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RESEARCH ARTICLE

Volumetric measures of the paralyzed vocal fold using computerized tomography; its clinical implication

Abdul-Latif Hamdan[a], Elie Khalifee[b], Natally Al Arab[b], Karl Asmar[b] and Roula Hourani[b]

[a]Amer Univ Beirut, Beirut, Lebanon; [b]American University of Beirut Medical Center, Beirut, Lebanon

ABSTRACT

Objective: To report the volumetric measures of the paralyzed vocal fold in patients undergoing injection laryngoplasty.

Material and method: All the medical records of patients with unilateral vocal fold paralysis who had high resolution computerized tomography scan of the neck and chest prior to injection laryngoplasty between October 2015 and May 2018 were included. Volumetric evaluation of the vocal folds was performed by measuring the vocal fold height using coronal images and the vocal fold length and width using axial images.

Results: A total of 21 patients divided into 13 males and 8 females were identified. The mean age was 56.66 ± 20.94 years. The mean volume of the paralyzed vocal fold was significantly smaller than that of the non-paralyzed vocal fold ($p < .05$). Similarly, the mean length and height of the paralyzed vocal folds were smaller than those of the non-paralyzed vocal folds ($p < .05$).

Conclusion: Volumetric measurements of the paralyzed vocal fold in comparison to the normal vocal fold in a group of 21 patients with unilateral vocal fold paralysis shows the presence of significant difference between the normal and affected site, and the presence of large inter-subject variation. Information on the volume difference between the two vocal folds may be used to better estimate the amount that needs to be injected in medialization procedures.

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Volumetric measurements; vocal fold paralysis; injection laryngoplasty; computerized tomography

Introduction

Computerized tomography (CT) is commonly used in the investigation of patients with vocal fold immobility [1]. A diagnostic yield in the range of 2.9% to 6% has been reported by many authors alluding to its judicious usage as a first diagnostic step despite its sound economic cost-effectiveness [2–4]. Computerized tomographic imaging has also been used in the pre-operative and post-operative assessment of patients undergoing laryngeal framework surgery [5,6]. Hara et al. have reported the added value of three dimensional laryngeal CT scan with multiplanar reconstruction in five patients with unilateral vocal fold paralysis undergoing thyroplasty type I. The digital imaging has facilitated the placement of the thyroid cartilage window and has helped in the success of the surgery [5]. Iwahashi et al. concurred the usefulness of CT in identifying the causes of poor outcome following thyroplasty type I. The study was conducted on 22 patients and the most common causes were inappropriate size of implant, poor positioning and the usage of expanded polytetrafluoroethylene [6]. Other added value of this imaging technique in patients with unilateral vocal fold paralysis include configuration of the glottal gap. Different types of glottal configuration in relation to thickness of the vocal folds on 3 D coronal images have been reported by Yumoto et al. [7]. Computerized tomography has also been used as a prognostic factor in patients with recurrent laryngeal nerve injury. In a study by Mengsteab et al. the authors reported that imaging of ventricular dilation symmetry, an indirect estimate of thyro-arytenoid muscle atrophy, relates significantly to improvement in vocal fold mobility [8]. Hiramatsu et al. have reported the usefulness of three-dimensional computerized tomography in evaluating complex laryngeal structures and in particular movement of the arytenoid cartilages and vocal folds before surgical intervention [9].

The difference in volumetric measures of the paralyzed vocal fold in comparison to its normal counterpart using CT of the larynx has not been reported. The authors of this manuscript aim at casting further information on the usage of computerized tomography in the evaluation of the differences in volumetric measures between the paralyzed and normal vocal folds. This information is paramount in the management of affected patients undergoing injection laryngoplasty.

Material and method

Subject recruitment

This is a retrospective study approved by the Institutional Review Board. All the medical records of patients with unilateral vocal fold paralysis on laryngeal examination who had computerized tomography scan of the neck and chest

CONTACT Roula Hourani rh64@aub.edu.lb American University of Beirut Medical Center, Beirut 1107 2020, Lebanon

prior to injection laryngoplasty were included from October 2015 till May 2018. It is worth noting that the CT scan was performed on the average at least 3 months from the onset of paralysis. Patients with other laryngeal pathology on endoscopy or with previous history of laryngeal surgery were excluded. Demographic data collected included age, gender, etiology of the paralysis, site of the paralysis, and evidence of synkynesis.

Imaging examination and analysis

CT scans were obtained using ICT 256 (Philips, Amsterdam, Netherlands) with scan parameters of 120kv, 159mAs and slice thickness of 0.6 mm on axial and coronal cuts. Omnipaque^{TM} 350 was used as contrast medium.

2D Measurements (transverse, anteroposterior and superior-inferior diameters) of the vocal folds were conducted by an expert radiologist to ensure the accuracy and precision of the results using hospital computers connected to PACS system. Philips Intellispace Portal 7.0 software (Philips, NL) was used for volume measurements of the vocal folds both paralyzed and normal sides. All volumetric measurements were performed by the same operator, using the CT viewer tool on Intellispace and tissue management tool for accurate measurements with the integrated volumetric calculator for volume measurements. All values were entered on a master excel sheet and Volume and 2D measurements difference between the healthy and paralyzed vocal fold was computed as well as percent difference and then adapted for SPSS entry.

Using coronal images, the vertical height was measured from the most superior aspect of the vocal fold down to the inferior edge (See Figure 1(A)). The antero-posterior length and width were measured using axial images (See Figure 1(B)). The length was measured from the anterior commissure to the vocal process of the arytenoid cartilage and the width of the thyro-arythenoid (TA) muscle was measured at the mid aspect of the muscle from the most medial edge (free edge of the vocal fold) to lateral edge. The volume of each TA muscle was calculated using Intellispace Philips software (See Figure 2(A,B)).

Statistical analysis

All statistical analysis was performed using IBM SPSS Statistics for Mac, Version 24. Frequencies and means (± SD) were used to describe the sample, for categorical and continuous variables respectively. For each subject, the parameters were collected for the fixed and normal vocal folds. Wilcoxon Signed Rank Non-Parametric Paired Test was used to analyze the volume difference as well as the 2D measurement difference between paralyzed and normal vocal fold as measured on CT scan images. Mann-Whitney U test was used to compare the means of the continuous variables between males and females. Differences were considered significant for $p < .05$ of 95% CI.

Results

Demographics

A total of 21 patients were identified and enrolled. These were divided into 13 males and 8 females. The mean age was 56.66 ± 20.94 years. Seven patients had right vocal fold paralysis and 14 patients had left vocal fold paralysis. The etiology included carcinoma in 7 cases (5 cases of primary or metastatic lung cancer, 2 cases of mediastinal mass), surgical trauma in 5 cases (2 cases post-thyroidectomy, 3 cases post-chest surgery), non-surgical trauma in 2 cases, and chemo-radiation to neck or chest in 2 cases. In 5 cases the etiology was unknown. Fifteen out of 21 patients had their videolaryngoscopic examination available for review. In 9 out of the 15 videorecordings there was evidence of synkynesis.

Computerized tomography parametrical results of the paralyzed vs non-paralyzed vocal fold

There was a statistically significant difference in the mean length and height of the paralyzed and non-paralyzed vocal folds in the total group ($p < .05$). There was also a significant difference in the mean volume of the vocal folds between the two groups ($p < .05$). The difference in the volume of the paralyzed and non-paralyzed vocal folds ranged

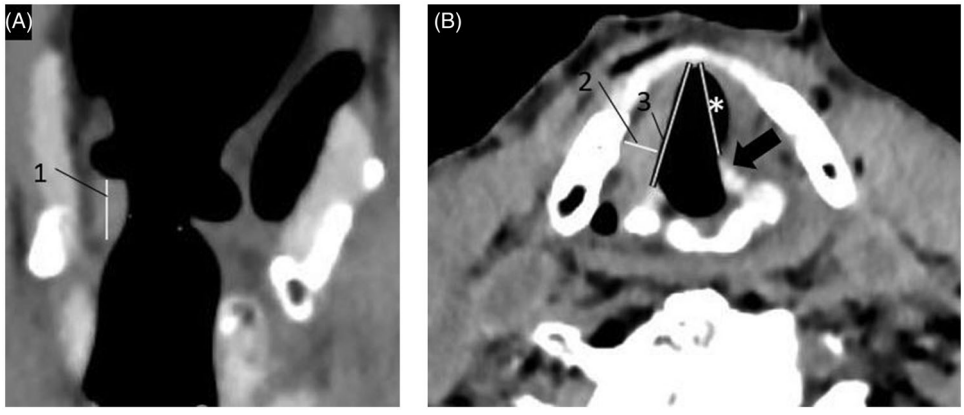

Figure 1. (A) Coronal CT image demonstrating the height of the vocal fold. (B) Axial CT image showing the width (line 2) and length (line 3) of the vocal fold. Note the anteromedially rotated left arytenoid cartilage (black arrow) and enlargement of the ipsilateral laryngeal ventricle (*).

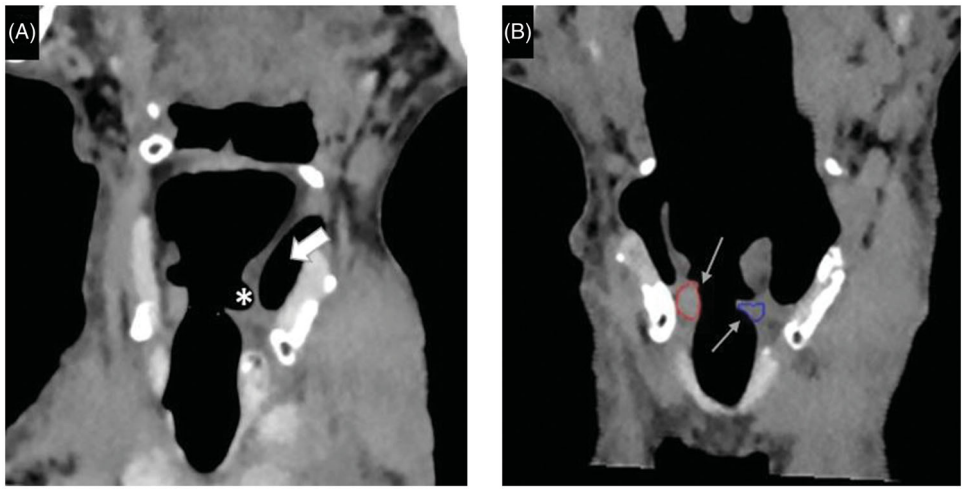

Figure 2. (A) contrast-enhanced CT coronal image in a patient with left vocal fold paralysis revealing dilatation of the left piriform sinus (arrow) and laryngeal ventricle (*). (B) 3D measurement of the volume of vocal folds on coronal images using Intellispace Philips software (arrows).

Table 1. Comparison of the CT parametrical results of the paralyzed vs non-paralyzed vocal folds.

	Paralyzed Mean ± SD	Non-paralyzed Mean ± SD	*p*-Value
Length (mm)	15.685 ± 3.294	17.315 ± 3.109	.000
Width (mm)	6.155 ± 1.636	6.519 ± 1.498	.056
Height (mm)	4.750 ± 1.062	6.082 ± 1.150	.000
Volume (mm^3)	339.395 ± 167.244	498.157 ± 220.029	.000

Table 2. Comparison of the CT parametrical results of the paralyzed vs. non-paralyzed vocal folds in males.

	Paralyzed Mean ± SD	Non-paralyzed Mean ± SD	*p*-Value
Length (mm)	16.246 ± 3.536	18.223 ± 3.190	.002
Width (mm)	6.107 ± 1.806	6.761 ± 1.512	.043
Height (mm)	4.900 ± 1.206	6.490 ± 1.166	.015
Volume (mm^3)	389.761 ± 180.210	571.507 ± 237.354	.001

between $-59mm^3$ and $452mm^3$ with a mean difference $167.95 \pm 121.53mm^3$. The mean width was lower in the paralyzed vocal fold vs normal vocal fold but did not reach statistical significance (paralyzed 6.15 ± 1.64 mm vs normal 6.51 ± 1.49 mm, $p > .05$) (See Table 1).

Further analysis taking into account age as a factor revealed similar pattern of findings. There was a statistically significant difference in the mean length and volume of the paralyzed and non-paralyzed vocal folds in the two subgroups of patients, those below the age of 65 years and those above the age of 65 ($p < .05$). The difference in the mean volume of the paralyzed and non-paralyzed vocal folds in patients below the age of 65 was less than that in patients above the age of 65 years ($152.04 \pm 90.07mm^3$ vs. $194.46 \pm 155.82mm^3$). The difference in the mean width between those with paralyzed and non-paralyzed vocal folds did not reach statistical significance in both subgroups ($p > .05$). There was no statistical difference in the mean height of the paralyzed and non-paralyzed vocal folds in patients below the age of 65 while it was significant in patients above the age of 65 years.

Table 3. Comparison of the CT parametrical results of the paralyzed vs. non-paralyzed vocal folds in females.

	Paralyzed Mean ± SD	Non-paralyzed Mean ± SD	*p*-Value
Length (mm)	14.775 ± 2.835	15.628 ± 2.270	.042
Width (mm)	6.242 ± 1.391	6.125 ± 1.485	1.000
Height (mm)	4.360 ± 0.415	5.500 ± 0.903	.066
Volume (mm^3)	257.550 ± 108.982	378.962 ± 124.559	.036

Computerized tomography parametrical results of the paralyzed and non-paralyzed vocal fold in males

The length, width, height and volume of the paralyzed vocal folds were significantly smaller compared to their non-paralyzed counter parts ($p < .05$). See Table 2.

Computerized tomography results of the paralyzed and non-paralyzed vocal fold in females

The length and volume of the paralyzed vocal folds were significantly smaller compared to their non-paralyzed counter parts ($p < .05$). The difference in width and height did not reach statistical significance ($p > .05$). See Table 3.

Discussion

Vocal fold paralysis is a common diagnosis in patients with dysphonia. The most common etiologies include iatrogenic injury, viral neuritis, and tumors compressing the recurrent laryngeal nerve along its course in the head and neck [10]. Patients usually present with breathiness, inability to project the voice, aspiration, dysphagia and at times shortness of breath. On laryngeal examination, incomplete glottic closure of the vocal folds with signs of bowing and atrophy are commonly seen [11]. Radiologic imaging has been thoroughly described in the literature in the pre-operative investigation of affected patients. Based on a report by Merati et al. CT analysis of neck and chest in addition to serologic testing are diagnostic tests commonly requested by otolaryngologists in the work-up of patients with vocal fold

immobility [12]. As previously discussed in the introduction, the linear and topographic characteristics of the vocal folds using CT have been thoroughly described in the literature. Previous studies have explored the utility of this radiologic imaging in drawing information on the vertical position of the paralyzed vocal fold and its activity in patients with unilateral paralysis [13], on the glottal configuration by inferring to ventricular dilation in patients with unilateral vocal fold paralysis [7], and in the assessment of thyroplasty following surgery [6]. In addition to the aforementioned clinical implications of CT, the results of this investigation indicate that CT is also valuable in providing information on volumetric measures of the vocal folds. This is important given that CT of the head and neck is the most common radiologic test requested in the work-up of patients with vocal fold paralysis. The results show that there is a significant difference in the volume of the paralyzed vocal fold in comparison to its normal counterpart, and more importantly the large individual variations in volume differences among affected patients. Moreover, the difference in the mean volume in the subgroup above the age of 65 years was higher than that of the subgroup below the age of 65 years. These findings are not surprising given the known atrophic changes of the intrinsic laryngeal muscles that may occur following injury to the recurrent laryngeal nerve, compounded by aging. Several animal studies have demonstrated morphologic changes post-denervation [14–19]. It is important to note that laryngeal muscles are less affected than limb skeletal muscles because of the different fiber composition, and that the thyroarytenoid muscle is also less affected than the posterior criocoarytenoid muscle [20]. Qiu et al. have investigated the effect of denervation on the morphology of both adductor and abductor muscle fibers and have demonstrated a gradual decrease in the myofiber transverse area more so in the abductor muscles in comparison to the adductor muscles [21]. Cheetham et al. have also reported a 37% decrease in muscle fiber diameter of the lateral cricoarytenoid muscle following 12 weeks of denervation. The study was conducted on 10 adult horses where the left recurrent laryngeal nerve was severed and the effect of functional electrical stimulation on the PCA was analyzed [22]. Similarly, Miyamaru et al. have reported atrophy of the TA muscle and proliferation of connective tissue in Wistar rats after transecting and removing a 10 cm segment of the recurrent laryngeal nerve [23]. However the denervation did not progress significantly after 10 weeks as evidenced by the lack of significant difference in the average area of the treated and untreated side on the long term. These histologic changes are commensurate with the endostroboscopic findings of bowing, impaired glottic closure and reduced mucosal waves seen in patients with paresis and or paralysis [24].

Notwithstanding the aforementioned histologic explanation for the significant decrease in the volume of the paralyzed vocal fold, the results of this investigation carry important clinical implication in patients undergoing injection laryngoplasty. Information on the volume difference between the paralyzed vocal fold and its normal counterpart is invaluable in patients with unilateral vocal fold paralysis undergoing injection laryngoplasty where individual tailoring of the amount to be injected is paramount. The disparity in benefit following injection laryngoplasty in the treatment of glottic insufficiency has always been an issue of debate in the literature. To that end, individual patient characteristics have been investigated, most important of which is gender and age. Studies have indicated that female patients with unilateral vocal fold paralysis need less injectable material in comparison to their counter male patients [25] and that elderly tend to benefit less from surgery than young patients [26]. Despite taking into account the aforementioned confounding variables, namely age and gender, the amount to be injected remains empirically determined in injection laryngoplasty. To that end, volumetric measurements of the paralyzed vocal fold in comparison to the normal vocal fold may assist the surgeon in better estimating the amount that needs to be injected keeping in mind the duration of vocal paralysis and the age-induced atrophic changes. Corralling the individual variability may enhance the surgical outcome and optimize the result of such a procedure. Nevertheless, the added-value of prior knowledge of the significant difference in the volumetric measurements of the paralyzed vs. non-paralyzed vocal folds and the large inter-subject variability, remains hypothetical given the lack of a prospective study investigating the predictive value of these measures in estimating glottic closure and voice outcome following injection laryngoplasty.

Conclusion

Volumetric measurements of the paralyzed vocal fold in comparison to the normal vocal fold in a group of 21 patients with unilateral vocal fold paralysis shows the presence of significant difference between the normal and affected site, and the presence of large inter-subject variation. Information on the volume difference between the two vocal folds may be used to better estimate the amount that needs to be injected in medialization procedures. A prospective study looking at the predictive value of this information in patients scheduled for injection laryngoplasty will be conducted in the future.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributors

Abdul-Latif Hamdan is a professor at the Department of Otolaryngology–Head and Neck Surgery at the American University of Beirut Medical Center (AUBMC).

Elie Khalifee is a senior resident at the Department of Otolaryngology–Head and Neck Surgery at the AUBMC.

Natally Al Arab and ***Karl Asmar*** are research fellows at the Department of Diagnostic Radiology at AUBMC.

Roula Hourani is an associate professor at the Department of Diagnostic Radiology at AUBMC.

ORCID

Abdul-Latif Hamdan http://orcid.org/0000-0003-1493-3568
Elie Khalifee http://orcid.org/0000-0002-1004-4387
Natally Al Arab http://orcid.org/0000-0002-8947-4100
Karl Asmar http://orcid.org/0000-0002-9548-4794
Roula Hourani http://orcid.org/0000-0002-5802-2611

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