A characterization of the vertebral body of L1 vertebra's mechanical properties through Statistical Shape and Appearance Modelling

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Spinal disorders: a worldwide issue

Wide range of deseases

- Back pain
- Disk degeneration
- Fractures
- Osteoporosis
- Tumours
- Scoliosis

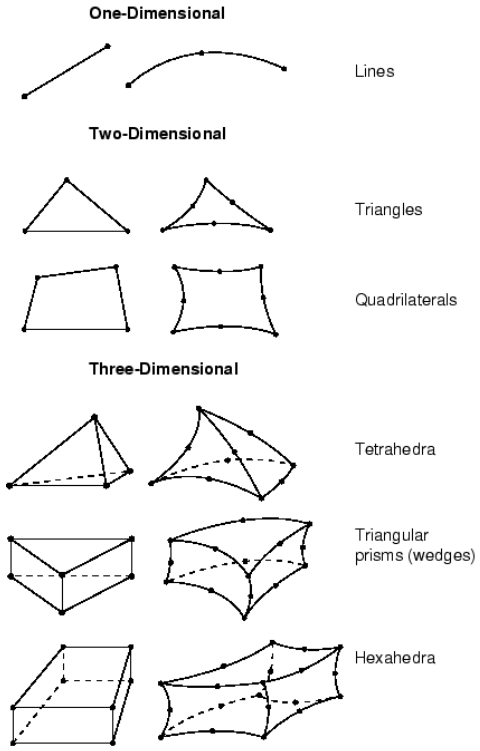
New techniques for surgeries

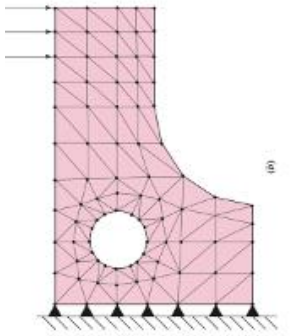
Theory and methods

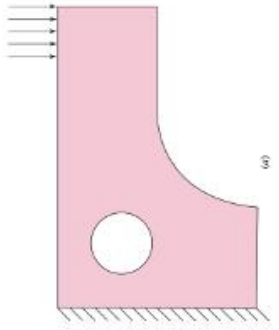
Finite Element Method (FEM)

- Numerical mathematic technique
- Mesh: discretization of continuous bodies
- Mesh morphing

  A method for changing the shape of a meshed surface while preserving the topology







Theory and methods

Principal Component Analysis (PCA)

$$\Sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \dots & \sigma_{1m} \\ \sigma_{21} & \sigma_{22} & \dots & \sigma_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{m1} & \sigma_{m2} & \dots & \sigma_{mm} \end{bmatrix}$$

By appropriately changing the Reference System

$$\Sigma = \begin{bmatrix} \sigma_{11} & 0 & \dots & 0 \\ 0 & \sigma_{22} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \sigma_{mm} \end{bmatrix}$$

New Reference System: **Principal Components (PCs)**

Each measurement can be expressed by
the linear combination of the main
modes of variation

PCA aims to represent the dataset in a smaller size space
with a diagonal covariance matrix

Tools

Ansys

(rbf-morph)™

Bonemat

MATLAB®

3DSlicer

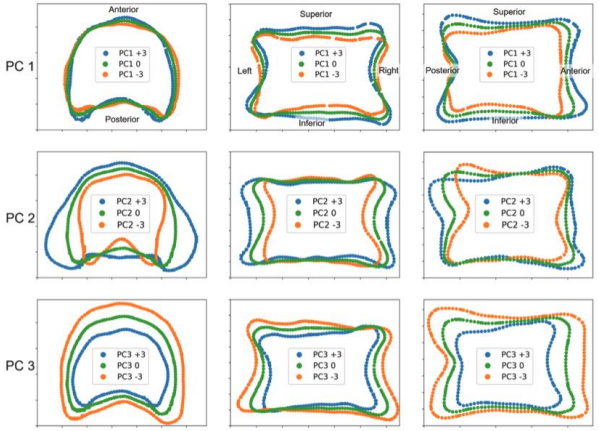
Theory and methods

Statistical Shape and Appearance Modelling

Training dataset

Statistical Shape Model

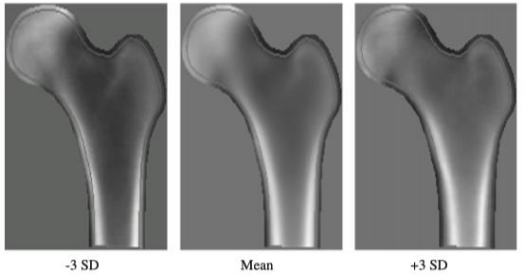
Mean shape extraction from a quantity of modes of variance from the training dataset



Statistical Appearance Model

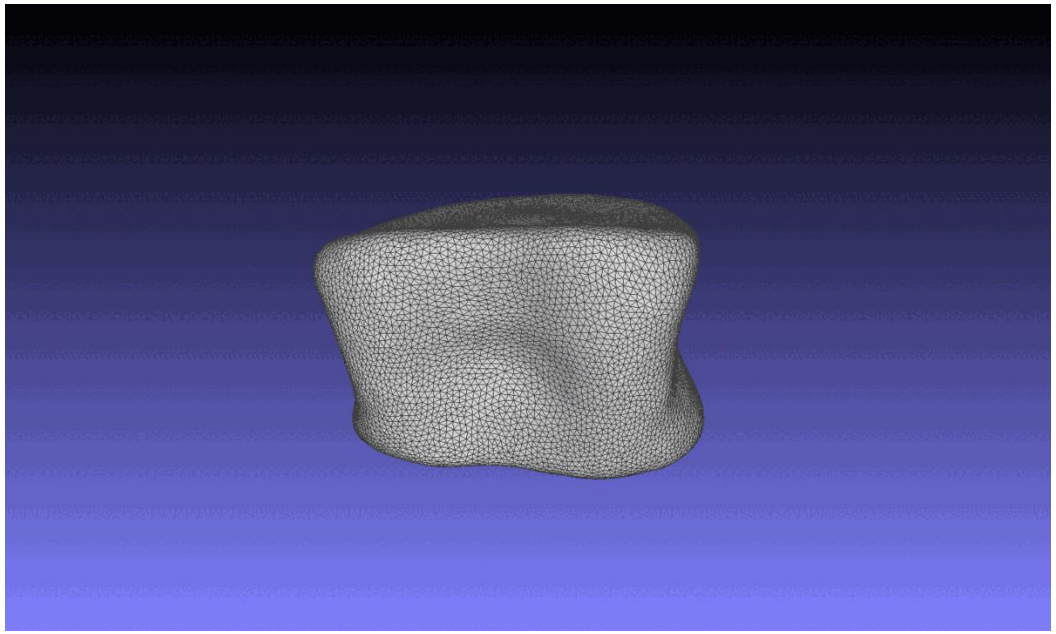
Distribution of material density of the specimen throughout the volume

- Pixels/Voxels intensities
- Density correlated to gray values



Data collection

- Sixteen Computed Tomography (CT) scans of lumbar vertebrae L1
  - Mean shape (reference) extraction with SSM

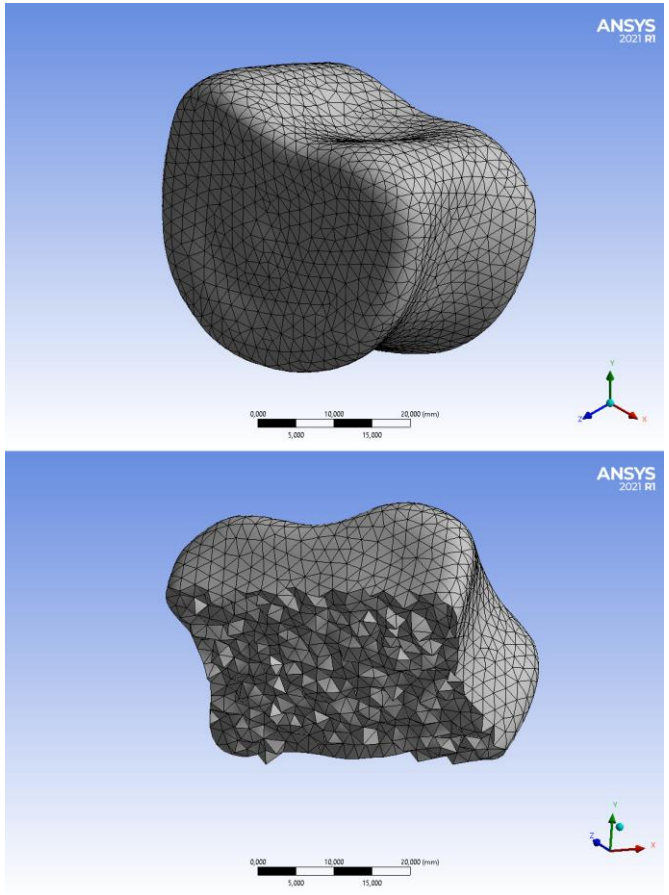


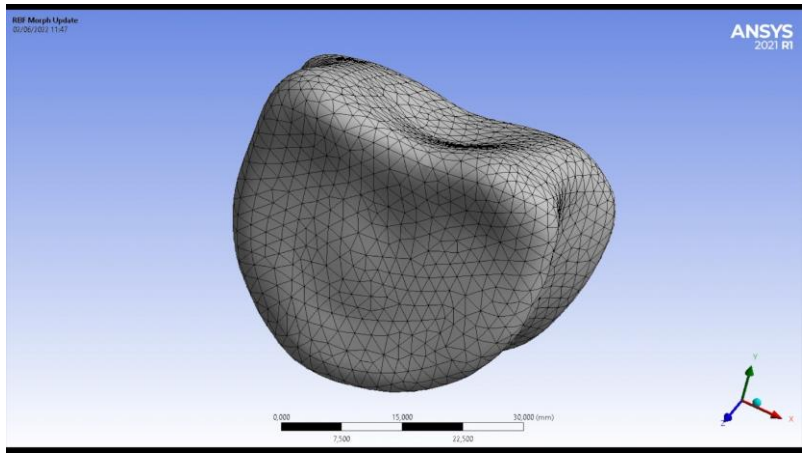
Reference mesh

Meshing & Morphing

Mesh generation

- Element size: 2 mm
- Element order: quadratic
- No adaptive sizing



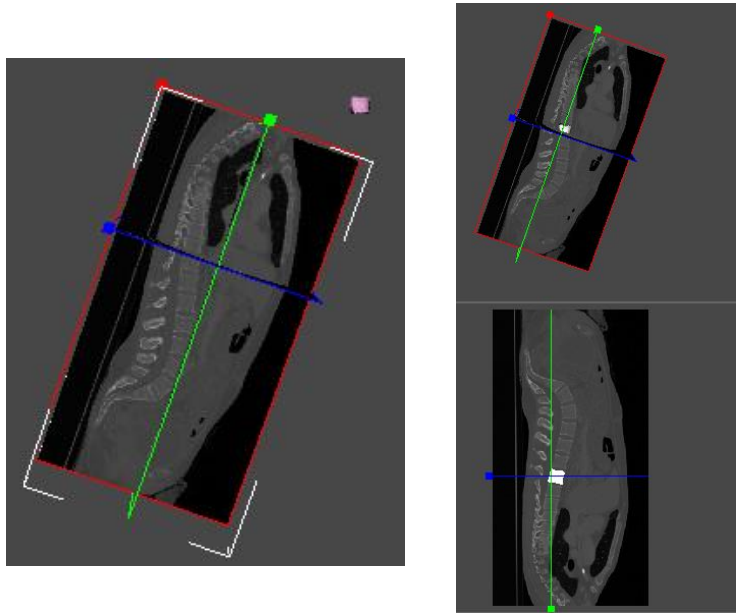


RBF Morphing for isotopologic meshes

Mechanical properties mapping

1) Allignment to CT Scan

Horn's method: rotational matrix and translational vector applied to nodal coordinates



2) Mechanical properties mapping

A-priori densitometric calibration supposed

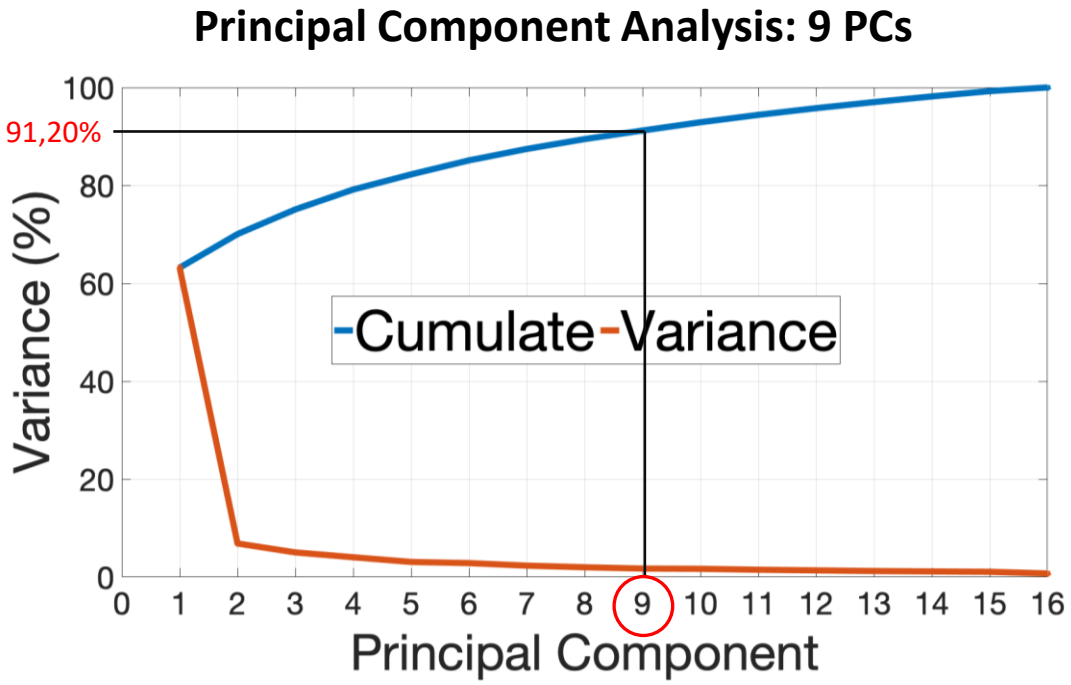
$$\rho_{QCT} = \rho_{app} \times 0.6 \frac{g}{cm^3}$$

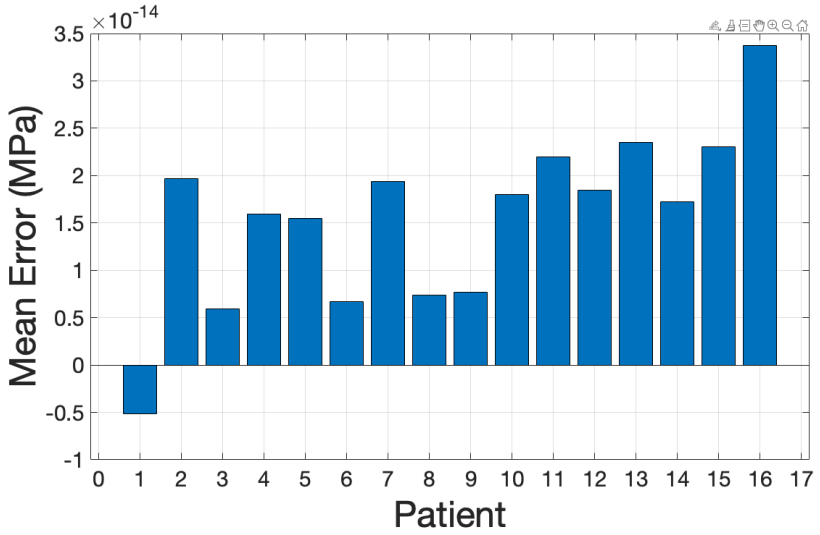
Young's modulus & Poisson's ratio

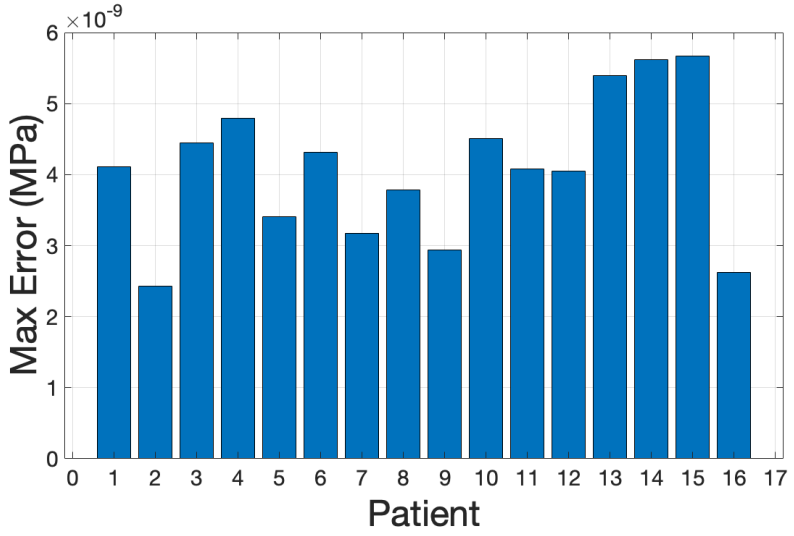
Outcome:

Volumetric mesh where each element is characterized by its mechanical properties

Statistical Appearance Model & PCA

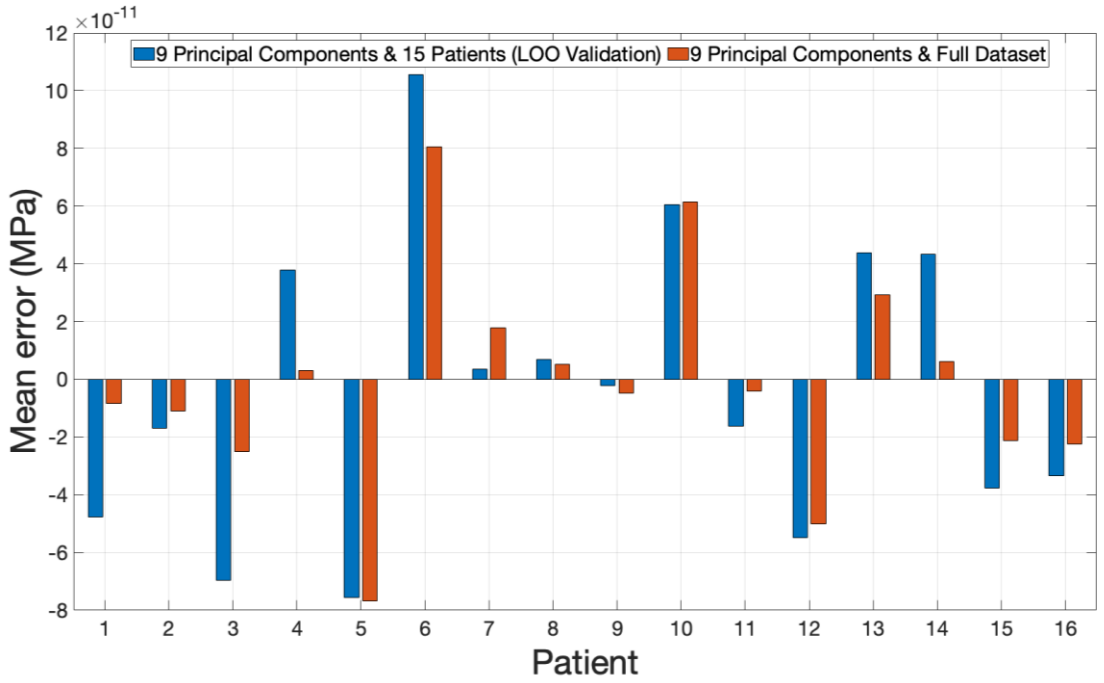


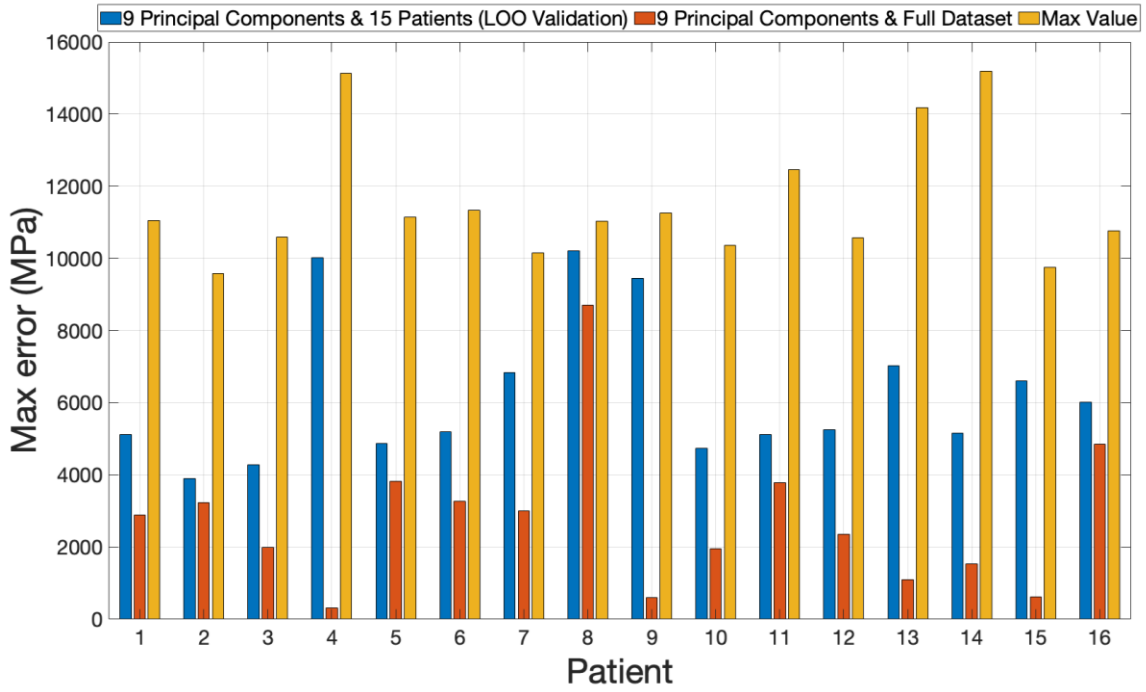




Leave One Out Validation

Iterative method in which a patient is removed from the dataset, PCA is performed on the remaining 15 and the one taken out is represented as a linear combination of the main modes found with the analysis





Limitations

1) Densitometric calibration

High variation of BMD between different scanners in case of lack of an appropriate calibration

2) Number of patients

Sample's size is not enough to represent the great anatomical variability among humans

3) Elements' relative position

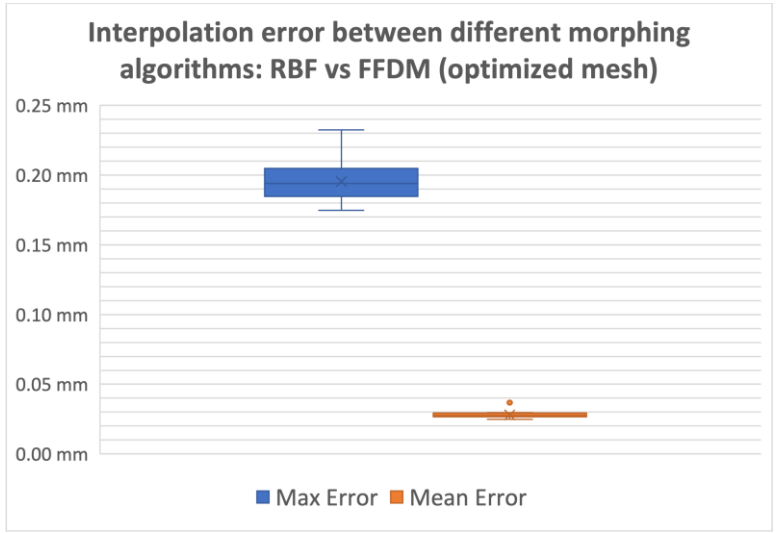
No control of compliance with the retention of the relative position between elements

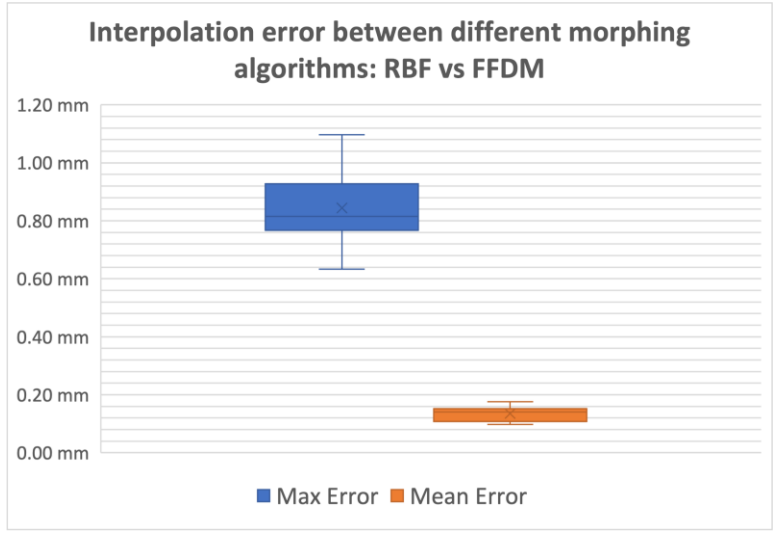
Limitations

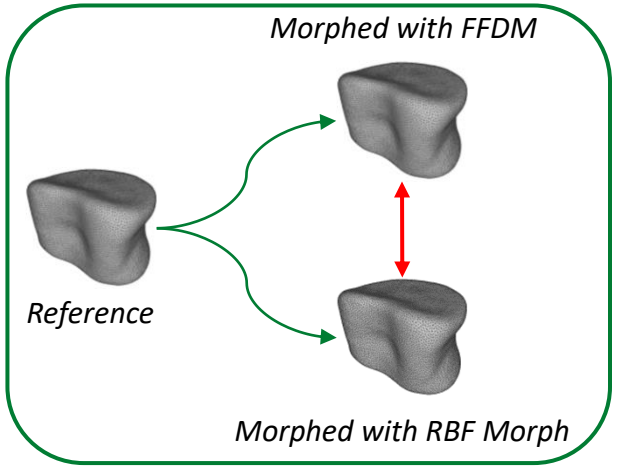
4) Mesh Morphing

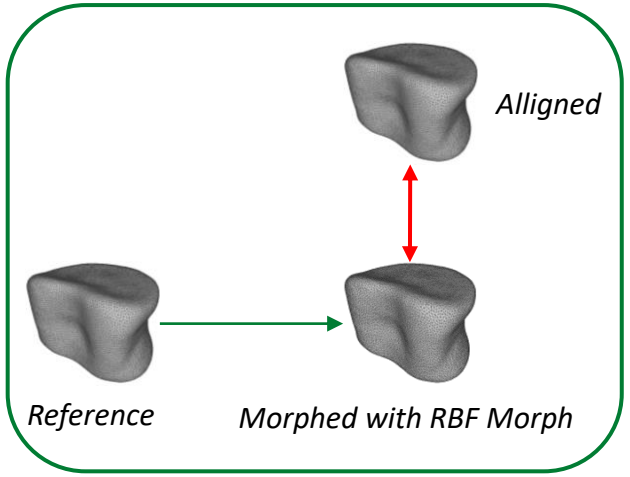
Interpolation error due to:

- Remeshing made by Ansys Mechanical
- Different morphing algorithms









Conclusions

- ✓ Morphing and volumetric meshes exportation
- ✓ Allignment to CT Scans
- ✓ Mechanical properties mapping
- ✓ Creation of a SAM of the L1 vertebral body
- ✓ Validation of the statistical model
- ✓ Mean errors acceptable, but max errors too high due to limitations

Next steps:

- ➢ Overcoming all the limitations explained above, one can obtain a more accurate SAM of the L1 vertebral body and extend the model to the entire vertebra
- ➢ Performing the analysis necessary for the planning of surgical operations or for the design of patient-specific devices

Thank you for your attention!