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Segmentation and 3D Visualization of Human Femur Bone from CT Images using CAD Tool

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ABSTRACT

Over the most recent couple of years, the advancement in the field of design and methodologies of careful strategies made the surgeons simple to handle with the medical procedures by decreasing the risk of the patient. The fundamental point of this work is to foster a 3D CAD model of femur bone from CT scan images, which can later be utilized in design of implants, substitution of bones and 3D printing. The femur model fond is saved in STL document design for additional processing.

KEYWORDS: Femur bone; CT scan images; DICOM images; 3D Slicer; STL

INTRODUCTION

The human skeleton is made out of around 270 bones at the time of birth and decreases to around 206 bones by the adulthood. The human skeleton performs six significant capacities: support, movement, protection, creation of blood cells, stockpiling of minerals, and endocrine regulation. The pelvis is the lower part of the human body between the abdomen and the thighs. The hip joint is one of the most essential joints inside a human body. This joint has the biggest weighing capacity of human body. The hip joint is a ball and socket joint. It frames an association between lower limb and pelvis as displayed in Fig. 1. In this way, it is intended for stability and weight bearing. Every hip joint should have the option to support a large portion of the complete body weight just as some other external forces following up on the body. It assists with keeping up with stability while standing, walking, step climbing, downstairs, running and so forth hip joint gives articulation between the top of the femur and acetabulum of the pelvis.

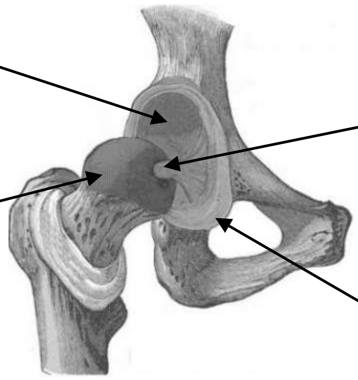

Fig. 1: The anatomy of hip joint

Fig. 1 shows that, the acetabulum is a cup-like depression situated on the pelvis. The acetabulum is exceptionally deep and encloses practically the entirety of the femoral head. Its cavity permits loads to be dispersed straightforwardly through the joint and into the femur while keeping the femoral head from slipping out of the socket. Around the outside of the acetabulum is a fibrocartilaginous ring which further expands stability of the hip by giving a large contact surface region for the femoral head. This is known as the acetabular labarum. The head of femur is of hemispherical shape and fits completely into the cavity of the acetabulum. Both of the acetabulum and head of femur are covered via cartilage, which is thicker at the spots of weight bearing. The acetabulum is framed at the connection of three bones specifically, ilium bone, ischium bone and pubic bone. Femur or thigh bone is the longest and strongest bone in the human body that is joined to pelvis. The one end (i.e., upper finish) of the femur bone is having a round head that articulates inside the acetabulum in the pelvis and structure the hip joint, while the opposite end (i.e., lower end) articulates with the tibia and kneecap, shaping the knee joint. Femur is a weight bearing bone and most and its weakest portion is the femoral neck. The fracture of femoral neck is perhaps the most widely recognized phenomena to the old person.

1.1 General Complications with Hip Joints

There are few problems related to hip joints:

i) *Osteoarthritis*: The most common hip issue in older individuals and as usually develops more than 45 years old albeit more youthful individuals can in any case be affected by the condition. It causes a lot of pain and discomfort in the hip joint and surrounding region. Osteoarthritis happens when the layer of cartilage between the femoral head and acetabulum erodes or breaks down. At the point when this occurs, bone on bone contact starts to create between the two surfaces of the joint and the surrounding tissue gets inflamed. Over the long run this can prompt stiffness and restricted movement of the joint.

ii) Fracture**:** Another problem is fracturing or breaking of the hip. However, the hip absorb shock yet, on the off chance that an impact force from exercise or a fall is significantly high, the hip might fracture or even completely break as it just can't disperse the shock from the impact. The individuals who have osteoporosis of the hip are at a lot higher chance of this problem occurring as the bone is brittle, even though this is substantially more pervasive in older individuals.

iii) Abnormal shape of femur: This problem occurs due to the abnormal shape of femoral head and acetabulum which makes rubbing together.

iv) Rheumatoid arthritis: Similar to osteoarthritis, a condition that causes swelling and stiffness in the joint.

v) Labarum Tear: A tear in the acetabular labarum

vi) Hip dysplasia: Another type of defect in hip joint. It causes inflamed ligaments and infection in the surrounding area.

1.2 Medication and Recovery:

Generally, these issues can be overseen utilizing pain medication and anti-inflammatory medications. Be that as it may, in serious cases like when the hip has been fractured or cartilage has been annihilated, surgical intervention is regularly required. There are a few kinds of hip medical procedure, each used to fix a particular issue, yet for complete replacement of the joint, a total hip arthroplasty (THA) or total hip replacement (THR) is required.

1.3 Total Hip Arthroplasty (THA)

In total hip arthroplasty, the damaged hip joint is replaced with a prosthesis which is implanted in the body. as shown in Fig. 2. A total hip prosthesis has three parts:

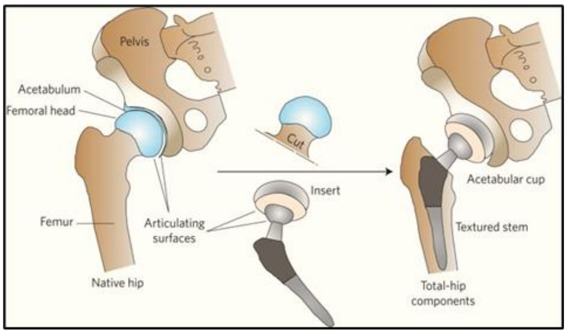

Fig. 2: Total hip arthroplasty

- A plastic cup to replace the acetabulum.
- A metal, polymer, ceramic or composite ball to replace the femoral head.
- A metal stem which is attached to the shaft of the bone.

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Implants or prostheses are accessible on the market, for certain standardized sizes and dimensions. Likewise, they are sold under three primary classifications; cemented, uncemented, and hybrid sort in any case, of some standard shape and size.

i) Cemented Implants: Cemented prostheses are fixed with bone utilizing an acrylic thermosetting polymer called polymethylmethacrylate (PMMA). The cemented bond gives a strong and dependable permanent fixation to the prosthesis. The principle complication of cemented hip implants is removal of embed because of concrete loosening and breaking from the parts. Likewise, concrete debris might contaminate encompassing tissue and cause inflammation nearby.

ii) Uncemented Implants: The implants are designed so that the actual bone is the alone source of fixation for the parts of the prosthesis, with no external bonding required. This is accomplished by take into account bone ingrowth, or osseointegration, which gets more grounded over the long time. No issues exist like cemented hip implants. More youthful patients with dynamic lifestyles are by and large given uncemented implants. The fundamental impediment is loosening of embed because of helpless bone fixation. Uncemented hip implants are for the most part more expensive than cemented because of the assembling strategies required.

iii) Hybrid Implants: The hybrid implant, combines a cemented component (usually femoral stem) with an uncemented component. This prosthesis is a compromise between the conventional methods of fixation to reduce the amount of cement used to secure the implant, thus reducing the chance of loosening.

1.4 Major Geometry of Proximal Femur

The following parameters comes under the geometry of femur to understand the anthropometry and eventually designing a best-fit femoral stem as shown in Fig. 3.

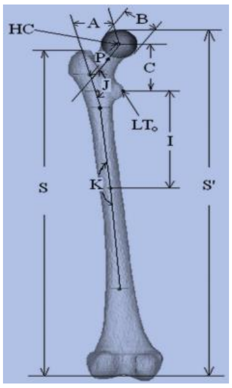

Fig.3: Measurement of femoral head offset (A), femoral head diameter (B), femoral head position (C), isthmus position (I), neck shaft angle (J), bow angle (K), femoral neck length (P) and femoral lengths (S)

- Femoral Head Offset (A)
- Femoral Head Centre (HC) and Femoral Head Diameter (B)
- Femoral Head Relative Position (C)
- Position of Shaft Isthmus (I)
- Neck-Shaft Angle (J) and Bow Angle (K)
- Femoral Neck Length (P)

2. Literature Review

In this research the literature has been reviewed in three aspects:

1. Anatomy of hip joint (healthy, injured, degenerated etc.)
2. Comparison of healthy hip joint and hip joint with implant and its suitability.
3. Customize hip implant, geometrical measurement and its suitability.

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The morphology and statistical analysis of proximal femoral anthropometry among different populations reveals a great amount of variation. The aim of their operations is to restore femoral anatomy to the normal as far as possible. This study will help the biomechanical engineers in altering the implant designs to suit the needs of Indian Population" Sultan et al. (2018). Lee and Chang (2009) suggested an integrated methodology of CAD and CAM for the concurrent development of custom-made femoral stem. A customized femoral stem was created and the geometric parameters dependent on surgical experience were integrated into the CAD system. The rapid prototyped model was worked for review. They work on CAM software for identifying the toolpath and the cutter location on NC machine. The cutting simulations for solid model are performed and generated toolpath had been verified. Ali et al. (2016) shows replacement of natural hip joint with an implant under Total Hip arthroplasty (THA). During the beyond couple of decades a few revisions were done because of improperly designed or inadmissible implants to the patients. The improper design might lead to certain issues like aseptic loosening, blood clots and infection around the implant and so forth. To stay away from this, there exist a strong necessity of properly simulated new plans of hip implant. The current work shows the plan and analysis of femoral stem part of a recently designed hip prosthesis alongside parallel comparison with pre-established plan finished with fabrication done one of the rapid prototyping techniques called fused deposition modelling. Lingamdenne and Marapaka (2016) evaluated the Osteometric measurements of the dry human femur (real bone available in medical colleges) of Hyderabad and Secunderabad population. Twelve parametric variables related to the femur were obtained from the head, neck, shaft, and distal end of the femur. The observed measurements were subjected to statistical analysis in the Hyderabad and Secunderabad regions are reported and the results are presented in their research. Talip, and Kişioğlu (2019) prepared a new design of stem for both cemented and uncemented implants. Mesh convergence study was performed by refining the element size from 6 to 2 mm at the 0.5 mm interval for the femur, 4 to 1 mm at 0.25 mm interval for the prosthesis and 2 to 0.5 mm at 0.25 mm interval for the cemented models. Uncemented hip prostheses are at the high risk of dislocation. The load values for FEA just regular walking have been considered. The other loading conditions might change results. Material properties of the FEA models were characterizing as isotropic material SolidWorks: Femur model was generated utilizing Computer Tomography (CT) images and Ansys Workbench to break down the system. Chethan et al. (2019) reported, four diverse stem shapes are designed as implant for the femur bone. Customized demonstrating has been done from the computed tomography images. Static structural analysis is performed on these models utilizing ANSYS. Identify the best design among these four models. The maximum total deformation was observed to be at the highest point of the femoral head, and von Mises stresses were more at the junction. Concludingly, these designs could be utilized for fatigue tests under dynamic conditions to predict the life of the implant. Siwach (2018) suggested the implants for fixation of proximal femur fractures and joint substitutions have been designed thinking about of the anthropometry of the Western population. His review depended on the morphology of the upper end of femur as for different diameters and angles alongside the external and internal geometry of proximal femur as acquired from radiographs in Indian population. Standardized techniques to get different anthropometrics measurements. It is recommended that implants designed for Western populations ought to be utilized judiciously and future implants be designed to match the morphology of the Indian bones. Rawal et al. (2012) reported measurements using computer aided design techniques based on computed tomography (CT) scanned images. The software used to convert the CT images into solid models was MIMICS. Kamath et al. (2020) reported geographical variety in proximal femur morphology to design uncemented femoral stems for south Indian population. A huge distinction was noted across different population subsets inside the Indian subcontinent and furthermore in contrast with the Western population

Latham and Goswami (2004) considered two 3D models were drawn, one modular and one integrated implant. These models were then altered geometrically one variable at a time, and finite element analysis (FEA) was performed on the models. Ro (2018)

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suggested femoral acetabular impingement after total hip replacement reduces range of motion (ROM), which leads to dislocation problems. Rahmati et al. (2012) shows, a time and cost-effective investment casting technique, based on AM technology, was used for fabrication of the prosthesis. Deokar and Thakur (2016) attempts to use the advanced Computer Aided Design and Finite component Analysis to see the stress inside the femur bone, and help the manufacture of artificial joints and limbs. This strategy takes input from CT scan or MRI, that is then taken care of into CAD by utilizing diverse programming resembles MIMIC and 3D slicer. Baradeswaran et al., (2014) applied reconstruction of images into 3D models using CAD techniques. Their strategy takes input from CT scan and converted to CAD model using MIMICS. George et al, (2016) reported 3D slicer as one of the powerful tools in understanding and treating structure lung diseases. Velazquez et al., (2013) shows volumetric CT-based segmentation of NSCLC using 3D-Slicer. Radu (2005; 2006) shows the applications of Computer Graphics in a 3D reconstruction of human ankle. Further, he suggested the automatic Reconstruction of 3D CAD Models from Tomographic Slices Via Rapid Prototyping Technology. Chen et al., (2017) showed 3D printing and modelling of customized implants and surgical guides for non-human primates. Oyama et al., (2013) worked towards improved ultrasound-based analysis and 3D visualization of the fatal brain using the 3D, Slicer.

3 Research Motivation

Improvement of innovation in clinical applications made the surgical strategies simple by diminishing the time factor to cure a patient. Specialists alongside engineers are simultaneously working together for the better comprehension of medical procedures on regular basis. Presently, the vast majority of the elderly persons are experiencing bone or joint wear issues due to aging of load bearing joints and their degenerative nature. One of the significant issues in surgical operations is the fracture of bones. This causes excessive pain on the joints while working. The essential clinical medicines will just reduce the pain temporarily. Sometimes the substantial damage of the bones leads to the entire part replacement. The replacement of damaged bone joint with artificial clinical implanted joint is the generally reasonable and long-lasting answer for these types of issues. However, the patient specific implants (customized implants) provide more body movement conditions and at minimum time to fix the problem with extremely less amount of pain. The patient specific implants are created with the specific individual's body geometry and medical or clinical conditions. To understand the bone condition and then further whether to fix it with the implants, a 3D Model of bone is required. In this paper, a patient-specific or customized femur bone is modelled from CT scan information. The Computer Tomography (CT) scan framework is utilized as information securing for producing joint bone calculation information in Digital Imaging and Communications in Medicine (DICOM) design. After obtaining the DICOM images, an open-source software programming such as 3D Slicer issued to change over DICOM information into CAD available STL record of bone joint model. The step-by-step methodology is as follows: Collection of Digital Imaging and Communications in Medicine (DICOM) images from the hospital.

i. Importing the DICOM images in 3D Slicer.
ii. Permitting the volume rendering option to show the 3D view.
iii. Selection of the type of bone, which removes all the unwanted things like skin, muscles and nerves.
iv. Correcting the frequency range to get a clear 3D image of the portion.
v. Cropping the volume to the required part.
vi. Editing the cropped part, for the better 3D model.
vii. Adjusting the threshold frequency.
viii. Enabling model effect option to get a final part.

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ix. This part is saved in .STL file format.

x. The nonlinear elements and errors are removed and softening of the part is done to get a better surface finish.

a. Construction of 3D model of femur

3D slicer is a free and open-source software that is widely utilized in clinical or clinical applications for the representation of pictures. In this work,3D slicer is utilized to fabricate the CAD model of the human femur from the CT scan pictures gathered from the medical clinic.3D Slicer is the software utilized in this work for the development of 3D CAD model of femur bone from the DICOM (Digital Imaging and Communications in Medicine) documents or CT (computed tomography) scan pictures gathered from the diagnostic centre.

b. Steps for segmentation of femur

The CT data of femur of normal individual male patient of 39 years is collected. This geometrical data of real proximal human femur bone is in the form of Digital Imaging and Communications in Medicine (DICOM) files. The CT scanning of patients are obtained using GE Ultrafast High Resolution Multislice CT Scanner (16 Slice) as shown in Fig. 4. containing total number of 504 images, pixel size of 0.7031 mm, 0.8867 mm and 0.9766 mm respectively, slice thickness of 1.5 mm and resolution of 512 x 512. DICOM file is a standard for handling, storing, printing and transmitting information in medical imaging and contains binary data elements.

Fig.4: GE Ultrafast High Resolution Multislice CT Scanner

Fig. 5 shows the screenshot of the 3D slicer window which will show the appearance when it will start for the first time.

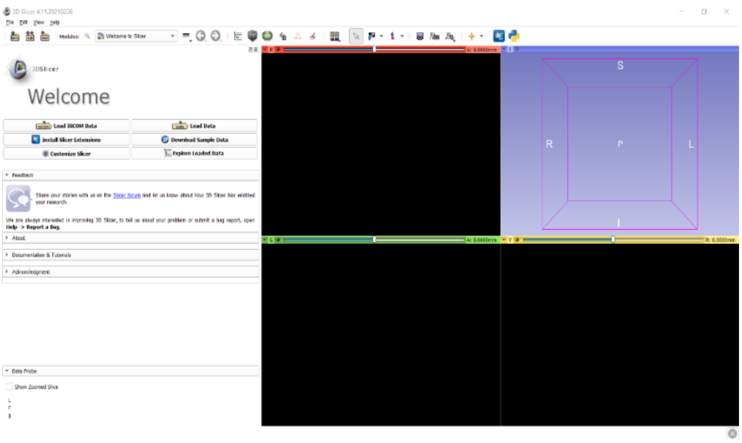

Fig. 5: 3D Slicer window appearance at start

Once the slicer is open then we have to load the data that can be done with the tab load DICOM data indicated with an arrow below as shown in Fig. 6.

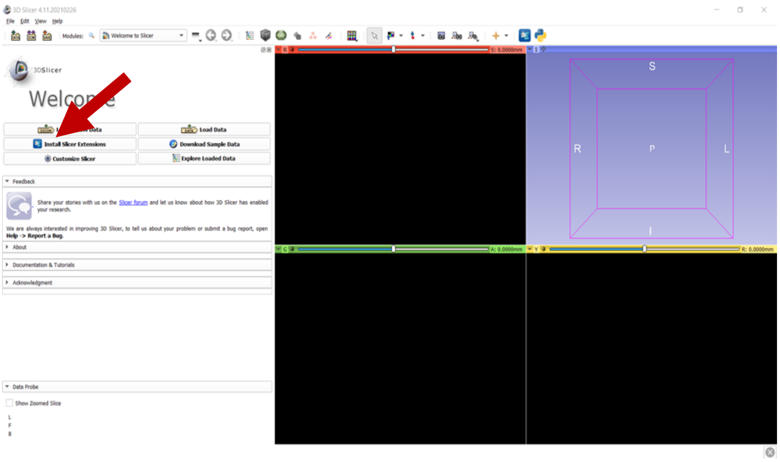

Fig. 6: Loading of DICOM files

After clicking the load DICOM tab we will get the screen which is shown below. We need to select the data of the appropriate person and that data will get uploaded to the screen and which will appear as shown in Fig.7.

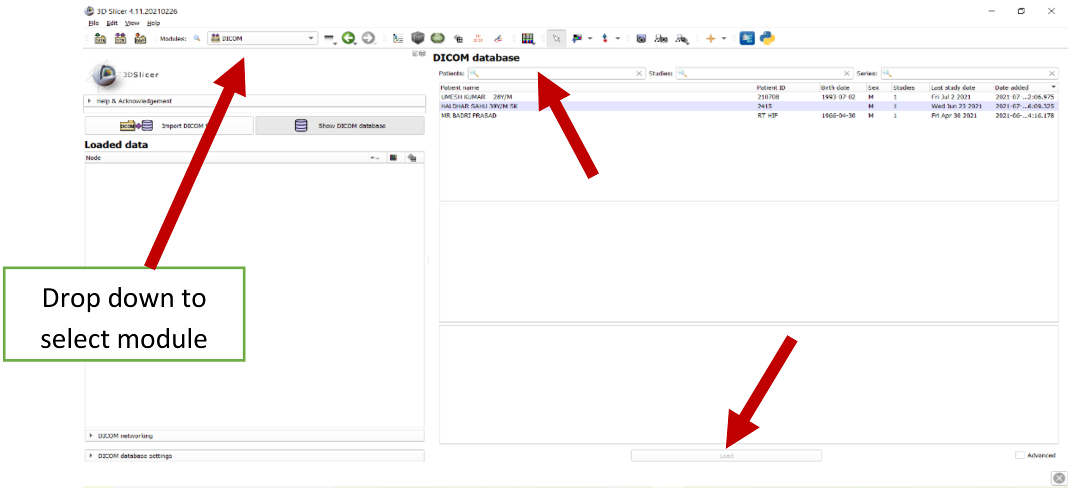

Fig. 7: Procedure of loading DICOM files

Once the files are loaded the screen will appear as shown below in Fig.8.

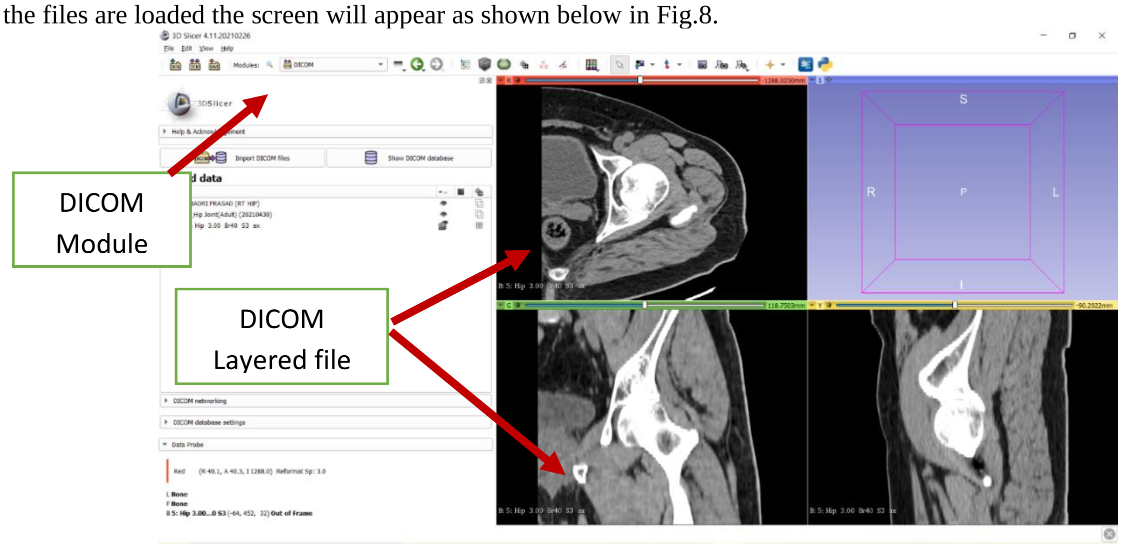

Fig. 8: Loaded DICOM layered files

Once the data is uploaded then the next step is "Volume Rendering". Now, select an appropriate area where the actual portion exist work from the directly scan file of the femur. In the previous steps no volume rendering process has been done. After uploading the DICOM files and enabling the volume rendering feature the visualization of the files on the slicer window in 4 views i.e., axial view, three-dimension view, sagittal view and coronal view is observed as shown in Fig.9.

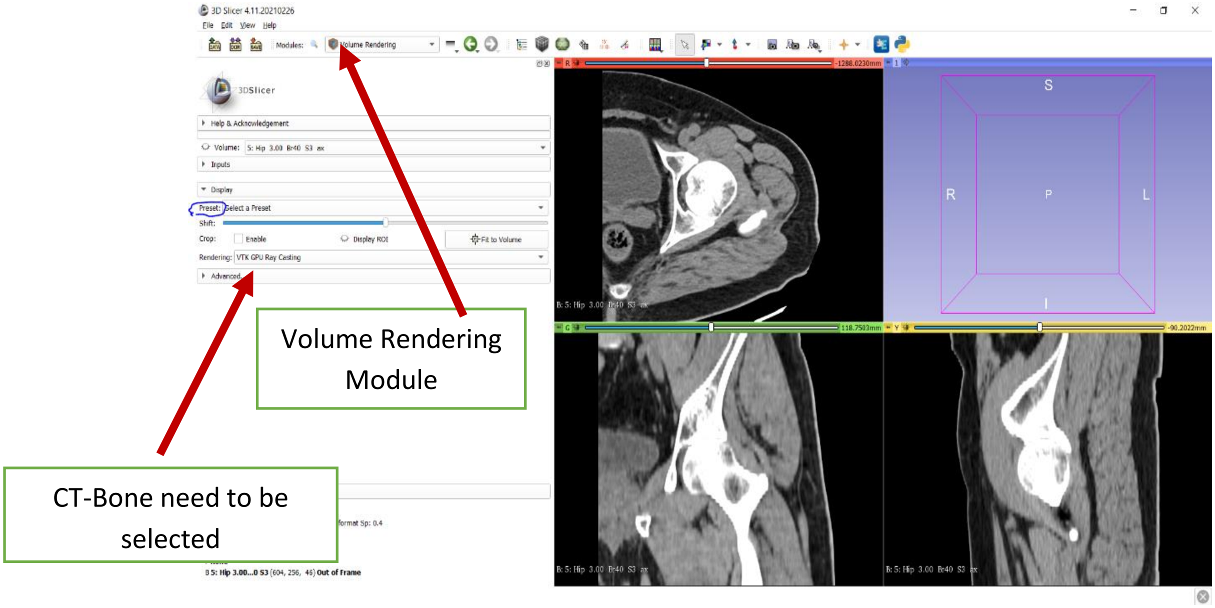

Fig. 9: Volume rendering

Fig.10 shows that in volume rendering we have one tab pre-set in this we select weather which part of the DICOM file we need to see whether we want to see the muscles or we want to see only the bones as per our interest area, we have selected over their bones.

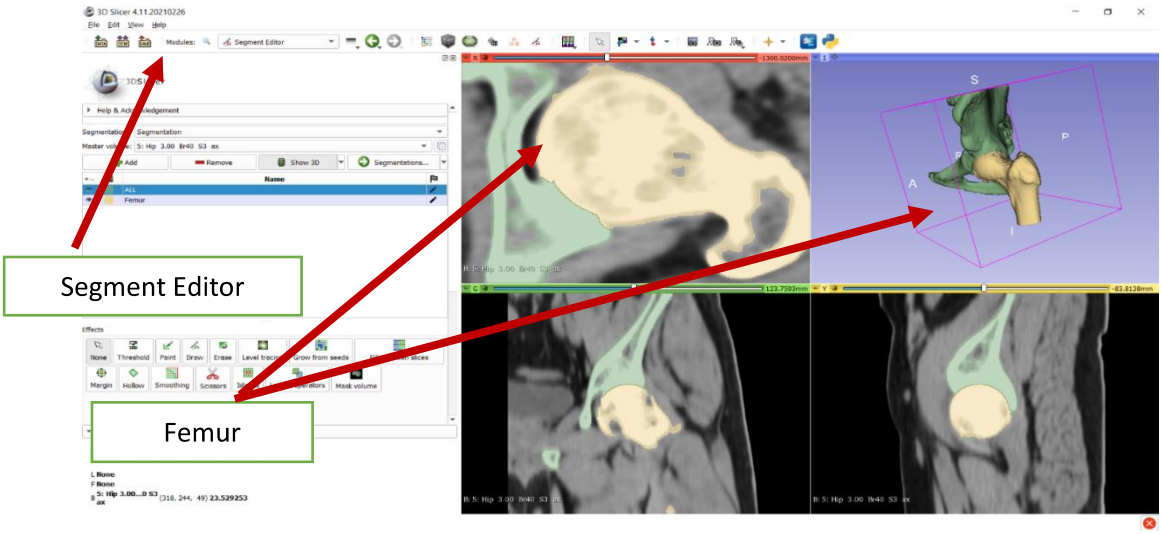

Fig. 10: Segment Editor

Once volume rendering is done, we have started doing the segmentation in this we have segmented femur from the other part of the bone, in the above figure it can be seen the segmentation tab. Once the segmentation is done we can have a 3D model in the fourth window it is evident from the figure that femur segmented differently appearing in different colour and rest of the path is appearing in different colour this is the most important step in the modelling of bones from the DICOM files as it requires careful use of the modelling tools present in the segmentation tab like paint draw thresholding grow from seeds all these steps are used for doing the segmentation from the DICOM file as shown in Fig. 11.

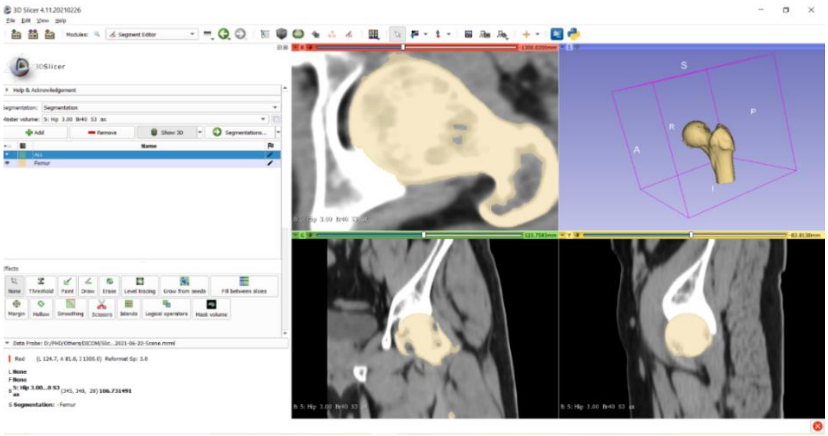

Fig. 11: Segmentation

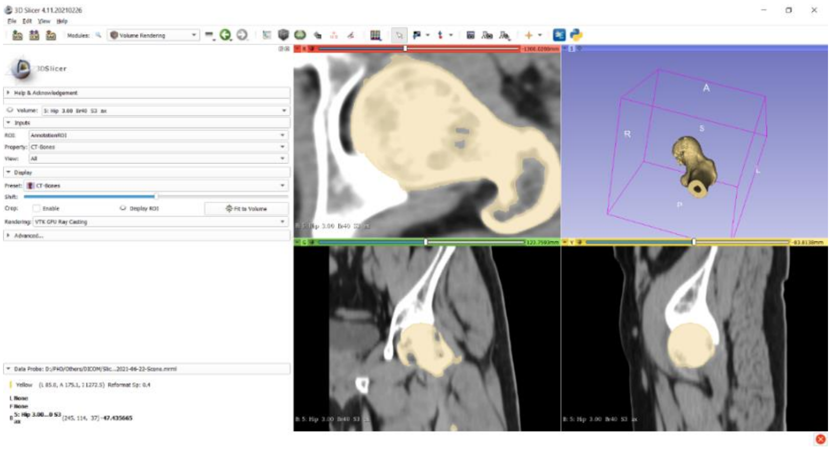

Fig. 12: 3D Slicer window appearance at start

Fig. 12 shows switch on and off the different segmented areas as our interest area is femur so rest other bones are switched off, which can be seen in the above figures. 3D models can now be exported as an STL file for the further analysis.

4. Another graphical illustration

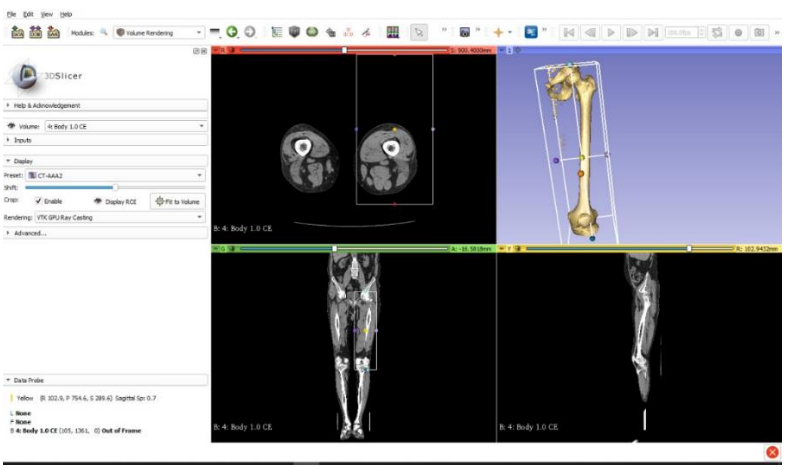

Fig. 13: Volume rendering

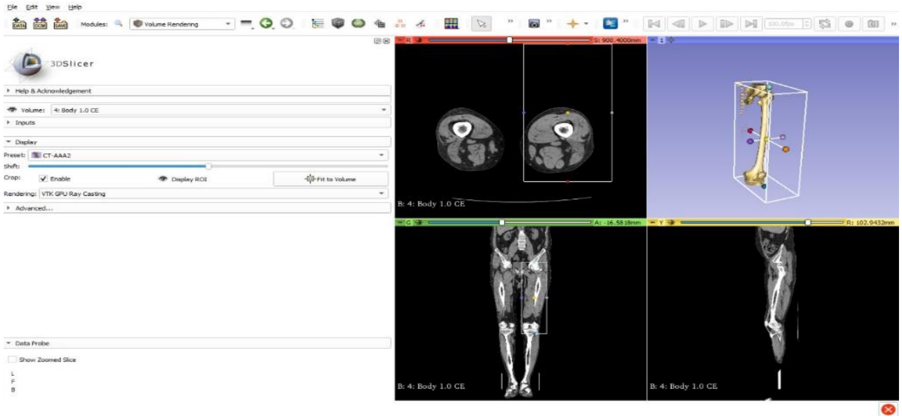

Fig. 14: Thresholding

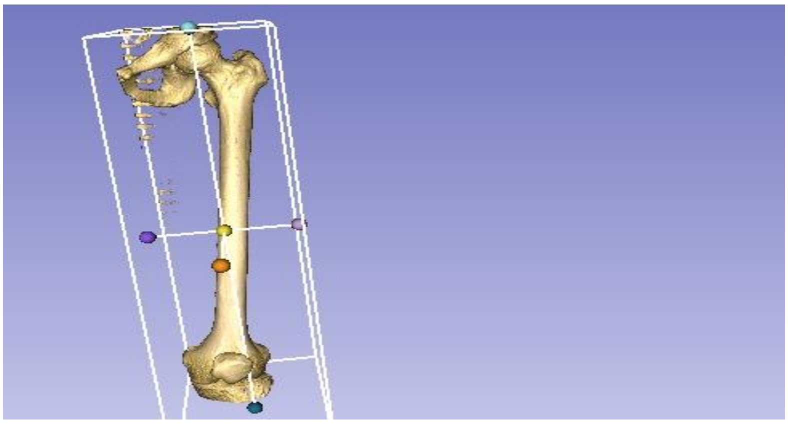

Fig. 15: Unsegmented femur

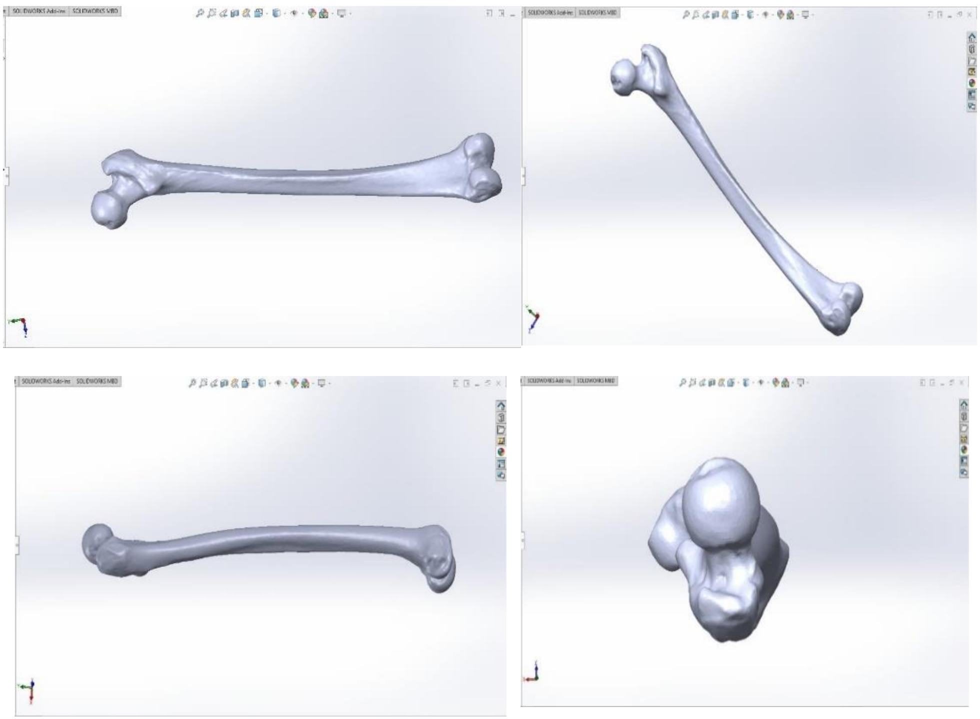

Fig. 16: Different views of segmented finished femur

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5. Conclusion

Slicer software is effectively used for the reconstruction of human femur bone from the patient-specific DICOM or CT scan images. The obtained model is used for further applications like 3D printing of a femur bone to use as a prototype, for carrying different analysis on femur bone, impanation study on femur bone and in other medical application to ease the surgeries of doctors.

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