DETAILED AND ACCURATE ASSESSMENT OF FEMUR ANATOMICAL INDICES USING CT-BASED 3D MODELS

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INTRODUCTION

Accurate measurement of the lower limb anatomy is clinically important not only for applications such as implants selection and fracture management, but also for planning the corrective osteotomy operations in case of having excessive deformities [1]. The 3D reconstructed anatomical models, based on CT or MRI, provide an effective tool for analysing the anatomy of long bones [2]. However, there is still a poor consensus about the most optimal technique for measurement and description of the anatomical features and assessment of the deformities, considering the complex 3D shape of bones. Researchers have used varieties of axes and reference landmarks for this purpose with no established standard in defining them, leading to a wide range of reported data that are not reproducible [3].

The purpose of the present study was to present a 3D analysing technique for the anatomical features of femur, which is simple, reliable and robust. Also, it was aimed to use the new method for assessing the detailed anatomy of the bone, including the distribution of curvature and torsion across its shaft.

MATERIALS AND METHODS

We assessed 30 femur specimens of 15 subjects sampled by a random process across patients who introduced to Imam Khomeini Biorobotics and Biomechanics Lab (Tehran, Iran). All examinations on the patients were according to the ethical policy approved by the Imam Khomeini hospital. The 3D models of the patients' bones were generated from their computed tomography (CT) data.

The models were then examined using an independent local coordinate system, defined based on three anatomical landmarks considered at the centre of the femoral head, and those of the posterior femoral condyles.The midpoint between the centers of the two spheres fitted to the condyles was defined as the origin of the coordinate system. The Y-axis was defined as the line connecting the two condyle centers with its positive direction towards medial. The Z-axis was defined as the line passing through the origin perpendicular to Y-axis in the plane passing through three anatomical landmarks The X-axis was defined as the cross product of the Y-axis and Z-axis with its positive direction towards anterior (Fig. 1).

In order to analyse the curvature of the femoral shaft, at first, sections were made parallel to the local transverse (XY) plane. The centres of areas of these sections were used to define the initial shaft curve. Next, cross sections were made perpendicular to this curve and their central points were connected to obtain the true shaft curve (Fig. 2.a). This curve was then registered and analyzed in the local coronal (YZ) and sagittal (ZX) planes. Finally, the 5th degree polynomial function was fitted into the curve using Matlab Software, to calculate the variation of curvature across the femoral shaft.

The distribution of torsion along the femoral shaft was analyzed in the same cross sections used to define the shaft curve. For each section, the Linea aspea longitudinal ridge, on the posterior surface of the femur, was considered as the reference (Fig 2.b). The angle of the line passing through this landmark and the center of the section from the anterior-posterior (X) axis was defined as the torsion angle at that section.

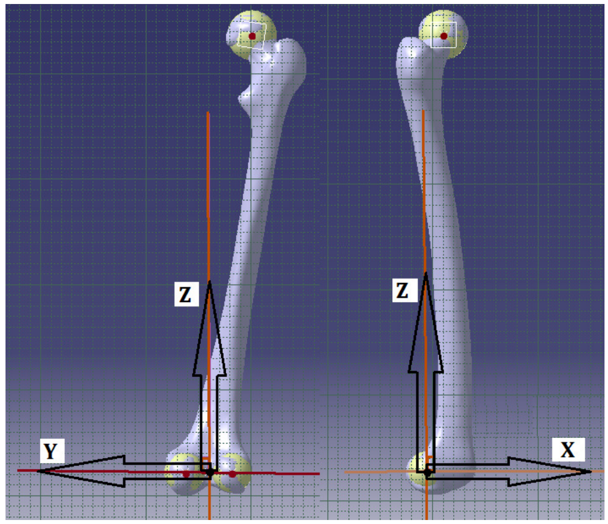

Figure 1- The proposed local coordinate system for a right femur.

Finally, the femoral neck anteversion was found using the axis of femoral neck, defined from the midpoint of the neck to its head center. Again, the midpoint was calculated initially at a section angled 135 degrees from the femoral local transverse plane (XY) and then corrected on the slice perpendicular to the line passing through the initial midpoint and the femoral head center. The femoral neck anteversion was considered as the angle between the femoral neck axis and the medial-lateral (Y) axis in the transverse plane (XY).

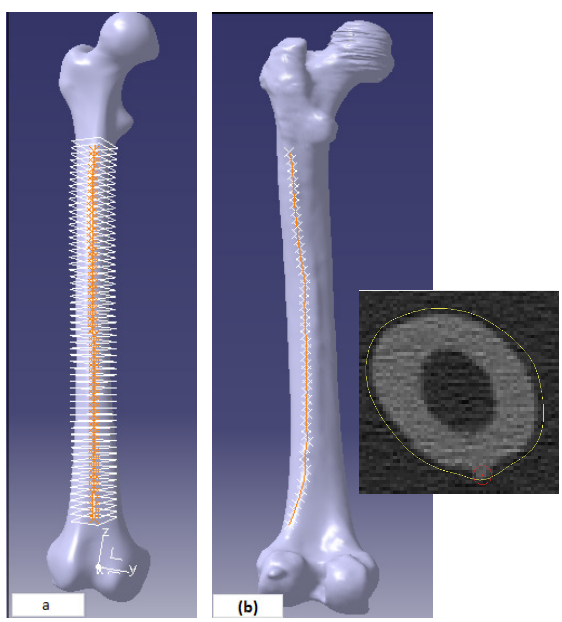

Figure 2- The femoral shaft curve (a) and the Linea aspea longitudinal ridge used to find the distribution of torsion along the femoral shaft (b).

RESULTS

The means (±SD) of the curvatures of the 30 femur specimens in the local sagittal planes were 0.0196 (±0.0079) /mm in the distal 10-30%, 0.0211 (±0.0089) /mm in the middle 30-60%, and 0.0249 (±0.0093) /mm in the proximal 60-80% of femoral shafts. The means (±SD) of the curvatures in the local coronal plane were 0.0040 (±0.0062) /mm in the distal 10-30%, 0.0045 (±0.0070) /mm in the middle 30-60%, and 0.0066 (±0.0096) /mm in the proximal 60-80%.

The mean (±SD) of the torsion angles in the middle third of the shafts of the 30 femur specimens was 0.5 (±6.3) degrees. The mean (±SD) of the anteversion of the necks was 13.3 (±12.7) degrees.

DISCUSSION

This study introduced a method for measurement and presentation of the anatomical indices of the femur. The method provides an independent local coordinate system, defined based on the most prominent anatomical landmark of the femur. All indexes are then measured and described for any individual bone model, based on this system, producing result that are independent from any global coordinate system of the body skeleton.

The proposed technique for measuring the shaft curvature, finds the centroid curve of the shaft using an accurate and precise technique, allowing the curvature to be evaluated in details in the coronal, sagittal and transverse planes. Also, for the torsion and anteversion of the femur, the proposed method is reliable and robust. Any estimate of the torsion of the long bones using CT slices depends greatly on the reference axes. In particular, it is assumed that the longitudinal axis of the bone is parallel to the scanning direction which is not usually true.

The results of study for the anatomical indices of the 30 specimens indicates a wide range of inter-specimen variation. This is particularly true for the curvature of the femoral shaft in the coronal plane, as well as the torsional angles of the shafts' middle third. It is suggested that a much larger number of specimens should be studied to provide generalizable data. This would also allow for detailed partitioning of the subjects in future, based on their sex, type of deformity, etc.

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