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Differentiating arytenoid dislocation and recurrent laryngeal nerve paralysis by arytenoid movement in laryngoscopic video

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Abstract

Objective—To present a new method of quantifying arytenoid movement during inspiration and determine if it can be used to distinguish arytenoid dislocation from vocal fold paralysis.

Study Design—Case series with chart review.

Setting—Retrospective study conducted in university laboratory based on university hospital data.

Subjects and Methods—Endoscopic videos from eight patients with dislocation and five patients with vocal fold paralysis diagnosed by electromyography were included. Vector analysis measured cuneiform movement, an indirect measurement of arytenoid movement, during one inspiration. Measurements normalized and not normalized to vocal fold length were evaluated. Interrater reliability (2 raters) and intrarater reliability (1 rater performing analysis twice) were evaluated using intraclass correlation coefficient (ICC) analysis. Raters were blinded to subject group during analysis.

Results—Pixel-valued cuneiform movement was 81.16 ± 25.62 for dislocation and 30.22 ± 23.60 for paralysis ($p=0.019$). Unitless cuneiform movement was 0.58 ± 0.17 for dislocation and 0.24 ± 0.18 for paralysis ($p=0.030$). Interrater ICC was 0.942 for pixel-valued measurements and 0.962 for unitless measurements. Intrarater ICC was 0.909 for pixel-valued measurements and 0.881 for unitless measurements.

Conclusions—Both pixel-valued and unitless measures of arytenoid movement were significantly greater in arytenoid dislocation than vocal fold paralysis. Pixel-valued measurements were included to demonstrate the ability to make quantitative comparisons across subjects without precise knowledge of camera precision provided position is approximately stable, as each measurement is inherently normalized by vocal tract length. Future studies will apply this new method of evaluating vocal fold immobility disorders on a larger scale and incorporate a more diverse group of etiologies.

Keywords

arytenoid dislocation; vocal fold paralysis; videolaryngoscopy; endoscopy

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INTRODUCTION

Arytenoid dislocation refers to complete separation of the cartilaginous surfaces of the cricoarytenoid joint. In subluxation, some contact between the joint surfaces is preserved.¹ While these are distinct conditions, they represent similar clinical entities.² Arytenoid dislocation is traditionally viewed as a rare event;³ however, it may be underreported due to confusion with recurrent laryngeal nerve (RLN) paralysis.⁴ Symptoms common to both disorders include hoarseness, aphonia, and dysphagia.⁵ Correctly distinguishing between arytenoid dislocation and RLN paralysis is important as the treatments differ; however, diagnosis remains a challenge.^{3,5-7}

Currently used assessments include laryngoscopy, computed tomography (CT), and laryngeal electromyography (LEMG), although none is ideal. EMG can be useful, but problems exist with probe placement and cost.^{5,8,9} Fibrillation potential and positive sharp waves can be found in laryngeal nerve injuries,¹⁰ while mechanically-based vocal fold disorders generally yield a normal LEMG evaluation. Successful differentiation of mechanical injury and paralysis has been shown using these criteria.¹⁰

A clinical sign which may be potentially useful in distinguishing the two disorders is arytenoid movement.³ The cuneiform tubercles abduct and adduct with the arytenoids.¹¹ During inspiration, these structures move in a lateral-rotational path with respect to the anterior commissure, an easily identified landmark immobile during a single inspiration. The arytenoid and cuneiform tubercle reach a maximum distance from the glottal midline and return to their original position during a single sequence of inspiratory glottal opening. In the presence of paralysis or dislocation, movement is reduced. While movement in the presence of dislocation is noticeably less than normal, movement in the presence of RLN paralysis can be nearly eliminated due to the lack of innervation to the posterior cricoarytenoid muscle.⁶

Differences in movement, though, can be subtle and not easily seen on laryngoscopy. An automated, quantitative method of describing this movement may facilitate differentiation between dislocation and paralysis. We present a video-based tissue tracking method which can be used to quantify arytenoid movement objectively.

MATERIALS AND METHODS

Data Collection

This retrospective study was approved by the ethics committee at Xiamen University. Relevant medical history included recent general anesthesia and intubation. Each subject was treated in one of ten hospitals, some affiliated with Xiamen University. Onset of vocal fold immobility was after surgery. Likely etiologies include intubation trauma (dislocation) or transection of the RLN (paralysis) when operating on the neck or chest. All patients were intubated only during surgery and did not remain intubated postoperatively. Subjects were excluded if laryngeal injury had occurred more than two weeks prior to laryngoscopy and LEMG. Laryngoscopy was performed on each patient, where it was observed that unilateral movement was restricted (no movement or almost no movement). The amount of movement on the affected side was qualitatively examined and laryngeal electromyography (LEMG) was performed as part of the patient examination to determine the etiology of vocal fold immobility.

During LEMG, patients were asked to lie supine with the neck extended and local anesthesia was applied. The thyroarytenoid and cricothyroid muscles were evaluated as part of the

standard LEMG procedure. With the needle positioned in the cricothyroid, patients were asked to inhale, and then exhale while producing a sustained /i/. During phonation, patients were asked to change from low to high registers. With the needle in the thyroarytenoid, the patient inhaled followed by phonation of a sustained /i/. All patients were asked to breathe normally prior to and during the procedure. The RLN and superior laryngeal nerve were also stimulated with a monopolar electrode (6.0–24.0 mA) to observe the evoked potential of the targeted intrinsic laryngeal muscles (thyroarytenoid or cricothyroid). No patients exhibited notably abnormal signals during cricothyroid electromyography, which ruled out superior laryngeal nerve paralysis.

LEMG signals for each fold were compared to a database of normal patient signal data taken by Lizhen et al.¹² RLN paralysis was defined as an increase or decrease in signal duration of more than 20%, abnormal wave patterns in the signal such as fibrillation, or an increase or decrease in the amplitude of the wave of 100% or 50%, respectively.¹² Laryngeal nerve disorders correspond with increased insertional activity, leading to positive sharp waves and fibrillation potentials.¹³ The motor unit potential is prolonged with an increased number of phases and the amplitude of the signal may be either increased or decreased. There is an incomplete interference pattern that decreases recruitment and rapid signaling of the remaining motor neurons.^{10,13,14} If no variation from normal signals existed, patients were diagnosed with dislocation of the cricoarytenoid joint. LEMG analysis of the posterior cricoarytenoid muscle was performed to rule out synkinesis as a potential explanation for LEMG data that appeared to be in the normal range. Patients with dislocation underwent closed reduction and all had good outcomes. The procedure was conducted in a special EMG room and data were interpreted by a physician with extensive experience performing the procedure.

Endoscopic videos were collected at a sampling rate of 25 frames per second from eleven patients diagnosed with RLN paralysis and fifteen patients diagnosed with arytenoid dislocation using the same protocol described above. The mean age of patients with RLN paralysis was 47 years (range: 33–58) and the mean age of the arytenoid dislocation group was 44 years (range: 19–67). Each patient underwent direct laryngoscopy (Toshiba, 3CCD, model JK-TU62H G endoscope and 9200C/E video recording system). Patient information is presented in table 1.

Data Analysis

A custom MATLAB program (The MathWorks, Inc., Natick, MA) was used to track movement over a sequence of video frames. In the first frame, the structure of interest was selected by the user. In the following frames, the location of this region was found automatically using a Normalized Cross-Correlation (NCC) matching criterion.¹⁵ This matching criterion was chosen because it is robust to lighting variation.

First, a sequence of frames that demonstrated a single inspiration sequence following phonation of /i/ was selected. The first frame in this sequence was chosen by qualitatively identifying minimum vocal fold abduction. The last frame was chosen by identifying maximum glottal opening. Sequences in which the anterior commissure was not visible during any one frame were excluded from analysis. If no acceptable frame sequence was observed, the video (and patient) was excluded from analysis. Proper landmark tracking was visually verified following the analysis of each video. Based on these criteria, eight of fifteen patients with arytenoid dislocation and five of eleven patients with RLN paralysis were included; videos which were excluded could not be used as the structures of interest were obscured at some point during the recording, precluding accurate measurement.

At the point of minimal arytenoid abduction, a region tracking algorithm was initiated at the anterior commissure and cuneiform tubercle. The positions of both were tracked automatically over the inspiration. We chose the anterior commissure because it does not move during inspiration. Movement of the cuneiform tubercle was used as a surrogate of arytenoid movement, as it adducts and abducts with those movements of the arytenoid,¹¹ but is easier to visualize. The cuneiform was visible on all on all videos included in the analysis.

Cuneiform tubercle displacement was measured in pixels. During endoscopy, camera position can change due to patient and examiner movement. Accordingly, the difference in position of the cuneiform tubercle represents the sum of the displacement due to arytenoid movement and camera movement. To address this issue, a normalizing factor is needed. We defined a vector from the anterior commissure to the cuneiform tubercle. The difference between this vector at the point of minimum and maximum abduction in the glottal opening sequence was recorded. The difference between these vectors represents cuneiform tubercle (and arytenoid) movement independent of camera movement (figure 1).

This relationship can be investigated theoretically using equations which relate relative and absolute distances. Pixel-valued measurements are a relative measurement of true object size or path length. This can be described mathematically according to the following relationship describing movement of an object (e.g., cuneiform tubercle) as observed across multiple frames of a recording:

$$U = f \frac{X}{Z}$$

where U is the size in pixels of the path length created by movement of an object, X is the true size of the path length in millimeters, Z is the depth in millimeters from the camera to the object, and f is a proportionality constant primarily dependent on the camera's lens and imaging sensor. Importantly, in this study, single inspirations were evaluated, during which vertical movement of the camera or larynx would be minimal. Thus, translational movement is much greater than vertical movement.

To avoid any potentially confounding effects of camera movement, a normalizing measurement of vocal fold length can be made:

$$V = f \frac{L}{Z}$$

where V is vocal fold length in pixels, L is vocal fold length in millimeters, Z is the depth in millimeters from the camera to the object, and f is another proportionality constant.

Computing the ratio of cuneiform movement to vocal fold length provides a normalized, unitless measurement given by the ratio of U to V :

$$\frac{U}{V} = \frac{X}{L}$$

While including a vocal fold length provides a normalized value, endoscopy includes its own inherent normalizing factor in the distance from the camera to the larynx. For subjects with a long vocal tract (and likely a large larynx and movements), the size of a movement or

structure on the pixel scale will appear approximately the same as in a subject with a shorter vocal tract and smaller larynx (figure 2). Absolute measurements in millimeters may be of interest academically, but normal size or movement relative to the subject's larynx and vocal tract are likely sufficient for most clinical scenarios. In this study, the unitless measurement is normalized by vocal fold length while the pixel-valued measurement is normalized according to distance from the camera to the larynx (proportional to vocal tract length). In both cases, the normalizing factor is a single anatomic measurement taken from a normally distributed population. Therefore, both measurements should exhibit similar trends in mean.

Statistical Analysis

A preliminary evaluation of intra- and inter-rater reliability was conducted. Two authors (SN and MRH) performed analysis to evaluate interrater reliability using intraclass correlation coefficient (ICC) analysis for both pixel-valued and unitless measurements. One author (SN) performed analysis twice to evaluate intrarater reliability using ICC analysis for both measurements. Both raters were blinded to which group (dislocation or paralysis) each video belonged.

A Mann-Whitney rank sum test with $\alpha=0.05$ was performed to evaluate differences in mean arytenoid displacement during inspiration between the two disorders. The first analysis performed by the second author (SN) was determined a priori to be used for hypothesis testing and interrater reliability analysis.

RESULTS

The mean pixel-valued movement of the cuneiform tubercle was 81.16 ± 25.62 for arytenoid dislocation and 30.22 ± 23.60 for RLN paralysis ($U=4.000$, $T=19.000$, $p=0.019$) (figure 3). The 95% confidence interval for the difference in the means was (17.26, 78.87). Mean unitless movement of the cuneiform tubercle was 0.58 ± 0.17 for arytenoid dislocation and 0.24 ± 0.18 for RLN paralysis ($U=5.000$, $T=20.000$, $p=0.030$) (figure 4). The 95% confidence interval for the difference in the means was (0.08, 0.53).

Interrater reliability analysis yielded an ICC of 0.942 for pixel-valued measurements and 0.962 for normalized measurements (table 2). Intrarater reliability analysis yielded an ICC of 0.909 for pixel-valued measurements and 0.881 for unitless measurements (table 2).

DISCUSSION

Our results indicate significantly greater arytenoid movement in cases of arytenoid dislocation than in cases of RLN paralysis, coinciding with the qualitative observations of Sataloff et al.³ A paralyzed vocal fold with disrupted neuromuscular transmission should exhibit little or no movement, and while arytenoid dislocation will certainly compromise normal range of motion, preserved innervation could allow for some movement. The preliminary inter- and intrarater reliability analysis included in this study provides support for the clinical potential of the method. While larger scale evaluations with more raters are warranted, the high reliability observed here demonstrates the user friendly nature of the method and potential value of an objective, quantitative technique to distinguish between these two disorders.

In addition to presenting a new method of distinguishing vocal fold paralysis from arytenoid dislocation, a justification for pixel-valued quantitative measurements is provided. While absolute magnitude of movement may differ across subjects, relative magnitude of movement (i.e., relative to the size of a particular subject's larynx and vocal tract) may be of greater clinical interest. For a given image of the larynx obtained endoscopically, a larger

larynx farther from the camera will appear approximately the same size as a smaller larynx which was closer to the camera (figure 2). Thus, all endoscopically obtained images have an inherent, internal normalization factor of vocal tract length. In this study, the same trend was observed for measurements normalized and not normalized to vocal fold length, a discrete normalization factor commonly used in deriving absolute, quantitative measurements from endoscopic videos. Additional basic science studies manipulating camera distance and larynx size will be performed to further explore this issue.

Critical to evaluating this new method is comparing it against an established method to ensure our predetermined classes of dislocation or paralysis are indeed correct. For this purpose, we used LEMG, an assessment frequently employed to distinguish the two disorders on which significant literature is available. While there is potential for misdiagnosis according to LEMG, we took measures to decrease that risk. First, patients were only included in the study if they had undergone endoscopic recordings within two weeks after their operation during which the injury resulting in vocal fold immobility occurred. Synkinesis following RLN injury can result in an LEMG signal which appears normal;¹⁶ however, this typically does not occur until at least 6–7 weeks after injury.^{16–18} Second, all tracings were acquired and analyzed by physicians well-versed in LEMG.

According to the descriptions of Lizhen et al.,¹² tracings exhibiting either a substantial increase or decrease in signal duration or amplitude were classified as RLN paralysis. While paralysis can result in a decreased LEMG signal, Woodson reported an increase in signal strength in cats following RLN transection due to reinnervation.^{19,20} This reinnervation does not necessarily restore normal muscle function. Therefore, an increase or decrease in LEMG signal more extreme than the aforementioned predefined threshold was considered reflective of paralysis. Additionally, it is true that LEMG may appear fairly normal in persons with vocal fold paralysis due to synkinesis of abductor and adductor muscles.¹⁶ However, synkinesis does not occur until at least 6 – 7 weeks following RLN injury, and may take as long as 3 – 6 months following injury.^{16–18} In addition to testing for synkinesis in the posterior cricoarytenoid muscle, subjects were excluded if LEMG and endoscopic video recording occurred more than two weeks following RLN injury. This effectively ruled out synkinesis in the subjects who were included in the study. Cricothyroid ankylosis may be difficult to differentiate from paralysis and requires general anesthesia to palpate the joint.¹⁴ The fact that immobility occurred within two weeks after an operation with intubation and general anesthesia provides evidence against the possibility of ankylosis as the cause of the immobility.

A limitation of this study is modest sample size. This is due to the data being retrospective; when videos were recorded, no standardized procedure designed for collecting movement data had been developed. We will employ the method described here on a larger scale in future studies. An additional limitation is the use of the cuneiform to indirectly measure arytenoid movement. While it would be preferable to measure arytenoid movement directly by monitoring the vocal process, doing so was not feasible in our sample. The vocal process was often obscured and could not be reliably tracked over an entire inspiration. In the future, focused assessment for the purpose of visualizing vocal process movement during inspiration may allow for use of this structure.

This method may be useful clinically when evaluating patients with new onset vocal fold immobility after surgery or intubation and could potentially eliminate the need for LEMG or joint palpation. Cases of severe paresis may also be able to be distinguished from dislocation; however, the reliability of this differentiation would depend on the severity of the paresis and this issue requires further investigation. Further research needs to be performed in a larger sample with more diverse etiologies of immobility and time following

presentation of immobility to determine if arytenoid movement measurements extracted from endoscopic videos could be of use in a wider variety of cases.

CONCLUSION

We hypothesized that subjects with arytenoid dislocation would exhibit greater arytenoid movement during inspiration than subjects with RLN paralysis. Both pixel-valued (inherently normalized to vocal tract length) and unitless measurements normalized to vocal fold length were significantly different between the two groups. This minimally invasive method shows promise for distinguishing between these two entities.

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Figure 1.

Top: Frames from an inspiration demonstrating movement of the larynx (center of square). A vector (dashed arrow) from the anterior commissure to the larynx defines larynx position. Bottom: first and third images overlaid showing translational movement of larynx (X).

Figure 2.
Schematic demonstrating normalization factor inherently present in endoscopic images.
While X_1 and X_2 are different, the ratios X_1/Y_1 and X_2/Y_2 are the same.

Figure 3.

Bar graph presenting pixel-valued data on cuneiform movement. The bar represents the mean and error bars represent standard deviation. Pixel-valued movement was significantly greater for dislocation ($p=0.019$).

Figure 4.

Bar graph presenting unitless data on cuneiform movement. The bar represents the mean and error bars represent standard deviation. Movement normalized to vocal fold length was significantly greater for dislocation ($p=0.030$).

Table 1

Summary subject descriptions.

Subject	Age	Sex	Dislocation/paralysis	Reason for surgery	Side
1	47	Male	Paralysis	Thyroid cancer	Left
2	39	Male	Dislocation	Lung cancer	Left
3	61	Female	Paralysis	Thyroid cancer	Left
4	48	Male	Dislocation	Thyroid cancer	Left
5	50	Male	Paralysis	Thyroid cancer	Left
6	36	Male	Paralysis	Lung cancer	Left
7	43	Male	Dislocation	Lung cancer	Right
8	45	Male	Dislocation	Stomach cancer	Left
9	48	Female	Dislocation	Breast cancer	Left
10	30	Male	Dislocation	Stomach cancer	Right
11	45	Male	Paralysis	Thyroid cancer	Left
12	40	Male	Dislocation	Pancreatic cancer	Left
13	42	Female	Dislocation	Thyroid cancer	Left

Table 2

Summary of inter- and intra-rater reliability.

	Rater 1-1		Rater 1-2		Rater 2		Inter-rater ICC
	RLNP	Dislocation	RLNP	Dislocation	RLNP	Dislocation	
Pixels	30.22±23.60	81.2±25.6	30.38±22.12	70.58±22.79	31.95±21.82	71.20±19.85	0.942
Unitless	0.24±0.18	0.58±0.17	0.24±0.17	0.49±0.13	0.25±0.18	0.52±0.17	0.962

1-1 = first analysis performed by rater 1; 1-2 = second analysis performed by rater 1; RLNP = recurrent laryngeal nerve paralysis; ICC = intraclass correlation coefficient.