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3D MODELLING WITH CT AND MRI IMAGES OF A SCOLIOTIC VERTEBRAE

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Abstract

Scoliosis is a lateral or sideways deviation of the spine or vertebral column. Scoliosis can be treated by postural correction, providing braces or by surgery. Even after treating scoliosis with the help of brace or surgery, the normal spine range of motion is not achieved in most cases. After treating scoliosis either by brace or surgery, the normal posture might be achieved. But, it is important to know whether the patient is able regain his/her functionality. The mechanical properties of the vertebrae and intervertebral disc pressure after the application of brace and surgery are unknown and yet to be explored. In order to explore it, we come up with the thought of creating a 3D model of vertebrae. Because scientists and researchers depend upon cadaver specimens to try new fixations where the number of people willing to donate their body for research purpose is very low or nil in most of the countries. Without a sufficient number of cadaver specimens, the research progress remains still or very slow. Thus, creating a 3D model of vertebrae could yield more importance and convenience to do spine research. A 3D model of human spine can help in 3D printing too. In this study, we propose a simple method where the 3D model of scoliotic vertebrae can be created with the help of DICOM files.

Keywords: Solid model, Scoliotic vertebrae, DICOM, InVesalius, Magics..

1. Introduction

It has been postulated that density of the bone decreases as the age increases [1]. This leads to decrease in the mechanical properties, function and stability in bones. Human spine consists of 33 vertebrae. 7 cervical, 12 thoracic, 5 lumbar, 5 fused sacral vertebrae and 4 fused coccygeal vertebrae. Each vertebrae is separated by an intervertebral disk, which acts as a shock absorber between each

Nomenclatures

a_i	ith row of the matrix A
b_i	ith component of the vector b

Greek Symbols

λ_k	Relaxation parameter

Abbreviations

3D	Three Dimension
ART	Algebraic Reconstruction Technique
CT	Computed Tomography
DICOM	Digital Imaging and Communication in Medicine
MRI	Magnetic Resonance Imaging
ROI	Region of Interest
ROM	Range of Motion
STL	STereoLithography

of the vertebrae in the spinal column when there is impact from activity. When the spine is affected by means of spinal deformity, the shape and properties of the vertebrae and intervertebral disc are also affected. The mechanical properties of the human vertebrae are of great importance. It plays a vital role in maintaining the ROM and stability.

The mechanical properties of vertebrae include stress, strain, shear, and torsion of the bone. These mechanical properties vary between the normal individuals and in the patients with spinal deformities. There are many structural changes in the human vertebral column, which are considered as spinal deformities. They are: Herniated disc, Spinal arthritis, Spina bifida Ankylosing spondylitis, Spondylosis, Spinal curvature issues like Scoliosis, Lordosis and Kyphosis. In this, scoliosis is quite common among the general population. Some are congenital and some are idiopathic. These abnormalities can be confirmed by using radiographic methods like x-ray, CT scan and MRI scan. Several studies were done on obtaining the mechanical properties of human vertebrae using cadaver models and digitizer. Only very few studies were done on obtaining the 3D model using the CT and MRI scan files (DICOM files). This gives the urge to conduct a study on 3D modelling with CT and MRI images.

Appearance of the scoliotic vertebrae differs from the normal vertebrae. Scoliotic vertebrae are wedge shaped. Because of this wedge shaped vertebrae, the normal pressure (0.7 kg/cm^2) exerted on the intervertebral disc is altered and concentrated on either side of the disc [1]. It may lead to further secondary complications. Due to this abnormalities, mechanical properties of the vertebrae and intervertebral disc pressure might vary between the normal persons and patients with spinal deformities (scoliosis). It can be treated by providing braces or by surgery. Braces are provided only for the young patients (teenagers) having congenital scoliosis or with the cobb angle lesser than 40 degree. Because the bone is not completely developed and can be corrected with the help of braces itself, whereas corrective surgeries are performed in adults for both the congenital and acquired scoliosis. With the advancement in medical field, scoliosis corrective surgeries are performed for teenagers in the recent years. Even after treating the spinal deformities like scoliosis or kyphosis with the help of brace or surgery, the normal spine range of motion is not achieved. The mechanical properties of the vertebrae after the application of surgery is unknown and yet to be explored. Thus an easy and non-invasive method is necessary to know the mechanical properties of the vertebrae.

The objective of this study is to provide a 3D model of a human spine using the DICOM files to understand the mechanical properties of the human scoliotic vertebrae.

2. Review of Literature

The previous studies associated with this study are classified into three major categories. Studies done using cadaver, on normal human beings and radiographs.

2.1. Studies done using cadaver

Many studies were done in the earlier days to find the mechanical properties of the human spine. Arno Bisschop, Jaap H. van Dieen and Idsart Kingma conducted a study on torsion biomechanics of the spine following lumbar laminectomy: a cadaver study, where they found the torsion biomechanics of spine using Instron [2]. Another study done by Hakan Bozkus, Ergun Bozdag and Ercan Tanyeli done a biomechanical pilot study on surface strain and stress analysis of mid-cervical vertebrae bony compartments using Strain gages [3]. M.M. Trexler et al., used modified split Hopkinson pressure bar to find the shear loading in soft materials and biological tissues [4]. Ling H.Y and Tan S.H used Dual-energy X-ray Absorptiometry (DEXA) to find the effect of bone density on the mechanical properties of human vertebrae [5]. Kim-Kheng Lee et al., done a 3-D finite element modelling of lumbar spine (L2/L3) using a digitizer. They used touch probe digitizer to extract the geometrical data of the lumbar spine. Using a software called Surfacer 7.0, the three dimensional data was processed and finite element mesh was constructed using ANSYS software [6]. All these studies were done on vertebrae obtained from human cadaver. None of those studies were conducted on a live human being. Only a very few studies were done with live human beings.

2.2. Studies done on normal human beings

Qinghu Meng and Chunyu Bao done a study on biomechanical characteristics of lumbar vertebrae for speed skating athlete using finite element analysis. In this study, a continuous scanning to the volunteer’s upper edge of fourth vertebrae to the lower edge of the fifth lumbar vertebrae was fulfilled through spiral CT scan. The CT images were processed in medicinal picture processing software in dicom format. The bony tissues were distinguished from CT images through region growing. The three dimensional geometrical model of L4-L5 was established by 3D calculation through region growing to segment the different regions. They found that “when speed skaters were skating, the stress on the disc mainly concentrated on annulus fibrosus” [7].

2.3. Studies done using radiographs:

Hendrik Schmidt et al., conducted a study on intradiscal pressure, shear strain and fiber strain in the intervertebral disc under combined loading using finite element analysis. A finite element model of human lumbar spine segment was generated based on CT scan. The model is transferred to finite element package in ANSYS and meshed [8]. T.A.C.P. Martins et al., did a study on InVesalius: Three-dimensional medical reconstruction software and found that InVesalius provides a good quality 3D image reconstruction based on CT and MRI DICOM files [9].

3. Method

Subjects with the history of scoliosis in the age group between 10 to 25 years were selected. Study was clearly explained to the subjects. Baseline assessment like age, sex, height, weight and date of treatment completion were noted for all the subjects participating in the study. The details obtained from the subjects are kept confidential and will be never shared with others. Some data were collected from in and around the scan centres of the state Tamil Nadu, India.

After finishing the baseline assessment, CT and MRI scan files (DICOM) were obtained from the subjects. Then these DICOM files were used in InVesalius software, version 3.0 [10]. InVesalius is an open source software for reconstruction of computed tomography and magnetic resonance images. It generates a 3D medical imaging reconstruction based on a sequence of DICOM files. The folder with DICOM files were imported into the InVesalius software and the region of interest is selected. The mask properties, surface properties and the threshold properties are adjusted according to the need. Once the properties are set, a 3D surface is created and it is exported in STL file format as shown in Fig. 1.

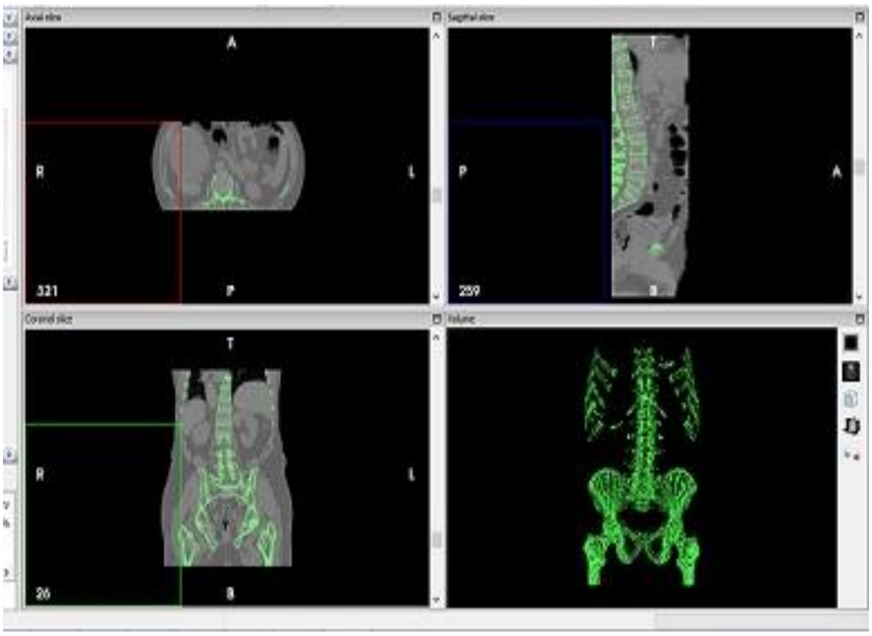

Fig. 1. Processing in InVesalius.

Once the 3D surface is created it is then imported in Magics software version 18 [11]. Magics is a data preparation software package and STL editor. It can guide through every step of additive manufacturing or 3D printing workflow. The file exported from InVesalius is imported into Magics as shown in Fig. 2.

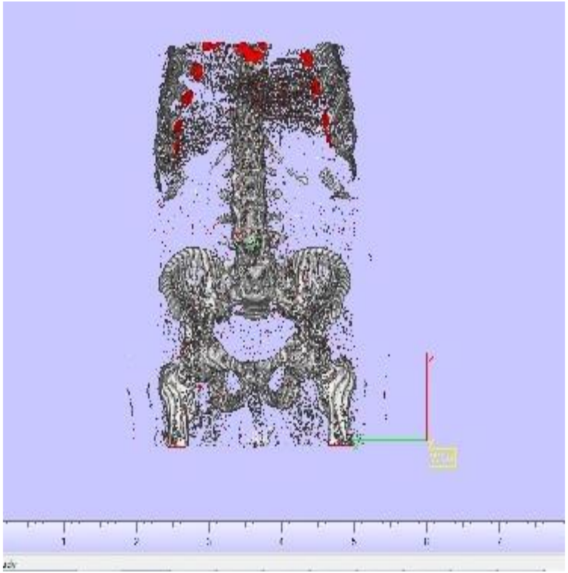

Fig. 2. Before processing in Magics.

The imported STL file is edited in Magics. Shells, holes, triangles, overlaps, stitching, etc., are edited to get the final 3D model of human vertebrae (Fig. 3).

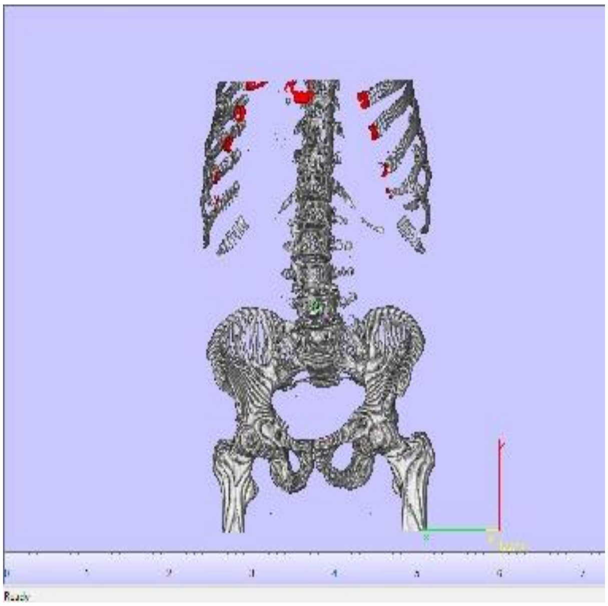

Fig. 3. After processing in Magics.

Methods like Kaczmarz is used in the field of image reconstruction from projections. It is an iterative algorithm for solving linear equation systems. It is also called as ART. It is denoted by the formula:

$$x^{k+1} = x^{k} + \lambda_k \frac{b_i - (a_i,\ x^k)}{||a_i||^2} a_i \tag{1}$$

where $i = k \bmod m + 1$, a_i is the ith row of the matrix A, b_i is the ith component of the vector b, λ_k is a relaxation parameter.

Figure 4 shows the flow chart of the followed method.

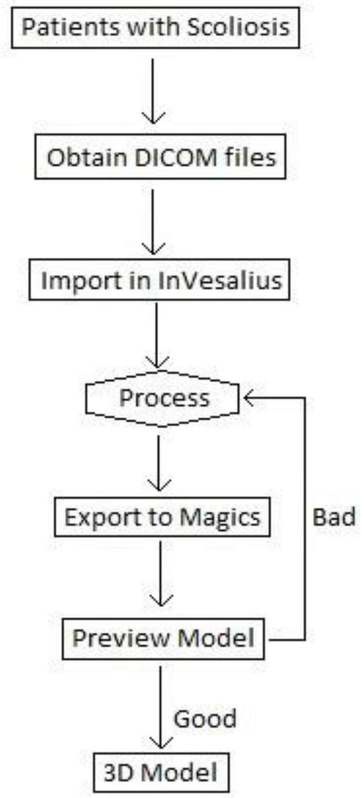

Fig. 4. Proposed method.

4. Results and Discussion

The imported file in Magics initially looked like a corrupted, noisy, untidy 3D model. The edges and the curves were not clearly visible. After processing in Magics, after fixing several issues, a clear 3D model of human spine is obtained with a diminished corruption. But much better than the previous model. This 3D model, when incorporated with its tissue properties can be used to find the mechanical properties of scoliotic vertebrae using the Finite Element Analysis. There are also other software's like ITKSnap which can convert the DICOM files into 3D model [12]. When we tried to create a 3D model using ITKSnap software, it didn't provide better result than InVesalius. Because DICOM file images contains lot of noises.

Unlike the olden days, here after the dependency on the cadaver will be diminished for medical research purpose, since the 3D model serves a much better option [13]. Previously, Janko D. Jovanovic and Miomir Lj. Jovanovic (2010) created a finite element modelling of the vertebrae with its geometrical and material properties retrieved from the CT scan data. The CT images of the vertebra was exported in common medical file format called DICOM (Digital Imaging and Communication in Medicine). The scanned images have CT numbers, which is converted to density of the bone tissue by Computed Tomography (QCT). Using the program Mimics (materialize software) CT images were processed to generate the geometric model of the vertebra. Their results showed that the model was capable of giving detailed quantitative information on the biomechanical behaviour of the vertebra and could be considered as a useful tool in risk evaluation of osteoporotic fracture of vertebra [14]. Ai-Min Wu, Zhen-Xuan Shao, Jian-Shun Wang, Xin-Dong Yang et al., (2015) conducted a study on the accuracy of a method for printing 3D spinal models. They concluded that the 3D model provides a protocol for printing accurate 3D models for surgeons and researchers. The resulting 3D printed model is inexpensive and easily obtained for spinal fixation research [15-23]. There are few limitations in this study. Availability of old records about the scoliosis patients in the hospitals is questionable, scoliosis patients opted for correction surgery is unknown, number of patients recovered from the scoliosis is unknown, willingness of spine surgeons to reveal patient's identity and time duration.

5. Conclusions

This method of creating a 3D model with the help of DICOM files could serve as a much better option to the researchers rather than depending on cadavers or digitizers. With a completely developed 3D model of a scoliotic vertebrae, its mechanical properties can be identified by finite element analysis. This 3D model also helps in 3D printing of vertebrae. Thus future researchers can use this method to do 3D printing.

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Appendix A

3D Model from ITK Software

ITK software has three main process in converting the DICOM into 3D model. Initially, ROI must be selected. Then followed by Pre-processing - which includes upper and lower threshold, Initialization- placing bubbles in the ROI and Evolution- contour evolution. Once all the editing is done, the final 3D model appears in the screen. The 3D model appears to be like a stack of bubbles placed one above the other. Marking the vertebrae and ribs using bubbles in a noisy image is merely impossible or highly difficult.

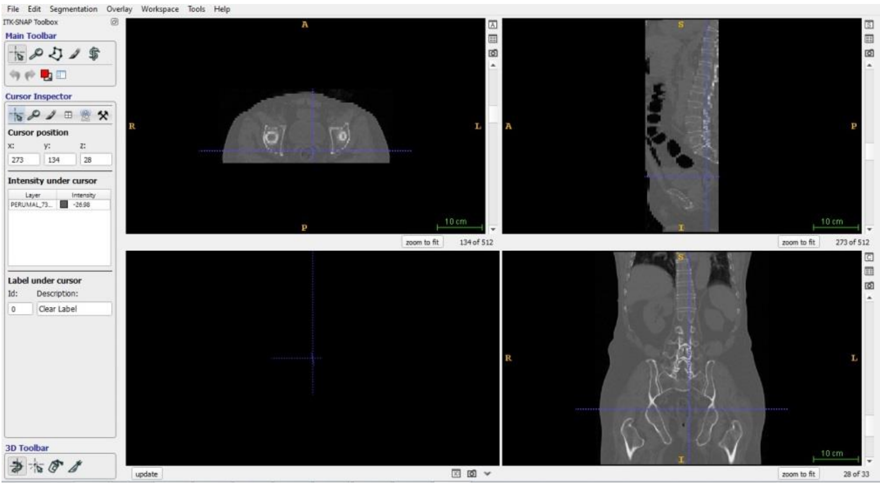

Fig. A-1. Processing in ITK.

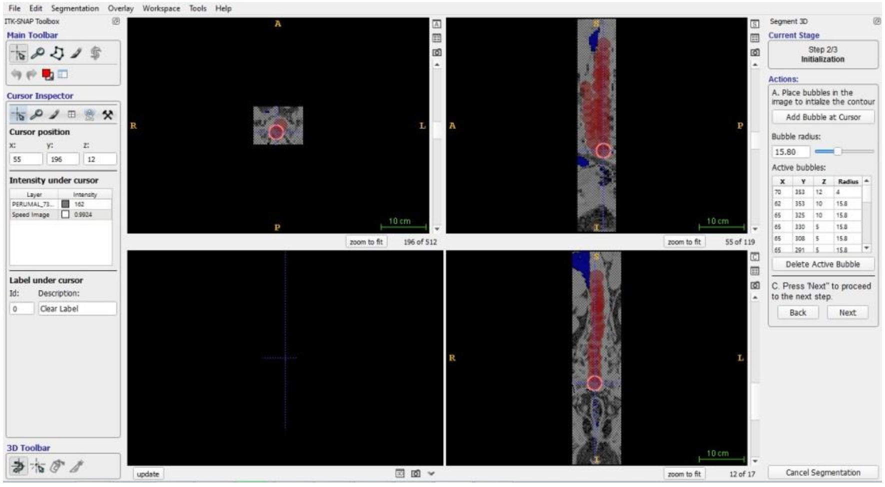

Fig. A-2. Adding bubbles to the image.

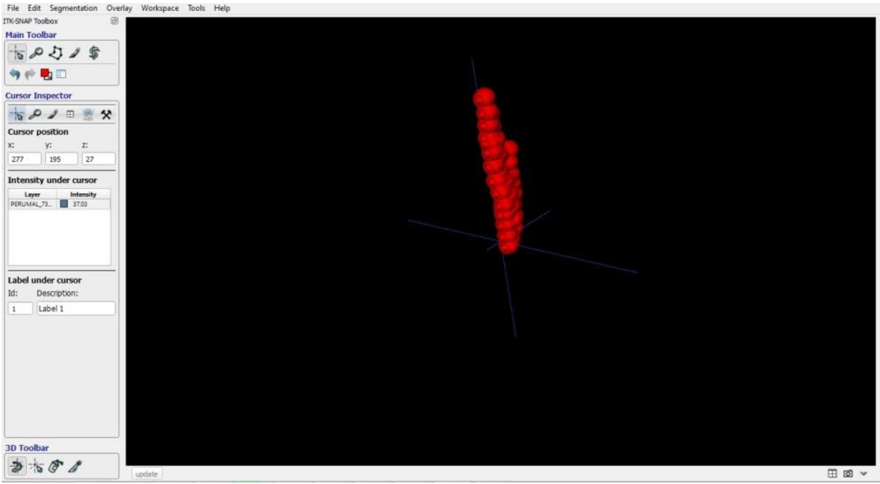

Fig. A-3. Final 3D model.