The Effect of Vocal Fold Inferior Surface Hypertrophy on Voice Function in Excised Canine Larynges

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Summary: Objective. This study aimed to explore the changes in vocal fold inferior surface hypertrophy (VFISH) on vocal fold vibration by aerodynamic and acoustic analysis. The present study allows us to gain new insights into the subglottal convergence angle (SCA), which will change with VFISH.

Study Design. The study is prospective, and designed for repeated measures with each excised canine larynx serving as own control.

Subjects and Methods. Three degrees of VFISH, initial, mild, and severe, were simulated by injecting different doses of fructose injections into the inferior surface of the vocal folds of 10 excised canine larynges. Computed tomographic images of the larynx were gathered, and three-dimensional models of the airway and vocal folds were reconstructed using the Mimics software. The SCA was measured from the reconstructed models. Phonation threshold flow (PTF), phonation threshold pressure (PTP), and mean flow rate (MFR) were recorded directly in the excised canine larynx phonation setup. Glottal resistance (GR), sound pressure level (SPL), fundamental frequency (F0), and formants 1–4 (F1–4) were measured when subglottal pressure (P_{sub}) was at 1.5 kPa or 2.5 kPa, separately. Using ordinary one-way analysis of variance, we compared the aerodynamic outcomes and voice quality among the three groups of hypertrophy.

Results. The SCA, PTP, and PTF increased with the degree of VFISH. When the P_{sub} was controlled at 1.5 kPa or 2.5 kPa, F0 also increased significantly with the degree of VFISH of the excised canine larynges. The MFR, GR, SPL, and F1–4 had little change between the three groups and were not significantly different.

Conclusion. The VFISH makes onset phonation more difficult, increases the SCA, and increases the F0 in sustained phonation.

Key Words: Excised canine larynges–3D model–Vocal fold inferior surface hypertrophy–Subglottal convergence angle–Aerodynamic and acoustic parameters.

INTRODUCTION

It has been known that the vocal fold is a three-dimensional (3D) structure that is deformed dynamically by a complex interaction from airflow going through the larynx. A significant amount of studies have highlighted and characterized relationships between vocal fold geometry and voicing. The current main study methods have been summarized as follows: (1) creating physics-based synthetic models to simulate the larynx[1]; (2) using computed tomography (CT)[2]/magnetic resonance image (MRI)[3]/X-ray stroboscopy[4]/optical coherence tomography[5] to obtain geometric data for 3D measurement of vocal folds; (3) making computer finite element and mathematical models to simulate vocal fold vibration.[6,7] Although these methods have made significant contributions toward investigating the role of the 3D structure of the vocal folds, the 3D structure of the inferior aspect in the vocal folds has yet to be investigated quantitatively for its influence in acoustic and aerodynamic outcomes.

Visualization of vocal fold vibrations is a commonly used tool in studying laryngeal pathology. The glottis is divergent during closing; therefore, the inferior edge can often be qualitatively seen. In the excised larynx, the inferior edge of vocal folds can be seen during the closing of both folds or during the opening and closing phase of the hemilarynx. However, in the living larynx, the vocal folds can only be viewed from above, so the inferior part of the vocal folds is hidden by the superior part. For this reason, it is difficult to clinically diagnose the disorders in the inferior part. Stroboscope is the most used method compared with digital kymographs, laryngoscope, and high-speed photography,[8] but only a small part of the inferior surface of the vocal folds can be seen by all these methods. CT is well suited for quantifying the geometry of the airway, cartilage, or bulk tissue, but it is not useful in distinguishing the change in the inferior surface of vocal fold hypertrophy. MRI has potential for imaging soft tissue layers, but it has not yet been widely used for imaging vocal fold layer structure because of challenges with spatial resolution and tissue distinction.[9] Electroglottography (EGG) is currently the sole method that can quantify the pathological changes in the lower lip of the vocal fold indirectly. Although EGG waveforms are easily confounded by normal variations, such as mucus that spans the width of glottis, so the EGG can't correctly measure the frequency and glottic cycles[10]: EGG reflects the glottal condition accurately during the closed phase beyond the limit of visualization, and quantitative interpretation of glottal condition is possible.

Previous studies of vocal fold structure mainly focus on the mechanism of voice function changing with respect to vocal fold tissue characteristics, but the subglottal convergence angle (SCA)

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may also be involved in the regulation of voice function. The SCA may affect subglottal pressure (P_{sub}) distribution in the subglottal shear or normal direction, making vocal fold vibration and vocal fold mucosal wave generation more difficult. The mucosal wave may originate from the subglottic region, and damage to this part may prevent the waves from generating.[4]

Our study was based on the previous research made by Jiang et al,[11] Xu et al,[12] and Smith and Thomson.[13] This study was aimed to examine the effects of the inferior surface of vocal fold hypertrophy on the phonatory characteristics by comparing the SCA, acoustic outputs, and aerodynamic outputs from the excised canine larynges with different degrees of the inferior surface of vocal fold hypertrophy. It was hypothesized that these results could help to explore the effective indication parameters for vocal diseases related to the hypertrophy of the inferior surface of the vocal folds.

METHODS

The acquisition of excised canine larynges

Ten excised canine larynges were obtained at Key Laboratory of Underwater Acoustic Communication and Marine Information Technology of Xiamen University, from animals sacrificed for nonresearch purposes. The animal handling protocol was approved by the Xiamen University Zhongshan Hospital Laboratory Animal Management Ethics Committee. Larynges included in the study showed no evidence of trauma or disorder by visual inspection. The size of excised canine larynges was controlled by the length of the vocal folds in the range 14.5–16.0 mm. All larynges were quickly frozen and stored in a freezer (–20°C). The frozen larynges were immersed in a saline solution that was maintained at a temperature of 20 ± 3°C for 3 hours before the experiment for slow defrosting. The epiglottis, cuneiform cartilages, corniculate cartilages, and ventricular folds were dissected away to expose the vocal folds immediately prior to the experiment according to the method described by Titze et al.[14] The tracheas were 5–7 cm long.

Data acquisition

In an anechoic room, the excised larynges were fixed onto a phonation experimental platform. Two steel needles held the larynges in a natural position with the inferior 5 cm of the tracheas placed over a rigid tube to create the initial model (Figure 1). The audio signal was obtained with a microphone (ECM-678; Sony, Tokyo, Japan) placed 15 cm from the vocal folds at a 45-degree angle from the surface of the vocal folds and was recorded using the Cool Edit2.1 software (Adobe Systems, San Jose, California). The high-speed camera (Phantom MIRO M110; Ametek, Tokyo, Japan) was positioned approximately 30 cm above the plane of the vocal folds and recorded with a resolution of 512 × 256 pixels. The P_{sub} was recorded with a diaphragm pressure gauge (YE-100B; Shanghai Huanhong Automatic Instrument Science & Technology Co., Ltd., Shanghai, China). An air compressor (2530; Xiamen Taixing Mechanical and Electrical Co., Ltd., Xiamen, China) produced airflow through a metal lung, causing the vocal folds to vibrate. Mean flow rate (MFR) was recorded by a digital airflow machine (MF-5706-N-10; Guangxi Nanning Kongxin Instruments, Ltd., Nanning, China). The audio signal was recorded under the P_{sub} of 1.5 kPa or 2.5 kPa, separately. The sound pressure level (SPL) was measured with a sound level meter (WS1361; Shenzhen Wanshengtong, Ltd., Shenzhen, China) placed 10 cm from the vocal folds. The initial air pump pressure was adjusted to ensure an adequate pressure in each data collection. Trials were conducted as a sequence of 5 seconds of phonation followed by a 30-second interval of no phonation. The voice signals were analyzed with the Praat v5.4.19 software (provided by Paul Boersma and David Weenink, University of Amsterdam, The Netherlands) to obtain the fundamental frequency (F0) and formants 1–4 (F1–4).

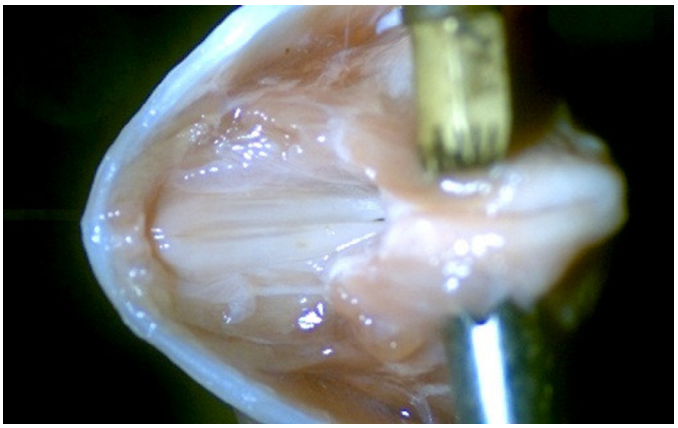

FIGURE 1. Top view of an initial canine excised larynx mounted on platform with both epiglottis and ventricular vocal folds removed.

The process of CT scan and airway model reconstruction had been described previously in a study by Xu et al[12] that was performed on human subjects. We scanned the larynges through routine CT with the Light Speed VCT 64 Slice CT scanner (GE, General Electric Company, Fairfield, Connecticut), and the slice thickness was 5 mm. The CT scans were then reconstructed and cut into thin-layer images with a gap size of 0.625 mm. The reconstruction models were finalized using the Mimics software (Materialise, Belgium). After combining the airway and vocal fold models, the SCA of the left vocal fold was measured using the Mimics software, as described in Figure 2.

Mild and severe vocal fold inferior surface hypertrophy (VFISH) models

Models of mild VFISH were produced by injecting 0.1 mL of fructose solution (12.5 g of fructose solution for intravenous injection dissolved in 50 mL of normal saline) into the inferior surface of each side of the vocal folds using a 1-mL syringe. Models of severe hypertrophy were created in a similar way by injecting an additional 0.1 mL of fructose solution into the inferior surface of each side of the vocal folds, totaling to 0.2 mL of injected fructose solution for each side. The injection volumes, 0.1 mL and 0.2 mL, used for the mild and severe hypertrophy models, respectively, were chosen based on three factors: (1) to prevent damage to the normal tissue; (2) to prevent leakage of fructose solution from the needle inlet; (3) to consider the size constraint of canine larynx. For the given P_{sub}, 1.5 kPa and 2.5 kPa were used because the most stable airflow control range in our

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