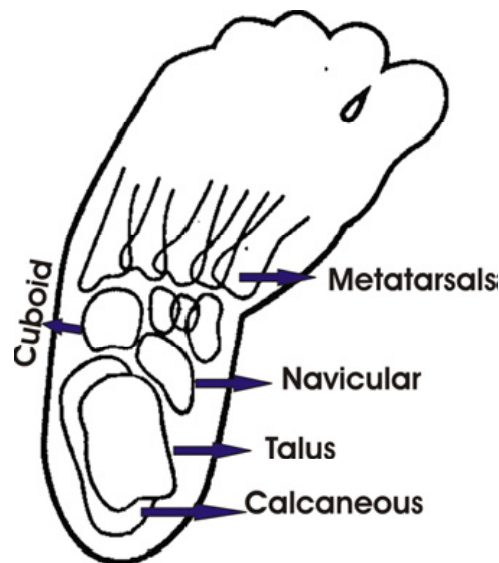


Fig. 4. Bone misalignments in clubfoot

With this background study in the biomechanics of the foot and the clubfoot deformity, it is planned to develop an external aid for the patients which will regulate the bone growth in the standard conditions.

#### IV. MODELING OF CLUBFOOT

In this study, three subjects were taken into consideration. The CT scans of the foot for a healthy subject, adult, and child with clubfoot were acquired using a SIEMENS Somatom Spirit with a slice thickness of 1 mm. The foot of a healthy subject is taken as reference for this study. The surface models of the foot were generated by reconstruction of CT images in MIMICS 12.1 (software developed by Materialise, Belgium).

The model of the healthy foot and clubfoot generated from MIMICS are shown in Fig. 5.

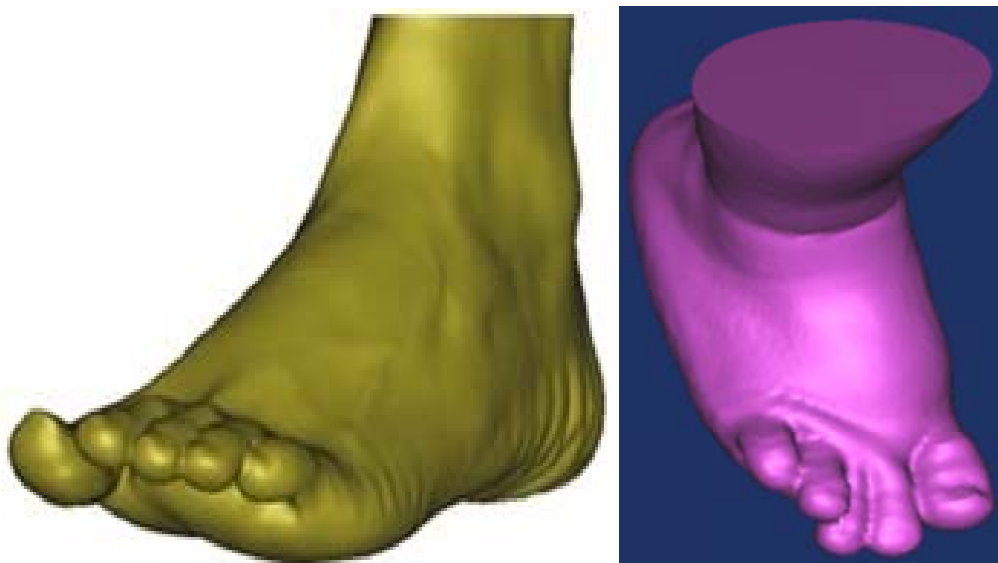


Fig. 5. Solid model of healthy foot and clubfoot

#### V. DESIGN OF EXTERNAL AID FOR CLUBFOOT

The non-surgical treatment for clubfoot is widely preferred over surgical treatment [12]-[14]. In this study, the external support (orthosis) is developed for treating patients with clubfoot. Orthosis is a specialty in the medical field concerned with the design, manufacture, and application. It is an externally applied device that is used to modify the structural and functional characteristics of the skeletal and neuromuscular systems. Orthotics combines knowledge of anatomy, physiology, design, and biomechanics. Foot orthosis comprises of an insert or foot bed which are more patient specific, fitted into a shoe. Commonly referred to as "orthotics" they redistribute the ground reaction forces in the foot during locomotion, as well as realigning foot joints during the Gait cycle. The combination of data related to pressure and bone geometry acquired from CT scans is used to model external aid for clubfoot treatment. The necessary wedge and the arch supports were shaped as per requirement. The external support (orthosis) consists of the shank, heel, wedge and other supporting mechanisms as shown in Fig. 6. These orthoses are used in case of adults where it reduces pain and enhances comfort. Orthosis for the child was developed with similar mechanisms and the supportive components are also modeled as shown in Fig. 7. The internal stresses measured by FE analysis were used to evaluate the effect of varying the slope of the wedge with reference to the trajectory of the centre of pressure.

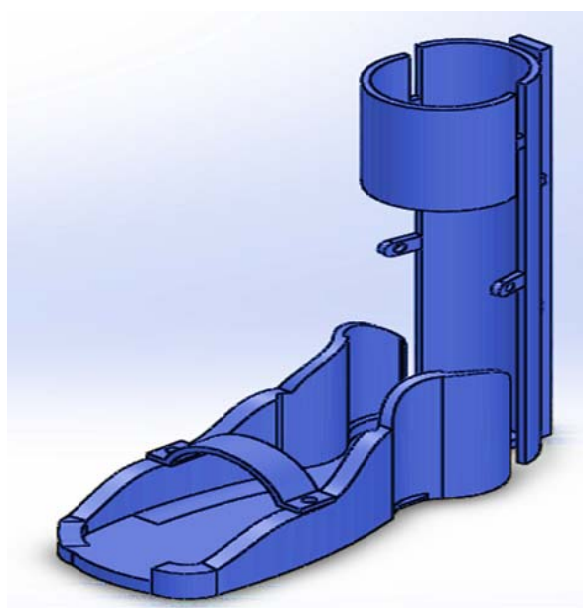


Fig. 6. External aid for treating clubfoot in adults

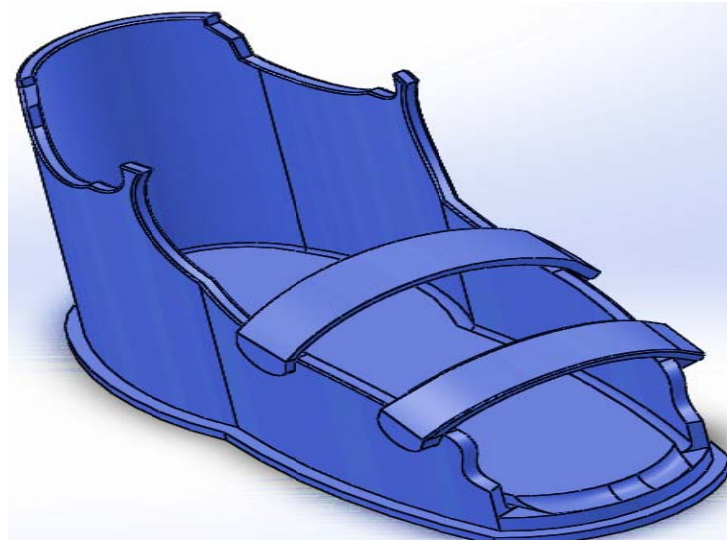


Fig. 7. External aid for treating clubfoot in children

**VI. FINITE ELEMENT ANALYSIS**

Finite element analysis (FEA) is a computer simulation technique which predicts the stress distribution and the deformation in a structure like such as bones, during application of load and provides the measure of stiffness. The model is divided into many discrete, finite elements called nodes. For each element, the material properties, such as Young's modulus and Poisson's ratio are well defined. Finite element analysis of a clubfoot and healthy foot is dependent on the overall dimensions which are described its geometry and material properties as specified in Table 1 [15]-[19].

TABLE 1 Material properties

Component	Modulus of elasticity (MPa)	Poisson's ratio	Cross-sectional area (mm <sup>2</sup> )	Element type
Bone	7300	0.3	---	3D tertahedron
Soft tissue	0.15	0.4	---	3D tertahedron
Cartilage	1	0.4	---	3D tertahedron
Ligament	260	0.4	18.7	Tension-only truss
Plantar Fascia	350	0.4	290.7	Tension-only truss
Ground support	20000	0.1	---	3D brick

The internal stress distribution in the healthy foot and clubfoot with and without orthosis is measured using finite element analysis. The distribution of internal stress in the healthy foot are shown in Fig. 8.

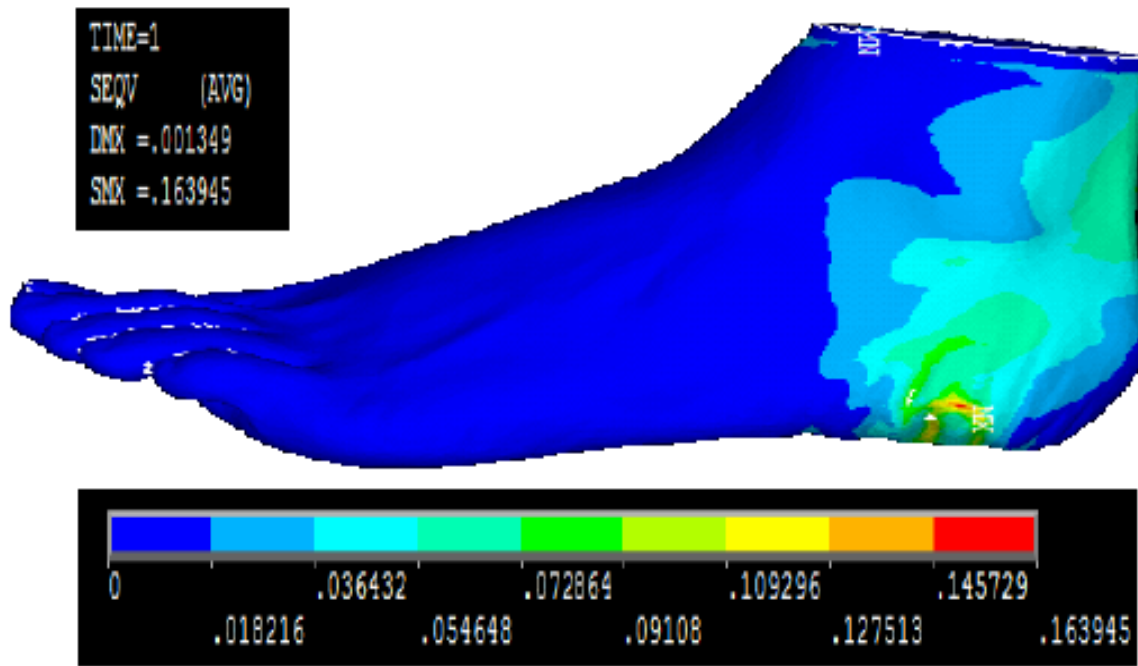


Fig. 8. Internal stress distribution in healthy foot

The Fig. 9 shows the internal stress distribution in the clubfoot with the orthosis. The deviation in the stress at the critical points was identified and in accordance to this, the orthosis is modified. It is found that the possibility of correcting clubfoot at the later stage is very less. Hence, this adult orthosis can be used as a supplement to improve the comfort during walking in case of adults.

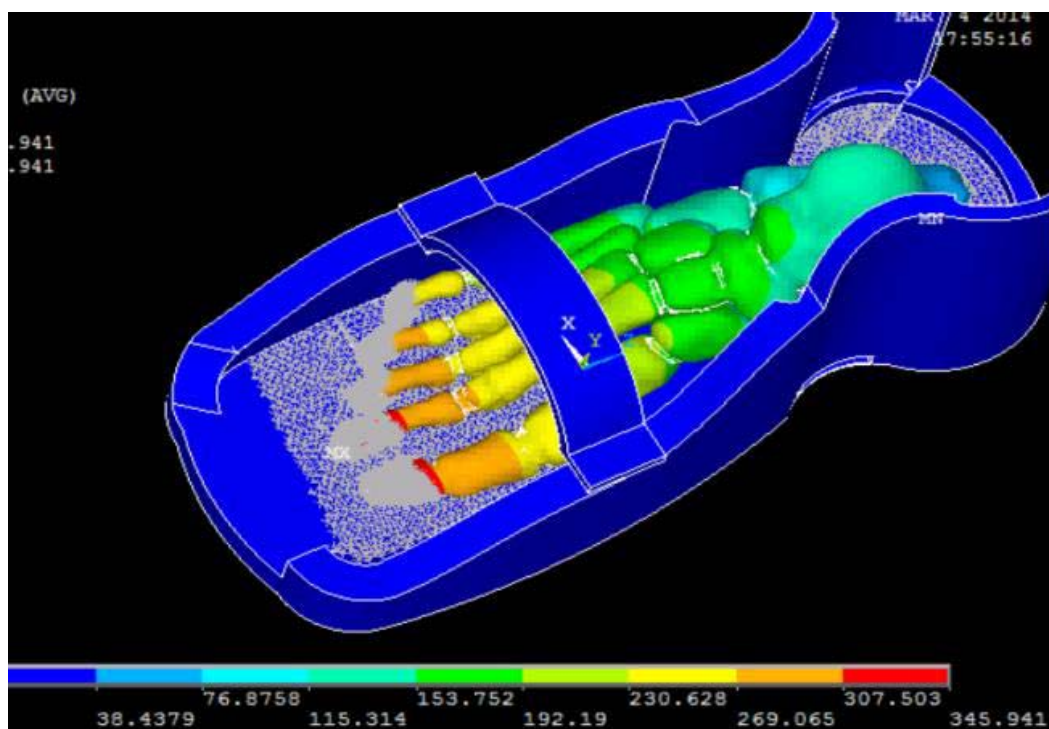


Fig. 9. Internal stress distribution in clubfoot with orthosis

The finite element analysis of clubfoot is shown in Fig. 10. The maximum internal stresses are developed in the ankle and the metatarsals.

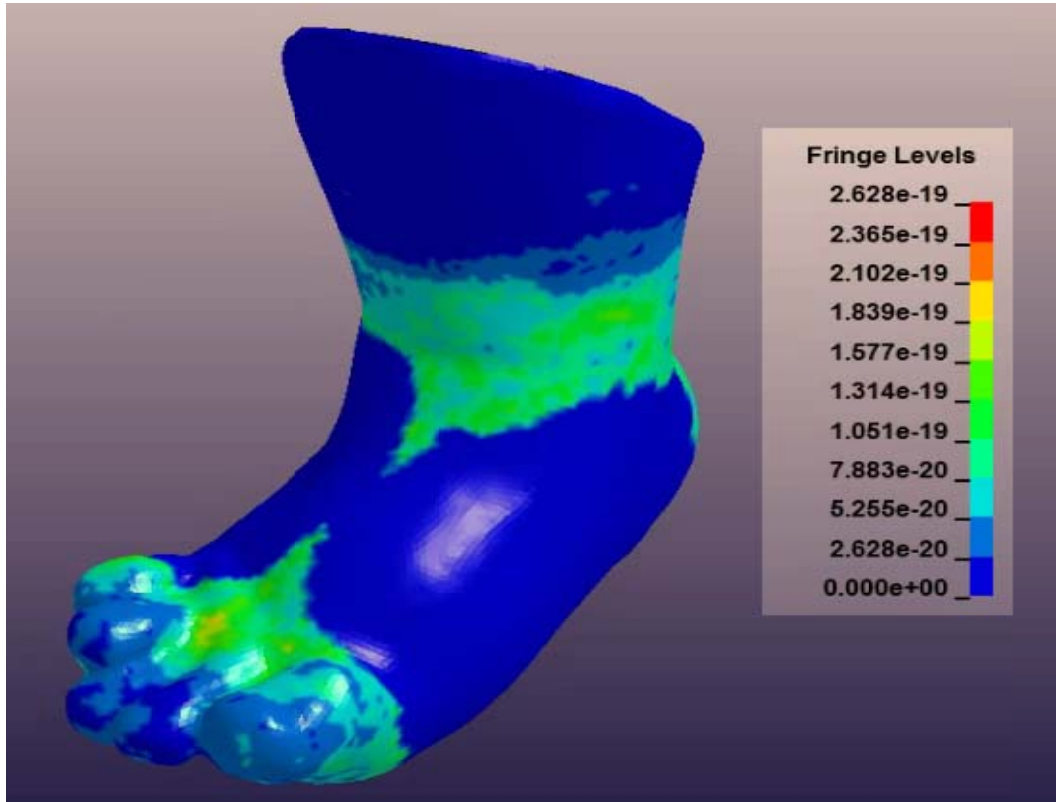


Fig. 10. Internal stress distribution in clubfoot of a child

The internal stresses are reduced by using the orthosis as shown in Fig. 11 for the child's foot.

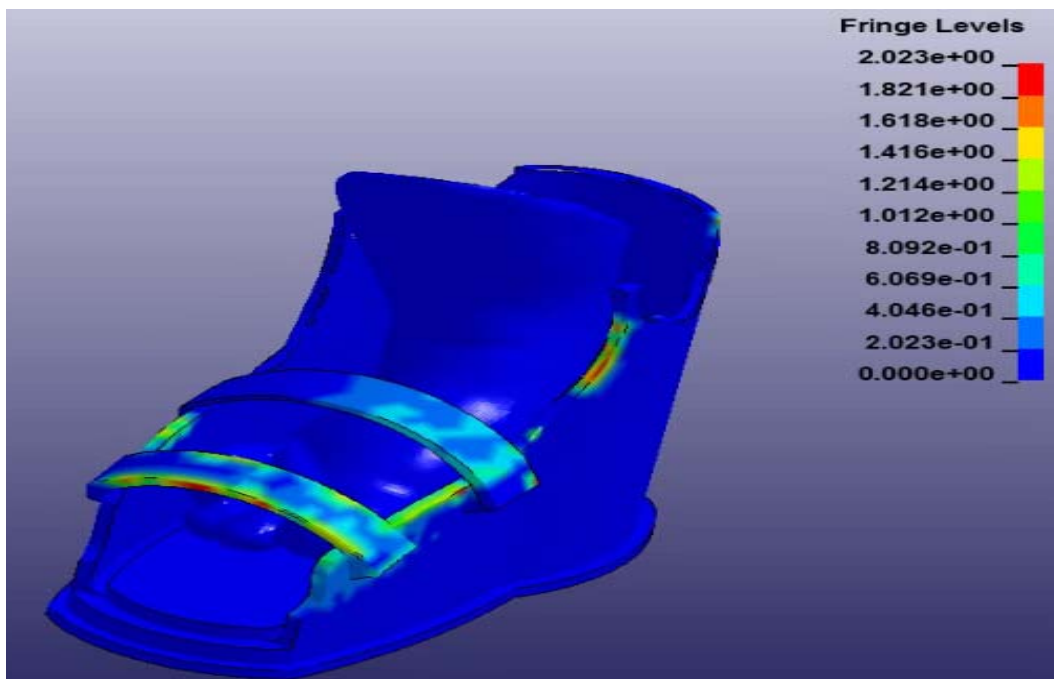


Fig. 11. Internal stress distribution in clubfoot with orthosis

## VII. CONCLUSION

Congenital talipes equinovarus (CTEV) is one of the birth defects that affects the musculoskeletal structure of the foot. The surgical treatment involves tectomy and anterior tibial tendon transfer. The non-surgical treatment includes intoeing, supination, and adduction. The subjects affected with clubfoot have persistent, abnormal motion at the feet. In this study, 3d FE model of the healthy foot and clubfoot is developed by image reconstruction of the CT scan data. This model is analyzed to study the stress distribution pattern in the healthy foot and clubfoot. The region of stress concentration was identified, and the external fixation device (orthosis) is developed to reduce the stress level in the club foot. These orthoses can correct gait in children affected by cerebral palsy and congenital flat feet. Also, the subjects with residual clubfoot deformities can also use the orthosis for their non-surgical treatment. This external aid helps the subjects to enhance their walking style and posture, thereby improving their physical growth and avoids psychological distress. Modeling of different external aids for the clubfoot treatment can be done and compared to identify the optimized design of the orthosis.

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### **AUTHOR PROFILE**



E. Vijayaragavan is a Research Scholar in the Department of Mechanical Engineering, SRM University, pursuing research in the field of non-surgical treatment of clubfoot. He has received M.E (CAD) and B.E. (Mechanical Engineering) from University Madras. He has more than 15 years of teaching experience and serving SRM University since Jan 2006.



T. V. Gopal is a Professor in the Department of Mechanical Engineering, SRM University. He has received M.E (CAD) from Anna University and completed his Ph.D. in the field of Computer Aided Assembly Planning at Anna University during 2007. He has more than 29 years of teaching experience. He has been working at SRM University since 1991. He also served as Dean – International Relation and visited many countries to initiate the global alliance with SRM University.