

Computer Aided Techniques for Knee Implant: Case Study

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Abstract— Combination of biomechanics, material science and expertise of surgeon plays an important role in Bone tissue engineering. Many researches are being performed worldwide in developing novel scaffolds for tissue engineering. The field of tissue engineering brings together the multidisciplinary research of life sciences and engineering to seek man-made substitutes for the regeneration of damaged tissue or organs. A key component in tissue engineering is the use of porous scaffolds to guide cells for attachment, proliferation and differentiation in the tissue regenerative process. Upon satisfactory in-vitro culture, this engineered living scaffold is implanted into the regeneration site of the patient to function as the tissue substitute. Using CATE, the design of intricate three-dimensional architecture of scaffold can be realized and these scaffolds can be fabricated with reproducible accuracy to assist biologists in studying complex tissue engineering problems. Recent advancement in Medical imaging technology and Biomedicine have created new uses for CAD with important biomedical applications, particularly tissue engineering in which CAD based bio-tissue informatics model provides critical information of tissue biological, biophysical, and biochemical properties for modeling, design, and fabrication of complex tissue substitutes. This paper gives methodology to construct 3D CAD models from CT image and the application of this model with implant on femur fracture

Keywords— Bio-CAD; Rapid Prototype; Computer aided tissue engineering; styling; insert

I. INTRODUCTION

Advancement are made in computing technologies both in terms of software and hardware have helped in the advancement of CAD in Bio-medical applications beyond that of traditional design and analysis. Bio-medical engineering is an emerging future technological field with great potential. This field encompasses medical treatment engineering, tissue engineering, genetic technology, and Medicine engineering [1,2]. Building sets of medical information, medical images, and bio-medical materials and applying these sets of medical data assists in the development of all aspects of biomedical engineering. In recent years, CAD has been increasingly applied in bio-medical design. Bio-CAD is a specialized field where deep study includes computer-aided surgery [7], regenerative medicine engineering, tissue informatics [8], structural modeling of tissue, design of orthopedic devices and implants, design of tissue scaffolds [9], reverse engineering (RE) and 3D reconstruction [10,11], heterogeneous tissue modeling [12], and solid freeform fabrication or bio-manufacturing [13,14]. Diagnosis of fracture is very difficult by x-rays as it does not allow surgeon to detect the crack clearly, whereas CT medical imaging is the key tool for

viewing the internal structure of the human body [15]. Medical images in 3D solid models are therefore very important in the diagnosis and treatment process. All reconstructed 3D solid models can be converted to RP physical models and Virtual Reality Modeling Language (VRML) format for visualization [16–19].

Providing basic morphology, anatomy and organization of the to be replaced tissue on which biological intent can be introduced can play important role in Bio-CAD modeling. For example, the definition of the cell-specific scaffolding biomaterials (for cell attachment), the material compositions (for scaffold controlled degradation), pore size, pore shape and ideal topology for inter-architectural connectivity (for cell proliferation, differentiation and new tissue growth), and the prescribed surface chemistry and topography (for cell mechanosensation).

Basically, Implants are made for regeneration of tissue when there are defects in articular cartilage. Articular cartilage is difficult to diagnose. There isn't a test at present that can be carried out as part of physical examination that can reliably diagnose an articular cartilage injury in the same way as you can, for ligament injury. The history of your problem can provide many clues. This regeneration of tissue needs the scaffolds to be accurately designed with suitable material bio-compatible with patient body. Recently many techniques are made to develop scaffolds.

II. GENERATION OF 3D CAD METHODOLOGY:

A. Step 1: Image Format Recognition and Interface:

Recently many CT/MRI scanners are technically advanced which can scan an image with wide range of formats that can be recognized and utilized (Philips, GE, Hitachi, Picker, Siemens, Toshiba, and Elscint). Software like Mimics, 3D doctor and ScanIP have tools that allow the recognition of almost all image data, including technical scan data. These software's can automatically detect the format of images which are imported and stored as a dataset. Interface problems of transferring data between various medical and engineering software packages and formats can be solved. Medical imaging data can be interfaced to various software environments as required.

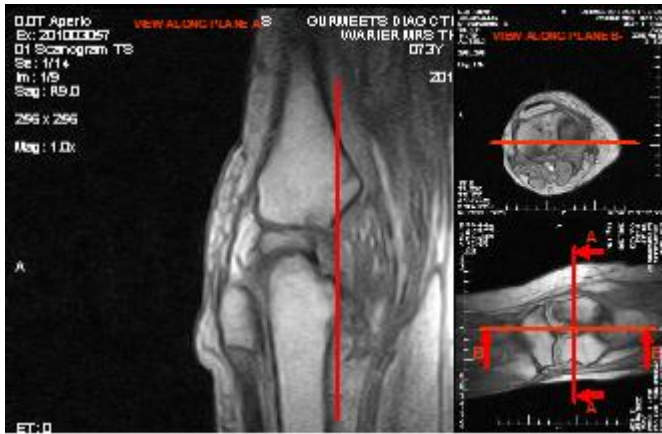


Fig. 1 Image format recognition and interface

B. Step 2: Image Processing and Tissue Identification

Wide ranges of tools give us the power to enhance the image data generated by the CT or MRI scanner. It is possible to enhance contrast; perform a fully automatic tissue selection; draw or erase tissues on each image as well as localize tissue selection; display the original scanned data along with two reconstructed views in the orthogonal planes and move images in each view in real time

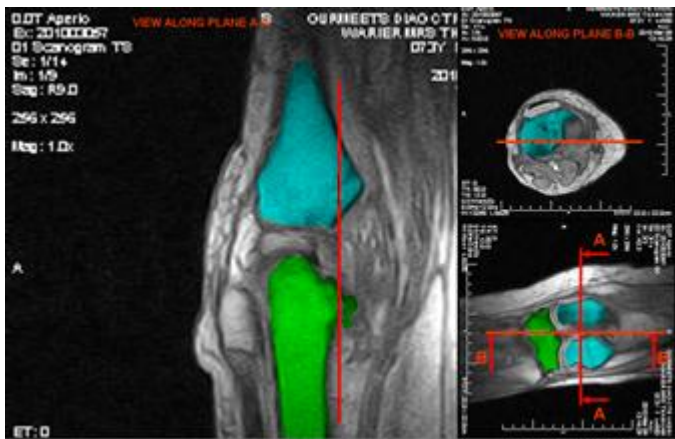


Fig. 2 Image processing and tissue identification

C. Step 3: Three-Dimensional Reconstruction

3D CAD models can be reconstructed from CT/MRI images with the medical software's available and these models can be exported to many formats for recognizing it in CAD software's. In CAD, these models can be oriented, rendered and sectioned as per user requirement. These CAD model can then be used for making stereolithographic which will help to make rapid prototypes and for surgical jigs and templates. Advanced visualization methods also allow the combination of the model or the images with Computer Aided Design (CAD) objects.

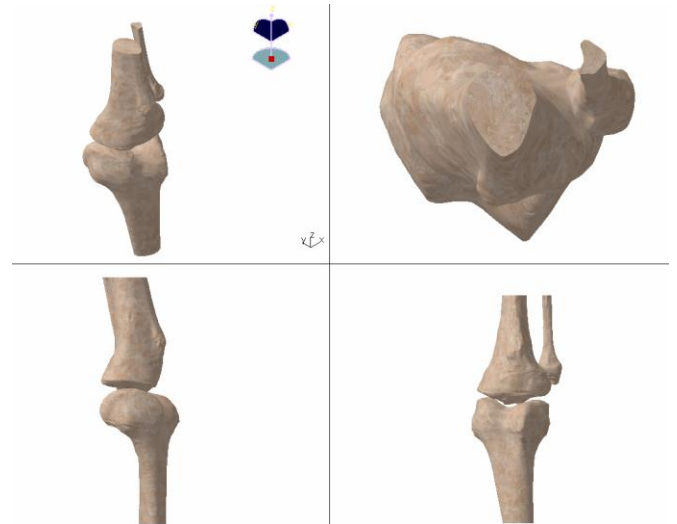


Fig. 3 Three-dimensional reconstruction

D. CAD Modeling of Anatomical Structures

Once the CAD model is constructed then it helps to select the suitable knee implants available in market. Also, it further helps surgeon for making plans before surgery. CAD generated within original imagining data and organs of complex geometry for the combination of medical devices in CAD environment. This CAD environment further helps to surgeon to have some special tools if needed, because the type of fracture is different in different cases. The anatomical structures developed from CAD further helps for making presentation and publication which enrich the knowledge base, which further helps to have a scope in improvement for other similar case. The only important challenge is how accurately these CAD environment is constructed.

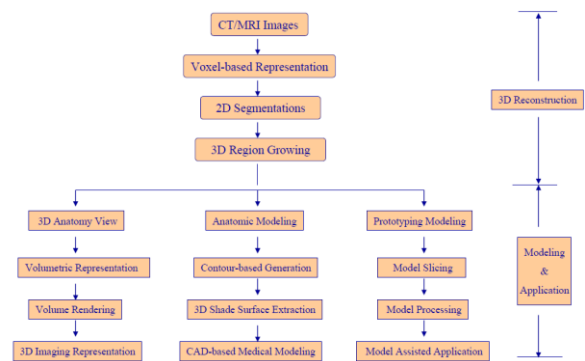


Fig. 4 Roadmap from CT/MRI to 3D reconstruction

III. CASE STUDY

Case study started with one patient with large defect of lower femur fracture has received individual prostheses for reconstruction. Patient data were acquired with MRI scanner. The MRI scans were delivered at 0.1mm intervals. Consistent setting of both the acquisition parameters and the scan reconstruction parameters was a must for consecutive 3D geometric reconstruction.

We started with 226 sections fig23, available as Dicom in std. format. The margins of bone were determined in the software Mimics 10.01 accordingly to statistical methods (cluster analysis, thresholding). The threshold frequency of

area of interested bone were selected by the command 'Draw profile line' by which the line profile is draw near to the bone and the frequency range window appears on the desktop as shown in fig 24. The whole proximal bone structure was grown into one single color mask representing one single threshold range as shown in fig 25. With this approach, the average threshold value for the whole structure could be obtained. This average threshold value was in turn correlated to the quantitative computed tomography number (QCT#) represented in Hounsfield units (HU) by using a simple relation as follows:

QCT# in the range of Threshold Value 208- 2385

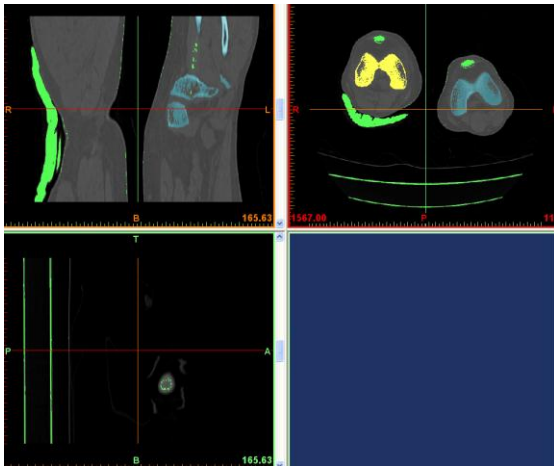


Fig. 5 Imported Dicom images in Mimics 10.01

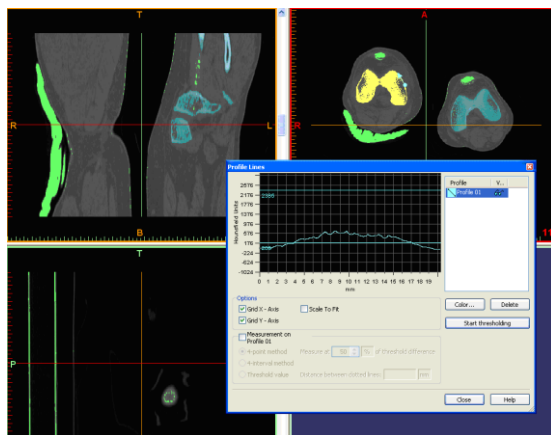


Fig. 6 Threshold with suitable frequency in Mimics 10.01

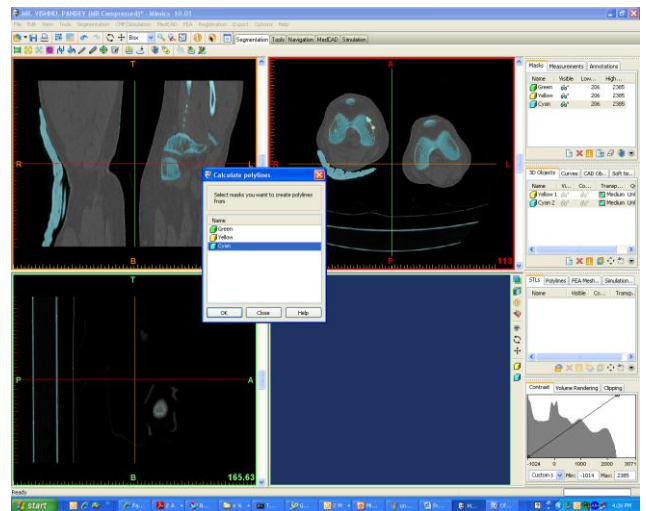


Fig. 7. Calculation of polylines in Mimics 10.01

The reduction of the bone density pixels yielded the basic data for the representation of the bony structures. The scan data was converted into 3D counter models Fig. 7. If clearly seen in the image we receive other garbage data. There is a limitation of software mimics which cannot remove the unnecessary garbage. Also, it is not good to build surfaces and solid models. Hence it becomes necessary to export the data in other good software CAD packages. IGES (Initial Graphics Exchange Specification) defines a neutral data format that allows the digital exchange of information among Computer-aided design (CAD) systems. The iges data was first imported in unigraphics Nx6 (Siemens PLM Software NX (formerly Unigraphics NX) covers the entire digital product development process with a suite of CAD, CAM and CAE software). The garbage data is first removed as shown in Fig. 9, and then the bones are separated to different individual files so that the file size becomes small and becomes easy to work on CAD. The detailed steps of cad modeling of bone are explained in Reconstruction of 3D model. Then all the individual solid model files of bone are exported in single file as shown in Fig. 10. Then the left bone data is superimposed on right defected data to identify the damage. The detailed roadmap steps from MRI imaging data to 3D solid data are shown in Fig.10.



Fig. 8 3D counter model converted from scan data. In mimics



Fig. 9 3D solid models from curve data in NX5 and rendered in Rhinoceros.

The generation of freeform surfaces in the CAD/CAM system required during first applications. This model was compatible to CAD and allowed geometric manipulations including the construction of attached functional elements. The patient had stored the Dicom file of his body parts under med claim library. The same data was used to build 3D cad data. With these data defected parts were identified and pre-surgical cutting plane was identified on the 3D solid model.

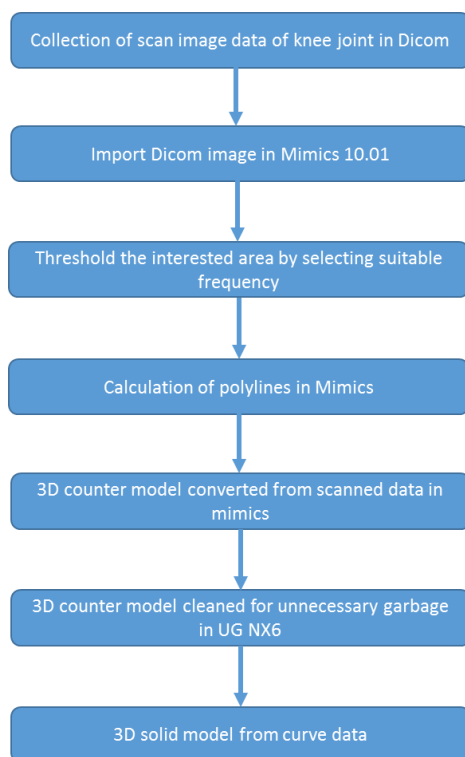


Fig. 10 The detailed roadmap steps from MRI imaging data to 3D solid data.

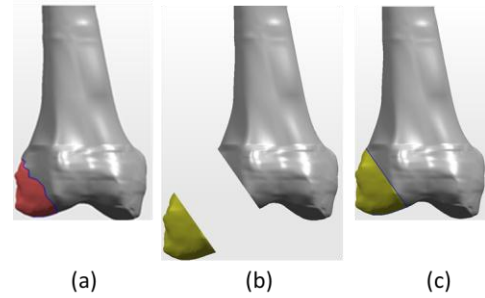


Fig. 11 (a) Identification of fracture on 3D data (b) Cutting plane to remove defected part properly. (c) Implant fitting after surgery.

With the cut data 3D prototype was prepared and checked for the fitment as shown in Fig. 11 (a). With the corrected prototype, actual implant was prepared and fitted to the patient with surgical methods by doctor as shown in Fig. 11 (b). The implant was fitted with the help of jigs and templates for better position and orientation as shown in Fig. 11 (c).

IV. RECONSTRUCTION OF 3D MODEL

Dicom file was imported to IGES format. Then surface to solid model was done by using software tool Unigraphics Nx6.

- A. Image based modeling by using Unigraphics Nx6.
- B. Iges curve data was imported to unigraphics Nx6.
- C. The imported curves were continuing and sharp. Hence the curve was divided into segments at every sharp corner.
- D. The sharp corners were smoothed by using the command Edit curve – smooth spline.
- E. Then surface between two curves were created by using through curve mesh command by selecting two primary curves and two cross curves.
- F. Then surface between two curves were created by using through curve mesh command by selecting two primary curves and two cross curves.
- G. Adjacent surface was created by applying tangency of earlier surfaces.
- H. After creating surface model, the model was having poor geometry (garbage surfaces). These surfaces were cleaned and new surfaces were created with proper tangency.
- I. Then the surfaces were stitched with 0.0001 mm tolerance. At these times, some surface found gaps as there mating tolerance were out of tolerance. For that surface, new surfaces were created for stitching it under tolerance. The stitching operation was made by sew operation.
- J. After sewing operation solid model was created by making 1 rectangular block covering the sew model and then subtracting the sew model from rectangular block.
- K. Thus, the solid model was created as shown in below Fig. 11

V CONCLUSION

A. The application case studies also show the capability and potential of computer aided tissue engineering. CAD in conjunction with advanced modeling and freeform fabrication technology can create scaffolds that go beyond conventional designs currently used in tissue engineering. It can create complex structures with functional components that are difficult, if not impossible to create with conventional chemical based tissue scaffold fabrication techniques.

B. The CAD model formed the data base of customized artificial joints applied in clinic medicine, in which we can select a suitable kind of artificial knee joint model to customize for the patient.

C. The application of CATE to tissue engineering also allows, for example, controlling and designing the overall shape of the scaffold to match a patient's CT or MRI data; the internal architecture (pore size, porosity, and interconnectivity) by using the power of CAD techniques; heterogeneous scaffold with different mechanical and geometrical properties, and to freeform fabricate the designed scaffolds.

D. This case study represents the first step of a wider experimental protocol regarding implant creation for bone regenerative medicine, and tested the CAD/CAM elaboration of the scaffold external complex surface.

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