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A COMPUTATIONAL STUDY ON THE IMPLANT SHAPE OPTIMIZATION FOR TREATMENT OF UNILATERAL VOCAL FOLD PARALYSIS

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INTRODUCTION

The most common permanent procedure for treating unilateral vocal fold paralysis/paresis (UVFP) is medialization laryngoplasty [1], which restores the vocal fold vibrations by implanting a configured support structure to the paretic fold to reduce the glottal gap during phonation. The optimal voice outcomes depend upon the exact placement of the implant relative to the position of the underlying vocal fold, specifically the shape and position of the implant. Suboptimal voice outcomes and high revision rates reflect the significant challenges inherent in this procedure. In this study, a computational framework is developed for searching for the shape of the implant that produces the optimal aerodynamic and acoustic outcomes of the medialization procedure. The algorithm combines a genetic algorithm (GA) based optimization program with a patient-specific larynx computer model, which simulates the entire phonation process from vocal fold posturing to flow-structure-acoustic interaction (FSAI) as well as virtual surgery of implant insertion.

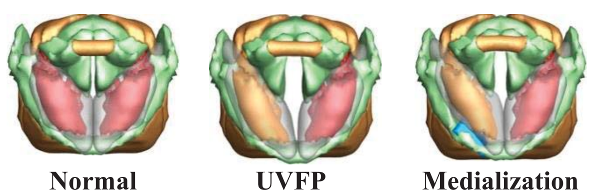

Figure 3. Vocal fold pre-phonatory configurations under normal condition, UVFP and surgical correction.

METHODS

A three-dimensional high-fidelity larynx model was previously developed to simulate vocal fold posturing with different combination of intrinsic laryngeal muscle activations [2]. This model is further utilized to generate the pre-phonatory configurations of the vocal folds under normal, UVFP and surgical correction conditions. The UVFP condition is modeled by deactivating all the intrinsic muscles from the right side. The medialization procedure is modeled by virtually inserting a trapezoidal prism-shaped implant into the paralyzed fold. Figure 1 shows the simulated three corresponding pre-phonatory configurations. The GA based optimization solver is further coupled with the FSAI simulations to optimize the implant shape, characterized by three parameters: the insertion depth, anterior-posterior angle, and inferior-superior angle, for the desired aerodynamic and acoustic outcomes. In this preliminary study, two different objective functions are used for the optimization: (1) the aerodynamic function including the maximum flow deceleration rate (MFDR) and flow leakage and (2) the acoustic function including the cepstral peak prominence (CPP) and sound intensity.

RESULTS AND DISCUSSION

For both objective functions, the GA algorithm is successfully converged after the 7th generation with a 63 population. To show the effect of the optimized implant on improving phonation, the aerodynamic and acoustic features of the healthy, UVFP, and two optimized medialization cases are compared in Table 1. The Imp_{Aero} and Imp_{Ac} represent the implants based on the aerodynamic and acoustic objective functions, respectively. The simulations show that both the aerodynamic and acoustic features of healthy case are well within the typical range of normal phonation [3-5]. The UVFP yields low MEDR, high leakage, low CPP and low sound intensity. Due to the high level of noise, HNR is not measurable under UVFP. Both medialization cases can restore the aerodynamic and acoustic quantities to a level close to the healthy case. For example, the MFDR, CPP and sound intensity in the medialization cases are close or even better than those in the health case, although the leakage flow in the medialization cases still remains relatively higher than that in the healthy case. The insertion of the implant does not affect the frequency. Comparing between Imp_{Aero} and Imp_{Ac}, Imp_{Ac} yields a better acoustic outcome with higher CPP, HNR and sound intensity.

Table 11. Aerodynamics and acoustic features of all cases.

Feature	Healthy	UVFP	Imp_{Aero}	Imp_{Ac}
F0 [Hz]	177	178	168	165
MFDR [ml/ms^2]	160	44	195	187
Leakage [ml/s]	12	570	23	45
CPP	24	14	21	29
HNR [dB]	23.5	N/A	15.1	28
Intensity [dB]	81.5	62.0	77.5	81.4

CONCLUSION

A computational framework was successfully developed to optimize the implant shape for Thyroplasty Type 1 phonosurgery. The implant was successfully optimized, and the voice outcomes are significantly improved using both aerodynamic and acoustic criteria.

ACKNOWLEDGMENTS

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REFERENCES

[1] Isshiki N, Okamura H, Ishikawa, T. Thyroplasty type I (lateral compression) for dysphonia due to vocal cord paralysis or atrophy. *Acta oto-laryngologica.* 1975;80(1-6); 465-473.

[2] Geng B, Pham N, Xue Q, Zheng X. A three-dimensional vocal fold posturing model based on muscle mechanics and magnetic resonance imaging of a canine larynx. *The Journal of the Acoustical Society of America*. 2020;147(4):2597-608.

[3] Peterson, G.E. and Barney, H.L., 1952. Control methods used in a study of the vowels. *The Journal of the acoustical society of America*, 1952;24(2):175-184.

[4] Teixeira JP, Fernandes PO. Jitter, Shimmer and HNR classification within gender, tones and vowels in healthy voices. *Procedia technology*. 2014; 16:1228-37.

[5] Brockmann-Bauser, M., Van Stan, J.H., Sampaio, M.C., Bohlender, J.E., Hillman, R.E. and Mehta, D.D. Effects of vocal intensity and fundamental frequency on cepstral peak prominence in patients with voice disorders and vocally healthy controls. *Journal of Voice.* 2019.