FRACTURE TOUGHNESS OF THE VOCAL FOLD LAMINA PROPRIA

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Introduction

The vocal folds are two pliable membranes in the larynx, which undergo self-sustained vibrations during phonation. Local rupture of the vocal folds (VFs) can occur from high impact stresses between two colliding vocal fold membranes [Gunter, 2003]. The rupture may lead to vocal fold bleeding and scarring. Numerical models have been used to study the behaviour of vocal folds under these conditions (e.g., [Gunter 2003]). Additional mechanical characterization of the VF lamina propria is required to improve the accuracy of predictive models. Fracture toughness measures the ability of a tissue to resist the propagation of cut or tear, known as a crack in classical *fracture mechanics.* No attempt has been made to quantify the fracture toughness of the vocal folds. Recently, the damage energy of animal aorta was characterized [Chu et al, 2013]. The same custom made device was used here to obtain the fracture toughness of porcine vocal fold lamina propria.

Materials and Methods

Fresh porcine larynges were harvested and dissected following the protocol in [Miri et al, 2012]. The vocalis muscle was excised out of the lamina propria using a sharp scalpel such that the surface of the lamina propria remained smooth. A schematic of the test apparatus is shown in Fig. 1. A 5-8 mm deep cut was made in each sample and the energy was calculated from blade displacement-force history. The fracture toughness was calculated from

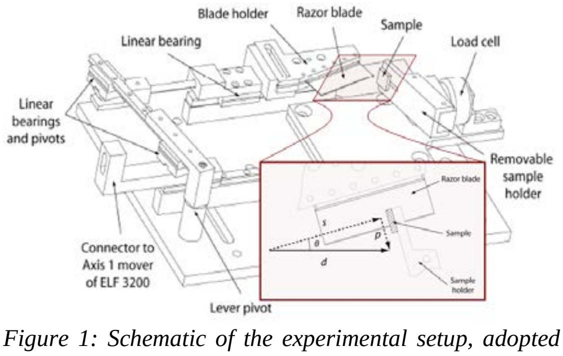

Figure 1: Schematic of the experimental setup, adopted from [Chu et al, 2013]

$$J = \int F_{\text{crack}}\, \mathrm{d}x / (hL_{\text{crack}}) \cdot \qquad (1)$$

in which F_{crack} denotes the normal force at the tip of the crack, h is the tissue thickness, and L_{crack} is the crack length.

Anterior (coronal) *n* = 5	**Centre (coronal) *n* = 9**	**Centre (transverse) *n* = 6**	**Posterior (coronal) *n* = 7**
259.5 ± 99.2	468.2 ± 183.8	169.4 ± 30.1	333.9 ± 82.4

Table 1: Fracture toughness values (J/m²) for porcine lamina propria from coronal cutting at three locations and transverse cutting in the centre.

Results and Discussion

Locations one-third anterior, one-third posterior, and one-third central within the vocal fold lamina propria were subjected to blade cutting along the coronal plane, perpendicular to the longitudinal direction (Table 1). The results show that the central region, which contributes to self-sustained oscillations more than the other areas, has the highest energy absorbance. The lowest value belongs to the anterior region, which the probability of vocal nodules growth is the greatest [Gunter, 2003].

The fracture toughness is a scalar quantity, but it depends on the cutting direction. The tissue response for cutting in a direction parallel to the anterior-posterior axis was investigated for some samples. The resulting value (~169.4) was significantly smaller than that for the normal direction (~468.2). The transverse direction is parallel to that of most of collagen fibrils. The coronal direction is normal to that of most of collagen fibrils. This result highlights the mechanical anisotropy observed in the porcine vocal fold [Miri et al, 2012]. Work supported by NIH grant R01-DC005788.

References

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