The Potential Role of Subglottal Convergence Angle and Measurement

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Summary: Objective. This study aimed to explore subglottal convergence angle measurement. We hypothesize that the angle will change with glottis closure condition. Changes to the angle may alter vocal fold stress distribution, which could result in vocal fold pathologies.

Methods. Three vocal fold positions were evaluated by the degree of glottal closure and divided into three groups. Neck computed tomographic images of the subjects were gathered, and three-dimensional (3D) models of the vocal folds and the airway were reconstructed using *Mimics* software, through which the subglottal convergence angle was measured. Using one-way factor analysis of variance, we compared the angle among three groups. We explored the effect of the angle on vibration based on the material oblique section stress analysis.

Results. The subglottal convergence angle was effectively measured from 3D models. The angle changed with degree of glottal closure, with statistically significant differences among the three groups ($P < 0.01$). Changes to the angle alter subglottal stress distribution in the subglottal shear or normal direction by the material oblique section stress analysis theory. Larger subglottal convergence angle might reduce subglottal pressure in the shear direction below the vocal folds, which would make vibration and vocal fold mucosal wave generation more difficult.

Conclusion. 3D model generation from computed tomographic data is an effective method of measuring the subglottal convergence angle, which changes with the degree of glottis closure, and may affect subglottal pressure distribution in the subglottal shear or normal direction and influence vocal fold vibration.

Key Words: vocal fold–3D model–oblique section–subglottal convergence angle–incomplete glottal closure.

INTRODUCTION

The larynx functions as a power transducer, converting aerodynamic power to sound energy. Functional vocal fold vibration relies on the unique morphological layered structure of vocal fold tissue and vocal fold geometry. The relationship of the layered structure of vocal fold tissue to laryngeal function has been widely studied. Vocal fold structure is made up of cells and their extracellular matrix. The layers consist of epithelium, superficial lamina propria, intermediate lamina propria, deep lamina propria, and the vocalis muscle.[1] Research into the effects of vocal fold geometry has been limited to glottal closure, glottal area, vocal fold length, vocal fold width, vocal fold thickness, and extrusion on the glottis.[2–6] In recent years, vocal fold research has focused on structure, such as high-speed photogrammetric mucosal waves of vocal folds,[6] and Hollien reported that the size of the larynx and length and thickness of the vocal folds would change along with the voice frequency.[3] Vocal fold adduction and abduction take place in three dimensions, and glottal function is best appreciated in the coronal plane.[7] The subglottal convergence is not, however, readily visualized in routine clinical examination and therefore may not have received as much attention from laryngeal surgeons as a two-dimensional parameter such as the size of the glottal gap as viewed superiorly.

Before initiating vocal fold vibration, the vocal folds are adducted to the midline. At this point, the tops of the bilateral vocal folds are relatively flat, and the area below the vocal folds forms an inverted slope,[8] which we called subglottal convergence, and the subglottis was defined as being below the lower lip edge line of the glottis and above the lateral vocal fold margin with the tracheal wall. The extension of the slope section plane would cross the extension of the plane of the superior surface of the vocal fold, and converge. We called this angle the "subglottal convergence angle." The material oblique section angle is an important feature in determining stress distribution according to the theory of stress.[9] Therefore, the subglottal convergence angle may be of great significance in the subglottal pressure distribution, which would change the deformation of vocal folds in the shear and normal directions of subglottal convergence, and we speculated that the angle of subglottal convergence was related to glottal closure.

In the present preliminary study, we reconstructed the vocal folds on the basis of computed tomographic (CT) data to measure the subglottal convergence angle in three groups: normal glottal closure, incomplete glottal closure, and open glottal phase. Finally, the subglottal convergence angle's influence on the subglottal pressure distribution was estimated using the material oblique section stress theory, and we discussed the potential role of the subglottal convergence angle in vocal fold vibration.

MEASUREMENT OF THE SUBGLOTTAL CONVERGENCE ANGLE

Subjects

The institutional ethics board approved this study. All participants were volunteers who provided signed informed consent.

Accepted for publication March 17, 2016.
Conflict of interest: None.
Disclosure: This study was supported by the National Natural Science Foundation of China, item number: 81371080.

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Journal of Voice, Vol. 31, No. 1, pp. 116.e1–116.e5
0892-1997

http://dx.doi.org/10.1016/j.jvoice.2016.03.009

TABLE 1.
Information of the Normal Subjects

		Gender	Age (y)	Glottal Closure
Normal subjects pronouncing /i/ during CT scan	1	Male	58	Normal
	2	Female	47	Normal
	3	Male	61	Normal
	4	Female	45	Normal
	5	Male	37	Normal
	6	Female	34	Normal
Normal subjects performing a deep inhalation during CT scan	1	Male	32	Open phase
	2	Female	43	Open phase
	3	Male	39	Open phase
	4	Female	47	Open phase
	5	Male	54	Open phase
	6	Female	56	Open phase
	7	Male	60	Open phase
	8	Female	48	Open phase

TABLE 2.
Information of the Subjects With Idiopathic Unilateral Vocal Fold Paralysis

	Gender	Age (y)	Hoarse Time (mo)	Vocal Fold Paralysis	Glottal Closure
1	Female	61	4	Right	Incomplete
2	Male	57	2	Left	Incomplete
3	Female	55	3	Left	Incomplete
4	Male	48	2	Left	Incomplete
5	Female	45	8	Right	Incomplete
6	Male	53	6	Right	Incomplete
7	Female	45	3	Right	Incomplete
8	Male	33	1	Left	Incomplete

We collected data from 14 normal subjects (eight men and six women), with a mean age of 40 ± 10.8 (standard deviation [SD]) years as shown in Table 1. All subjects consented to a laryngoscopy, had bilateral vocal fold edges that were smooth, and could adduct their vocal folds to the midline when pronouncing /i/.

Eight subjects with idiopathic unilateral vocal fold paralysis were also recruited. Their characteristics are shown in Table 2. The vocal folds were positioned between adduction and abduction of normal vocal folds (as shown in Figure 1).

FIGURE 1. Laryngoscope of one patient with right vocal fold paralysis.

Experimental equipment and software

A GE LightSpeed VCT 64 Slice CT scanner which is from Siemens in German was used to collect image data. *Mimics* 10.0 software which is from Materialise in Belgium was used to reconstruct the three-dimensional (3D) images of the larynx and trachea. *SPSS Statistics* 19.0 software which is from IBM in America was used for statistical analysis.

METHODS

Experimental group

Six subjects had both vocal folds observed with full glottal closure and pronounced /i/ while a CT scan was taken of their neck; eight subjects had both vocal folds observed while performing vocal fold abduction, by performing a deep inhalation while the CT scan was taken. The eight subjects with vocal fold paralysis had their paralyzed vocal fold observed with incomplete glottal closure, and performed a deep inhalation while the CT scan was taken.

CT scan

We scanned each subject's neck through routine CT, slice thickness of neck CT was 5 mm with the GE LightSpeed VCT 64 Slice CT scanner, then, and turned to be 0.625 mm by reconstructing the images and cutting it to thin layer images, and there