WAVE METHOD FOR THE MEASUREMENT OF THE SHEAR MODULUS OF SOFT TISSUE AND BIOMATERIALS

Siavash Kazemirad[1], Hani Bakhshaee[1], Luc Mongeau[1], Karen Kost[2]

[1] *Department of Mechanical Engineering McGill University Montreal Canada*

[2] *Department of Laryngology McGill University Montreal Canada*

Introduction

A knowledge of the mechanical properties of vocal fold tissue is needed for the development of injectable biomaterials used for vocal fold augmentation and repair, for the diagnostic of scarred tissue, and for the assessment of surgical procedures used in vocal fold treatment. The *frequency-dependent* viscoelastic properties of injectable biomaterials are needed to ensure compatibility with those of the vibrating tissue.

Methods

A non-invasive method was developed to determine the shear modulus of human vocal fold tissue *in vivo* via measurements of the mucosal wave propagation speed during phonation. Images of four human subjects' vocal folds were captured using high speed digital imaging. The mucosal wave propagation speed was determined for each subject and at each pitch value using an automated image processing algorithm. The transverse shear modulus of the vocal fold mucosa was calculated using a surface wave propagation dispersion equation from the measured wave speeds.

The characterization method to measure the viscoelastic properties of soft biomaterials at high frequencies, based on Rayleigh wave propagation, was validated for polymeric materials. Planar harmonic Rayleigh waves at different frequencies were launched on the surface of a sample composed of a substrate with known material properties coated with a thin layer of the biomaterial to be characterized. A transfer function method was used to obtain the complex Rayleigh wavenumber. The complex shear modulus of the sample materials was then calculated through the proposed dispersion equation using the measured wavenumbers.

Results

The mucosa shear modulus was measured for four human subjects at different pitches, for fundamental frequencies in the range from 110 to 440 Hz. The complex shear modulus of subjects' vocal fold mucosa obtained from the Voigt viscoelastic model fitted to the measured shear wave velocities are shown in Table 1.

Subjects	Shear modulus [Pa]
# 1	$415 + i\omega 0.40$
# 2	$878 + i\omega 0.52$
# 3	$1496 + i\omega 0.67$
# 4	$2722 + i\omega 1.01$

Table 1: The complex shear modulus of human subjects' vocal fold mucosa.

Layered silicone rubber and gelatin samples consisting of a substrate with known properties under a thin layer of a soft material with unknown properties were fabricated and tested. The shear/elastic moduli of the samples were measured at frequencies up to 4 kHz.

Discussion

The results obtained from human vocal fold tissue *in vivo* were in good agreement with those from other studies obtained via *in vitro* measurements [Chan and Rodriguez, 2008], thereby supporting the validity of the proposed measurement method. This method offers the potential for *in vivo* clinical assessments of vocal folds viscoelasticity from HSDI. The results obtained from soft biomaterials were found to be in good agreement and improved upon those of [Nenadic *et al*, 2011]. Furthermore, they emphasized the need for quantifying the *frequency-dependent* viscoelastic properties of gel-like biomaterials over a broad frequency range to accurately characterize the viscoelastic properties of injectable phonosurgical biomaterials and hydrogels used for vocal fold treatment.

References

Chan and Rodriguez, J Acoust Soc Am, 124:1207-1219, 2008.

Nenadic *et al*, Phys Med Biol, 56:6723-6738, 2011.