Quantitative Analysis of the Visor-Like Vertical Motion of the Cricoarytenoid Joint in the Living Subject

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Summary: Objectives. The cricoarytenoid joint has a loose capsule and large cavity and may allow the arytenoid distanced from the cricoid cartilage. The objective was to quantify vertical motion of the arytenoid cartilage in the living subject.

Study Design. This is a prospective study.

Methods. Axial computed tomography images from 35 healthy subjects and seven patients with unilateral vocal fold paralysis were collected at inspiration and phonation. The perpendicular distance from the arytenoid vocal process (VP) or muscular process (MP) to the cricoid plane was measured and analyzed.

Results. During phonation, the range of the vertical movement of the VP was significantly wider than that of the MP. The vertical motion varies in sides, sexes, and ages. The vertical gaps of the VP and MP between the paralyzed and contralateral sides were about 0.8 mm and 1.5 mm, respectively.

Conclusions. This study confirms a visor-like downward vertical motion of the arytenoid cartilage during phonation.

Key Words: Vocal fold–Cricoarytenoid joint–Vertical motion–CT images–Quantitative analysis.

INTRODUCTION

The cricoarytenoid joint (CAJ) plays a pivotal role in respiration and phonation and has been extensively studied.[1–4] On the basis of the surface topography of the facets of the cricoid and arytenoid cartilages, the motion of the CAJ has been considered as gliding, rocking, and rotating.[1,2,5–8] The size of the articular cavity and configuration of the articular capsule, however, are also the key determinates for the mobility of a joint.[9,10] Using microcomputed tomography (micro-CT) and epoxy sheet plastination to correlate the three-dimensional appearance of the CAJ cavity and the configuration of the CAJ fibrous capsule, a recent cadaveric study found that (1) the dimension of the CAJ cavity was much larger than that of the CAJ articular surfaces and (2) the loose CAJ capsule, large peripheral recesses of the CAJ cavity, and the small contact area between the cricoid and arytenoid facets distanced the arytenoid cartilage away from the cricoid cartilage, particularly at the superior and medial aspects of the CAJ.[11] Thus, it was proposed that in coordination with gliding, rocking, and rotating, a visor-like vertical motion of the CAJ may provide further adjustment in the length, depth, and tension of the vocal fold.[11] The aim of this study was to verify and quantify the visor-like vertical motion of the CAJ in the living subject.

The vertical positional difference between the paralyzed and normal vocal folds has been well recognized.[12–17] Using conventional CT,[12] 3D-CT,[15,16] or videostroboscopy,[14] attempts have been made to assess the vertical movement of the vocal fold in the living subject, but to our knowledge, no quantitative analysis has been reported. The vocal fold consists of an anterior membranous part and a posterior cartilaginous part which is the vocal process (VP) of the arytenoid cartilage. The movement of the vocal fold is mainly controlled by the CAJ where the arytenoid cartilage moves along the superior rim of the cricoid cartilage. In this study, thus, to quantify the vertical movement of the arytenoid cartilage against the cricoid cartilage, the level of the superior margin of the cricoid arch was defined as a reference base plane which was parallel to the axial CT scan angle from the supraorbital ridge to the inner table of the posterior margin of the foramen magnum—the cricoid plane (CP), and the perpendicular distance from the VP or muscular process (MP) of the arytenoid cartilage to the CP was measured and compared.

MATERIALS AND METHODS

A total of 42 subjects (20 women and 22 men; age range 24–78 years; mean age 50.4 ± 14.8 years) were selected for this study. Thirty-five of them (15 women and 20 men; age range 24–78 years; mean age 50.3 ± 15.9 years) had no laryngeal disorders, and the indications for the CT scans were the annual health check (n = 4) and suspicion of dizziness (n = 6), vertebral-basilar artery insufficiency (n = 5), cerebral infarction (n = 4), neck pain (n = 4), hypertension (n = 3), rhinitis (n = 3), headache (n = 3), epiglottic cyst (n = 1), gastritis (n = 1), and Hodgkin lymphoma (n = 1). The other seven subjects (five women and two men; age range 41–60 years; mean age 50.6 ± 7.5 years) had unilateral vocal fold paralysis due to recurrent laryngeal nerve damage that was caused by thyroid tumors (n = 5), surgical injury (n = 1), and middle esophageal cancer without laryngeal dislocation (n = 1). The diagnosis of unilateral vocal fold paralysis was mainly based on the patient's history and laryngoscopy with assistance of CT and EMG examinations in the thyroid tumor cases. No indication of the cricothyroid muscle dysfunction was noticed. The investigations

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were performed on the subjects with their informed consents. The study was approved by our institutional Ethics Committee.

Axial CT images of the CAJ during quiet inspiration and sustained /i/ phonation at comfortable pitch and loudness were obtained by a GE Lightspeed VCT 64 Slice CT Scanner (General Electric, USA) under the conditions of resolution, 512 × 512 pixels; slice thickness, 0.625 mm; slice interval, 0.625 mm; pitch, 0.984; tube voltage, 120 kVp; tube capacity, 440 mA. The millsievert (mSv) received during examination of both scans was <25.76 mGy for every subject. The fundamental frequency (F_0 value) of /i/ phonation varied among individuals and ranged from 110 to 260 Hz for men and 200 to 350 HZ for women. A scan angle (a reference plane) in a line parallel to one joining the supraorbital ridge and the inner table of the posterior margin of the foramen magnum was applied to all the subjects.

A combination of "3D Viewer" and "Slice Viewer" functions of the *3D Slicer* open-source software (Version 4.4.0 64-bit, Harvard Medical School, Boston, MA) was used to localize the level of the superior margin of the cricoid arch, which was parallel to the scan angle and was termed as CP in this study, the most anteromedial point of the VP, and the most posterolateral point of the MP of the arytenoid cartilage (Figure 1). The number of slices from the identified VP or MP to the identified CP was counted. The perpendicular distance from the VP or MP to the CP (Figure 1A) was calculated by the number of the counted slices times the interval of 0.625 mm. The difference between the distances of the VP to CP or the MP to CP of the same side at quiet inspiration and at phonation was referred to as the range of the VP or MP vertical movement during phonation. In addition, the "3D volume rendering" tool of the *OsiriX* imaging software (Version 5.8.5 64-bit, Geneva, Switzerland) was used to generate the 3D movie of the arytenoid and cricoid cartilages (Figure 2).

Statistical analysis

The distance and the range of the vertical movement were compared between the processes, sides, sexes, and ages (adult, <65 years old; elderly, ≥65 years old) in the subjects without laryngeal disorders and between the paralyzed and contralateral sides of the patients with unilateral vocal fold paralysis. All data were tested to determine whether they fulfilled the assumptions of normality and homogeneity of variance. When these assumptions were violated, the data were natural log transformed and retested. The data were analyzed with a linear mixed model (LMM) analysis using a restricted maximum likelihood procedure, in *IBM SPSS 22.0 Statistics* software (IBM Corp, Armonk, NY),[18] with the between-group factors side (left and right), process (VP and MP), sex (male and female), age (adult and elderly), and subject category (with and without unilateral vocal fold paralysis) of which the side and process as repeated measures.[19] LMM analyses were used in preference to repeated measures ANOVAs because of the problems caused by extensive autocorrelation in repeated measures data; LMM analyses model the covariance structure of the repeated measures data to address this problem.[18] The most appropriate covariance matrix structure was chosen on the basis of the smallest Akaike Information Criterion. $P \leq 0.05$ was considered significant.

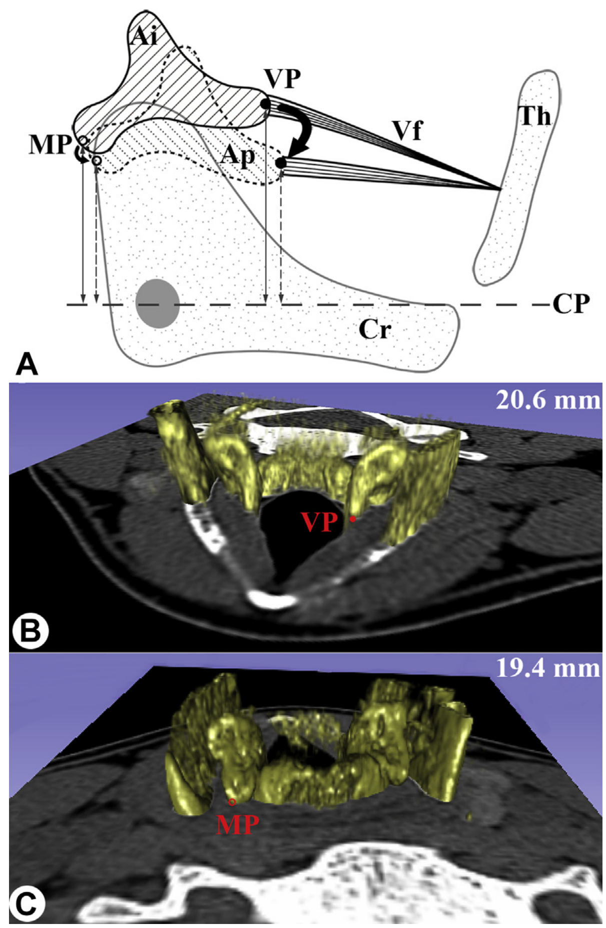

FIGURE 1. Localization of the cricoid plane (CP), vocal process (VP), and muscular process (MP) of the arytenoid cartilage, and measurement of the perpendicular distance from the VP or MP to the CP. (**A**) The perpendicular distance from the VP (*solid circle*) or MP (*empty circle*) of the arytenoid cartilage (Ai or Ap) to the CP (*dashed line* at the level of the superior margin of the cricoid arch) was measured at quiet inspiration (*solid two-headed arrows*) and phonation (*dashed two-headed arrows*). The CP was parallel to the scan angle which was from the supraorbital ridge to the inner table of the posterior margin of the foramen magnum. *Curved arrows* indicate the direction of the vertical movement during phonation. (**B** and **C**) A combination of "3D Viewer" and "Slice Viewer" of the *3D Slicer* open-source software was used to localize the CP, the most anteromedial point of the VP (*solid circle* in B), and the most posterolateral point of the MP (*empty circle* in C). The numbers indicate the perpendicular distance from the VP (**B**) or MP (**C**) to the CP, which were calculated by the number of the counted CT imaging slices times the interval of 0.625 mm. Vf, vocal fold; Th, thyroid cartilage; Cr, cricoid cartilage.

RESULTS

The relative position of the vocal and muscular processes of the arytenoid cartilage in the living subject

To localize the relative position of the VP and MP of the arytenoid cartilage, the perpendicular distance from the process to the CP was measured. At quiet inspiration, on average, the VP (19.7 ± 3.3 mm) was about 1 mm higher than the MP