

**Title:****Surface Metrological and Computer-Aided Designing of a Tibia Bone for Region-Specific Implants****Authors:**

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**DOI:** 10.14733/cadconfP.2019.367-371**Introduction:**

Load bearing joints such as knee and hip are the most-prone joints of osteoarthritis. Predominantly, Total Knee Replacement (TKR) and Total Hip Replacement (THR) are done to repair the affected knee and hip joints and reconstructed with metal implants. Proper implant fitting to the patient will avoid further revision surgeries. But, the loosening of implant is the major problem due to the unavailability of suitable implants. Implant manufactures have designed the implants mostly with respect to the certain region-based population pool data. Most of the time, these implants don't fit for other region's people, creating implant loosening problem that leads to revision surgeries. Therefore, this research was aiming at designing region-specific implants with respect to regions. To retrieve the morphometric data from the regions, there is a need for efficient method to measure bones and create Computer-Aided Design (CAD) models. Tibia was taken as the subject for measurement to check for proper method to retrieve dimensions. Co-ordinate Measuring Machine (CMM), contact mode was used to extract the dimensional data. Since tibia bone is a complex-shaped object, reverse engineering technique was used to develop a fixture box with an aid of Three-Dimensional (3D) printer, to hold the tibia bone for measuring its complex features in eight planes (0°, 45°, 90°, 135°, 180°, 225°, 270° and 315°).

The measured data of eight planes were used with the careful usage of pre-processing, registering and merging tools, to generate the master point cloud. The master point cloud was used as base with the integration of CAD tools to design 3D modelling of tibia. A comparative analysis was done between original tibia model and 3D CAD model. Deviation analysis between the master point cloud and the 3D model was also done and the error was minimal (0.314274 mm). Thus, this work gave accurate results for using alternate scanning system other than Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) for the measurement of bone. This method can be used for retrieving bone dimensions from bone samples obtained from various regions for generating region-specific implants [2-5],[7-10].

**Methodology:*****Design and development of a fixture box***

Non-contact measurement was done using a CCD camera that was available with the CMM. Tibia bone was placed on the CMM table and the camera has taken the data points. From that, the outer profile of the tibia bone was measured. Bone features were not able to measure using the CCD camera. Therefore, only surface models were obtained not the 3D CAD model. Measurement of tibia bone needs fixture for holding it and rotating through various angles for obtaining point cloud data to obtain 3D CAD model.

Measurement of the geometrical characteristics of any object using CMM that needs a fixture to hold. Due to the complexity of the complex-shaped object, a customized fixture is needed. When a

complex-shaped object is subjected for measurement, the designing of parts of the fixture box with respect to the complexity (size and shape) of complex-shaped object is needed. For that, some initial reference to designing of the parts using CAD software is normally involved. In addition to that, some of the analog-based measuring instruments are used to measure some of the features of complex-shaped object. These measured values can be used as a reference for making an acceptable CAD models of the parts that involve in fixture designing. In our earlier work [6], fixture box was designed and developed for complex-shaped femur bone and procedure was explained in detail. First level of measurements were done with only four planes of femur bone without any measurement principle. No merging operations were done due to less number of points. Only surface models were generated, 3D CAD model of the femur bone was not generated in that work [6]. In this work, tibia bone was taken for CMM measurement which is having more complex shape than femur bone. To generate a 3D CAD model of the complex-shaped object like tibia bone using CAD software, there is a need of surface points of the tibia bone. Phantom model of tibia bone was procured for the measurement process. For measuring the surface points of the phantom model of tibia bone using CMM, it has to be oriented to different angles for the measurement process. All the sides of tibia bone need to be measured at a specific angle to obtain the surface points which can be later used for CAD modelling of the tibia bone with respect to the specific angle. In order to rotate the tibia bone to a specific user defined angle and to hold it rigidly in a fixed position, a fixture box with rotating holder was used.

The fixture holder specifically for holding tibia bone was designed using CAD software and developed using 3D printer with Polylactide (PLA) material. Largest circumferential diameter of the tibia was taken as a reference for designing the holder for the bone. The assembled fixture box with specific holder for tibia bone is shown in Fig. 1.

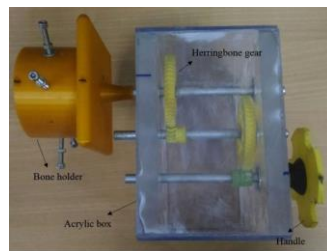


Fig. 1: Assembled fixture box for tibia bone measurement.

#### *Contact measurement of a tibia bone using fixture box*

Tibia bone phantom model was used for the measurement. Points were marked all over the tibia bone surface for measuring with contact probe (Fig. 2(a).) Measurements were made at  $0^\circ$ ,  $45^\circ$ ,  $90^\circ$ ,  $135^\circ$ ,  $180^\circ$ ,  $225^\circ$ ,  $270^\circ$  and  $315^\circ$  planes by rotating the holder with handle.

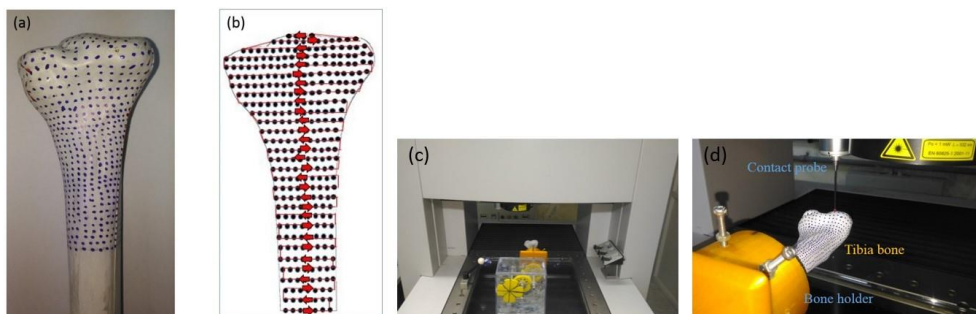


Fig. 2: Measurement setup: (a) Tibia bone with points marked over it for measurement, (b) Scanning path followed during contact measurement for  $0^\circ$  angle, (c) Measurement set up for contact measurement using CMM, and (d) Contact probe tracing the scanning path.

All the measurements were made at 0<sup>th</sup> plane with tibia bone oriented to respective degrees. All the marked points were measured manually with contact probe and recorded with respect to scanning path. The scanning path for 0° plane of tibia bone using fixture box is shown in Fig. 2(b).

Likewise, scanning path for other planes were followed after rotating tibia bone to respective angles. While measurement process, one point common to both the planes (0° and 45°) in the lower most scanning line was chosen as origin point (point correspondence) and measured in both the plane measurement for merging procedure during the CAD modelling. Likewise, one point common to other pair of planes were chosen as origin point and were measured. Those point correspondences will be used in merging process of all plane measurement data. Measurement set up is shown in Fig. 2(c). and Fig. 2(d). Calypso software was the measuring software. The collected data points were exported as pdf files by the calypso software.

#### *CAD modelling from contact measurement*

There were eight different points clouds which were measured at 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315° rotations of the fixture box, respectively. Preprocessing steps like data acquisition, noise removal and format conversion were done. Calypso software was used to export the point cloud as pdf files. These pdf files were converted to excel files for manually removing erroneous points like 2D line points. After filtering, the excel files have been converted into text files.

Registration process involves transforming all the plane measurement data to their respective degrees and to have common frame of reference. As all the measurements were made at 0<sup>th</sup> plane, there was a need for point cloud orientation. Each point cloud was oriented to their respective degrees about Y-axis using the rotation parameters in mesh preparation wizard of Solidworks. While doing measurement at various degrees, one common point to 0° and 45° point cloud was chosen as origin point (point correspondence) and measured in both the plane measurements. In 0° point cloud, that point was chosen as origin and other points were 3D marked with respect to the origin and exported as text files using macro. Likewise, for 45° point cloud, with respect to origin point all other points were 3D marked and exported as text files. So, for the chosen origin point, the co-ordinates of the points in both the point clouds were changed. The XYZ points of both the point clouds were saved as one text file which were imported to CAD software as one-point cloud for further processing as shown in Fig. 3(a). Likewise, remaining point clouds were merged to previous point cloud with respect to point correspondence and exported as one text file (master point cloud) as shown in Fig. 3(b)., Fig. 3(c)., Fig. 3(d)., Fig. 3(e)., Fig. 3(f)., and Fig. 3(g).

The master point cloud which was obtained after preprocessing and registration from the raw data was imported to Solidworks. The mesh preparation wizard and surface wizard of Solidworks was used for the generation of the 3D CAD modelling. The modelling steps are shown in Fig. 4(a)., Fig. 4(b)., Fig. 4(c)., Fig. 4(d)., Fig. 4(e)., and Fig. 4(f). The holes which were not filled using Solidworks fill option were repaired using Meshlab software [1]. The Close hole option under remeshing tool was used to repair the 3D CAD model. Threshold with respect to hole size was fixed for repairing holes.

Deviation between master point cloud data and generated 3D CAD model was analyzed using Cloudcompare software. The final model was compared with point cloud data using cloud/mesh distance tool. The maximum error was found to be 0.314274 mm. Deviation analysis was also done using Autodesk Netfabb which gives tolerance value of 0.0001 mm.

The 3D models were compared by measuring some of the features of the tibia. The features such as tibial maximum proximal epiphyseal breadth, tibial maximum shaft diameter at nutrient foremen, tibial mediolateral shaft diameter at nutrient foremen and tibia circumference at nutrient foremen in the original phantom model were measured using Vernier caliper and flexible cloth tape. Tibia's circumference was measured for phantom model using flexible cloth tape. The other features in the phantom model were measured using Vernier caliper. In CAD models, circumference was found by measuring radius at the foremen using 3-point arc method using the measurement tool in Autodesk Netfabb standard software. The other features in the CAD models also were measured using Netfabb. Measured data is shown in Tab. 1. The obtained measured values using Netfabb were in close to the Vernier caliper and cloth tape measurement value.

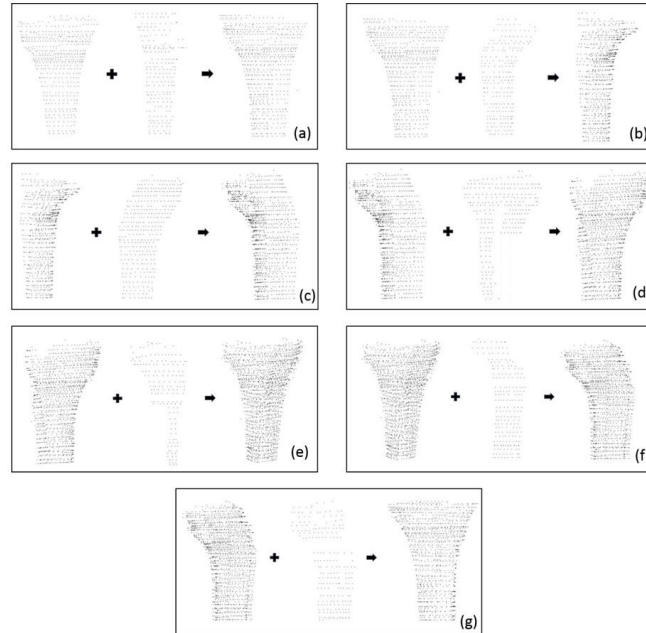


Fig. 3: Merging of point cloud using point correspondence: (a)  $0^\circ \times 45^\circ \Rightarrow (0^\circ - 45^\circ)$ , (b)  $(0^\circ - 45^\circ) \times 90^\circ \Rightarrow (0^\circ - 45^\circ - 90^\circ)$ , (c)  $(0^\circ - 45^\circ - 90^\circ) \times 135^\circ \Rightarrow (0^\circ - 45^\circ - 90^\circ - 135^\circ)$ , (d)  $(0^\circ - 45^\circ - 90^\circ - 135^\circ) \times 180^\circ \Rightarrow (0^\circ - 45^\circ - 90^\circ - 135^\circ - 180^\circ)$ , (e)  $(0^\circ - 45^\circ - 90^\circ - 135^\circ - 180^\circ) \times 225^\circ \Rightarrow (0^\circ - 45^\circ - 90^\circ - 135^\circ - 180^\circ - 225^\circ)$ , (f)  $(0^\circ - 45^\circ - 90^\circ - 135^\circ - 180^\circ - 225^\circ) \times 270^\circ \Rightarrow (0^\circ - 45^\circ - 90^\circ - 135^\circ - 180^\circ - 225^\circ - 270^\circ)$ , and (g)  $(0^\circ - 45^\circ - 90^\circ - 135^\circ - 180^\circ - 225^\circ - 270^\circ) \times 315^\circ \Rightarrow$  Master point cloud  $(0^\circ - 45^\circ - 90^\circ - 135^\circ - 180^\circ - 225^\circ - 270^\circ - 315^\circ)$ .

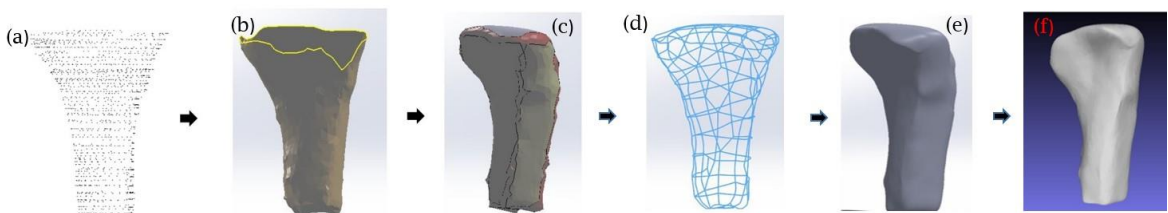


Fig. 4: Steps in generation of the 3D CAD model of the tibia bone: (a) Master point cloud, (b) Filling holes, (c) Surface model, (d) Knitting the surface, (e) 3D model, and (f) Complete model after repair.

| Features in the tibia                                  | Original model (phantom) (mm) | Obtained 3D CAD model (mm) | Error |
|--|-------------------------------|----------------------------|-------|
| Tibial maximum proximal epiphyseal breadth             | 61.48                         | 60.5                       | 0.98  |
| Tibial maximum shaft diameter at nutrient foremen      | 23.22                         | 23.814                     | 0.594 |
| Tibial mediolateral shaft diameter at nutrient foremen | 27.25                         | 27.396                     | 0.146 |
| Tibia circumference at nutrient foremen                | 94                            | 94.787                     | 0.787 |

Tab. 1: Comparative analysis of the generated CAD model with original phantom model of a tibia.

### *Advantages of the method*

Disadvantages of other scanners with laser as a source is that, measurement of reflective materials gives patches while scanning. Since, CMM is using touch probe, reflective materials can be measured and inspected. This method uses point correspondence manually while doing measurement itself unlike other methods which chooses the point correspondence iteratively. Future work is to develop the method of inspecting complex-shaped components with custom-designed fixture boxes using CMM.

### Conclusions:

Complex-shaped object (tibia) measurement was done using CMM with AM aided fixture box and 3D CAD model was generated using Solidworks. The components of the fixture box were designed using Solidworks and were printed using 3D printer. The parts of the fixture box were assembled inside acrylic box. Eight plane measurement of a tibia bone at 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315° were done using fixture box. Pre-processing and registration was done for all the point cloud. The point cloud obtained from each plane measurement were merged to obtain the final master point cloud. This master point cloud was used for the CAD modelling. CAD modelling was done using various tools in mesh preparation wizard and surface wizard and the 3D model was generated. The generated model from Solidworks has some small patches and that was repaired using tools in Meshlab software. The final obtained CAD model was compared with master point cloud for deviation analysis using Cloudcompare and Netfabb softwares. Comparative analysis between CAD model and original phantom model of the tibia bone was done. The features values in the CAD model was approximately equal to the feature values measured in original phantom model of the tibia bone. This CAD model can be effectively used for medical applications such as accurate implant modeling and pre-surgical planning.

### References:

- [1] Cignoni, P.; Callieri, M.; Corsini, M.; Dellepiane, M.; Ganovelli, F.; Ranzuglia, G.: MeshLab: an open-source mesh processing tool, Sixth Eurographics Italian Chapter Conference, 2008, 129-136. <http://dx.doi.org/10.2312/LocalChapterEvents/ItalChap/ItalianChapConf2008/129-136>
- [2] Loures, F. B.; Goes, R. F. A.; Palma, I. M.; Labronici, P. J.; Granjeiro, J. M.; Olej, B.: Anthropometric study of the knee and its correlation with the size of three implants available for arthroplasty, Revista Brasileira de Ortopedia, 51(3), 2016, 282-289. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4887459/>
- [3] Pal, C. P.; Singh, P.; Chaturvedi, S.; Pruthi, K. K.; Vij, A.: Epidemiology of knee osteoarthritis in india and related factors, Indian Journal of Orthopaedics, 50(5), 2016, 518-522. <https://doi.org/10.4103/0019-5413.189608>
- [4] Rawal, B.; Ribeiro, R.; Malhotra, R.; Bhatnagar, N.: Anthropometric measurements to design best-fit femoral stem for the indian population, Indian Journal of Orthopaedics, 46(1), 2012, 46-53. <https://doi.org/10.4103/0019-5413.91634>
- [5] Shah, D. S.; Ghyar, R.; Ravi, B.; Hegde, C.; Shetty, V.: Morphological measurements of knee joints in indian population: Comparison to current knee prostheses, Open Journal of Rheumatology and Autoimmune Diseases, 4(2), 2014, 75-85. <https://doi.org/10.4236/ojra.2014.42012>
- [6] Sindhu, V.; Soundarapandian, S.: Additive manufacturing fixture box for bone measurement, Procedia Engineering, 184, 2017, 1-9. <https://doi.org/10.1016/j.proeng.2017.04.063>
- [7] Slover, J.; Zuckerman, J.: Increasing use of total knee replacement and revision surgery, Journal of the American Medical Association, 308(12), 2012, 1266-1268. <https://doi.org/10.1001/jama.2012.12644>
- [8] Thilak, J.; George, M. J.: Patient - implant dimension mismatch in total knee arthroplasty: Is it worth worrying? An indian scenario, Indian Journal of Orthopaedics, 50(5), 2016, 512-517. <https://doi.org/10.4103/0019-5413.189618>
- [9] White, T. D.; Black, M. T.; Folkens, P. A.: Human Osteology, Elsevier, USA, 2012.
- [10] World health organization, The world health report 2002: Reducing risks, promoting healthy life, WHO, Geneva, Switzerland, 2002.