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MULTIPLE REGRESSION FROM PELVIC AND FEMORAL ANATOMICAL LANDMARKS FOR PROXIMAL FEMUR MORPHOLOGY PREDICTION

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INTRODUCTION

Several clinical applications rely on the accurate estimation and description of the proximal aspect of the femur in order to obtain satisfactory results. The femoral neck axis is usually defined as a straight line connected between the femoral head center and the mean point of middle part of the neck. These two anatomical landmarks (ALs) are not directly accessible by palpation. The femoral neck axis must therefore be estimated indirectly using other ALs or external device (such as fluoroscopy). Such estimation has been previously performed using multiple regression [1] from palpable ALs [2] and the availability of a database including the required information, i.e., femoral head center and neck orientation locations [3]. Accuracy level for the hip joint and femoral neck was too low for surgery application and further development was requested.

Quantification of the proximal femur morphology requires examining the relationships between the femoral shaft and the femoral neck [4]. Such relationships are usually based on the determination of the so-called inclination angle (or neck-shaft angle, NSA) and femoral anteversion angle (FNA). These angles are used to explain various pathogenic mechanisms. FNA is usually linked to in- or out-toeing during gait, and might explain hip joint dislocation or range-of-motion limitation after total hip arthrosplasty [5]. It should be emphasized that, although NSA and FNA have been widely investigated by various previous methods [4], no accurate consensus can be found about a strict definition about how to determine these angles. Comparison of different statistical approaches and types of predictors related to model-based shape prediction was recently published [6]. Results advised a method using multivariate regression techniques based on anthropometric and morphological data constraints applied during minimally invasive surgery.

This paper presents a method to create a database of pelvic and proximal femoral morphological information including, for each bone, surface data and spatial coordinates of manually palpable ALs. This database should allow on fly evaluation of multiple regression coefficients between the available ALs and femoral neck pose (location and orientation) in specified hip joint pose. The adopted multiple regression approach is similar to [3]. In-vitro accuracy analysis and in-vivo was performed. Another aim was to predict the best drilling pathway to allow insertion of a surgical pin following the femoral neck towards the femoral head from manually-palpable ALs.

METHODS

Fifty-two bodies from donators were obtained from the Body Donation program of the University Libre de Bruxelles. X-ray control allowed to ensure the lower limbs of the donators did not show any osteosynthesis material that would lead to artifacts during CT imaging. CT imaging datasets were performed on the lower limbs of all donators. One retrospective in-vivo clinical dataset of the same area as above was obtained from one volunteer to perform in-vivo accuracy assessment.

Data Collection. For each donator, CT datasets were obtained from above the iliac crests until below the joint space of both knees (CT system and imaging sequences used in this study were: Siemens SOMATOM, helical mode, slice thickness: 1 mm for the pelvis area and both femoral epiphyses, and 10 mm for the femoral diaphysis). After segmentation, 3D models of the specimen pelvis and two femoral bones were obtained. Virtual palpation was then performed following strict definitions [2] in order to ensure reproducibility of the palpation results. Eventually, 5 pelvic and 3 femoral ALs (highlighted in the Figure 1) were palpated on each bone. Supplementary ALs were virtually palpated on the surface of the acetabulum, femoral head and neck surfaces. These ALs were further used for the procedure performed to morphologically characterize this surface-of-interest using shape approximation [3].

Data Processing. Several steps of data processing were implemented in order to unify the collected data. Each left hip joint data were mirrored before transformation in order to double the database size. At first, all ALs and bone model vertices were converted in pelvic local coordinate system (Figure 1). Then, using supplementary-palpated landmarks, acetabulum, femoral head and neck vertices were fitted by quadric surfaces [3]. The spatial coordinates of the fitted surfaces were used as hip joint center (HJC, i.e., acetabulum center), RFHC (i.e., femoral head center) and RFNC (i.e., femoral neck center). Finally, one pelvis-femur joint pair was used as reference assuming the hip joint as a ball-and-socket joint. The pose of the remaining hip joints from the database were adjusted by rigid transformation using the reference pair to obtain all available hip joints in the same joint orientation.

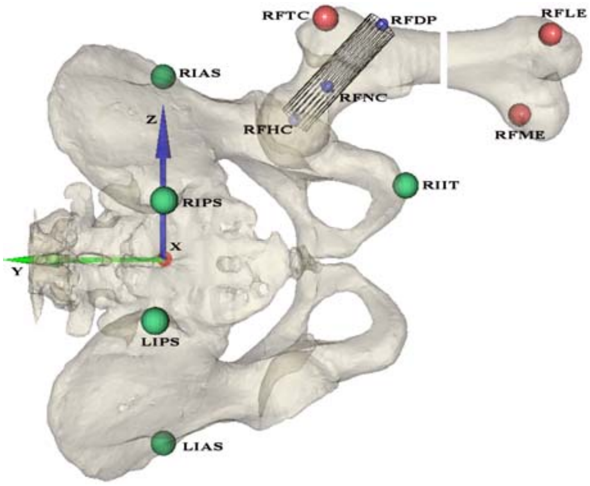

Figure 1: Pelvis and right femur, posterior view in pelvic LCS. The 5 pelvic and 3 femoral ALs used in this paper to predict values for RFHC and the drilling point (RFDP) are also visible. The transparent cylindrical mesh shows the maximal prediction error of the drilling pathway between RFDP and RFHC.

Prediction Method. The developed prediction method finally used a standard multiple regression approach [3], but applied on adjacent bones (i.e., the pelvis and the femur-of-interest) instead of on one bone only. For the new coming palpation data the above database procedure unification has been followed. As such, database hip joint orientations were adjusted according to the orientation of the joint under investigation. Then advanced scalable registration [3] was applied on each item of the database to register it to the new AL cloud. Finally the adjusted database AL clouds was processed to predict drilling point position and femoral neck orientation by multiple regressions. For both the RFHC and RFDP position prediction, a systematic leave-one-out (LOO) cross validation is performed to evaluate the prediction accuracy.

RESULTS AND DISCUSSION

The mean accuracy of the acetabular and femoral head surface vertices fitting was about 0.5 mm. Right iliac joint center (RIJC) ellipsoid estimation was about 3 mm closer to RFHC then the spherical estimation of the same acetabulum. For each joint, the final value for HJC was determined as the mean of RIJC and RFHC. Femoral neck surface vertices fitted by one sheet hyperboloid showed a mean accuracy of 1.1 mm. RFNP location was defined as the center of the ellipsoid cross section. The distance between the estimated RFNC and RFMM (estimated from the virtually palpated supplementary ALs) was 2 mm.

Since estimation RHJC from pelvis ALs only was not satisfactory, a combination of pelvis and femoral ALs was used to build regression equations. The newly-developed method, combining pelvis and femoral ALs (Figure 1) does not allow suggesting any set of regression equation coefficients, due to necessity of evaluating them "on fly", taking into account the hip joint pose of the subject under investigation (note that an example of regression coefficients are given in one particular pose in the supplementary material). Nevertheless, an accuracy evaluation by leave one out (LOO) cross validation was applied. Each hip joint pair, i.e. including one femoral and one pelvis, defined 104 hip joints. The orientation of each available joint was sequentially flexed within the range [-30°, 30°] using 3° step. For each orientation step of the current hip joint, the location of RFHC, RFDP and RFNC were compared with the prediction values obtained from the remaining 103 bone couples. Results of this LOO cross validation showed that the RFHC, RFDP and RFNC mean prediction error was 5.1(2.1) mm, 9.6(4.1) mm and 4.5(2.1), respectively (Table 1).

Table 1. Femoral neck axis point position prediction error in mm. X, Y, Z are the prediction error along each pelvic LCS axis; XYZ is the predicted distance error compared to the true point position value.

	RFHC			RFDP			RFNC		
	mean	**std**	**max**	**mean**	**std**	**max**	**mean**	**std**	**max**
X	**3.0**	**2.1**	**8.7**	**6.7**	**4.3**	**21.5**	**2.8**	**2.1**	**8.8**
Y	**2.2**	**2.0**	**8.8**	**4.8**	**3.3**	**15.0**	**1.9**	**1.4**	**6.4**
Z	**2.3**	**1.7**	**7.3**	**2.8**	**1.9**	**7.4**	**2.1**	**1.6**	**7.0**
XYZ	**5.1**	**2.1**	**10.0**	**9.6**	**4.1**	**22.9**	**4.5**	**2.1**	**11.0**

CONCLUSIONS

Results of this study show that proposed method can be used to predict parameters such as the femoral head center location and the most optimal entry point to insert a trephine along the femoral neck while remaining within an intraosseous pathway following the femoral neck. The obtained accuracy suggests that the method could be used as an alternative or complementary to fluoroscopy during osteonecrosis treatment by core decompression of the hip with a trephine.

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