

## Mechanical Stress Levels in Vocal Fold Tissue as Predictors of Tissue Injury

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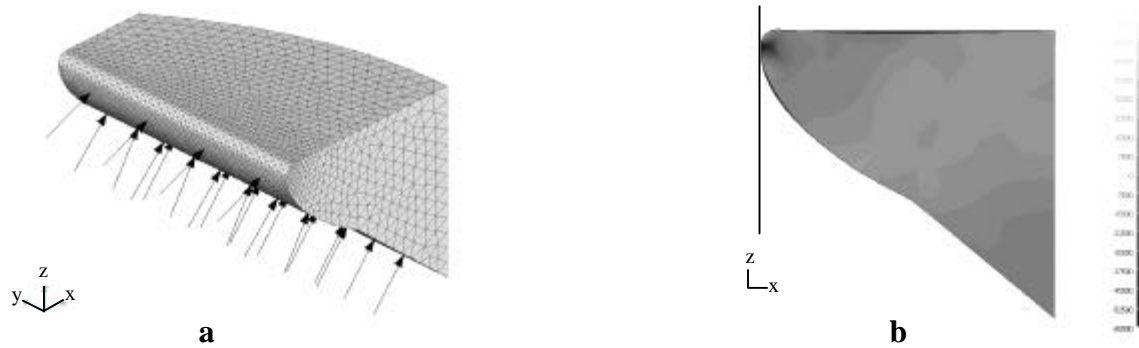
Knowledge of the factors that govern mechanical stress in vocal folds is critical to understanding and predicting injury due to mechanical trauma. Stress in tissue results both in chemical changes, such as alterations in gene transcription, and in mechanical changes, such as breakage of intracellular bonds. These result in characteristic patterns of injury including increased extracellular matrix production (Ressler et al, 2000) and disruption of tissue organization (Gray, 1991). A number of benign vocal fold pathologies, such as vocal nodules, bear histological resemblance to mechanical stress induced injuries (Massallam et al, 1986), which suggests that mechanical stress contributes to their formation (Titze, 1994).

We are using a finite element model of vocal fold tissue mechanics (Gunter et al, 2000) to examine vocal practices and configurations that have been hypothesized to increase mechanical stress levels in vocal fold tissue. Practices that increase impact stress (i.e. collision force) are candidates since collision force is often used as an indication of tissue stress (Jiang & Titze, 1994). Configurations such as abduction may increase longitudinal stress due to increased vibration amplitude (Hess, personal communication). Our model has the temporal ( $1 \times 10^{-5}$ s) and spatial (0.125mm) resolution necessary to examine dynamic tissue stress levels and therefore to make predictions about vocal fold tissue injury. Other published models of vocal fold mechanics (Alipour et al, 2000; Farley, 1996; Jiang et al, 1998) are either static, lack adequate spatial resolution or lack the collision output variables necessary to perform this analysis.

**Methods:** Vocal fold collision during phonation is modeled as a dynamic contact problem in order to calculate stress levels in the tissue during closure and impact. The model incorporates a three dimensional, linear elastic, finite element representation of a single vocal fold, a rigid midline contact surface that simulates the opposing vocal fold, and a simplified aerodynamic waveform (see figure 1). Ascending impact stress time course and the relationship between subglottal pressure and peak collision force agree with published experimental measurements (Jiang & Titze, 1994), which indicate that it is a reasonable model of vocal fold closure and collision.

We extracted data pertaining to local collision force, transverse compressive stress, sagittal shear stress, and stress invariants, such as Von Mises stress, in superficial tissue layers in order to determine the relationship between collision force and internal tissue stress.

**Results & Discussion:** The magnitudes of transverse compressive stress, Von Mises stress and vertical shear stress in medial tissue layers correlate positively local contact force. The sensitivity of the correlation is a function of the location (i.e. the longitudinal distance from the mid-membranous point). The maximum values of these stresses and the maximum contact force occur simultaneously in the mid-membranous region, which is a common site of nodule formation. There is no correlation between longitudinal shear stress and contact force. This suggests that vertical shear, compression and overall deformation are candidates for collision-induced vocal fold injury. We are currently analyzing data pertaining to the effect of abduction and subglottal pressure on tissue stresses, including the relationships between contact force and tissue stress, and are preparing to expand the model to reflect layered vocal fold geometry.



*Figure 1:* Finite element model of vocal fold collision a) model of a single membranous vocal fold (undeformed); arrows denote medial application of subglottal pressure; triangles illustrate three-dimensional solid elements b) mid-membranous coronal section of vocal fold model during impact with contact plane (vertical line); contours represent compressive stress perpendicular to contact plane and show a superficial compressive stress concentration (black)

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