THE ROLE OF STATISTICAL SHAPE MODELS IN THE DESIGN FRAMEWORK OF OSSEOINTEGRATED IMPLANTS FOR DISTAL FEMUR

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Introduction

The femoral morphology shows a high inter-subject variability. Thus, standardized prosthetic devices (e.g. osseointegrated stems for amputees or revision knees) may not sufficiently match with the anatomy of each individual [1]. In recent years, Statistical Shape Models (SSMs) have been largely employed to represent the average form out of many three-dimensional objects, as well as their variation in shape [2]. However, such statistical representations have not been used to solve the unmet needs associated to the design of prosthetic components yet. Therefore, the aim of this study was to evaluate the main modes of variation in the shape of the femoral canal, also considering different levels of osteotomy, which might support patient-matched implants design.

Methods

A total of 72 CT-scans of the lower limb were segmented to isolate the femoral canal region of interest (ROI), ranging from the tip of the lesser trochanter down to 75% of the total length of the femur (Fig.1,a). The canals were then scaled, aligned, and 16 levels of resection were simulated, starting from a section corresponding to 25% of the ROI up to the distal section (Fig.1,b). For each resection level, the main modes of variations were identified through Principal Component Analysis (PCA), extracting Principal Components (PCs) and defining the variability model [3]. After obtaining the average shape $\bar{M}$, the geometries corresponding to ± 2 standard deviations from $\bar{M}$ where computed as:

$$M_{i,\pm 2\sigma} = \bar{M} \pm \varphi_i \cdot 2\sqrt{\lambda_i} \qquad (1)$$

Where φ_i are the eigenvectors representing the PCs, and λ_i are the associated eigenvalues, providing the respective variance. The shape of the canal for $M_{i,\pm 2\sigma}$ was reconstructed every 10 mm and best fitted with an ellipse (Fig.1,c and d). The following parameters were then calculated: i) *radius of curvature (Rc)*, by reconstructing the arc of circumference passing through the centroids of the canal; ii) *ellipticity*, as the ratio between the major and the minor axis of the ellipse at the distal-most section; iii) *conicity*, obtained as the square root of the ratio between the area in the distal segment and the minimum area; and iv) *mean diameter*. In order to identify which are the main variations in shape explained by the main modes, these parameters were compared, for each level of resection, between the two geometries of the main modes of variation ($M_{i,\pm 2\sigma}$), calculating their difference divided by the average of their values [$var_{\%}$], thus reporting the range of values.

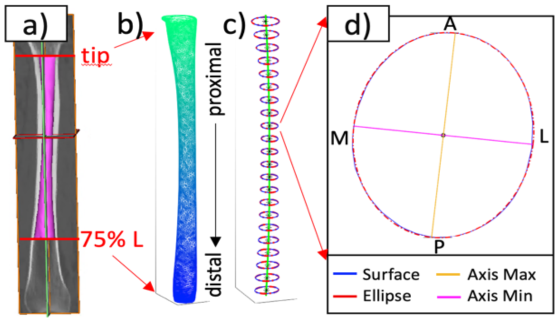

Fig.1: The procedure to obtain the parameters. a) Section of the ROI of the canal segmented from a CT scan, and b) Shape for a given level of resection; c) Reconstruction of the shape, with the Rc in green; d) enlarged view of a slice: the real shape of the canal (blue) and the best-fitting with an ellipse (red).

Results

The first three PCs explained more than the 87% of the total variance, for each level of simulated osteotomy. By analysing $M_{i,2\sigma}$ and $M_{i,-2\sigma}$ for a distal osteotomy (e.g. 70% of the length of the canal), the first PC was associated to a combination of *Rc* ($var_{\%}$=40%) [625-855 mm], conicity ($var_{\%}$=13%) [1-5 mm], and ellipticity ($var_{\%}$=9%) [1-3 mm]. PC_2 was still associated with the *Rc* ($var_{\%}$=17%) [806-850 mm], while PC_3 with the diameter ($var_{\%}$=67%) [9-20 mm].

Discussion

The SSM presented in this study allowed to i) evaluate the variance in shape of the femoral canal, and ii) parametrize these variations according to the level of resection. For instance, the results for the segment corresponding to the 70% of the length of the canal showed that, at that specified level, the parameters with the highest range variability for the first two PCs were the *Rc*, conicity and ellipticity respectively, while the variations of the diameter were more prominent for the third PC. Therefore, this analysis proved able to provide information about the relevance of these parameters depending on the level of osteotomy suffered by the amputee. In this way, optimal solutions for the design and/or customization of osteo-integrated prostheses can be delivered, according to the patient's residual limb.

References

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