Prediction of the shape of human lumbar vertebrae from adjacent ones by Singular Values Decomposition

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Summary

Reduction is a primary objective of most treatments for vertebral fractures. However, the pre-fracture height and 3D shape of the vertebral body are unknown. Therefore, it is unclear how much height to restore in order to reestablish the pre-fracture biomechanics of the spine. In this study we propose a method based on Singular Values Decomposition (SVD) to predict the shape of a lumbar vertebral body from adjacent ones. A dataset of 20 patients was processed in a leave-one-out experiment. The L1 shape of the left-out vector was reconstructed with good accuracy. This method, once validated on a large cohort of patients, could be used to estimate the pre-fracture shape of a vertebra during the planning of the treatment strategy.

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 SVD to predict the shape of the vertebral body of L1 from the shapes of T12 and L2.

Methods

The geometries of T12, L1 and L2 of 20 patients were extracted from the VerSe'20 database [3]. The STL file of each vertebra was cut to remove the posterior elements. The resulting surfaces of the vertebral bodies were aligned based on 14 anatomical landmarks identified on the two endplates. Each surface was morphed to a template mesh in Scalismo [4]. For each patient, a vector $\mathbf{h}$ with the nodes coordinates of the morphed T12, L1 and L2 surface meshes was built. Each time, one vector was left out, and the dataset of 19 remaining vectors was compressed with SVD keeping the first 15 modes. The left-out vector can be expressed as a linear combination of the 15 modes as: $\mathbf{h}_{\mathbf{proj}} = A * \boldsymbol{\alpha}$, where A is a matrix composed of the 15 modes and $\boldsymbol{\alpha}$ is a vector of 15 parameters. The L1 vertebral body was reconstructed from $\mathbf{h}_{\mathbf{proj}}$ and compared with the reference shape (morphed) to evaluate the compression. Then, a vector $\mathbf{h}_{\mathbf{T12\text{-}L2}}$ was obtained by considering only the coordinates of T12 and L2 from the left-out vector. The following linear system of equations was considered: $A_{T12\text{-}L2} * \boldsymbol{\alpha} = \mathbf{h}_{\mathbf{T12\text{-}L2}}$, where $A_{T12\text{-}L2}$ is the part of the A matrix that includes only the coordinates corresponding to T12 and L2 from the 15 modes. A linear-least-squares (LLS) solution $\boldsymbol{\alpha}'$ of the system was calculated. These coefficients $\boldsymbol{\alpha}'$ were used to reconstruct the vector of coordinates of L1 ($\mathbf{h}_{\mathbf{L1}}$) as: $\mathbf{h}_{\mathbf{L1}} = A_{L1} * \boldsymbol{\alpha}'$, where A_{L1} includes only the nodes coordinates corresponding to L1 from the 15 modes. The mean and max relative distances between the predicted and the morphed shapes of L1 were calculated for each left-out vector.

Results and Discussion

The mean and max projection distances between the morphed and original vertebral bodies, averaged over the 60 vertebrae, were 0.31±0.03mm and 2.51±0.44mm. The mean and max projection distances between the L1 vertebral body projected in the basis of modes and the reference morphed shape were 0.93±0.19mm and 4.08±0.71mm. The mean and max projection distances between the shape of L1 predicted from the shapes of T12 and L2 and the reference morphed shape were 0.95±0.22mm and 4.23±0.83mm, on average over the 20 bases built during the leave-one-out (Figure 1). The results suggest that this method can predict the shape of the vertebral body of L1 from the shapes of the two adjacent vertebrae with a reasonable accuracy. The distances obtained by LLS optimization were similar to the distances obtained by projecting the left-out vector in the basis of modes.

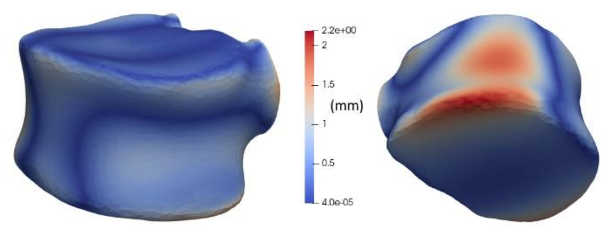

Figure 1: Distance map between predicted and morphed shapes (Patient #10).

Conclusions

The shape of a L1 vertebral body could be predicted by the adjacent ones. This method will be tested on a large database of patients.

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