

“3D Digitization technique for the Assessment of clubfoot deformity in new born baby”- A Review

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ABSTRACT

Computed Tomography(CT) is the most popular medical Imaging techniques. Medical image analysis is one of the important fields of study in the field of medicine. The analysis of image works as a guide for the radiologist in diagnosis, planning the treatment and verifying the administered treatment. Conventional CAD Software cannot create bones easily, Therefore techniques such as X-RAY Computed Tomography (CT scans), Magnetic Resonance Imaging (MRI) are widely accepted as the procedure to create the geometry of a bone. This complexity makes it difficult to formulate methods to analyze the clubfoot deformity under normal conditions and even more in specific pathologies CT scan is a trustworthy option to model biological tissue. It provide a deeper understanding of different pathologies . This paper study the talus of babies based on CT scans & to demonstrate volume and surface rendering for a two dimensional CT image of the abnormal clubfoot.

Keywords: Clubfoot; CTEV; Talus, Computed Tomography, Segmentation

INTRODUCTION

Congenital talipes equinovarus (CTEV) or clubfoot is a common pediatric congenital foot deformity that occurs about 1 in 1,000 live births (Wynne-Davies, 1964; Shiels et al., 2007; Hussain et al., 2014; Meena et al., 2014; Smith et al., 2014), [1-4] i.e. characterized by four sections: hind foot equinus, midfoot cavus, forefoot adductus, and hindfoot varus (Solanki et al., 2010; Meena et al., 2014; Shabtai et al., 2014) [4-6]. The “Ponseti method” has been widely accepted worldwide to correct the clubfoot deformity which works with manipulation, serial casting and bracing (Lykissas et al., 2013; Shabtai et al., 2014) [6,7]. The evaluation of clubfoot is very essential to assess the success rate, to monitor the progress and to evaluate the relapses and treatment follow-up of clubfoot treatment. (Wainwright et al., 2002; Herd et al., 2004; Ramanathan et al., 2009; Ramanathan and Abboud, 2010; Bergerault et al., 2013; Cosma and Vasilescu, 2015; Lampasi et al., 2017) [8-12]. A study put forward by Gutekunst (2012) recommends that using (3D) modalities, such as MRI, would be useful for determining the severity of foot deformities by calculating bone to bone orientation analysis in the following conditions: club foot, rheumatoid arthritis, Charcot-Marie-Tooth disease, diabetic neuropathy, and Charcot neuroarthropathy [13]. However, as MRI and CT are expensive procedures for computing and evaluating the severity of clubfoot. This would have need of sedation or anesthesia for infants to make them calm or relax during the MRI procedures. The International Clubfoot Registry Database (ICRD) recommends to record the biomechanical aspects of objective assessment methods such as measuring the angle of foot positions of four components of clubfoot deformities as well as Pirani score [15,16]. Due to no agreed standard objective assessment methods for evaluating and monitoring the severities of the club foot, various studies suggested that the need of objective evaluation method to compute the severity and predict the diagnosis of the treatment (Wainwright et al., 2002; Herd et al., 2004; Siapkara and Duncan, 2007; Ramanathan and Abboud, 2010; Jain et al., 2012, 2017; Fanet et al., 2017) [8-12, 18, 19] and these studies also focused on the accuracy, reliability and validity of the assessment to predict the prognosis of the clubfoot. Therefore, we put forward this study of using a low-cost 3D scanner to explore the structural changes in clubfoot and compute the severity of clubfoot. The geometry of foot’s bones was rather approximate in their model. Many new domains for real 3D modeling of anatomic sculpture require input images from variety of sources like photographs, sketches, computer made images from CT, MRI, Sonography and X-ray images etc [36,37]. 3D modeling of human anatomy is an open area of research and much works reported under this domain for different organ of the human body. 3D model of human foot using CT/MRI etc is, reported in few engineering literatures. The present paper offers a 3D representation of Clubfoot’s bones specifically talus bone. This proposed a novel approach for 3D, talus representation of clubfoot by integrating MRI and medical image processing tools and this provides a computer-aided tool in the form of 3D talus representation [30-36]. The major outcome of this work is the 3D model of talus that assists in diagnosis and better treatment of a historical CTEV foot deformity.

FOOT AND ANKLE PATHOLOGIES

The foot and ankle have the primary function of providing mobility to the human body. This is possible through electrical impulses from the brain to the terminals in the tissues surrounding bones. Any alteration in the limb, making it difficult to accomplish its principal function, results in foot pathologies. In addition, pain is a considered variable when determining an associated pathology. The clinical assessment, usually offers information about different birth conditions. Main pathologies can be detected since childhood and further procedures to assess it such as MRI Scans, CT Scans or X-rays can be used to determine the severity and the right available treatment. The first step is to detect a possible deformity. Pediatricians commonly detect it in a general assessment after birth. Upcoming assessments can be performed to diagnose the right pathology. The proper assessment tools provide information to determine the correct diagnosis and treatments which vary from simple to severe or relapsed cases.

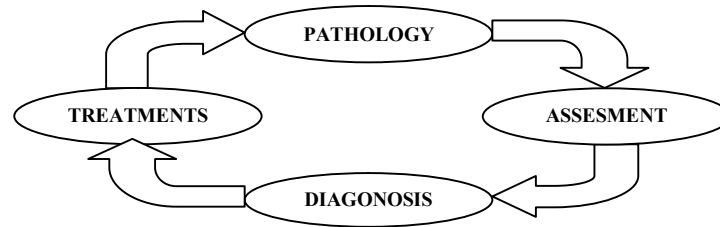


Figure 1 Course of action for foot deformities correction

Pathologies in the foot are a frequent combination of two or more different deformities. Thus, it is common in the clinical inspection to detect many of them to be treated. Clubfoot or talipesquinovarus is an appropriate example, where four different medical conditions, cavus, varus, equinus and adductus are combined to describe the pathology. Table 2 summaries the different possibilities according to the movement of the foot and articulations

Table 1 Normal movements of the foot and its relationship to different deformities (Muñoz, 2006) [38]

Articulation	Movement	Deformity
Ankle	Dorsiflexion	talus
	Plantar flexion	equinus
sub astragalus	inversion	varus
	eversion	valgus
	abduction	abductus
	adduction	adductus
	pronation	Pronation
Metatarsus	supination	supination
	plantar flexion	cavus
	dorsal flexion	Flatfoot

CLUBFOOT ASSESSMENT AND DIAGNOSIS

During the first days after the birth pediatrician carried out general assessment of Clubfoot which provides information to determine pathology, level of severity, adequate treatment. Improper assessment before six month old results in stiffness of soft tissues. Mistakes in corrective procedures can be attributed to the lack of training, an improper assessment, misinformation on the corrective procedures by parents so on. Generally, the assessment is based on diverse methods such as X-Rays, ultrasounds, MRI's, CT scans and others. Firstly, clinical observation which gives enough information to suspect about foot pathologies by identifying pain or unusual foot angles [40]. Secondly, X-rays and pain scales results in more precision & have been proposed by clinicians for the assessment. Even though if the usage of X-rays is not regular, they can be immediately ordered when there is doubt of clubfoot (Anand&Sala, 2008) [39].

MATERIALS AND METHODOLOGY

Conventional modeling of bones on a CAD design software is difficult due to its asymmetric cross-sectional slices along the length of the bone. However, it is better to build the CAD model geometrically similar to real tissues for more precision which also reduce computation time. Computed Tomography (CT scan) , an image generation technology

produces images of the cross-sectional area, perpendicular to the analyzed subject using X-Rays beams and generate Dicom files i.e., the CT scan data of bones can be imported into a dedicated modeling software to generate the bones and create surfaces and solid parts by using additional software by Dicom file CT scan of the abnormal foot (clubfoot deformity) are taken for study, the 2D CT slices are converted into a 3D image. Volume and surface is rendered for the 3D image. Point cloud data is generated for the surface rendered image. The point cloud data (PCD) is taken as the input parameter for the computer aided designing (CAD). From the point cloud data a rapid prototype (RPT) of the surface model is generated, the surface model is then converted to a solid model. CT scan is the preferred tool because of the following reasons

- High precision when compared to the other methods
- Minute details are enhanced and highlighted
- Cost effective and easy availability.

128 slices CT of the abnormal foot was taken with the subject in supine lying, the foot and the ankle joint in the biomechanical neutral alignment. The 2D CT images in the **dicom** format were taken as the input for the surface and volume rendering. The 2-dimensional images are stacked into a 3-dimensional image. Stacking is the process by which all the 2 dimensional slices are arranged in a 3D format. A 3D volume image includes a stack of 2D images. A 3D volume image can be stored in a single image file or multiple files where each file contains one image slice or plane.

The general description of the procedures to create the CAD models and the FE analyses of bones and can be summarized in the following steps:

- Data Acquisition using CT scans. The geometries are taken from CT scans as a series of raw images taken from different angles to produce slices of the bone tissues.
- 3D Geometries creation of bones. ScanIP Software enables to generate the 3D geometries of the bones from imported 2D images in grey scales.
- The design of the frame geometries using CAD software such as Inventor, SolidWorks, Catia, and other.
- Verifying for errors and discontinuities in the geometries. PowerSHAPE enables verifying the geometry for errors as well as converting the surfaces defining the bones geometries into solid as well as changing geometry files to the required formats.
- Bone Assembly. This process is carried out by importing the models into the assembly module of CAD software.
- Pre-processing. Applications of mechanical properties, boundary conditions, loads, displacements, mesh, and so on.
- Numerical Analysis: carried out in finite element software such as Abaqus.

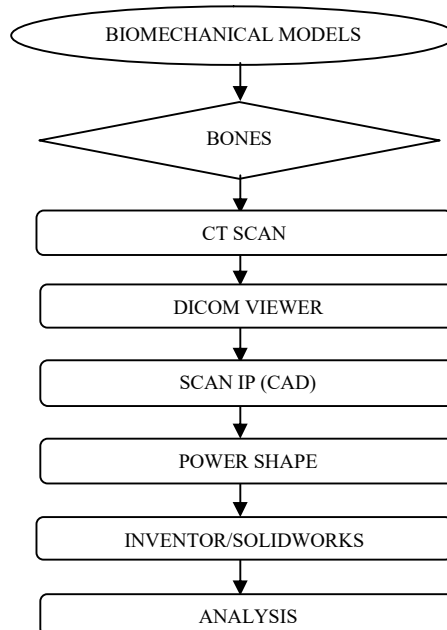


Figure 2 Procedures to develop the biomechanical models of bones

Figure 2. Summaries the procedures for the development of CAD models of bones. Dicom (Digital Imaging and Communication in Medicine) files with *.raw or *.img extensions consist of a standardized communication protocol to store and transmit data from the Scan sessions and also stores additional information such as patient's ID (e.g. name and age), patient's data being inseparable from the CT scan related data. After while the folder containing data (highest

number of images with better contrast) is processed to create the 3D model is selected which enables a) smaller spaces between scan slices, b) superior image clarity resulting in resulting in smaller modeling processing time. Subsequently, the files are converted into *.iges files and pre-processed for identifying errors in the geometries and convert it to solid models using PowerSHAPE from Delcam. The CT scanners work under mathematical algorithms to reconstruct the images of the scanned bodies, such as the Linogram.

DATA ACQUISITION SYSTEM

The process of converting 2D images to 3D images which comes after CT scan is defined as follows: Images from CT are obtained from the real patient and then imported to SCANIP software. The images obtained through CT images are in the form slices, and the information in every slice is in grey scales that defines the geometry. Slices are used in the creation of 3D geometry of human bones.

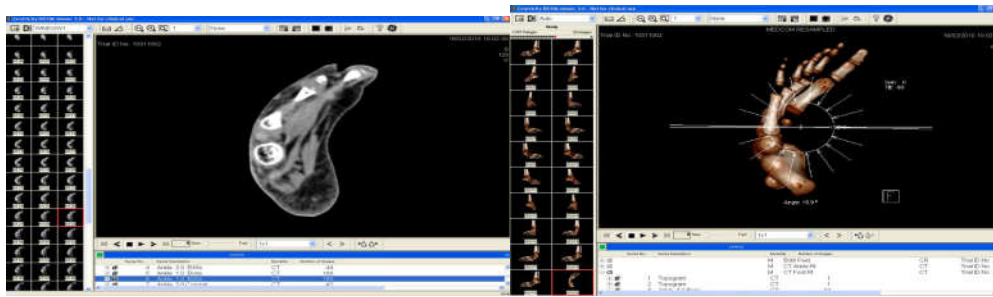


Figure 3 Dicom 2D images of clubfoot in babies[35] , Figure 4 Dicom 3D view of clubfoot in babies (Courtesy of Hernandez-Hernandez, G., Oyadiji, S. O., Zenios, M., Zou, Z. (2015))[35].

In figure 3 every image of baby's clubfoot is slice to create solid image. & Figure 4 defines lateral view of foot and the center is a 3D preview of the foot. Dicom files of the images are imported to ScanIP software. After importing these files are displayed in the three planes, sagittal, coronary and axial, as shown in Figure 5. The software displays grey scale images at the beginning. After the images in grey scales, it is obligatory to apply a mask of any colour. The whiter dots of the images will be covered by the mask as they represent the bones. Usually, a clearer perspective has been provided by an axial plane which is sufficient to start working by filling the white dots to build the bone geometry. Different Filters applied in the geometry enables users to achieve precise geometry.

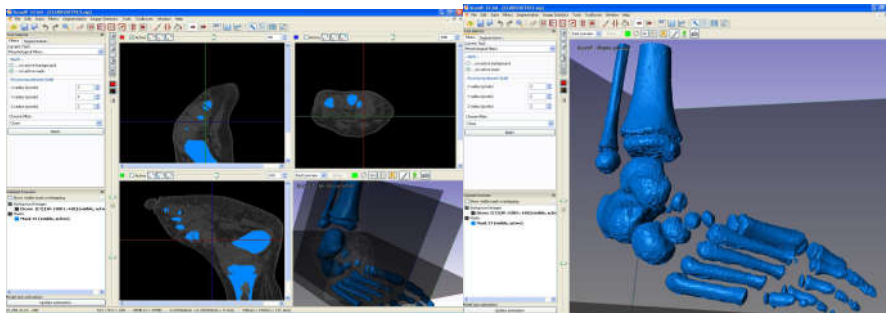


Figure 5 ScanIP perspectives of the CT scans in, the sagittal, coronary, axial planes and the preview of the solid model, Figure 6 Clubfoot geometries in babies before applying a filter (Courtesy of Hernandez-Hernandez, G., Oyadiji, S. O., Zenios, M., Zou, Z. (2015)) [35]

Figure 5 shows a Scan IP slice during the bone construction. The iteration process of creating bone geometry requires filling up of gaps slice by slice carefully. Esoteric knowledge of the anatomy of the limb enables an accurate creation of geometry. For every slice the procedure must be repeated. It is obligatory to create the spaces between bones by erasing the colors to separate the geometries after applying the filters. Figure 6 is the representation of the bones geometries before applying a filter to reduce noise. Filters are the predefined algorithms that are applied to the constructed geometry to improve its meshing process in the Finite element Software. The surface usually softens by Binarization filter, before applying other filters. In a *.iges file format the geometries are saved and the number of faces can be determined by geometry in this section. Figure 7 shows the bones geometries after applying different filters. Next step is to remove the undesirable dots in the geometry. Otherwise, when schematizing the FE software will display an error message or meshing will be complex. The ready geometry needs to be exported to the POWERSHAPE by Delcam to create amicable

file with Abaqus.*iges is a common design extension for surface geometry. Errors and open edges in the geometry is easily identified by the POWERSHAPE. To reshape the geometry and achieve a better mesh, alternative software such as 3D Max or Rhino can be used. Also, pre-processing software such as Ansys, Hypermesh or Patran, have a multiplicity of tools to the mesh in asymmetric geometries such as bones. Due to the software availability, the geometries were checked for errors in PowerSHAPE and by using the Abaqus (version 6.10 to 6.13) tools of mesh and part sections of the surfaces of the bones were improved by reshaping.

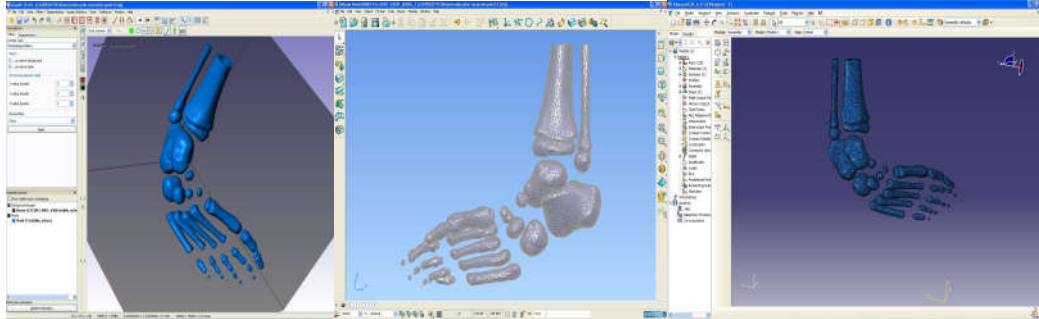


Figure 7 Clubfoot after applying filters, Figure 8 Solid geometries created in PowerSHAPE, Figure 9 Geometry of a clubfoot case exported to Abaqus (Courtesy of Hernandez-Hernandez, G., Oyadji, S. O., 2015)) [35]

Figure 7 shows the final geometry of a clubfoot after working on the images and applying different filters. The geometries of the bones are clean and smooth. After verifying for errors in the geometry, the surface files are converted into solids in order to prepare them to be imported to Abaqus. As shown in Figure 8, it is possible to convert surfaces to solids and to save the file in Abaqus with the format *.x_t from Parasolids to perform the Finite Element Analysis. Also, the files can be imported as *.sat files, Figure 9 shows the geometries imported from PowerSHAPE to Abaqus i.e. converted into a solid model. During the process, the coordinates and dimensions of the solids are respected. This is a crucial consideration when the pieces are needed to be assembled in the source position. Triangles in the geometry can result into meshing difficulties in Abaqus. The solid can be reshaped by the use of tools of the mesh and part module of Abaqus.

GENERAL DISCUSSION

The foot is a very complex structure. For modeling a foot there requires great efforts to understand its biomechanical, biomechanics in association with a pathological foot and it becomes difficult to develop the models of veins, ligaments, muscles due to its complexity. Thus, the model generally aims to examine isolated elements, or specific elements and these helps to build up knowledge of the foot by means of independent analysis. Due to stiffness of tissues and position of bones there comes a difference between club and normal foot. The clubfoot analysis follows a very pathological, very specific treatment & the challenges occur during process are, “the variables & methods to perform the analyses”. Due to lack of data & literature in mechanical properties of clubfoot babies there comes limitation & challenges on the analysis that need to be performed. Thus, the development of a 3D model for clubfoot is obtained clinically based on the use of CT scan images. This review paper proposes a novel computer assisted representation of clubfoot by integrating MRI and image processing tools which focus on new insights belonging to the thorough look of talus bone based on patient-specific image data. This approach provides a good perspective of normal and clubfoot & helps in comprehending the ankle joint anatomy of clubfoot. By depicting the true shape geometry of talus of clubfoot, it increases its clinical importance. By this study orthopaedician gets clear information of major orthopaedic drawback in clubfoot which helps in its treatment. As the research is integration of MRI scan with Computer Aided Design (CAD) and Rapid Prototyping (RP) in the domain of clubfoot and further used for evolution of dynamic ankle foot orthosis (AFO).

CONCLUSION

The paper here describes the role of advance medical computer technology based on complex image processing, 3D digitization techniques that will provide an effective clinical decision support tool for non-surgical correction of challenging club foot deformity in new born babies. This works provide a gateway to the computer aided tools in the form of 3D digitization technique in the field of medical sciences providing beneficial use of technology for the community. Thus, this research unites CT and clinical study of the club foot deformity in a new born baby by effective use advance imaging resources (CT and mimics). Further this review will generate a way for the finite element analysis for the future biomechanics research on human clubfoot.

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