NON-RIGID REGISTRATION OF DEFORMABLE SHAPE MODELS PRODUCES A SUPERIOR NORMATIVE FEMUR MODEL

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INTRODUCTION

Quantifying shape variation for anatomical structure is a complicated task. In general, it requires an accurate shape description, registration of shapes and an ability to study shape variation on both a global and a local scale. Usually, a statistical normative shape needs to be generated first as the reference. Early studies of creating normative femoral shapes were mainly based on rigid registration methods using surface landmarks. Recently, non-rigid registration has been used to create normative shapes, but most of them were limited in their ability to interpret shape variations or lack anatomical meaning (Tang 2005). In order to better describe both local and global variations between bones, a multiple vector bursts (MVB) method was created that could describe shape in a hierarchical way with integrated anatomical meaning. Using non-rigid registration to fit the MVB into individual shapes, the local variation was described by first quantifying and then removing the global variation.

The purpose of this study was to compare the normative femoral shapes generated based on rigid and non-rigid method.

METHODS

17 legs of 17 volunteer subjects with no injuries or illness affecting their lower extremities were scanned with a T1-weighted spin echo MRI sequence in axial plane with 15mm slices at the main shaft and 4mm slices at the distal and proximal femur. The in-plane resolution was 0.94 mm for all images. Geometric femoral models were segmented from the MRI data. All femurs were aligned and scaled based on mean palpable length. First, a 49 vector burst (VB) MVB model created from a randomly selected femoral shape based on a central axis that was extracted using the maximal sphere theory. Second, in order to generate a rigid normative femoral shape, this MVB model scaled its vectors to fit within the individual femurs, generating 17 MVB models. These models were averaged to create an initial average model. To remove the influence of the femur selection, a new MVB model was created for this initial average model and was then used to generate the final rigid normative femoral shape. In order to generate a non-rigid normative femoral model, non-rigid registration was applied to the MVB model, created from rigid normative femoral shape, and the MVB was deformed to fit within the individual femurs, generating 17 MVB models. The non-rigid normative femur was created by averaging these MVB models.

Four global shape parameters were automatically defined from the MVB model and compared to values available in the literature: 1) PAA (pseudo-anteversion angle): the projection into the axial plane of the angle connecting the femoral head vector burst origin (VBO) to the central greater trochanter VBO and a line connecting the lateral and medial condylar VBO; 2) SAA (standard anteversion angle); 3) PD (proximal distance): the distance measured from the femoral head VBO to the central greater trochanter VBO; 4) FSC (Femoral Shaft Curvature): the radius of the best fit circle of all VBOs in the main shaft. To validate the MVB methodology's ability to quantify local shape variation, the deviation in the average femoral surface was quantified and compared between the rigid and non-rigid normative femoral shape. In order to validate the accuracy of the non-rigid registration, a synthetic model with artificial deformation was used.

RESULTS AND DISCUSSION

The goal of this work was to develop a new methodology that could accurately quantify shape on a hierarchical scale from global to local variations. The rigid normative femoral shape had higher surface standard deviations and underestimated values of normative shape as compared to the non-rigid method (Fig 1). Thus, the MVB methodology, based on non-rigid registration provided an improved method for determining local shape variations.

Global shape parameters produced values that matched with previous studies, but typically had a smaller standard deviation (Table 1). The pseudo-anteversion angle, defined within this study, had a smaller variability than the standard anteversion angle due to its use of more stable interior feature points than surface landmarks.

The synthetic model demonstrated that PAA measurement based on a MVB model was consistent with the true value, only slightly higher (0.2 degrees or 4%) and that a small surface deformation could be detected. This further demonstrated that non-rigid registration of the MVB method was accurate in quantifying both global and local shape deformation.

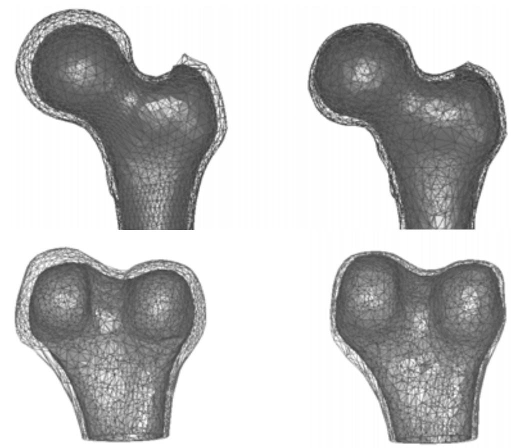

Figure 1: Local shape variation at proximal femur and distal femur. The solid model was the normative femoral shape (left: rigid normative, right: non-rigid normative) and the mesh was the one SD plus model. The standard deviation was higher and the normative model was smaller for rigid normative femoral shape as compared to the non-rigid normative femoral shape.

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Measure	Current Mean	Current SD	Past Study	N	Mean	SD
PAA (deg)	19.2	8.3	(not available)			
SAA (deg)	19.6	10.8	Sugano et al	30	19.8	9.3
PD (mm)	50.1	6.7	Demissie et al	346(M) /592(F)	54.0/46.0	8.0/7.0
FC (cm)	114	28.3	Egol et al	948	120	36

Table 1: For each measure the mean and SD are provided for the current study (column 2&3) and past studies (column 6&7). Column 5 provides the number of subjects.