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Assessment of 3D elasticity data of the larynx for FE models of phonation

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The quality of numeric models of phonation is strongly dependent on the accuracy of geometric and elastic tissue data because of the inhomogeneous and anisotropic nature of these structures. The dynamic elasticity of the vocal folds can be assessed in vivo and in vitro with a linear skin rheometer. This method has been applied in parallel and normal to the vocal fold surface of excised larynges. The data was collected in several directions and for two layers of the tissues which provides a base for a finite-element model. The results of the measurements are presented and consequences for the simulations are discussed.

1 Introduction

The elastic and geometric properties of the vocal folds determine to a huge extend the vibrational behavior during phonation. Fundamental frequency, voice level and more complex voice properties such as timbre result from individual settings of the glottal tissues. During voiced phonation, the vocal folds perform a transverse motion that modulate the volume flow through the glottis during each cycle of their self-sustained oscillation. The tissues are able to perform complex vibration patterns while stretched by action of various muscles. This task is distributed among three different tissue types: the ligamentum vocale is strained between cartilages and supports high tension during excessive voice use, the musculus vocalis adds mass and volume to the vocal folds and is capable of active contraction, and the mucosa serves as a relocatable layer which allows for complex shapes and dynamics of the glottal channel.

Some of the tissues are usually assumed to be isotropic, so that a single value for the elasticity of the vocal folds is used for all directions.

Hirano et al [1] and Story and Titze [2] propose a body layer representing the muscular tissue and the ligamentum vocale responsible for the tensioning of the vocal fold and a cover layer representing the mucosa. It has been reported that the cover layer is an isotropic tissue, as stated by Rosa [3] and Berry and Titze [4], with a shear modulus of about 5 kPa. The body layer is assumed to be anisotropic with a shear modulus ranging from 7 kPa to 20 kPa.

In the FE-model by Gömmel et. al. [5] and the multiple mass model Vox by Kob et. al. [6] the tissues of the vocal folds are modeled using these layers. Modeling tasks for complex phonation types such as vocal fold pathologies or other than modal register seem to require a more accurate representation of the anisotropic vocal fold structure.

The present study investigates the validity of the above assumptions of the vocal fold properties by measuring the elasticity of human vocal folds in all three dimensions and at different positions on the vocal fold cover and on the body layer. In a first series of measurement, the vocal folds were excited on the mucosa, in a second step the mucosa covering the vocal folds was removed and the underlying muscular tissue was measured the same way.

The variation of the elasticity with respect to location, direction and vocal fold tension is investigated in a first set of larynx samples. This text extends the manuscript given on occasion at DAGA 2010 in Berlin by Mario Otten [7].

2 Assessment of tissue elasticity

The elasticity of the oscillating tissue was investigated with the "Linear Skin Rheometer" (LSR). This device was constructed by Matts and Goodyer [8], and uses a servo-motor and a load cell to measure elongation vs. applied force. Originally designed to measure skin elasticity, the device has been used to measure the elasticity of the mucosa as well [9]. To connect the tissue to the probe of the device, several methods can be used. One is to puncture the tissue with a needle, but by doing so not only the topmost tissue layer is affected, potentially the layers beneath are affected as well, especially if, like in our case, more than one measurement is taken and the moving needle may migrate deeper into the tissue. Another method is glueing a steel rod to the tissue under test. Whilst this is a good approach when measuring the epidermis, the moist mucosa needs special adhesives to be properly fixed to the probe. As we wanted to take multiple measurements regarding the same vocal fold, the potential damage to the tissue when removing the probe were debilitating. For these reasons we used a vacuum pump and a glass tube of 1 mm (inner) respectively 2 mm (outer) diameter to affix the tissue to the probe similar to the method used by Goodyer er al. [9].

A problem during measurement arose from the mucous nature of the tissue: The probe tended to slip

away from the target measuring point. This problem was solved by abrading the initially polished tip of the probe. But because of this the effective diameter was doubled, as now not only the bore of the probe stuck to the tissue but the whole outer diameter had to be taken into account.

To improve repeatability of the boundary conditions, a mount was constructed which did not deform the tissue but kept it in a stable form by molding the outer and subglottal part of the larynx. A material was found that was viscous after compounding with water but became solid within a few minutes and enclosed the larynx tightly without deforming it, see fig. 1.

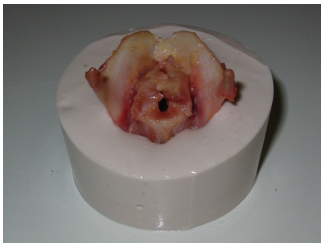

Figure 1: Encasted larynx

To reach the vocal fold and measure the elastic properties with respect to all directions, the larynx needed to be split. A grid of three measuring points in three rows was established. The first row divided the vocal fold into 4 equally long segments along the anterior-posterior axis. The other rows were placed caudal to the first row with a distance of 2 mm. Figure 2 shows the split larynx with the measuring points indicated by black dots. In the following text the measuring points are described by a pair of a letter and a number.

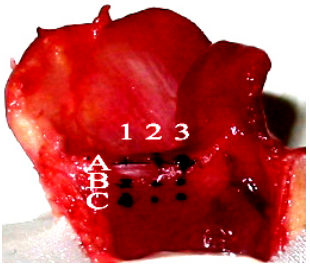

Figure 2: Split larynx with markers

Every point was measured in three axes: the axis parallel to the vocal fold and the vertical and horizontal axes normal to this axis. For the measurements normal to the intersecting plane a straight probe was used, the other directions were measured with a bended probe. Every point in every direction was measured 10 times and the probe was loosened and afresh fixed to the tissue several times. This was done for each left and right hemi-larynx.

After the first measurements the mucosa was incised along the vocal fold and the mucosa was unsoldered from the underlying muscle tissue in the area where the measurements took place. To keep the tissue in its anatomical context, the mucosa was not removed completely. The probe was attached to the underlying tissue through the incision.

During voiced phonation the tension of the vocal folds is a key parameter for voice pitch. One way to change the tension is to turn the arytenoid cartilages. To add this option to the set-up, a fixture was developed which can embrace the arytenoid cartilage without puncturing the surrounding tissue. This construction made it possible to turn the cartilage and thus alter the vocal fold tension (see fig.3)

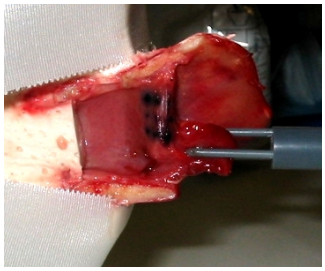

Figure 3: Arytenoid cartilage in fixture

3 Results

In a preliminary study these new methods were applied to two larynges with the aim to prove that they produce reliable data. Since then, three more larynges were measured as described above, the results of these measurements are reported in the following. There will be more measurements in the near future to build a database of elastic properties.

Larynx 1 was dissected from a 56 year old male. The larynx showed no apparent damages, the length of the vocal folds was 15 mm. Larynx 2 was dissected from a 39 year old male. The length of the vocal folds was 16 mm. This larynx exhibited a cyst near the anterior commissure of the left vocal fold, but this did not seem to alter the measurements as it was anterior to the first measuring point. Larynx 3 was dissected from a 28 year old female. The length of the vocal fold was 12 mm. Besides the expected smaller size in comparison to the male donors the ventricular fold was pronounced. As the measurements took place caudal to the ventricular folds this fact should not bias the results.

3.1 Differences between hemi-larynges

As previous studies already showed, e.g. [10], huge differences between different investigated larynges could be observed. Even within the same larynx differences between left and right vocal fold occur, as fig. 4 for the three investigated larynges shows.

Point A2 was chosen as the reference point since this point is investigated in most studies. The values range from 500 to 1000 Pa while the standard deviation is below 20 % and typically below 10 %.

3.2 Differences between directions of measurements

The shear modulus obtained from measurements on the vocal fold mucosa differs significantly with direction of excitation. Exemplary for the anisotropy between

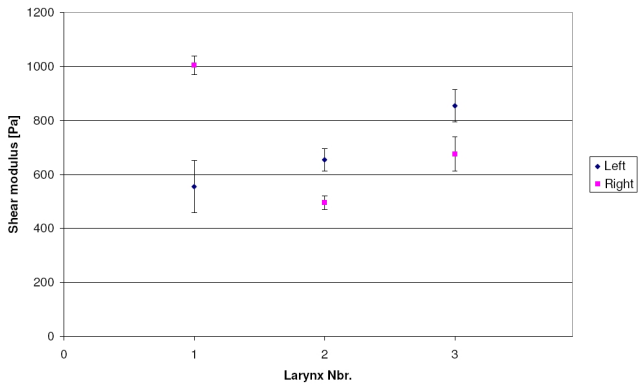

Figure 4: Shear modulus for left and right vocal fold measured at point A2 in cranial-caudal direction, n=10, mean

cranial-caudal and anterior-posterior direction, figure 5 shows the differences of the shear modulus at the three points in column 2.

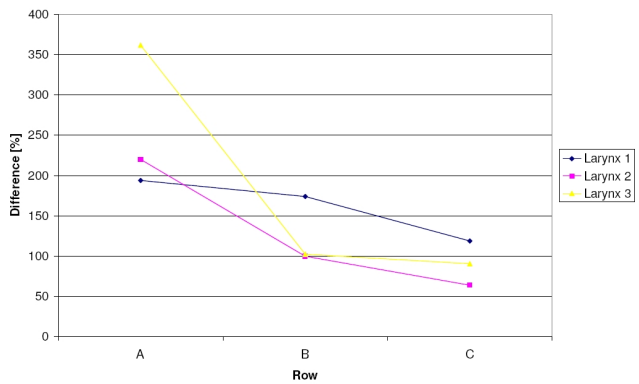

Figure 5: Increase of shear modulus in cranial-caudal direction with respect to the anterior-posterior direction in column 2, right vocal fold

The anisotropy is strongest at the upper edge of the vocal folds. The shear modulus increases about 200 % to 360 %.

3.3 Differences between layers

Table 1 shows relations between measurement results of the muscle tissue with the mucosa being detached. The differences are well below 10 % so that an isotropic behavior can be assumed. It has to be mentioned that the vocal ligament was also removed and that the muscle fibres were not activated during the measurement like they would be during phonation.

Regarding the same direction of elongation but different measuring points along the vocal fold respectively parallel to it one can detect a change of elasticity. This difference is by far not as dramatic as the gap between different directions, but differences are detectable.

Table 2 shows the relation between the values measured at the point in the middle of the accordant row of measuring points and the point anterior respectively posterior that point. The values are taken from only one larynx, but the results of the other investigated larynges are comparable.

Table 1: Difference between elasticity in cranial-caudal and anterior-posterior direction with respect to column 2 with removed mucosa

Larynx	Row		
	A	B	C
1	0%	0%	2%
2	3%	4%	-6%
3	-6%	-2%	4%

Table 2: Difference between elasticity within the anterior-posterior direction for one larynx

Points	Row		
	A	B	C
1-2	7%	29%	7%
2-3	18%	26%	45%

Table 3 shows the relations between points with respect to the cranial-caudal axis. Tables 2 and 3 reveal that the assumption of a constant value for the elasticity, be it in cranial-caudal or anterior-posterior direction, is not consistent with the measurements. In fact a distinct value for each point has to be used for the simulation.

Table 3: Difference between elasticity within the cranial-caudal direction with respect to a measuring point on column 2 for one larynx

Rows	Column		
	1	2	3
A - B	38%	25%	27%
B - C	59%	45%	35%

3.4 Differences between different vocal fold tensions

In the next step the arytenoid cartilages were turned as described above. A force of 0.2 N was applied perpendicular to a lever of 5 cm length, resulting in a torque

$$M = F \cdot l = 0.2[\mathrm{N}] \cdot 0.05[\mathrm{m}] = 0.001[\mathrm{Nm}] \qquad (1)$$

With this torque applied to the tissue, surprisingly the shear modulus of the muscle tissue was not altered by more than 10 %. This is possibly due to the fact that most of the additional force is absorbed by the not entirely removed mucosa, as in an intact mucosa the shear modulus changed significantly, as shown in table 4. But the change can not be related to the position of the measuring point. When observing larynx 1 the highest difference in can be regarded in row 1, observing larynx 2 the highest difference occurs in row 2 and regarding larynx 3 the highest difference occurs in row three. Table 5 exposes similar behavior with respect to the cranial-caudal axis. An explanation for this characteristics could not be found, more measurements will help to elucidate the behavior under tension.

Table 4: Difference of elasticity between relaxed and strained larynx with respect to column 2 for movement in anterior-posterior direction

Larynx	Row		
	A	B	C
1	62%	10%	49%
2	91%	100%	70%
3	193%	197%	320%

Table 5: Difference of elasticity between relaxed and strained Larynx with respect to column 2 for movement in cranial-caudal direction

Larynx	Row		
	A	B	C
1	14%	5%	12%
2	93%	387%	236%
3	592%	197%	152%

4 Conclusion

The results differ by a large amount from the data taken from literature, it was discovered that the elasticity of the muscle tissue is isotropic rather than anisotropic. The data for the cover layer in [11] were taken from a dissected mucosa and measured using a parallel plate rheometer, in the present study the mucosa was measured in its anatomical context, so that the results may be altered by the underlying muscle tissue. But it could be asserted that the mucosa when measured within the larynx showed anisotropic behavior rather than isotropic.

Further this study shows once more that the differences between larynges are significant, so that a general assumption of the elasticity is difficult. The simulation of the vocal fold needs reliable data to base the models on, until now no assumption can be made. The difference between the measured values in this study and corresponding values in literature may relate to the different measurement techniques. This study measures the entire vocal fold. It was anticipated that the first measurements with an intact mucosa would only affect the mucosa itself, the differences to other studies, especially the anisotropic behavior, suggests that the underlying tissue and the boundary conditions evoked by the geometry of the larynx alters the measurements. The measurements revealed an isotropic behavior of the muscle tissue beneath the mucosa, the measured anisotropic characteristics of the vocal fold has to relate to the combination of both tissues, the vocal ligament and the geometry of the vocal fold. The FE-model of the vocal folds needs to take this fact into account. To elucidate the difference between measurements of the sole mucosa tissue in literature and the measured values in anatomical context, optimization calculations are performed including geometry data. It is planed to perform measurements of the vocal fold elasticity in-vivo as well to study the differences between in- and ex-vivo measurements. Furthermore it is planed to use high resolution MR-images of the same larynges to obtain corresponding measurements of the larynx geometry.

Acknowledgments

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References

[1] Hirano, M., Kurita, S., Nakashima, T.: The structure of the vocal folds, in Vocal Fold Physiology, 1984 pp. 33-41

[2] Story, B.H., Titze, I.R.: Voice Simulation with a body cover model of the vocal folds, J. Acoust. Soc. Am. 1995, 97, 1249-1260

[3] Rosa, M.O., Peraira, J.C., Grellet, M., Alwan, A.: A contribution to simulating a three dimensional larynx modell using the finite element method, J. Acoust. Soc. Am. 2003, 114, 2893-2905

[4] Berry, D.A., Titze, I.R.: Normal modes in a continuum model of vocal fold tissues, J. Acoust. Soc. Am. 1996, 100, 3345-3354

[5] Gömmel, A., Butenweg, Ch., Kob, M.: A fluid-structure interaction model of vocal fold osciallation, Proc. 5th Int. WS on Models and Anal. of Vocal Emissions for Biomed. Appl.(MAVEBA) in Florence, Italy 2007, pp. 127-128.

[6] Dejonckere, P.H., Kob, M.: Pathogenesis of Vocal Fold Nodules: New Insights from a Modelling Approach. F. Phon. et Logo. 2009, 61, 171-179.

[7] Otten, M., Müller, F., Rohlfs, A.-K., Gömmel, A., Hess, M., Kob, M.: 3D measurement of vocal fold elasticity using the linear skin rheometer. Fortschritte der Akustik – DAGA 2010, Berlin, in print.

[8] Matts, P.G., Goodyer E.: A new instrument to measure the mechanical properties of the human stratum corneum. J. Cosmet. Sci. 1998;49:321-323

[9] Goodyer, E., Welham, N.V., Choi, S.H., Yamashita, M., Dailey, S.H.: The shear modulus of the human vocal fold in a transverse direction. J. of Voice 2009, Vol. 23, No. 2 151-155

[10] Goodyer, E., Hemmerich, S., Müller, F., Kobler, J.B., Hess, M.: The shear modulus of the human vocal fold, priliminary results from 20 larynxes. Eur. Arch. Otorhin. 2007; 264:45-50

[11] Titze, I.R.: The Myoelastic Aerodynamic Theory of Phonation. NCVS, 2006