REFINEMENTS IN MODELING THE MECHANICAL PROPERTIES OF LARYNGEAL SOFT TISSUE

Eric J. Hunter [1], and Ingo R. Titze[1,2]

[1] National Center for Voice and Speech, Denver, Colorado, USA
[2] NCVS, Dept. Speech Pathology and Audiology, University of Iowa, Iowa City, IA, USA

E-mail: ehunter@dcpa.org; www.ncvs.org

INTRODUCTION

Significant advances have occurred in our understanding of the structure and function of the human laryngeal system, whose main functions are airway protection, respiration, and phonation. Nevertheless, there is still much to learn and apply; for this to happen, the composition of the larynx (geometry and properties) must be accurately defined. Of particular importance are the vocal folds, the primary sound generator of the human voice, as well as a source of airway protection.

The kinetics of the vocal folds can be classified into two parts; vocal fold vibration with (small and relatively fast deformations at 100 – 1000 Hz or more) and vocal fold posturing (large and relatively slow deformations at frequencies of <1 – 10 Hz which occurs when the vocal folds are positioned for prephonation, pitch change, inhalation, and airway closure). Vocal fold posturing is powered primarily by the laryngeal muscles, with passive contributions by the vocal ligament, laryngeal muscles not in contraction, and surrounding cartilages and joints.

The purposes of this report were to measure more accurately and quantify in greater detail the passive properties of the canine LCA, IA, and PCA by using Titze's adaptation of the Kelvin model (Titze, 1996, Hunter, 2004). New details of the hysteresis of the vocal ligament's stress-strain curve were also presented. A summary of all five intrinsic laryngeal muscles (using canine tissues), in addition to the human vocal ligament and mucosa, was given in terms of the tissue model parameters. This paper then provides the mathematical model and parameters to simulate the dynamic longitudinal stress-strain response of the five laryngeal muscles, vocal ligament, and vocal fold mucosa.

METHODS

The tissue data used in the current study was collected as part of several previous experiments on human and canine laryngeal tissue conducted at the National Center for Voice and Speech at the University of Iowa (Alipour, 2005, Min, 1995). To obtain the passive properties of the tissues, samples were stretched and released by applying a 1-Hz sinusoidal signal (approximating the rate of vocal fold posturing and similar to other comparable studies). Sample freshness was maintained in a warmed, oxygenated, Krebs-Ringer solution.

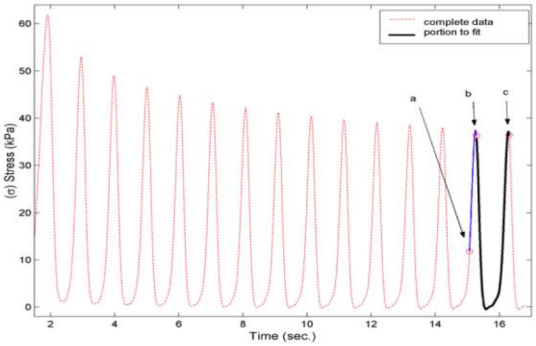

Figure 1. Stress from a sinusoidal (1 Hz) elongation of a PCA muscle. Stress in time

with the solid line between Points **b** and **c** is the portion of the data modeled.

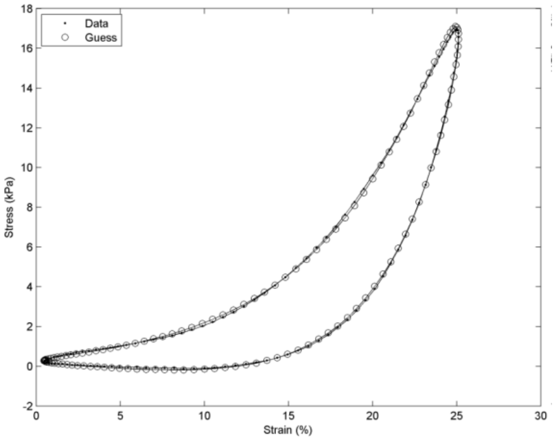

Figure 2. A good fit of the model to stress-strain data from a PCA muscle. Notice that there is little difference between the data points (dots) and the modeled stress (circles).

Stress-strain data from fifteen canine laryngeal muscle samples and eight human vocal ligaments were used to find parameters of a modified Kelvin model; a bounded Nelder and Mead Simplex method was the technique used to fit the parameters.

RESULTS AND DISCUSSION

Parameter optimization was used to obtain parameter values. As the modified Kelvin model was nonlinear, average parameter results are not always useful; therefore, a method of obtaining mean stress curve parameters was used to get the most representative parameters.

SUMMARY/CONCLUSIONS

Passive parameters of the modified Kelvin model were summarized for the vocal ligament, mucosa and all five laryngeal muscles. Results suggest that the LCA, PCA and IA muscles are functionally different from the TA and CT muscles in their load-bearing capacity. Further, the LCA, PCA and IA have a much larger stress-strain hysteresis effect than has been previously reported for the TA and CT or the vocal ligament. The variation in this effect suggests that the connective tissue within the TA and CT muscles is somehow similar to the vocal ligament but different from the LCA, PCA or IA muscles. The grouping of abductor/adductor muscles vs. pitch control muscles is in general agreement with the histology and muscle fiber-type found in the laryngeal muscles where abductor and adductor muscles are described as “allotypically different” and “kinetically faster than the fastest limb myosin heavy chain”. Further demonstrating the potential significance of grouping tissues in the laryngeal system by functional groups was the unique finding that, over their working elongation range, the LCA and PCA were nearly as exponentially stiff as the vocal ligament (in the healthy functional range of each tissue). Finally, from the optimized parameters and related information, have helped increment the ability to apply this knowledge to realistic laryngeal models using computational simulations and laboratory experiments.

REFERENCES

Titze IR. (1996). In: *Vocal fold physiology: controlling complexity and chaos*, Singular Publishing Group. 47-62.

Hunter EJ, Titze IR, Alipour F. (2004). *J Acoust Soc Am* **115**: 1747-1759.

Alipour F, Titze IR, Hunter EJ, Tayama N. (2005). *J Voice* 19: 350-359, 2005.

Min YB, Titze IR and Alipour-Haghighi F. (1995). *Ann Otol Rhinol Laryngol* **104**: 563-569.

ACKNOWLEDGEMENTS

Muscle data was collected with support from DC004347 (NIDCD). The analysis and modeling were conducted also supported by the NIDCD (DC006801).