Extraction and Analysis of Knee Joint Parameters by using CAD base Solid Modelling Techniques

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ABSTRACT

The success of the custom made human joint replacement surgery depends on exact extraction of the geometric shape and size of the joint. Further enable its modelling and manufacturing [7]. The accurate prostheses design will lead the patient's long term comfort and range of motion. The geometry of knee joint was extracted from CT (computer tomography) scanning. The 3D model of knee reconstruction helps in a better understanding of anatomical functionality and morphological analysis [2]. The 3D solid model was developed from 2D CT images using CAD software like Pro-E creo parametric, NX6.0 and MIMIC 10.0.The model developed was validated by measuring various geometric parameters like Anteroposterior diameter & width of the lateral & medial femoral condyle,The width and heigth of articular surface of the patella etc.on the solid model.The results are presented in a tabulated fashion.The methodology could be adapted for other joints like Scholder,ankle etc.

Keywords: **knee joint**, 3D reconstruction, Geometry parameters, MIMIC, Pro-E Creo Parametric, NX 6.0

1. INTRODUCTION

Total knee arthroplasty (TKA) has evolved towards a reliable and long lasting surgical procedure, offering pain relief and improved function to many patients who suffer from degenerative arthritis of the knee. Improvements in surgical technique and prosthesis design continue to enhance long-term outcomes. The ability to reproducibly restore walking without pain and limping in more than 90% of cases has led surgeons to offer this operation to younger patients. [4] However, the functional demandsand activity levels of these younger patients exceed our current capacity to restore the damaged knee joint. In the recent advances in computing technologies both in terms of hardware and software have helped in the advancement of CAD in applications beyond that of traditional design and analysis. CAD is now being used extensively in the biomedical industry in applications ranging from clinical medicine, customized medical implant design to tissue engineering. Several studies have been reported in literature that has made use of 3D reconstruction to help in a better understanding of

anatomical functionality and morphological analysis.[7] The use of three dimensional reconstructions can also be used in surgical assessment and planning of various bones. The Bio Medical Modeling Unit is not only engaged in fundamental research in many areas related to Bio Medical modeling but also provides a commercial service to clinicians to aid in pre-operative planning as well as clinical research. Unit can provide a comprehensive service in all areas associated with modeling using state-of-the-art technology [5]. Bio Medical Modeling embraces various techniques that allow the development of virtual or physical models of anatomical structures based on the information present inmedical images CT (Computed Tomography), MRI (Magnetic Resonance Imaging). [8]. In this paper, we have described in detail methods by which 3D CAD models of knee (femur part) can be obtained from CT images through a number of different process.

Modern knee replacement surgery has had a high success rate, but patients sometimes do not regain the expected range of motion, or say that their knee feels "tight" or unnatural after surgery. There are three major reasons for this:

1.1 "Balancing" soft tissue

Total knee replacement must provide good function with stability, range of motion and long durability. The easiest part of the surgery concerns bone cuts. It is widely accepted today that the quality of the results mostly relies on the soft tissue management. Intraoperative soft tissue management is still challenging since pre-existing soft tissue quality and bony anatomy have to be respected. The surgeon may have to address the soft tissue to fit with the new alignment and prosthetic mechanics. This challenge must be mastered with correct understanding and use of instruments to quantify these soft tissues. Tensors, distracters, spacer blocks and use of navigation were evaluated, and the authors compared these methods. The parameters for better use of soft tissues are described. Objective measurements are still difficult due to the pre-operative conditions that influence measurement accuracy. [9]

1.2 Alignment
All conventional knee replacements have been performed in order to restore an alignment in the leg known as the "mechanical axis". Surgeons developed this concept many
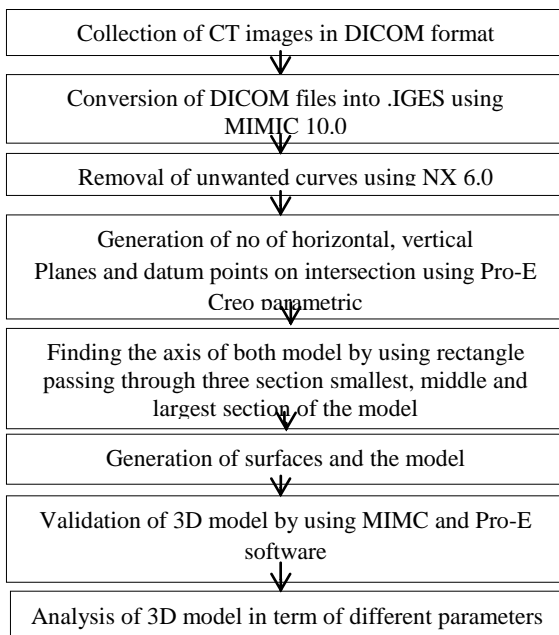
years ago and it has been the basis for knee reconstruction ever since. The concept is that the femur should be angled on the tibia at approximately a 5 degree angle. Nearly all knee replacements try to recreate this ideal "proper" pre-arthritic mechanical axis alignment. Yet recent studies show that only 1 out of every 65 normal (non-arthritic) legs actually conform to this "ideal." Every individual and every individual knee is to varying degrees, unique [12]

1.3 Rotational

The other challenge the surgeon faces with proper alignment has to do with rotation. Unless the femur and tibia are aligned in proper rotation, the foot may also be improperly rotated. This could lead to less range of motion and pain. In conventional knee replacement, surgeons use two little bumps (epicondyles) on the inside and outside of the end of the femur as anatomic landmarks. [10] They calculate an imaginary line passing between the epicondyle bumps. Orthopaedic surgeons have been taught that when we draw a line through the bone, connecting those two bumps, that we can use that line to judge the rotation of the knee. Once again, recent studies show that this transepicondylar axis is as inaccurate as the mechanical axis discussed above. With CFTKR we no longer have to rely on this inaccurate measuring system, as the computer model finds a much more accurate "rotational axis" which is the basis for proper knee function.

2. KNEE MODELLING AND ANALYSIS Flow chart of modelling procedure: [3]

Collection of CT images in DICOM format
↓
Conversion of DICOM files into .IGES using MIMIC 10.0
↓
Removal of unwanted curves using NX 6.0
↓
Generation of no of horizontal, vertical Planes and datum points on intersection using Pro-E Creo parametric
↓
Finding the axis of both model by using rectangle passing through three section smallest, middle and largest section of the model
↓
Generation of surfaces and the model
↓
Validation of 3D model by using MIMC and Pro-E software
↓
Analysis of 3D model in term of different parameters

1.4 Relevant data collection of knee

Computed tomography images have been collected in a hospital 'Jalna' (Maharashtra, India). The data in the format of Digital Imaging and Communications in Medicine (DICOM for short) was taken as an important source of key.

1.4.1 Import images

This is the very first step where the images were imported and converted scan data through "Import Images" from the "File" menu. Then Changed Orientation The operation is shown in Fig.1. The orientation parameters are necessary to display the images correctly in MIMICS. Then MIMICS software generates automatically coronal and sagittal images, and the result is shown in Fig.1

Fig.1

1.4.2 *Organize images*

If there more no of CT images then it may take more time for further process and unnecessarily it will create problem in reconstruction of 3D model. So we have to simplify the number of CT images to reduce the workload and improve the efficiency through "Organize Images". In the "Organize Images" interface we can choose images as per our requirement in MIMICS project which should be visible and used while working with MIMICS.[3] The operation is shown in Fig.2

Fig 2

Thresholding:

As different organizations will have different gray value in CT images, so it is required to set accurately the threshold value. We can observe the CT images to view the required part of the extracted organizations when set the threshold value. The threshold value should be kept as lower as possible to avoid the noise. Conversely, will loss many organizations. Here the setting of thresholding is shown in Fig.3
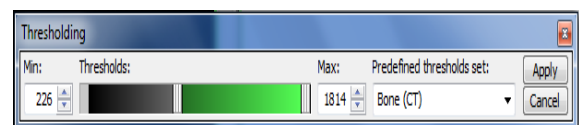

Fig.3

1.4.3 *Region growing*:

This command is used when the selected region is to be taken from whole figure as in below figure it shown by cyan colour which will be taken into consideration rather than taking whole part.
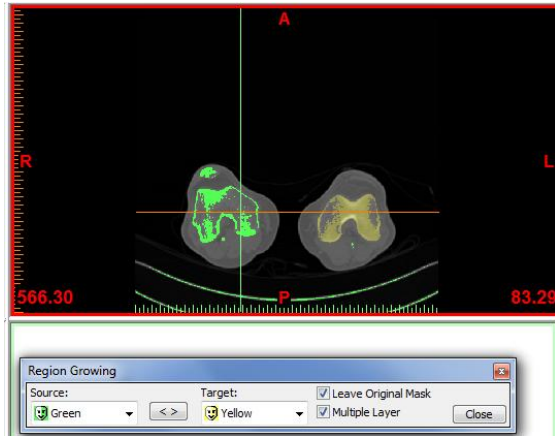

Fig.4

2.1.5 **Edit masks**:

Here we can manual edit the functions which are performed on the active mask. We can draw, erase, or restore the image with a certain threshold value indicated below. The drawing cursor can be a rectangle or a circle (ellipse) and can have different sizes, or you can use the lasso tool to draw a shape. The operation is shown in Fig.5
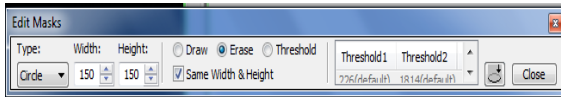
Fig.5

If the holes in the femur are more it will create more trouble. So we need to modify carefully all CT images carefully and fill all the holes in the femur. The holes are due to the setting of thresholding of CT images, not the original. So it can't affect the follow-up calculations. How to handle holes is shown as in Fig.5

2.1.6 *Calculate 3D:*

After having done all above steps "Calculate 3D" from the "Segmentation" Menu. The 3D structure of the femur can be visualized clearly.
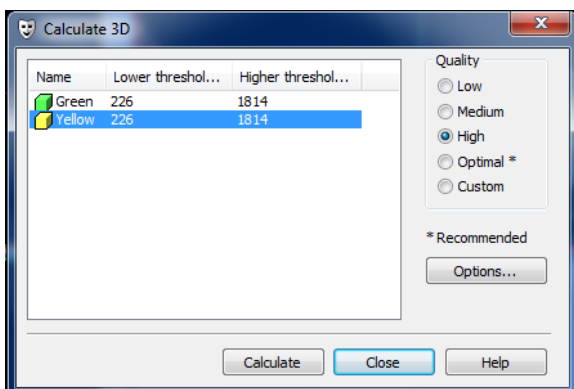

Fig.6

3. CONSTRUCTION OF DATUM, PLANE

Above done procedure in MIMIC is for getting the input data in terms of .iges format for PRO-E and used as a raw data for 3D modelling.

Now below procedure will give the idea about constructed 3D model in Pro-E creo parametric.

1. The obtained raw data in .prt form is imported in Pro-E, height of left femur(LF) and right femur(RF) is maintained from both reference plane.
2. After maintaining the height of both RF and LF axis of both curved data is generated by taking three section top most, longest section in the middle and bottom most, drawn the rectangle such that it is passed just touching from all four side and hence got the intersection of both diagonal of a rectangle, the same procedure was followed for other two rectangle in this way we got three point finally a line is drawn as axis of the 3D model.
3. As the raw data obtained is in curved form, section of section curves with equidistance from bottom reference of both RF and LF is generated.
4. Planes were created passing through all section.
5. Converted all MIMIC horizontal section into Pro-E sketch by using spline command.
6. Created no of vertical planes passing through vertical axis.
7. Created datum points by intersecting.
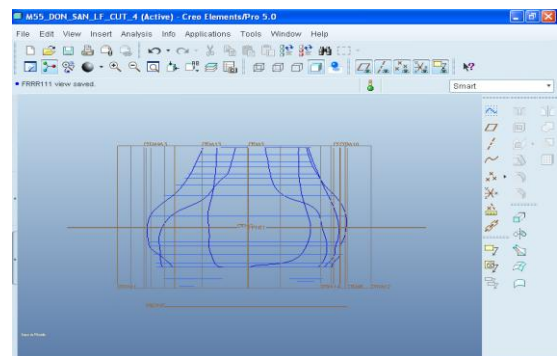8. Created vertical curves (spline) passing through points on plane which is used for creating datum points.
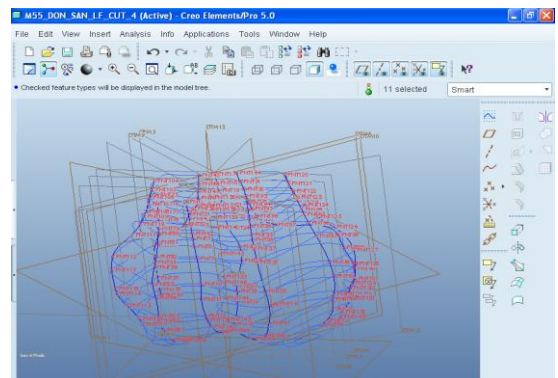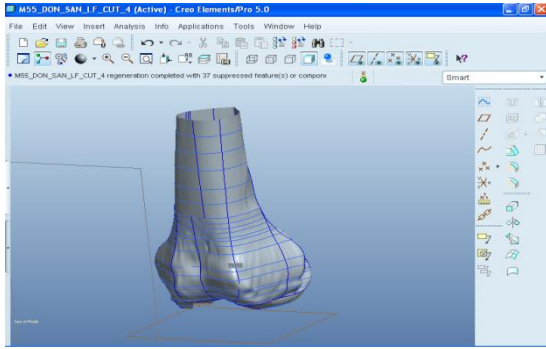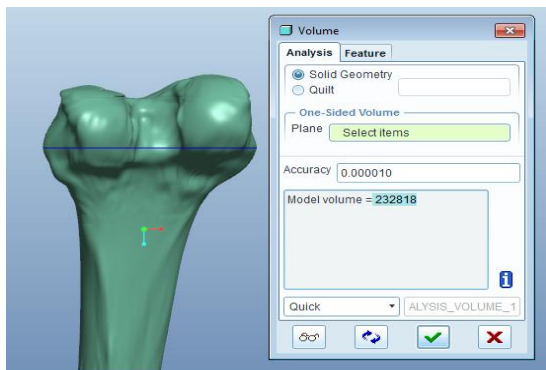

Fig.7

Fig.8

Fig.9

Below figure shows the final constructed 3D knee model of RF (right femur)
Figure. 10

Fig.12

Fig.13

4. VALIDATION AND ANALYSIS OF 3D MODEL

The following parameters are measured using Pro-E and MIMICS

a =Anteroposterior diameter of the lateral femoral condyle
b=Anteroposterior diameter of the medial femoral condyle
c=The width of the lateral femoral condyle
d=The width of the medial femoral condyle
e=The width of femoral condyle
j=The width of tibial straight part
k=The height of tibial straight part

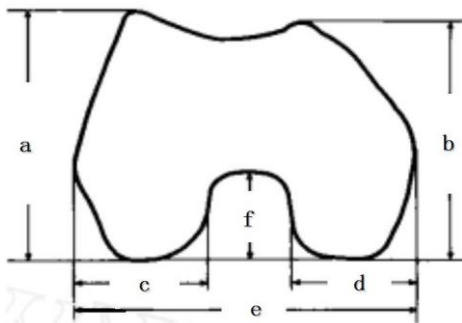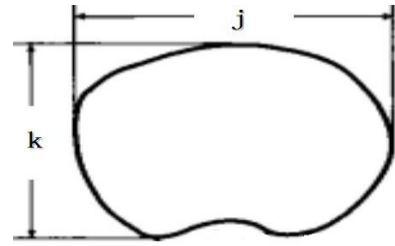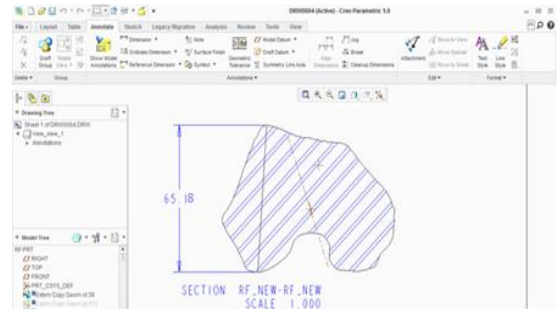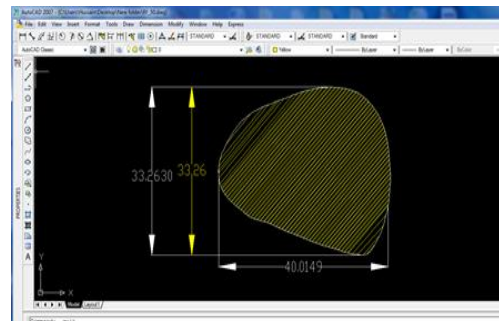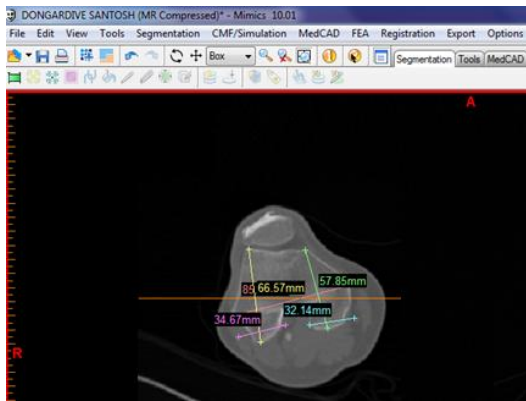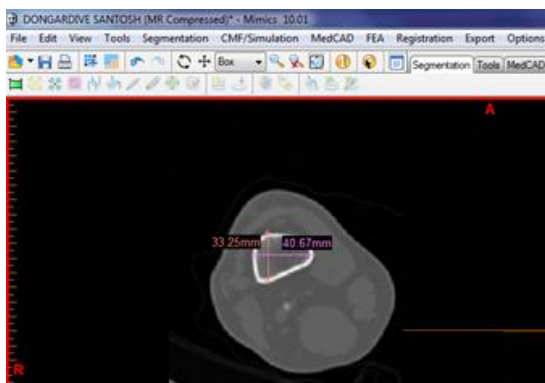| Data obtained from reconstructed 3D knee model					
SR No.	Measuring Part	RF PROE	RF CT	Diff. (mm)	% age deviation
1	a	65.18	65.18	0	0
2	b	57.015	57.85	0.835	1.4433881
3	c	34.4705	34.67	0.1995	0.5754254
4	d	32.3528	32.14	-0.2128	-0.6621033
5	e	85.9824	85.87	-0.1124	-0.1308955
6	f	19.24	19.43	0.09	0.9758603
7	j	40.1049	40.67	0.5651	1.3894763
8	k	33.26	33.25	-0.01	0.030075

Fig.11

Fig.14

Fig.15

Fig.16

As the 3D model of both knee is constructed in Pro-E creo parameters and all the parameters are measured in the same along with the Auto/CAD. After all above, the same parameters are measured using MIMIC 10.0

CT images consist of in stacking format like one above other horizontally, which is called as axial CT images so to get dimension of all above said parameters. We have found the proper image and then by using 'measure distance' command distances are measured in above figure using MIMIC10.0. It is totally trial basis where all the said parameters are measures on various layer for both knee. In our case the distance between two layers are 0.1 mm.

5. RESULT

All measured dimensions from the CAD solid model of distal femur are found to be approximately same as that measured from the input CT dimensions. The found values are given in the below table

6. CONCLUSION AND FUTURE SCOPE:

This paper presents the methodology to develop 3D CAD model from CT via use of CAD tools. The mentioned parameters are measured from the developed 3D solid model and compared it with the dimensions extracted from the CT images in the Dicom (Digital imaging communication) format. It is found that the data available from the CT images are approximately same as that of data measured from reconstructed models. The minor

deviations are due to the difficulty in locating and picking the particular landmark. In order to avoid the same the repetitive measurements were required to be done. Therefore the reconstructed model is authentic and geometrically valid but more clinical validation needs to be done. Also other different parameters can be measured from the same model which is not possible in 2D images or curve data.

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