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Intra-observer variations of femoral bony landmarks using three different methods for the design of custom knee implant

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Abstract

This study investigated the variability of the manual localization of anatomical landmarks of the distal femur using 3 different methods: CT, Mesh, and 3D printed models. From a CT database of 50 knees, 3D meshes were automatically generated and 3D printed. The main author performed twice, for each case, a registration of 11 distal femoral landmarks.

We investigated for each landmark and modality the:

- mean distance per modality
- averages distance between each modality
- deviation of each modality from the barycentre
- position of the new planes and axes relative to their starting position

Finally, the study was carried out on 41 knees, 9 of which had to be excluded because of 3D printing issues. 2706 manual annotations were performed.

Regarding the Intra-operator reproducibility, the average distances for each point and modality were between 1.49mm and 6.34mm. As for the analysis considering the barycenter no differences were found between the three modalities. However, some points showed more variability. But their impact on the 3 axes and the planes studied were found negligible. Mean angular variations for either axes or planes are all less than 0.5°.

In summary, no differences were found between the three modalities but some points showed more variability.

1 Introduction

Clinical results and long-term survivorship of total knee arthroplasty are related to the accuracy of bone cuts with respect to the different axes of the femur and tibia[1]. In search of that accuracy many systems were developed enhancing the surgeon's hand. Nowadays, the precision of the available robotic solution is closed to 0.5mm and 0.5°[2]. But all these systems are based on the intraoperative acquisition of landmarks usually performed by surgeons. All CAOS systems, either Personalized Surgical Instrumentation, image-based or image free navigation and robotic systems have as foundation the registration (mostly manual) of bony landmarks. Those landmarks are used to calculate axes and (cutting) planes. A lot of literature is available on how accurate bone cuts are [2–4]but only a few studied the precision and variability of the landmarking process[5–7].

Moreover, as more and more image-based systems are converging towards a semi or fully-automed process, the question of the veracity of the "ground truth" that is challenging the algorithm has to be risen.

Thus, the aim of this study was to investigate the manual registration's variation of selected anatomical landmarks of the distal femur using 3 different methods: CT-Scan, 3D Mesh and 3D printed models.

2 Material and Methods

2.1 Data

Fifty CT scans of lower limbs (right and/or left) from 30 patients were randomly selected from a CT database of the Brest University Hospital. They were automatically segmented using a U-Net model in order to obtain a 3D mesh of the distal femur[5].

A base plate was automatically added to the 3D Mesh (without modifying the orthonormal system XYZ). That baseplate was necessary for printing of the 3D models and in order to make registration. These 3D meshes were loaded on 3D builder (Microsoft) to be optimized for 3D printing. They were printed in PLA filament on an Ultimaker Pro S5 machine with a definition of 15microns using Cura (v. 5.2b).

2.2 Methods (Figure 1)

For each case, the following 11 landmarks were identified:

- Medial epicondyle;
- Lateral epicondyle;
- Medial anterior condylar edge (AML med), anterior most medial condylar ridge point;
- Lateral anterior condylar edge (AML Lat), Anterior Most Lateral Condylar ridge Point;
- The medial distal condyle (distal medial point);
- The lateral distal condyle (distal lateral point);
- The medial posterior condyle (PML medial point);
- The lateral posterior condyle (PML lateral point);
- Anterior cortical point (AP sizing point) located in the anterior cortical inflection area;
- Trochlea point which is the most anterior and proximal point of the trochlear groove;
- Intercondylar notch point.

Four points located on the corner of the baseplate were added in order to allow the registration between the different modalities. Based on those 11 landmarks 3 axes (mechanical axis, primary axis, antero-posterior axis) and 3 planes (anterior, posterior and distal resection planes) were computed.

Picking on CT-Scan (CT) was performed under 3D Slicer (v.4.13) with the MultiPlanar Reconstruction (MPR) mode (figure 1a) while the picking on the 3D mesh (CC) was performed with Cloud Compare (v. 2.12b) (figure 1b). For the picking on the 3D printed models (PR), a tracker was attached to the printed 3D model (figure 1c) and using an homemade navigation software and system the landmarks position were acquired (figure 1d).The optical tracker of the navigation system was a Polaris Vicra.

The main author performed the picking of all the landmarks twice for each modality, giving us 7 positions for each landmark (CT 1 and 2, CC 1 and 2, PR 1 and 2 and Barycentre from all previous). The Barycentre was set as a reference for the calculation of the position the 3 main axes and planes.

We assessed the:

- mean distance for each landmark per modality;
- averages distance between each modality;
- deviation of each modality from the barycentre;
- position of the new planes and axes relative to their starting position.

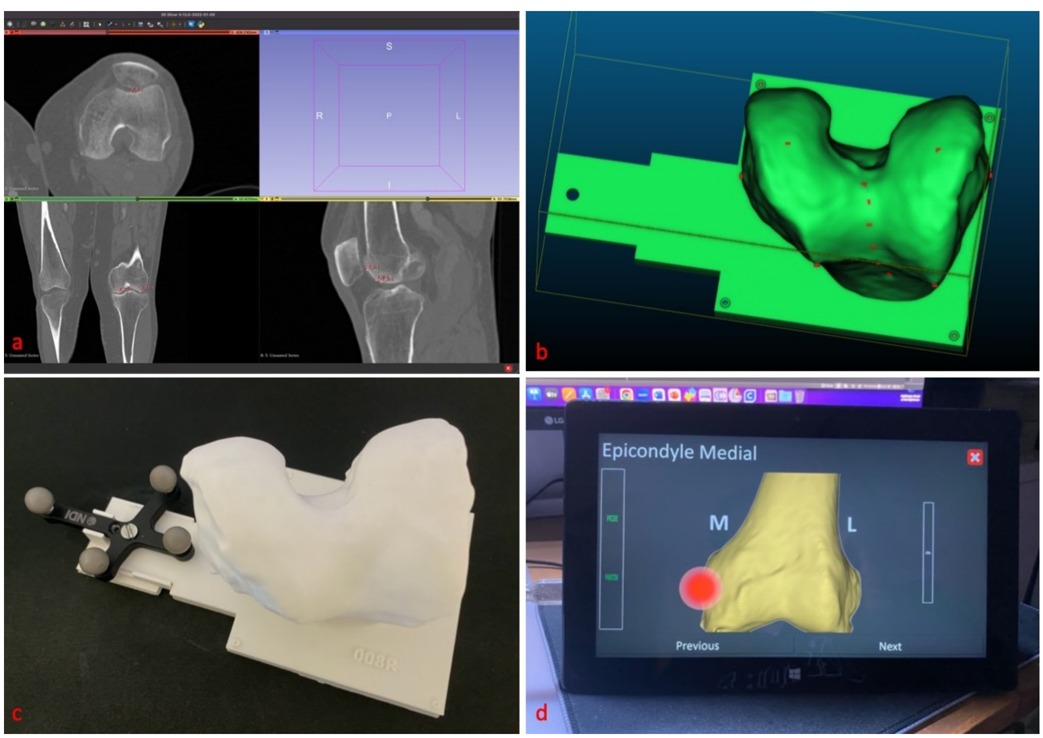

Figure 1: a) picking on CT ; b) picking on 3D mesh with CC ; c) 3D printed model with the optical tracker ; d) homemade navigation software

3 Results

The study was carried out on 41 knees, 9 of which had to be excluded because of 3D printing issues. 2706 manual annotations were performed.

Main results are presented in figure 2. The analysis doesn't reveal any differences between the three modalities. However, some points showed a greater variability. The average distances to the barycentre of the 3 modalities were the lowest indicating a learning curve or self-approval effect.

The impact of the landmark's variation on the 3 axes and cutting planes were negligible. Mean angular variations for either axes or planes were all less than 0.5°(figure 2b).

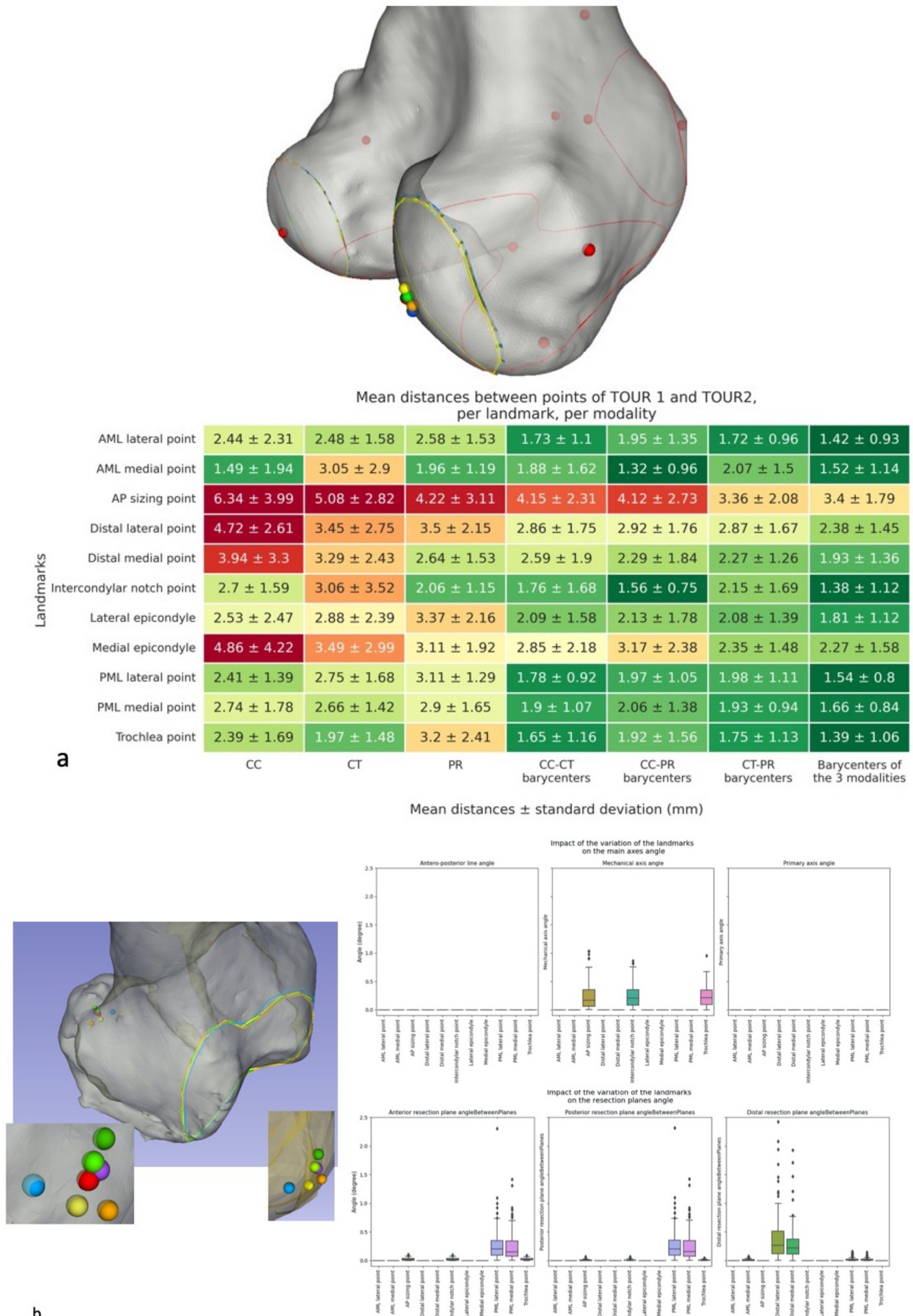

Figure 2: a) mean distance variation of the landmarks ; b) impact of the variation on the axis and resection planes

4 Discussion

Even if we found a supra millimetric variation in our landmarking, the impact on the axes and cutting planes seems to be negligible. Moreover, no modality seems to be more reliable or precise. However, our results are very different and not as good as those obtained by J. Victor and J. Bellemans[6]. They are more consistent with those of Yau et al. who used an optical navigation system[7]. Nevertheless, the conclusions of these two teams were that these variabilities had no significant impact on the calculation of the axes and planes of interest[6,7].

A second operator has to perform the same procedure in order to evaluate the inter-operator reproducibility. An expert consensus could be determined based on a review of the issues and/or landmarks with the greatest difference. Especially as sometimes the picking variation seems more due to a vague definition of the landmarks position than to its identification. The self-agreement effect we found supports this hypothesis.

It can also be used to implement an automatic detection algorithm by providing it, for each landmark, with the most reliable points based on those 3 modalities.

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