Determination of vocal fold geometry from excised larynges: Methodology and preliminary results

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Abstract

The goal of the present study is to measure the variations of the vocal fold geometry with changes of the fundamental frequency of phonation. Here a methodology comprising creation of plaster laryngeal molds of human excised larynges, mold digitizing and further software processing as well as the first results are presented.

3D computer models of the laryngeal cavities (glottal airways) obtained from two excised human larynges each vibrating at two different fundamental frequencies were studied. The shapes of vocal folds in the entire glottal region – not only the subglottal part – were described and fitted by a piecewise defined low-order polynomial curve.

1. Introduction

Vocal fold geometry is highly important in determining the vibratory pattern of the vocal folds in phonation position. Yet the detailed information on the vocal fold shape is largely incomplete due to their inaccessibility and limited resolution of standard imaging methods such as CT and MRI. Berry et al. [1] was the first to succeed in measuring the vocal fold geometry in excised larynges using wax molds. The geometry of canine vocal folds in pressed, barely adducted and slightly abducted position was studied.

This study reports on an alternative casting methodology for creation of laryngeal molds using plaster instead of wax. The casting method makes it possible to remove the material from the larynx without destroying the larynx itself and therefore it can be used to create more casts from the same larynx and to study changes of geometry of specific vocal folds with different glottal configurations.

2. Creation of laryngeal casts

The larynx was fixed into the phonatory adjustment and phonation was initiated. The vocal fold vibrations were excited by airflow and monitored acoustically, as well as by means of laser vibrometer, videostroboscopy and pressure transducers in the subglottal space. Prior to the casting procedure the airflow was stopped. Then a thin mixture of dental plasters was slowly poured into the larynx from above. After the mixture hardened, the fixed larynx was turned upside down and the plaster was poured into the intralaryngeal space. A plaster or metal bridge joined both parts in order to fix the exact position of the upper and lower parts of the airways casting. After hardening the plaster cast was broken into supraglottal and subglottal parts and removed from larynx. Then all plaster pieces were put back together in the correct position and fixed by fast-ticking glue.

Figure 1: *Plaster cast of larynx No.2, F0=112Hz, Q=0.6l/s*

The sample plaster cast is shown in Fig.1. For making copies the plaster cast was submerged into a can containing mixture of a silicone material prepared for fabrication of the mould. Wood type low-fusing metal or plaster was used to create copies of the original cast for further analyses.

3. Digitizing of the casts

Several in principal very different methods for evaluation of the shape of the plaster casts were tried. First, the shapes of the vocal folds were analysed by optical moire topography, which uses a method of a line raster projected on the plaster cast. Second, they were examined by the scanning electron microscope and third by CT imaging. However, it was possible to utilize these evaluation methodologies only for parts of the vocal fold surface or for selected cross-sections.

However, the best results were obtained with the help of the Wenzel LH-87 bridge-type coordinate measuring machine (CMM). With the scanning probe head, CMM can measure complex surfaces with high density (approximately 30 samples/mm) and precision up to 1µm. The precision of the digitizing equipment far surpasses the surface quality of the casts, which seems to be the limiting factor of the method.

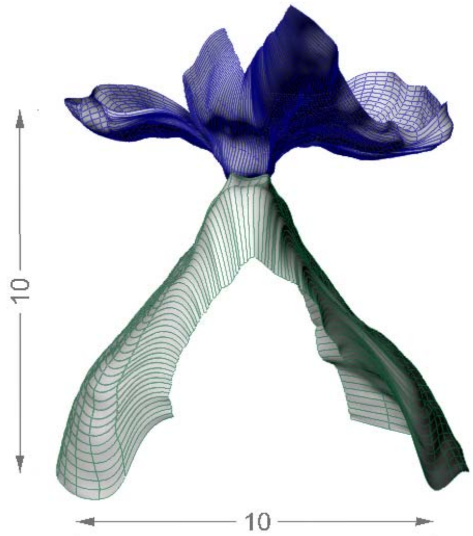

Figure 2: *Computer model of the glottal space - larynx No.8, F0=308Hz , p_{sub}=1.2kPa, Q=0.6 l/s*

Since the instrument requires the surface to be accessible from one direction, the subglottal and supraglottal parts of the cast were measured separately. To increase accuracy, the contact points between the probe and the cast were not determined automatically by the CMM (as usual), but computed from the envelope curves. Afterwards, the entire glottal space was reconstructed in the Rhino 3D NURBS modelling software (Fig.2). The length of the vibrating membranous part of the vocal folds was estimated from the videostroboscopic record taken just before casting. In corresponding region of the computer model, the vocal fold shapes in coronal sections were determined and analysed.

4. Determination of vocal fold shape

For each larynx, the geometry of the vocal folds vibrating at two different frequencies was determined. Considering the character of the shapes obtained from the coronal sections, the data were fitted by piecewise defined low-order polynomial curves. In addition, a thickness of the vocal folds along their length was determined using a methodology similar to Hollien's approach [2]. A sample shape of the coronal section of the vocal folds is presented in Fig.3.

5. Conclusions

With the method developed, it is possible to measure more casts of the same larynx in different glottal configurations. The vocal fold shape is obtained in both inferior and superior parts, the limiting factor of the method seems to be the cast quality.

A new description of VF shape based on piecewise defined low-order polynomials was proposed, and the function parameters for mid-membranous sections of two larynges vibrating at two fundamental frequencies were calculated.

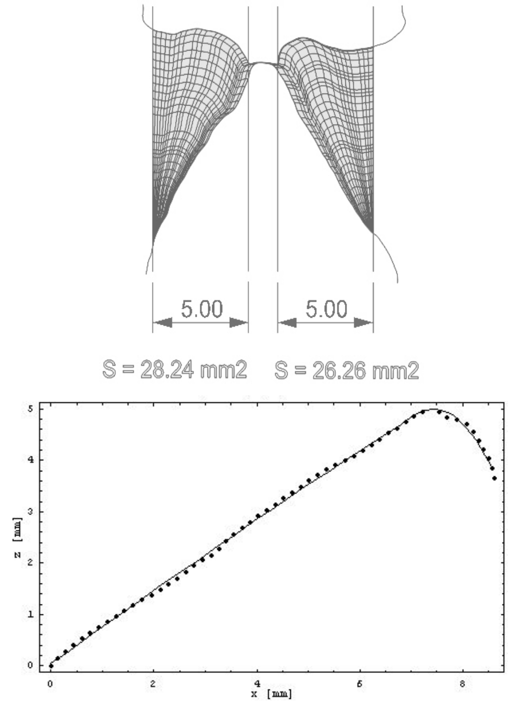

Figure 3: *Coronal section through the glottal space near the mid-membraneous point with calculated vocal fold cross-sectional areas and fitted shape of the right vocal fold.*
Larynx No.8, F0=308Hz , p_{sub}=1.2kPa, Q=0.6 l/s

In accord with Berry's results on canine larynges, the bottom part of the vocal fold is approximately linear. The bulging of the vocal folds is dependent on the fundamental frequency and generally lower than usually assumed, the convergent parts are often linear or even convex with a negative bulging. However, this might be caused by inactivity of TA muscle on excised larynges.

6. References

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