Inverse finite element of the aortic arch, implications for UVP patients

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Introduction

It is known that unilateral vocal fold paralysis (UVP) is a laryngeal disorder that occurs as a result of trauma, surgical intervention, respiratory infections or neurologic diseases. However, the etiology for several other cases remains unknown. The recurrent laryngeal nerve (RLN) is the motor supply of all the muscles of the vocal folds except for the cricothyroid. Damage to the RLN causes UVP. On the left side, the RLN loops around the aortic arch and other pulsating vessels which exposes the nerve to supraphysiological levels of stretch and compression. Previously, our research group found that the compliance of the aortic arch at the level of the brachiocephalic vein was higher in iUVP patients than in their age-gender matched controls [1]. Compliance of the aortic arch is greatly influenced by the biomechanical properties of the arch. In this study, we were interested in investigating the difference of these mechanical properties between iUVP patients and their matched controls.

Methods

We used an inverse finite element (FE) approach to model the patient-specific mechanical properties of the aortic arch in 10 iUVP patients and 10 matched controls. Gated MR images were taken of each subject over one cardiac cycle. With these, we defined geometrical and displacement boundary conditions. A digital volume correlation (DVC) algorithm was utilized to determine the displacement field that defined our boundary conditions. The aortic arch was described as an anisotropic hyperelastic tissue and the Holzapfel model was used to solve our simulation. Fiber orientation was defined from our prior work using small-angle light scattering [2]. The particle swarm optimization method was used to iteratively solve the FE model and calculate the unknown material parameters. The objective function was optimized to minimize the difference between the computed aortic arch diameter and the diameter measured using the gated MRI data at the level of the brachiocephalic vein.

Results

As shown in Figure 1 (top), matrix stiffness increased with age on both groups (iUVP and controls). In addition, for the old age group, iUVP patients had a smaller matrix stiffness than the healthy subjects. Similarly, in Figure 1 (bottom), fiber stiffness increases with age on the iUVP and control groups. Also, collagen fiber stiffness is significantly smaller in old iUVP patients than in the healthy controls.

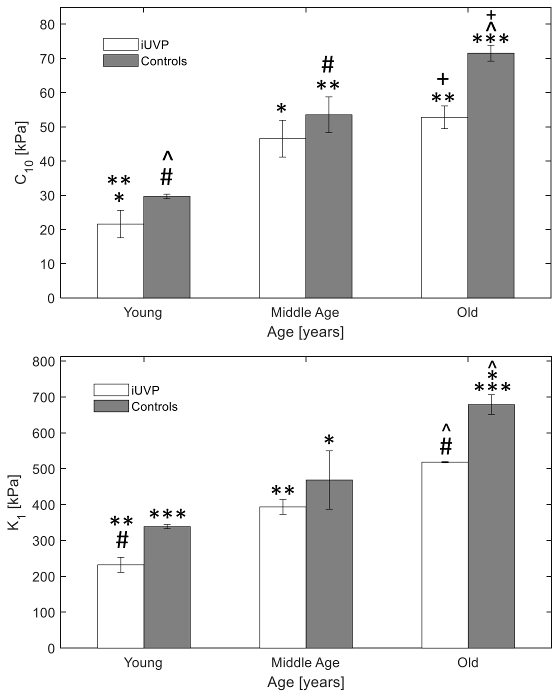

Figure 1: Matrix stiffness, C_{10} (top). Fiber stiffness, K_1 (bottom).

Discussion

Our results showed that matrix and fiber stiffness increased with age, which agrees with previous studies. More importantly, our results present smaller matrix and fiber stiffness in old iUVP patients compared to their age-gender matched controls. This suggests a lack of load-bearing, stiff structural components that might allow for supraphysiological loads on the RLN. These loads that generate tension or compression on the RLN might cause irreversible damage to the RLN.

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References

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