Prediction of the pre-fracture shape of the L1 vertebral body from adjacent vertebrae

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Introduction

Vertebral fractures are a widespread disease which is often related to age and low bone mineral density [1]. The main goals in treating vertebral fractures are the reduction of the fracture and the stabilization of the structure to allow bone healing [2], but the shape of the vertebral body before the fracture is unknown. The goal of this study was to develop and evaluate a method based on Singular Value Decomposition (SVD) to predict the shape of the vertebral body of L1 from the shapes of T12 and L2.

Methods

The segmentations of T12, L1 and L2 vertebral bodies of 40 patients were extracted from the VerSe'20 database [3]. Each mesh was aligned and registered to an optimal template mesh in Scalismo. For each patient, a vector **h** with the nodes coordinates of the morphed T12, L1 and L2 surface meshes was built. SVD was applied with the "leave one out" approach. The left-out vectors were expressed as a linear combination of the first 6 modes (previously optimised) as: $\mathbf{h_{proj} = A * \alpha}$, where **A** is a matrix composed of the 6 modes and $\boldsymbol{\alpha}$ is a vector of 6 parameters. The L1 vertebral body was reconstructed from $\mathbf{h_{proj}}$ and compared with the reference shape (registered) to evaluate the accuracy of the compression. Then, a vector $\mathbf{h_{T12\text{-}L2}}$ was obtained by considering only the coordinates of T12 and L2 from the left-out vector. The following linear system of equations was considered: $\mathbf{A_{T12\text{-}L2} * \alpha = h_{T12\text{-}L2}}$, where $\mathbf{A_{T12\text{-}L2}}$ is the part of the **A** matrix that includes only the coordinates corresponding to T12 and L2 of the 6 modes. A linear-least-squares (LLS) solution $\boldsymbol{\alpha'}$ of the system was calculated. The coefficients $\boldsymbol{\alpha'}$ were used to reconstruct the vector of coordinates of L1 ($\mathbf{h_{L1}}$) as: $\mathbf{h_{L1} = A_{L1} * \alpha'}$, where $\mathbf{A_{L1}}$ includes only the nodes coordinates corresponding to L1 from the 6 modes. The mean and Hausdorff distances between the predicted and the original shapes of L1 were calculated for each left-out vector.

Results & Discussion

The mean and Hausdorff distances between the registered and original vertebral bodies were 0.14±0.02mm and 0.96±0.30mm, respectively. The mean and Hausdorff distances between the L1 vertebral body projected in the basis of modes and the reference morphed shape were 0.46±0.19mm and 1.93±0.71mm, respectively. The mean and Hausdorff distances between the shape of L1 predicted from the shapes of T12 and L2 and the original shapes, averaged over the 39 bases built during the leave-one-out, were 0.55±0.11mm and 2.11±0.56mm, respectively. The distances obtained by LLS optimization were similar to the distances obtained by projecting the left-out vector in the basis of modes showing that the optimization was successful.

Conclusions

The shape of a L1 vertebral body could be predicted by the shapes of the adjacent ones with a good accuracy. This method will be extended to different thoraco-lumbar levels and applied to clinical datasets to identify the pre-fracture shape of L1 from the available adjacent vertebrae.

References

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