A finite element model of the interaction between intra- and extralaryngeal muscles

Malte Kob[1] *& Christoph Butenweg*[2]

[1] Dep. of Phoniatrics, Pedaudiology and Communication Disorders, University Hospital, RWTH Aachen University, Pauwelsstr. 30, D-52074 Aachen, mkob@ukaachen.de
[2] Institute of Structural Statics and Dynamics, RWTH Aachen University Mies-van-der-Rohe-Str. 1, D-52056 Aachen, butenweg@lbb.rwth-aachen.de

Abstract

The interaction of intra- and extralaryngeal muscles is to be considered for voice diseases that originate from load or movement in parts of the body different from the larynx. These interactions are known from situations where patients have to carry heavy load and reveal hoarseness after some time. This investigation shall help to describe quantitatively the change of the glottis status caused by the application of forces on the external muscles of the corpus.

1. Introduction

Within the frame of the Aachen Bionic-center a joint project of the faculty of medicine and the faculty of civil engineering has been established. The aim is the realisation of a tool for modeling of pathologic voice generation that can be used by phoniatricians or speech therapists in therapy and teaching. Such a model can be used for the visualisation of the interaction between muscles of the neck and the configuration of the larynx during phonation in patients with hypertension in the muscles of the neck. An algorithm is being developed that calculates the force distribution between intra- and extralaryngeal muscles in 3D space.

2. Method

2.1. Vocal fold model

A multiple-mass vocal fold model [1] is used for simulation of vocal fold movement in the time domain. In Figure 1, a view on top of the model is shown. The dark gray structure shall represent the vocalis and ligament tissues, the light gray areas symbolise the mucosa membrane.

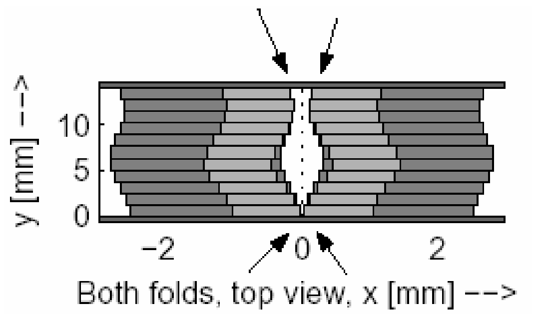

Figure 1: *Set-up of vocal fold model.*

The glottal status is determined by the adduction or abduction of the intralaryngeal muscles. The points of suspension is indicated by arrows. The change of the suspension due to the muscle movements is controlled by the FE-model described in the following section.

2.2. Finite-Element model

A three dimensional numerical model of the larynx and its suspension is used to study the interaction between the intra- and extralaryngeal muscles. The model, which was built up by using the Finite-Element software package ANSYS [2], represents the cartilages, ligaments and membranes with finite beam-, shell- and volume elements.

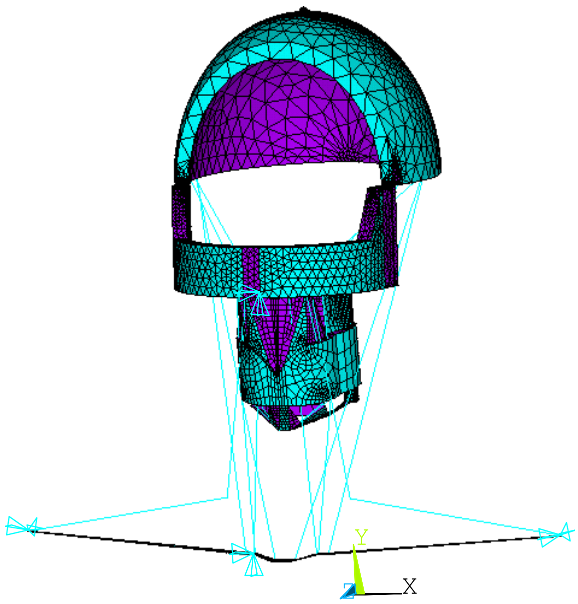

Figure 2: *Finite-Element model of the complete model.*

The specific muscle behaviour is considered by the implementation of a one dimensional user element with three nodes and piecewise linear shape functions into ANSYS. The element formulation is based on a Three-Element Model according to Hill [3], which consists of a contractile element (CE), a passive element (PE) and a serial element. The CE represents the active muscle behaviour, the PE describes the mechanical behaviour of the muscle connective tissue and the SE corresponds to the tendon connections to the bones or cartilage at each end of the muscle. The input parameters to describe passive and active nonlinear muscle properties within the model are taken from literature and will be completed by experimental studies carried out at the Department of Pathology, University Hospital Aachen. Figure 2 shows the complete finite-element model consisting of the larynx, the larynx suspension by the extrinsic muscles and the rough idealization of the external skull and shoulder structures. The extrinsic muscles have one attachment to a laryngeal structure and one attachment to the external structure.

In Figure 3 the details of the larynx and the position of the intrinsic muscles responsible for opening or closing the glottis slit and stretching the vocal folds are shown in a side and top view. The finite-element model allows the calculation of the vocal fold elongation caused by an increased tonus of the extralaryngeal musculature over the time. This result can be used as an input for the vocal fold model to study the influence of an increased muscle tonus on the vocalization.

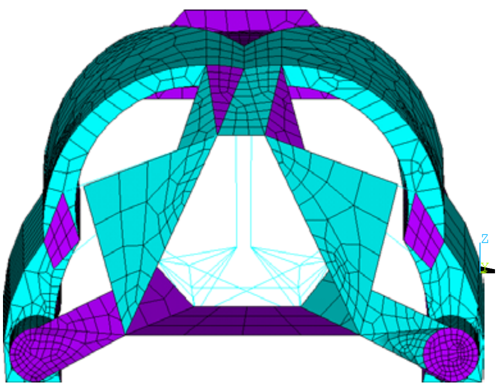

Figure 3: *Finite-Element model of the larynx (top view).*

3. Conclusions

In the current implementation, the data exchange between the two models is accomplished by an ASCII file that contains a series of parameter changes for discrete time steps. These data are used for updating of the boundary conditions in the time-domain vocal fold model. The reliability of the simulation strongly depends on the accuracy of the geometrical and material input parameters of the FE model. Current investigations aim at optimising these properties.

4. References

[1] Malte Kob. Physical modeling of the singing voice. *PhD thesis, Aachen University (RWTH)*, 2002.

[2] SAS IP Inc. ANSYS FE-Software, 2003. URL: *www.ansys.com*.

[3] A. V. Hill. The Heat of Shortening and the Dynamic Constants of Muscle. In *Proceedings of the Royal Society of London*, volume 126, pages 136–195, 1938.