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INFLUENCE OF TYPE I THYROPLASTY IMPLANT STIFFNESS AND LOCATION ON THE GLOTTAL PRE-PHONATORY SHAPE, STIFFNESS AND VIBRATION

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Abstract:

Objectives / Introduction:

Thyroplasty Type I (TT1) is a common procedure for treating unilateral vocal fold paralysis. The procedure involves creating a window in the thyroid cartilage, allowing for the placement of an implant within the paraglottic space. This procedure aims to improve voice outcomes by narrowing the glottal gap between the paralyzed and healthy folds, thereby reducing leakage and threshold pressure. Traditionally, surgeons manually carve the implant, determining its specifications, including location, stiffness, and shape, through a trial-and-error approach. The impact of these implant characteristics on voice outcomes remains an ongoing research topic.

Clinical observations indicate that medialization in the infraglottal region yields better voice outcomes than medialization in the glottal region, although the exact reason remains unknown. In a study by Zhang and Chhetri [1], local medialization using a 2mm-diameter wood stick on excised human larynges showed improved glottal closure and higher-order harmonic excitation in voice when performed at a more inferior location. They hypothesized that inferior medialization contributed to a thicker vocal fold, but the medial surface's shape, including thickness, was not quantified, leaving the hypothesis unconfirmed. Zhang et al. [2] provided detailed structural changes before and after implant insertion using magnetic resonance imaging on ex vivo human larynges. They observed increased vertical thickness and significant stretching of the vocal fold tissue in the coronal plane, leading to a decrease in thyroarytenoid (TA) muscle dimension in the medial-lateral direction. However, since phonation experiments were not conducted, the direct relationship between structural changes and the produced sound is unclear.

The current study aims to investigate the impact of TT1 implant location and stiffness on vocal fold dynamics and voice outcomes using numerical methods, establishing a direct link among the implant characteristics, vocal fold prephonatory conditions, and sound characteristics. Compared to glottal-level medialization, we hypothesize that infraglottal medialization will create a slightly divergent pre-phonatory shape and a more substantial vertical stiffness gradient, potentially enhancing the produced sound.

Methods:

Geometry model. The geometric models of the larynx and implant were created from computed tomography scans of an ex-vivo canine larynx. Both the cartilage and vocal fold were reconstructed. The vocal fold was represented as a two-layer structure consisting of the cover and body layers.

Material property. Indentation tests were performed using a sphere indenter on the medial surface of two canine larynges (Figure 1). The tissue was indented with a maximum of 2 mm. The indentation was performed at three coronal planes from anterior to posterior sides and eleven vertical locations from the superior edge to 5 mm below the superior edge. In each location, a force-displacement relationship was obtained.

In the numerical simulation, the vocal fold was assumed to be a two-layer structure, including the body and cover layers. The material was assumed to be fiber-reinforced in each layer, and a vertical stiffness gradient exists in the cover layer [3], [4]. Material parameters were determined by matching the indentation measurement. The implant employed the Neo-Hookean material model with a stiffness ranging from 5 kPa to 1400 kPa.

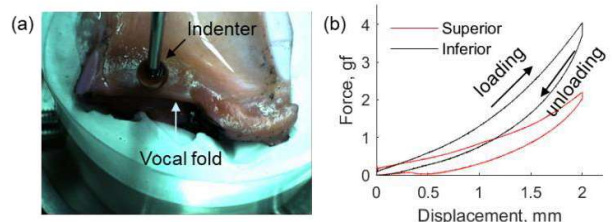


Figure 1. Indentation measurement. (a) Setup. (b) Example for force-displacement curves from inferior and superior measurements at the mid-coronal plane.

Simulation setup. The simulation comprises two steps. In the first step, we insert the implant and perform numerical indentation with the inserted implant on the medial surface. The obtained stiffness distribution was used to compare with the experiment measurement. In the second step, we performed a fluid-structure interaction (FSI) simulation with the inserted implant to capture vocal fold oscillation, glottal flow waveform, and sound generation [4], [5]. The glottal flow employed a one-dimensional flow model, and the tissue deformation was modeled using a finite element method. The height of the implant was constant and set to half of the vertical height of the fold. The vertical insert location of the implant was varied between the superior and inferior aspects of the fold medial surface.

Results:

In the baseline case of the numerical simulation, we inserted an implant with a height matching the vertical height of the fold at the glottic level. The insertion depth was adjusted so that 80% of the medial surface was adducted to the midline. The implant stiffness was 120 kPa. The results show that the implant could effectively adduct the fold toward the midline with only a small leakage in the posterior side, but the shape of the medial surface profile does not show a significant difference before and after the implant was inserted (Figure 2a). The stiffness gradient was calculated between the superior and inferior sides of the medial surface along three Anterior-Posterior locations (Figure 2b). It shows that with the implant inserted, the stiffness gradient increased in all three locations and that the largest increase occurred on the anterior side.

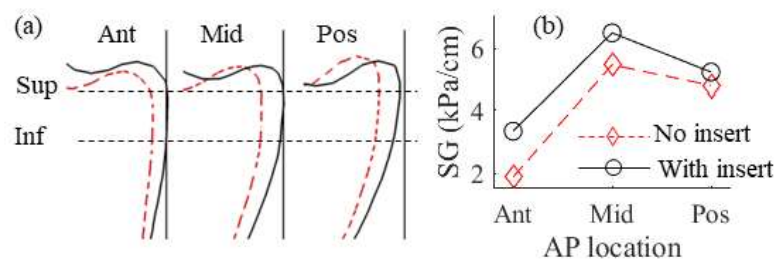


Figure 2. Influence of implant on pre-phonatory status from numerical simulations: (a) medial surface profile; (b) stiffness gradient (SG).

Conclusions:

The preliminary results show that the numerical model can simulate the impact of TT1 implant on vocal fold deformation and stiffness distribution before phonation. In subsequent simulations and analysis, we will change the implant height, vertical location, and stiffness. The effects of these parameters on vocal fold pre-phonatory deformation and stiffness will be investigated. Additionally, FSI simulations will be performed before and after the implant is inserted. The relationships among implant characteristics, vocal fold pre-phonatory conditions, vocal fold vibrations, and voice acoustics will be studied. We will discuss the results by comparing them with the experimental measurements [1,6,7].

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