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Research Article

Three-Dimensional (3D) Modeling of the Knee And Designing of Custom made Knee Implant Using Mimics Software

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Abstract

Osteoarthritis is the disease which occurs due to degeneration of the cartilages. The disease cannot be completely cured but the total knee replacement implants can delay the degeneration and reduces the pain in osteoarthritis case. Modeling of natural knee and designing the knee implant have been tried earlier using a CAD model but the accuracy of the model was compromised in terms of matching the exact geometry of the knee. Due to constantly varying curvature of medial and lateral condyle for every person, the knee implant design requires a reverse engineering approach in order to design an accurate knee implant for the patients. In this paper, CT/MRI images were used as an input data for modeling of the knee which has produced an accurate model of the distal femur and proximal tibia using MIMICS software. Segmentation using reliable profile line function was used in order to achieve an exact 2D surface which was further stacked together to convert it into 3D geometry. Custom made design for the knee bone was attempted here, which mimics the exact curvature required for the specific patient. The knee model and the custom made design were also meshed in case of further finite element analysis .

Keywords: *Mimics, Profile Line, Reverse Engineering, Segmentation.*

1. Introduction

The human knee is the largest joint present in the body. Due to its non uniform and complex structure, it has been a difficult task for researchers to build a 3D model of the knee over the years. The first ever knee model was designed for FE analysis was in 1983, after a decade of FE establishment in research work(Huiskes R et al,1983). Computer assisted models (CAD) have been used to build a 3D model of the knee for a long time now. Based on 3D measurements of the knee model, total knee replacement implant was designed but the complete recovery of the knee after the implant fixation was remain a challenging task for researchers. Recently in 2012, Hybrid segmentation method, followed by a statistical model with fine segmentation was used for the purpose of designing an accurate 3D model, which was supported by fast marching algorithm by Ringehbech(Ringebach et al,2012). In this paper, with the goal of designing an accurate model of the knee joint (distal femur and proximal tibia) for FE analysis, we have used MIMICS software. Including the 3D knee model, the total knee replacement implant was designed using reverse engineering, supported by MIMICS software. Accuracy of the model can be reliable because it uses CT/MRI images as an input data to design the 3D surface through stacking up 2D data in synchronized manner (G Mallesh et al,2012).

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2. Materials and Methods

A CT image with 0.99 mm thickness of Indian male was imported into MIMICS software. MIMICS works on the concept of stacking the two-dimensional images in order to convert it into three -dimensional images. The procedure of segmenting the knee joint begins with cropping the CT images in all three views (Sagittal, coronal and axial)(Zhang MC et al,2003). Cropping operation reduces the chances of segmenting unwanted geometry and fixes the region of interest that has to be a segment of the remaining part. *Profile line* was drawn in axial view between two extremities of cortical bone in the distal femur part (Fig 1)

Based on *profile line* value, which gives the Hounsfield unit variation over the line drawn; thresholding operation was performed to create a mask which connects all the regions of the same threshold range. The green mask was created automatically which falls inside the cropped region after the accomplishment of thresholding operation (Fig 2).

Termination of any connectivity of neighboring pixels using multi-slice editing between distal femur and tibia enables region growing operation (fig 3). While operating region growing function, termination of all connectivity

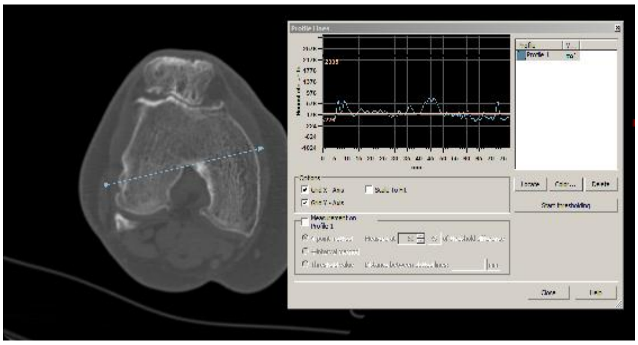

Fig 1: Profile line drawn on axial view.

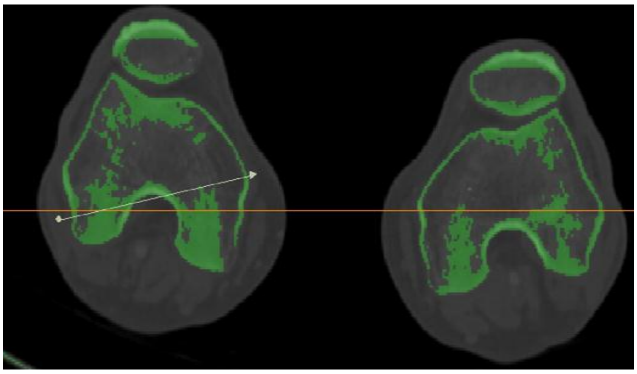

Fig 2 : Creating a mask using threshold operation .

between distal femur and proximal tibia part should be strictly followed. Calculate 3D function was called to convert the green mask into three-dimensional surface (fig4) Center line was drawn in distal femur part using MED CAD tools in order to find the curvature tilt in the medial and lateral part of the structure.

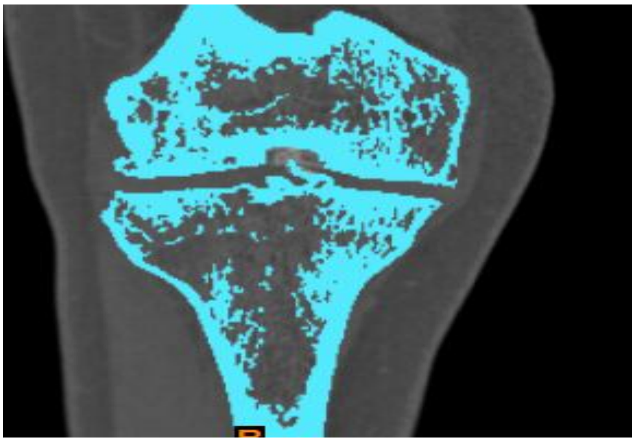

Fig 3: Region growing operation

Once after obtaining the three-dimensional (3D) surface, the geometry was selected to do the remeshing operation in MIMICS remesher, which starts with smoothening operation with the factor of 0.4. Height/base (A) parameter was used to check the qualities of the triangles with good triangles contain the quality of one and bad triangles contain the quality of zero. Part quality sheet was enabled in order to fix the histogram value accordingly and arrange the triangles quality data. Initially after surface calculation

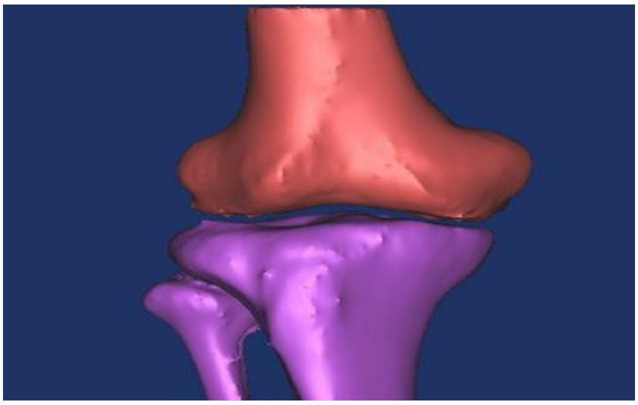

Fig 4: 3D view of the knee

in order to fix the histogram value accordingly and arrange the triangles quality data. Initially after surface calculation numbers of triangles presented in the surface were very high to perform any FE task, triangle reduction was done using normal method in two consecutive steps for edge and point reduction. Parameter chosen for the point reduction and edge reduction were chosen as tolerance of 0.1 with angle 15(degrees) and the number of iteration as 5. Split based method was selected for auto remeshing where the minimum edge length and maximum edge length was assigned to 2.5 and 4 respectively. After satisfying with mesh quality *self intersection test* was called in case of intersection triangle, the mesh was successfully exported into the mimics again (fig 5).

STL supported surface mesh was imported in *Abaqus* after converting it into .Inp file in Mimics. *The edit mesh option* was used to convert a triangle mesh into the tetrahedral mesh in order to convert surface mesh into volume mesh (G Mallesh et al, 2012)and then it was imported again in MIMICS using FEA tools to assign the material properties. Bone density varies in distal femur and tibial part significantly, as cortical bone which mostly lies outside periphery and cancellous which has more of spongy character, lies inside the cortical region. MIMICS provides an accurate way to assign the materials in the bony regions as it based on Hounsfield variation in input CT images. In presenting cases, 10 materials were assigned based on Hounsfield variations which were shown previously in (Fig 5).

Condyle surface of the knee joint varies for different population over the world , in fact the researches has shown the condyle surfaces varies person to person(G Mallesh et al,2012) ; however the implant used in case of total knee replacement has its own limitation in terms of gender and size. Customization of the knee implant was tried after achieving three-dimensional geometry in this work. Reverse engineering process (Vinesh Raja)was adopted to build the implant which exactly mimics the bone curvature and guarantees the complete fixation of the implant. MIMICS has the option of the *osteotomy wizard* where the virtual arthroplasty procedure was done.

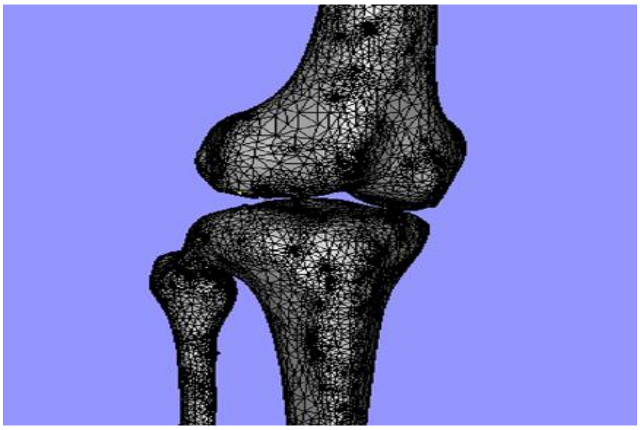

Fig 5: Remeshing operation using mimics remesher tools.

The desired condyle part was cut from the original distal femoral bone with thickness 10mm and imported in CAD for converting it in to implant (Fig 6-7).

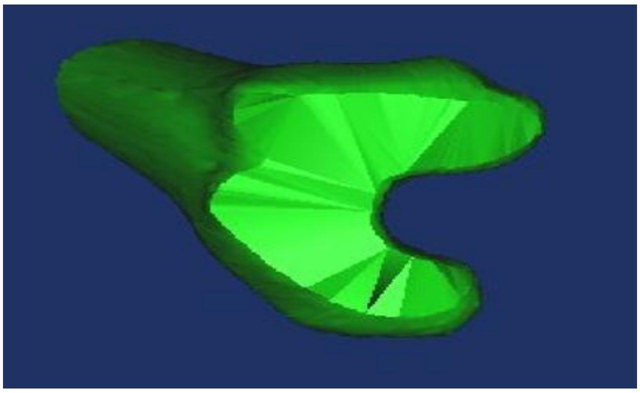

Fig 6: Cutting the condyle region

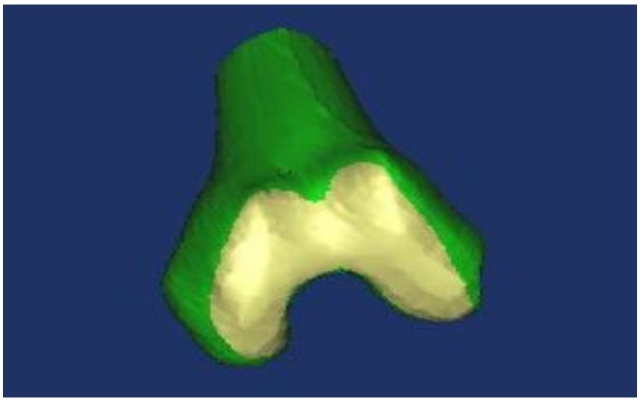

Fig 7: Assembling the femoral part with custom fit.

Bone cut can be done using plane cut or freeform curve cut. The free form curve cut can be only operated in case of the curve drawn does not touch the geometry which has to be removed. Increasing the extension value the condyle part was removed from the original bone. Similar operation was done for the proximal tibia part where the thickness of bone cut was limited to 4mm (Fig 8,9). Femoral and tibial implant was remeshed with similar manner as before. Assembly of implant with distal femoral and proximal tibia (Andrew R et al,2010), was also done in the osteotomy wizard manually.

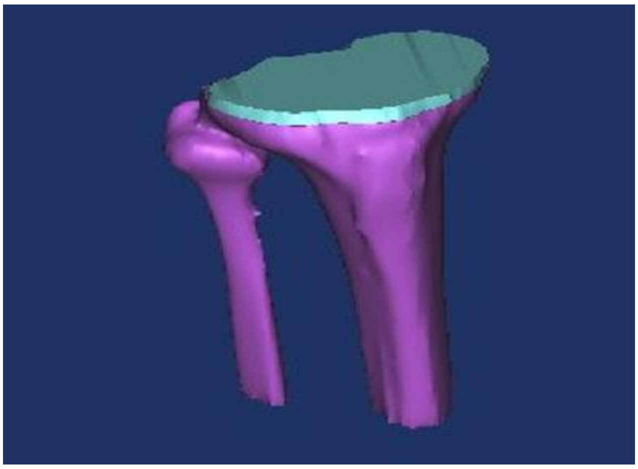

Fig 8: Tibial bone cuts.

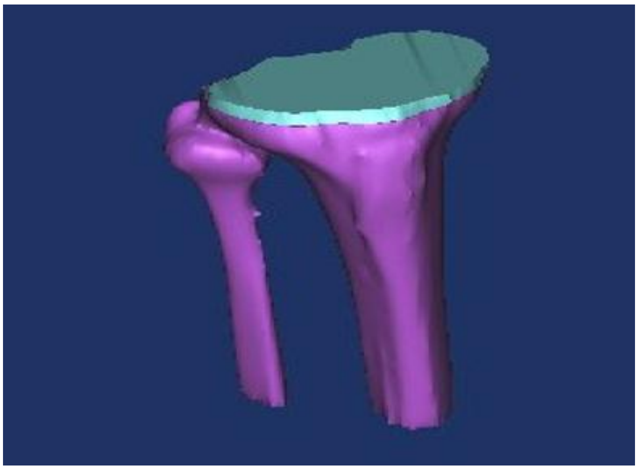

Fig 9 :Placing tibial part over tibial plateau.

3. Results

3D Segmentation of the knee was achieved, which was founded more accurate and real than any CAD model. The concept of using CT/MRI images as input data supports the accuracy and reliability of the model. Using Boolean operation the distal femur was easily separable from the tibial part. Center line operation with polyline function described the medial part is more tilted towards the center of the line compared to lateral part. The center line length of lateral to the medial part of distal femur was found 68.66 mm (Fig 10). Hence the quality of original knee joint was preserved during the bone cut and implant fixation by minimal and very precise bone cut.

Triangles of bad quality were reduced significantly in order to make model accessible for analysis using Abaqus. MIMICS provided an efficient and user friendly method to mesh the surface of the knee joint in STL format, which was easily converted into a volume mesh in Abaqus by converting triangular mesh into tetrahedral mesh. Result of

FE analysis is widely dependent on the accurate material

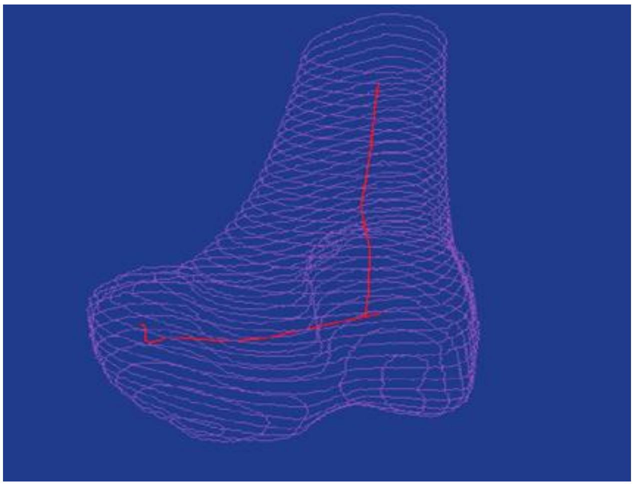

Fig 10: Center line drawn on 3D geometry of knee

assignment. The idea of assigning material based on the basis of Hounsfield variation on FE model, gives the freedom of including all significant changes in bone density (Fig 11); here in the present case distal femur and tibial bone was assigned 10 different materials based on the geometry and a Hounsfield unit variation of bone.

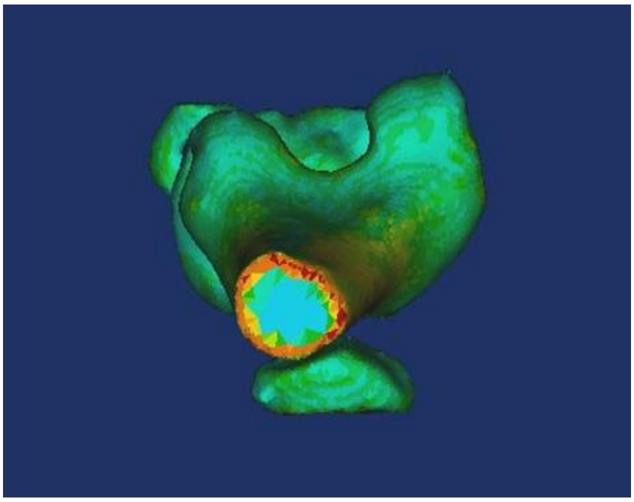

Fig 11 :Material properties assigned using mimics.

Implant designed using the reverse engineering procedure in mimics was found exactly negative to the patients distal femoral and proximal tibial bone. Curvature of the condyle part was exactly matched to the parent bone; providing the patient almost natural degree of motion in flexion and extension case.

Conclusion

The study reveals that the segmentation based on CT/MRI images helped to get the more accurate geometry of distal femur and proximal tibia bone. Segmentation supported by thresholding and profile line function ensured that only desired part involved in the knee model. Converting the geometry into surface mesh and importing it in STL format can be used to validate the knee model along finite element analysis. The Unique approach of material assignment with Hounsfield value adds the reliability of exact results in case of finite element analysis. *Draw Polyline* and *center line fit* operations were very effectively used to examine the medial and lateral curvature. The further polyline function can be smartly used to create the surface and can be imported in order to convert the surface into customized implant. Another effective method that's used here in this work was the concept of reverse engineering in order to improve the implant design and make it more customized.

References

Huiskes R, Chaos EY (1983), A survey of finite element analysis in orthopedic biomechanics: the first decade;16 (6): 385-409

Hung-Shyoong Chen , Tsai Yau Bin and Chyouhwu Jung (2012), The Critical Dimension of Femoral for Custom –made Total Knee Arthoplasty by application of Gemoetric Modeling,*Life Science Journal*

Ringebach, and Alex Schwangli (2012) , Tobias A robust an accurate segmentation of knee bones from CT data. *Biomed Tec* 2012;57

Ola LA Harrison, Yassir A Hosni and Jamal F. Nayfeh (2007) ,Custom-designed Orthopaedic implants evaluated using finite element analysis of patient specific computed tomographic data: femoral component case study.

G Mallesh and Sanjay .S.J (2012),Finite Element Modeling and Analysis of Prosthetic Knee Joint (ISSN 2250-2459, Volume 2, Issue 8.

Reverse Engineering: An Industrial perspective by Vinesh Raja and Kiran Jude Fernades, page 189-194.

Manglam Sankupellay, Selvanthan Narainsamy , Nadia Binti Mohd. Ismail Simulation of implant fitting in the femur bone *Sunway Academic Journal*, 2. pp. 67-75

Andrew R. Hopkins, Andrew M. New, Ferdinando Rodriguez-y-Baena and Mark Taylor (2010),Finite element analysis of unicompartmental knee arthroplasty *Medical Engineering & Physics* 32 (2010) 14–21

Three-dimensional Reconstruction for Medical-CAD Modeling B. Starly Z. Fang W. Sun Computer-Aided Design & Applications, Vol. 2, Nos. 1-4, 2005, pp 431-438

Zhang MC, Zhao WD, Yuan L, Li JY, Tang L, Zhong SZ , Three-dimensional reconstruction of the knee joint of digitized Virtual Chinese Male No.1 by finite element simulation Di 1 jun yi da xue xue bao = Academic *Journal of the First Medical College* of PLA [2003, 23(6):527-529