Computing Average Anatomical Images: Comparison between Thin Plate Spline and Log-Euclidean Approach

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Introduction

Current implant design techniques in orthopedics are based on manual fitting and fixation procedures applied on cadaver bones; in this way it is difficult to assess whether implants will fit most of the population. An alternative way can be to use a statistical model that is able to describe bone shape and mechanical properties in a given population. The model allows to create new plausible instances from the original bone database in order to evaluate and optimise the design of orthopedic implants.
Here we propose the creation of the average bone using two different techniques: Thin Plate Spline (TPS) and Log-Euclidean approach, and we compare the differences in the results obtained, evaluating the average deformation vector fields.

Material and Methods

84 segmented Caucasian female left femurs CT images

Rigid registration (alignment)

Affine registration (scaling)

Diffeomorphic Log-Euclidean non-rigid registration (correspondences)

LOG-EUCLIDEAN APPROACH

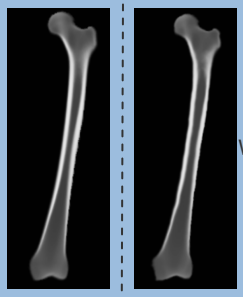
Velocity Fields (VF)

$$\overline{VF} = \frac{1}{n}\sum_{i=1}^{n} VF_i$$

$$\overline{DVF} = \exp(-\overline{VF})$$

Warping of the bone registration reference bone with average intensities

Bone with mean shape and mean intensity



Deformation Vector Fields (DVF)

Calculation of the landmarks that describe the average bone shape

Warping of the bone registration reference bone with average intensities using the TPS $\overline{DVF}$

Bone with mean shape and mean intensity

THIN PLATE SPLINE APPROACH

Comparison:

1. Calculation of the Jacobian of the $\overline{DVF}$s
2. Propagation of a 3D mesh created on the registration reference bone to the mean one using the two $\overline{DVF}$s and comparing the results in ABAQUS (quality of the mesh)

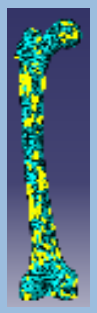
Results

1. Jacobian of the DVFs

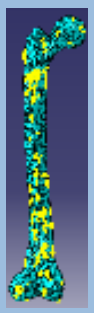
TPS DVF	Marrow	Trabecular bone	Cortical bone
Mean	0.949715	0.958231	0.920983
Std dev.	0.155919	0.258035	0.174192
Minimum	0.63486	0.447828	0.362108
Maximum	2.0463	2.56912	2.55726

Log-Eucl DVF	Marrow	Trabecular bone	Cortical bone
Mean	1.03676	1.00061	1.00049
Std dev.	0.0443482	0.134618	0.121937
Minimum	0.225861	0.160208	0.260365
Maximum	2.01647	1.85155	1.92761

2. 3D Mesh propagation


Log-Euclidean

	Element number	Analysis error	Analysis warnings
Reference mesh	20316	0 (0%)	51 (0.25%)
TPS mesh	18904	0 (0%)	123 (0.65%)
Log-Euclidean mesh	18417	0 (0%)	137 (0.74%)


TPS

Discussion and conclusion

The results show that there is not big difference between the two methods. However further tests need to be done when deformations involve bigger differences between the reference and the bone to be calculated since the TPS is a linear local approach while the Log-Euclidean is a large deformation one.

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