Disambiguation of 3D reconstruction of lower limbs from biplanar X-rays using shape criteria

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Introduction: Three-Dimensional (3D) reconstruction of lower limbs is a major concern for clinical outcome and surgical indications. Computerized Tomography Scan (CT-Scan) is used for this purpose. 3D reconstruction from Biplanar X-rays (BXR) including low dose and standing position is an alternative method [Dubousset et al. 2005]. A fast 3D reconstruction of the lower limb was proposed by [Chaibi et al. 2012], this method relies on a priori statistical model based on geometric primitives and their descriptive parameters extracted from a CT-Scan database. Statistical inferences allow to estimate the full set of parameters from a reduced set of predictors obtained via BXR digitization. From the full set of parameters a 3D generic mesh is deformed globally/locally obtaining the Initial Solution (IS);

Nevertheless, this IS needs further manual adjustments and an expertise to discriminate the medial and lateral side of the femoral and tibial condyles. A proper detection of the femoral and tibial condyles should robustify the calculation of routinely used clinical measurements such as femoral and tibial torsion.

[Serrurier et al. 2012] proposed a method for detecting the medial and lateral condyle of the femur using similarity scores. This method relies on the computation of two 3D femur surfaces, one directly from the operator digitization and the other from the same digitization with medial and lateral condyle automatically swapped using Moving Least Squares (MLS) deformation handles [Cresson et al. 2008]. From both reconstructions, Digitally Reconstructed Radiographs (DRR) [de Bruin et al. 2008], have been computed and the closest pair to the original X-rays is selected based on similarity scores, pointing the correct 3D surface. This method, while powerful when there is a clear gap between the femoral condyles, is less effective when the condyles are superposed. Characterization of the morphological changes during an inversion of the femoral and tibial condyles is an alternative to methods using similarity scores.

The aim of this study is to propose a method to disambiguate the 3D reconstruction of lower limbs from BXR using shape criteria.

Materials and Methods: Based on a qualitative and quantitative analysis of the inversion of the femoral and tibial condyles, a set of shape parameters are proposed in order to define a method to disambiguate the 3D reconstruction. For the femur, $D_i$ and $D_m$ [figure 1 a] are defined as the distance between the centers of the best fitting spheres to regions which correspond to the distal posterior condyles ($B_i$ and $B_m$) and the barycenter of a region corresponding to the distal diaphysis ($B_d$). For the tibia, $D_i$ and $D_m$ are defined as the distance between the barycenter of the regions which correspond to the lateral and medial posterior condyles and the barycenter of a region corresponding to the proximal diaphysis.

The projection of these distances in the transverse plane defines $D_i$ and $D_m$. The ratio between the distances $D_i$ and $D_m$ define the parameters $R_f$ [figure 1 a] and $R_t$ respectively for the femur and the tibia. Based on $R_f$ and $R_t$, a disambiguation method has been proposed, [figure 1 b]. The shape parameters $R_f$ and $R_t$ are calculated for both Inversed (Inv) and Non-Inversed (Non-Inv) reconstructions and the disambiguation hypothesis is verified to perform the choice. Same approach is used for the tibia.
**a)** Shape parameters calculated for the femur. **b)** Non-inversed and inversed reconstruction of the femur, 3D surface in the left, retro projection of the 3D contours in the lateral BXR in the right. A set of shape parameters are calculated for both reconstructions and a disambiguation hypothesis is proposed.

**Evaluation:**

1. $R_f$ and $R_t$ have been calculated for a CT-Scan Post Mortem Human Subjects (PMHS) database (29 femurs and 24 tibias).

2. The disambiguation hypothesis has been verified for 74 femurs (38 healthy, 36 pathologic) and 45 tibias (18 healthy, 27 pathologic) reconstructed from BXR.

3. Since the reconstruction process proposed by [Chaibi et al. 2012] is operator-dependent, the sensitivity of the disambiguation method has been calculated for a set of 8 femurs (4 healthy, 4 pathologic) and 8 tibias (4 healthy, 4 pathologic) reconstructed twice by three operators; to verify that the choice performed by the disambiguation hypothesis hasn’t changed taking into account the variability of digitization of anatomical landmarks performed by each operator.

Non-Inv reconstructions were taken as reference; these reconstructions were made by expert operators with extensive experience in 3D reconstruction and medical anatomy.
Results and Discussion:

1. PMHS database: \( R_f \) has a mean value of 0.73, 2SD (0.06), and \( R_t \) has a mean value of 1.06, 2SD (0.14), both parameters are homogeneous along the database.

2. BXR reconstructions database: for 100% of the tibias and 93% of the femurs the disambiguation hypothesis was verified. No reconstructions were discarded. [Serrurier et al. 2012] reported 90% of good detections, not taking into account the BXR images where the femoral condyles were superposed. For this study, the cases when the disambiguation hypothesis of the femur didn’t work out were analyzed and it was remarked that the non-signed difference of femoral torsion between Inv and Non-inv reconstructions was between (0.5° - 4.5°); this means that even making an incorrect choice the femoral torsion hasn’t been modified significantly.

3. BXR reconstructions database sensitive study: the decision never changed along the different operators, thus showing the robustness of this criterion.

Conclusions: Shape parameters for the femur and the tibia and a criterion to disambiguate the reconstruction of lower limbs from BXR have been proposed. This relevant criterion is easy to calculate, robust and is an alternative with respect to methods based on similarity scores. To improve the performance, a further combination of both methods (morphologic and similarity scores) is considered.

References