AUTOMATIC FEMUR CONDYLES DISAMBIGUATION FOR 3D RECONSTRUCTION FROM BIPLANAR RADIOGRAPHS

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SUMMARY
3D bone reconstructions from biplanar radiographs showed an increasing interest in the last decade. Three-dimensional (3D) reconstruction process of the femur as proposed by recent works (Chaibi et al., CMBBE, 2011) relies on the identification by an operator of a few landmarks on the radiographs to initiate the procedure. Among others landmarks, the operator needs to identify the medial and lateral condyles on the two radiographs. Their discrimination remains however difficult on the lateral view due to their superposition. Inversion of the condyles on this view can lead to erroneous 3D reconstructions and incorrect parameter estimation useful for clinical diagnosis. We propose an original method to discriminate automatically the correct condyle configuration. This method relies on the automatic inversion of the two condyles in the 3D surface to simulate the two possible 3D reconstructions and the use of volume models (Serrurier et al., CARS 2011, submitted) to simulate artificial radiographs for the two solutions. Similarity measures between these radiographs and the original ones enable the discrimination of the correct configuration. Preliminary results completed on 19 femurs without known pathology showed a success rate of 84% to discriminate the correct condyle configuration whatever the original choice of the operator.

INTRODUCTION
Three-dimensional (3D) bone reconstructions from biplanar radiographs showed an increasing interest in the literature in the last decade because of its crucial clinical relevance [1-4, 6]. Iterative reconstruction process consists in creating a first 3D surface of the bone structure from a few sets of stereo-corresponding landmarks clicked by an operator on the images, in retroprojecting this surface on the X-rays and adjusting it by aligning the resulting planar contours on the radiographs [1]. The first estimate depends thus on the operator analysis of the image. Due to the projection of a 3D structure on a planar image, X-rays remains however occasionally hard to interpret [4]. In the case of distal femoral radiography, as illustrated on the Figure 1, lateral X-rays show regularly two distinct circular shapes for the two condyles, without the possibility for the operator to discriminate accurately the medial condyle from the lateral one.

METHODS
A population of 9 men and 1 female, with a mean age of 31 years, spanning from 24 to 40, without known pathology of the lower limb, were selected on a voluntary basis for the study. Full body frontal and lateral biplanar X-rays with a resolution of 0.186 mm/pixels were recorded by means of the EOS® system [3]. The subjects were recorded with shifted feet [1] to decrease superposition of the left and right distal femurs on the radiographs.
The 3D reconstructions of the 20 femurs were made by one operator according to the method proposed by Chaibi and colleagues [1]. For each 3D reconstruction the first stage of the process consisted in simulating the inversion of the two condyles on the 3D surface. This step was performed (1) by inversing the 2D coordinates on the radiographs of the retroprojection of the centres of two spheres fitting at best the condyles of the 3D surface and (2) by deforming accordingly in 3D the femur surface by means of the Moving Least Squares technique [2]. Each femur was consequently represented by two 3D objects having inverted condyle configurations. Each original and inverted surface has then been enhanced with cortical thickness according to the cortical thickness model proposed recently [6]. Two simulated biplanar radiographs with similar characteristics than the EOS images have subsequently been obtained by simulating radiographic projection through each volume object. Five intensity-based similarity measures have been derived from the work of Penney and colleagues [5] and calculated between each pairs of reconstructed and original images. The final stage consisted in deciding which condyle configuration was correct according to the similarity measures. For each femur, a A score has been given to the highest of the 5 measures for the original reconstruction and a B score to the highest of the 5 measures for the inverted reconstruction. The chosen configuration has eventually been given by the maximum amount of A or B.

In order not to be dependant of the condyle configuration of the original reconstruction, the full process has been repeated using 20 other 3D reconstructions made by the same operator instructed to inverse the condyles. The final result for a given femur was considered as correct if the same condyle configuration was retrieved whatever the original reconstruction and if it corresponded to the correct configuration pointed by an expert.

RESULTS AND DISCUSSION
Preliminary tests have been carried out on 19 out of the 20 femurs recorded, one of them presenting superposed femurs on the lateral radiograph, so that it could not be a case of inversion. 16 correct detections out of 19 femurs were obtained by our method. In other words, our method appeared successful to discriminate the correct condyle configuration with a success rate of 84% whatever the original choice of the operator. Only three cases failed, among which two of them showed rather superposed condyles on the lateral radiographs, for which inversion has smaller impact. In terms of impact on the clinical parameters, 16 out of 17 cases where condyles inversion causes an error on the FT parameter higher than 7° have been successfully disambiguated, this limit angle being close to the precision of the parameter [1]. In other words, 94% of the cases where condyle inversion has a big impact on the FT parameter are successfully disambiguated by our method.

CONCLUSIONS
In the context of 3D reconstructions from biplanar radiographs for the lower limb, this study complements the current results [1] with an original method. In terms of methodology, this study validates the proof-of-concept of comparing reconstructed radiograph with original radiographs rather that contours superimposed on the original radiographs. Secondly, it makes a further step towards automatic 3D reconstruction which both reduces time reconstruction, which appears crucial for clinical use, and decreases the dependence to the operator. Finally, in terms of results, this study brings robustness in the 3D reconstruction by reducing the possibility of condyle inversion, critical for the estimation of clinical parameters such as TF. Further investigations are currently carried out in order to increase the robustness of the automatic detection.

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REFERENCES