MRI Anatomical and Morphological Differences in the Vocal Tract Between Dysphonic and Normal Adult Women

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Summary: Objective. To analyze the vocal tract morphometry of women with vocal nodules (VN) compared with normal subjects by means of magnetic resonance imaging (MRI) at rest position.

Study Design. Prospective study.

Methods. The present research included 20 young adult women, aged 18–40 years: 10 dysphonic patients with VN and 10 normal subjects. All participants were tested using MRI; 12 measurements of the vocal tract were performed: nine in median sagittal section and three in axial section.

Results. The 12 measurements were smaller in the dysphonic group; statistical significance was obtained for three parameters: in the sagittal plane, the laryngeal vestibule area was significantly smaller in the dysphonic group, with $P = 0.012^*$ (* = statistical significance); in the axial section, the distance between the right and left vocal processes of the arytenoids' cartilages and the distance between the anterior commissure of the glottis and the laryngeal posterior wall were also significantly lower in the dysphonic group, with $P = 0.036^*$ and 0.010^*, respectively. Significant differences in the vocal tract morphometry of individuals with VN were observed compared with normal subjects, at rest position.

Conclusions. Results obtained from this study suggest that patients with VN may present a constantly increased tension of the laryngeal muscles, even at rest; moreover, reduced anterior-posterior dimension of the larynx may be a morphological characteristic of patients with VN.

Key Words: Dysphonia–Vocal nodules–Larynx–Magnetic resonance imaging.

INTRODUCTION

Vocal tract corresponds to the upper airway, superiorly limited by the nasal cavity and inferiorly by the glottis.[1] Functions of the vocal tract concerns production of different articulatory gestures and modification of the acoustic properties of the sound wave generated by the vocal folds. Its length and shape depend on genetic factors and on the speaker's muscular adjustments.[2,3] Thus, each individual has a unique vocal tract, with specific characteristics.

Increased or imbalanced tension of intrinsic and/or extrinsic laryngeal muscles may modify the configuration of the vocal tract, and one of the most frequent lesions related to these alterations are vocal nodules (VN), which are considered as a common manifestation of vocal hyperfunction. The development of such lesions may be either gradual or acute, as a result of an immediate reaction to a period of intense phonotrauma.[4–7]

Magnetic resonance imaging (MRI) has been considered as a valuable feature to investigate the anatomy[8,9] and the morphology[10–12] of the vocal tract and to conduct phonetic studies on speech and voice production.[13] However, it still is underused in the analysis of the vocal tract of dysphonic patients, probably because of the high costs involved and the methodological difficulties related to the acquisition time of the image frames.

This study was designed to investigate the morphology of the vocal tract of women with VN, because the etiology of this condition is related to the imbalance of laryngeal muscles, and its incidence is considerably high in children and young adult women.[5,7,14,15] A better comprehension of the characteristics of the vocal tract of such patients may impact on the process of vocal rehabilitation. Thus, the aim of this research was to analyze the morphometry of the vocal tract of women with VN compared with that of normal subjects, at rest position, using high-field MRI.

METHODS

This project was evaluated and fully approved by the Ethics Committee of the Federal University of São Paulo, under the ID number 1316/7, and all participants had read and singed an informed consent.

The VN group (VNG) was comprised of patients with vocal complaints, enrolled in the Multidisciplinary Larynx and Voice Sector, Federal University of São Paulo. The control group (CG) was comprised of undergraduate and graduate students, without vocal complaints or history of dysphonia, at the same university.

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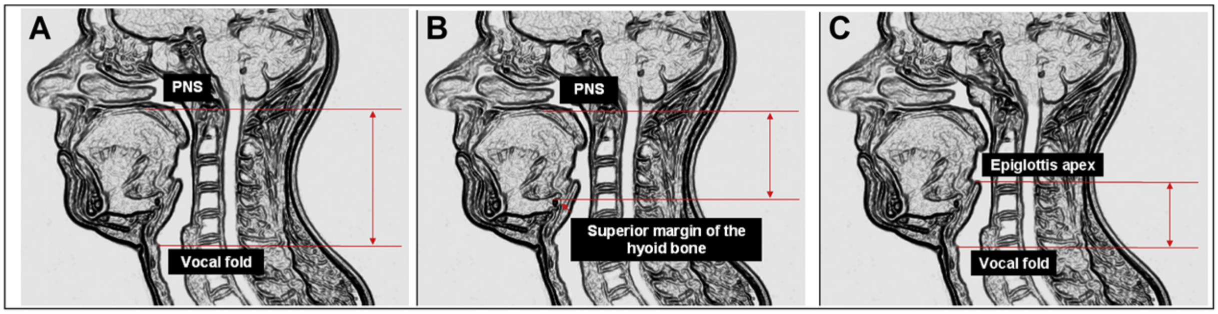


FIGURE 1. Diagrams showing anatomical landmarks and vertical measurements in median sagittal section. **A**. Measure 1: distance from PNS to the vocal fold. **B**. Measure 2: distance from PNS to the superior margin of the hyoid bone. **C**. Measure 3: distance from the epiglottis apex to the vocal folds.

The exclusion criteria for both groups were as follows: subjects of oriental descendence, based on the study of Xue and Hao;[16] presence of pacemaker; claustrophobia; previously diagnosed disorder of vertebral column, in the cervical region; neurological or psychiatric conditions; previous voice rehabilitation or training; presence of dental implants; and subjects younger than 18 years or older than 45 years.

Inclusion criteria to the VNG were as follows: presence of more than three vocal signs and symptoms of a Questionnaire of Vocal Signs and Symptoms that was adapted from the questionnaire originally published by Roy et al[17]; history of dysphonia related to vocal use; G—overall grade of vocal deviation superior to 50 mm in the visual analog scale[18,19]; laryngeal diagnosis of VN, characterized by bilateral tissue thickening, symmetrically positioned at the middle of the vocal folds; and presence of glottic chink—medium-posterior, triangular or hourglass shaped, with a triangular component. The mean number of signs and symptoms, from the questionnaire applied in this group, was 8.57.

Inclusion criteria to the CG were as follows: presence of up to three vocal signs and symptoms; absence of vocal complaints or previous history of dysphonia; G—overall grade of vocal deviation until 35 mm in the visual analog scale; and normal laryngological examination. The mean number of signs and symptoms, from the questionnaire applied in this group, was 0.5.

From the 30 patients who agreed to be a part of the VNG, 10 individuals could fit the inclusion and exclusion criteria. The CG, initially with 15 volunteers, also ended up with a final number of 10 participants. Age ranged from 18 to 40 years. Statistical analysis revealed that both VNG and CG were not different with respect to age range, weight, and height, a fundamental observation to proceed with the study.

MRI examinations were performed in the Department of Diagnostic Imaging, with the 1.5T SONATA equipment (Siemens). Participants were positioned in dorsal decubitus at rest. The imaging acquisition protocol was comprised of three sequences: Sagittal T1 spin echo (SE), Sagittal T2 turbo spin echo (TSE), and Axial T2 TSE, with a slice thickness of 3 mm.

The selected anatomical landmarks were as follows: posterior nasal spine (PNS), vocal fold, superior margin of the hyoid bone, epiglottis apex, dorsum of the tongue, pharyngeal posterior wall, epiglottis plane, vocal process, anterior commissure of the glottis, and laryngeal posterior wall. They are displayed in Figures 1–4. Twelve measurements were performed, nine in the sagittal section and three in the axial section.

The measurements were performed by a voice specialist under the advisement of a radiologist, using the Leonardo Workstation (Syngo 2003A; Siemens). The images were presented randomly, and the voice specialist did not have information about the groups. The confidence level of the measurements was tested among the subjects, by retesting the measurements performed by another professional of the Department of Diagnostic Imaging, in two randomly selected samples. Statistical analysis, performed with the Student's t test, revealed no

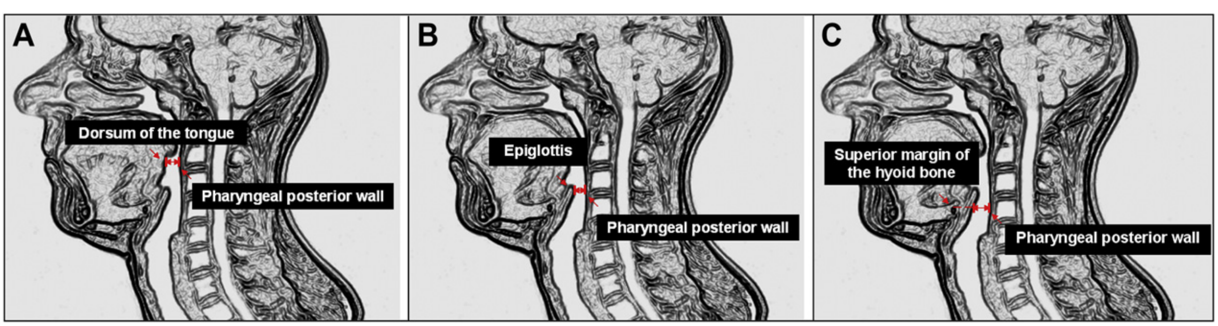


FIGURE 2. Diagrams showing anatomical landmarks and horizontal measurements in median sagittal section. **A**. Measure 4: distance from the dorsum of the tongue to the pharyngeal posterior wall. **B**. Measure 5: distance from the epiglottis apex to the pharyngeal posterior wall. **C**. Measure 6: distance from the epiglottis to the pharyngeal posterior wall, at the level of the superior margin of the hyoid bone.

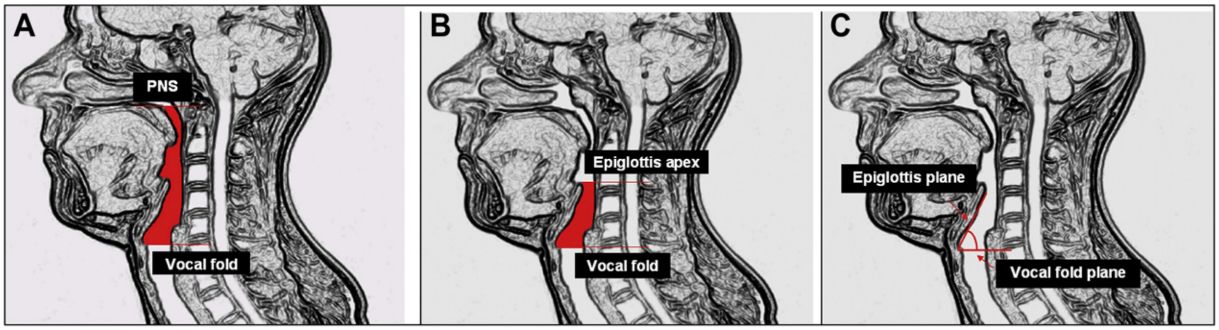


FIGURE 3. Diagrams showing anatomical landmarks, areas and angular measurements in median sagittal section. **A**. Measure 7: vocal tract area, superiorly limited at the level of PNS and inferiorly limited by the vocal fold. **B**. Measure 8: laryngeal vestibule area, superiorly limited at the level of epiglottis apex and inferiorly limited by vocal fold. **C**. Measure 9: angle between the epiglottis plane and the vocal fold plane.

significant differences between measurements. For comparisons between groups, the analysis-of-variance test was used, with a significance level of 5%.

RESULTS

The quality of all MRI was good enough to enable reliable measurements, both in the medial sagittal plane and in axial sections. The results obtained from the 12 measurements performed are shown in Tables 1 to 4. These 12 measurements were smaller in the VNG. Three significant differences were observed in addition to two tendencies.

No significant differences between the groups were observed in what concerns vertical measurements (Table 1). However, the distance from PNS to the superior margin of the hyoid bone, measure 2, presented a tendency to be smaller in the VNG. This might indicate that the position of the hyoid bone would be slightly shifted upward in patients with VN when compared with that of the CG.

Table 2 shows the values obtained from three horizontal measurements. Measure 5, from the epiglottis apex to pharyngeal posterior wall, presented a tendency to be smaller in the VNG. The remaining two measurements presented no significant differences.

Table 3 shows the values from area and angle measurements. The laryngeal vestibule area was significantly smaller in the VNG—measure 8. The total area and the angle formed by the epiglottis and the vocal folds presented no statistically significant differences between the groups.

In axial measurements, two statistically significant differences were observed: the distance between the vocal processes (measure 10) and the distance between the anterior commissure of the glottis and the laryngeal posterior wall (measure 11) (Table 4). The angle between both vocal folds (measure 12) was not different between the groups.

DISCUSSION

Patients with VN usually present with excessive laryngeal tension[14,15,20,21]; abusive vocal behavior, including phonotrauma[5,7,22,23]; and anatomical predisposition[5] to develop these lesions. A relatively higher position of the hyoid bone and larynx as well as an evident constriction of the laryngeal vestibule are usually observed in these patients compared with those of normal subjects.[4,7,21,24]

The magnetic resonance images allow for measurements at the supralaryngeal region, which is not possible in traditional laryngological examinations. MRI was used rather than computed tomography, because the MRI presents as advantages an outstanding soft tissue contrast resolution and the absence of ionizing radiation.[25] To identify the possible morphometric differences between the studied groups that could be related

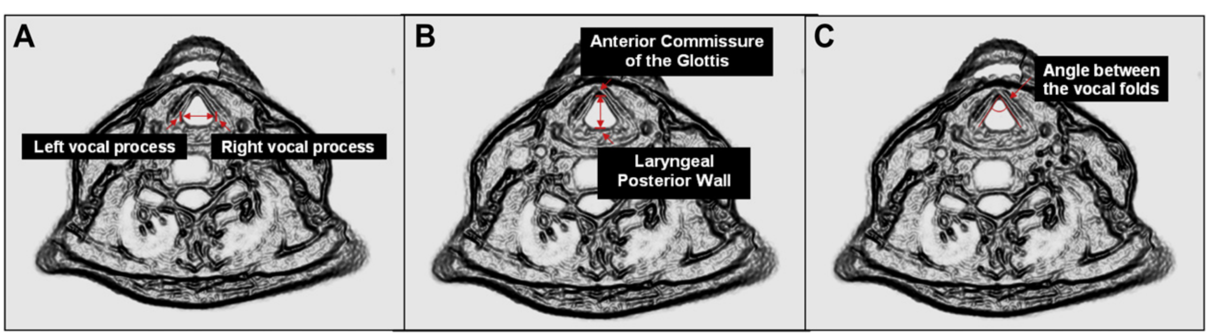
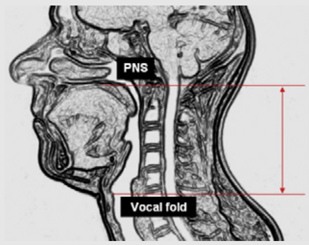
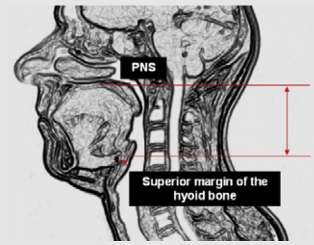


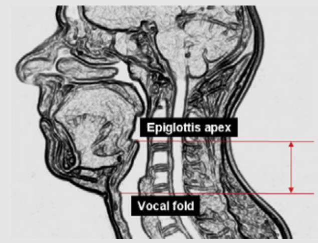
FIGURE 4. Diagrams showing anatomical landmarks and transverse, anterior-posterior, and angle measurements in axial section. **A**. Measure 10: distance between the vocal processes of the arytenoid cartilages. **B**. Measure 11: distance between the anterior commissure of the glottis and the laryngeal posterior wall. **C**. Measure 12: angle between the free margins of the vocal folds.

TABLE 1.
Values of the Vertical Measurements in Median Sagittal Section

	Measure 1: PNS-VF (cm)		Measure 2: PNS-SMHB (cm)		Measure 3: Epiglottis Apex-VF (cm)	
	Dysphonic	Normal	Dysphonic	Normal	Dysphonic	Normal
Mean	7.12	7.43	4.67	5.05	3.34	3.56
Median	7.13	7.37	4.70	5.05	3.38	3.62
Standard deviation	0.30	0.71	0.31	0.58	0.37	0.30
Minimum value	6.45	6.36	4.10	4.10	2.42	3.03
Maximum value	7.50	8.67	5.00	6.00	3.77	3.94
Variation Coefficient (%)	4.3	9.6	6.50	11.60	11.2	8.5
Confidence limit	0.19	0.44	0.19	0.36	0.23	0.19
P-value	0.218		0.085#		0.153	





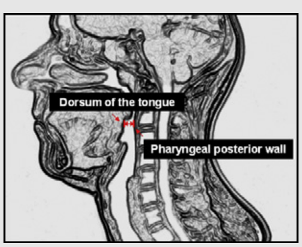


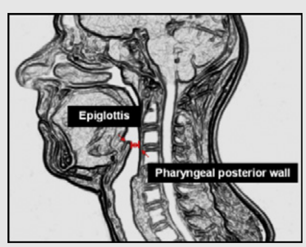
Abbreviations: PNS, Posterior nasal spine; VF, Vocal fold; SMHB, Superior margin of the hyoid bone.
Tendency to statistically significant difference.

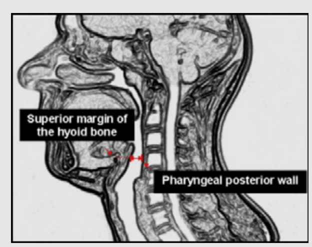
to these clinical findings, diverse measurements of the vocal tract were investigated. The selection of the anatomical landmarks was one of the major challenges of this study, mainly because the larynx is a mobile organ, only attached to the hyoid-bone, which is not articulated with any other bony structure of the skeleton. Furthermore, the literature on specific

TABLE 2.
Values of the Horizontal Measurements in Median Sagittal Section

	Measure 4: Dorsum of the Tongue-PPW (cm)		Measure 5: Epiglottis Apex-PPW (cm)		Measure 6: Epiglottis-PPW at the Hyoid Bone (cm)	
	Dysphonic	Normal	Dysphonic	Normal	Dysphonic	Normal
Mean	0.95	1.03	0.37	0.53	0.85	1.07
Median	0.92	0.99	0.37	0.48	0.82	1.04
Standard deviation	0.20	0.38	0.13	0.21	0.31	0.26
Minimum value	0.60	0.65	0.19	0.27	0.38	0.68
Maximum value	1.38	1.91	0.60	0.92	1.41	1.51
Variation Coefficient (%)	21.50	37.10	34.80	40.10	36.60	24.30
Confidence limit	0.13	0.24	0.08	0.13	0.19	0.16
P-value	0.539		0.052#		0.106	



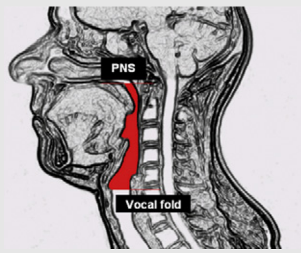


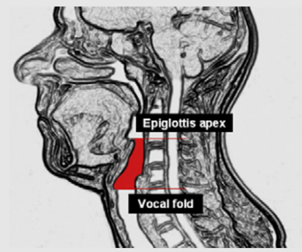


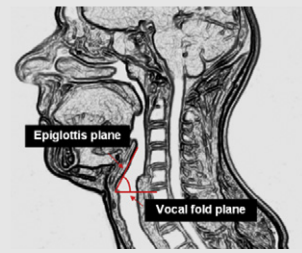
Abbreviation: PPW, Pharyngeal posterior wall.
Tendency to statistically significant difference.

TABLE 3.
Values of the Area and Angle Measurements, in Median Sagittal Section

	Measure 7: Total Area (cm^2)		Measure 8: Area of the Laryngeal Vestibule (cm^2)		Measure 9: Angle Between the Epiglottis and the VF (x°)	
	Dysphonic	Normal	Dysphonic	Normal	Dysphonic	Normal
Mean	7.37	8.33	3.66	4.53	61.00	63.40
Median	7.14	8.26	3.67	4.60	58.00	62.50
Standard deviation	1.46	1.53	0.57	0.81	5.06	5.91
Minimum value	5.42	5.76	2.71	3.19	56.00	57.00
Maximum value	10.92	11.74	4.40	6.02	68.00	77.00
Variation coefficient (%)	19.30	18.40	15.50	17.80	8.30	9.30
Confidence limit	0.90	0.95	0.35	0.50	3.13	3.66
P-value	0.169		0.012*		0.342	







Abbreviation: PNS, Posterior nasal spine.
* Statistically significant difference.

morphological measurements of the vocal tract of dysphonic patients by imaging methods is still relatively scarce. The use of the cervical vertebra as a landmark was not reliable because of the wide anatomical variability among subjects. Therefore, the PNS was selected as the fixed bone landmark, also used in methods already developed by Vorperian et al[11] and by Roers et al.[26]

The results showed three statistically significant differences between the groups: measurement of the laryngeal vestibule area (measure 8), distance between the vocal fold processes of the arytenoid cartilages (measure 10), and distance between the anterior commissure of the glottis and the laryngeal posterior wall (measure 11), as well as two tendencies, namely, measure from PNS to the superior margin of the hyoid bone (measure 2) and measurement from the epiglottis apex to the pharyngeal posterior wall (measure 5).

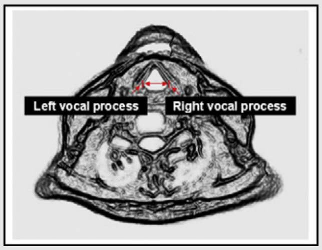
The laryngeal vestibule, which corresponds to the space limited superiorly by the apex of the epiglottis, inferiorly by the vocal folds, anteriorly by the epiglottis, and posteriorly by the laryngeal and pharyngeal posterior wall, was significantly smaller in the VNG. It shows an important constriction region of the vocal tract (measure 8) (Table 3). This area was measured by drawing a line around the inner part of these structures. The fact that the laryngeal vestibule area was significantly different between the groups—despite no significant differences being observed with respect to the distance from the apex of the epiglottis to the vocal folds (measure 3) and also with respect to the angle between the epiglottis and the vocal folds (measure 9)—suggests that the size reduction of the laryngeal vestibule in the VNG predominantly occurs in the anterior-posterior axis, rather than in the craniocaudal axis. The typical tongue retraction in hyperfunctional voice disorders, described by Boone and McFarlane,[21] may be considered as an explanation for this finding. According to Colton and Casper,[27] laryngeal anterior-posterior constriction is observed in patients who tend to present a tense laryngeal posture. The anterior-posterior reduction of the laryngeal vestibule may result from the action of the hyoglossus muscle, which retracts the base of the tongue toward the posterior wall of the pharynx.[28] This constriction has been observed in patients with VN during the laryngological examination.[24]

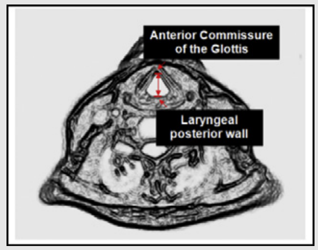
The analysis of the axial measurements revealed that the distance between the vocal processes (measure 10) (Table 4) was significantly smaller in the VNG. This means that this group presents a narrower glottic space, probably because of the constantly increased tension of the laryngeal muscles, such as the lateral fibers of the thyroarytenoid (TA) muscle or the even the lateral cricoarytenoid (LCA) muscle. It is important to mention that, to minimize the influence of the breath during the examination, all participants were asked to breathe as slowly as possible, and that this measurement was made with the participants in the same position and in the same situation.

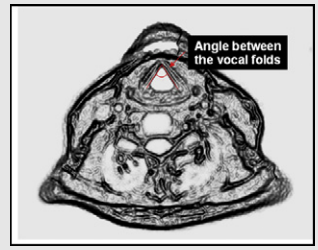
Another interesting finding was related to measure 11—the distance from the anterior commissure of the vocal folds to the laryngeal posterior wall—(Table 4), which was significantly smaller in the VNG. A hypothesis to this observation concerns the laryngeal morphology itself. In the same way that the female glottic ratio is considered a predisposition factor to the

TABLE 4.
Values of the Distance Between the Vocal Folds, Anterior Commissure of the Glottis, and the Laryngeal Posterior Wall, and the Angle Between the Free Margins of the Vocal Folds, in Axial Section

	Measure 10: Distance Between the Vocal Processes (cm)		Measure 11: Anterior Commissure of the Glottis-LPW (cm)		Measure 12: Angle Between the Vocal Folds (x°)	
	Dysphonic	Normal	Dysphonic	Normal	Dysphonic	Normal
Mean	0.86	1.03	1.41	1.61	46.40	52.10
Median	0.80	1.00	1.40	1.60	47.50	50.00
Standard deviation	0.17	0.17	0.15	0.16	6.47	10.34
Minimum value	0.60	0.80	1.30	1.30	37.00	36.00
Maximum value	1.20	1.30	1.80	1.90	53.00	70.00
Variation coefficient (%)	20.30	16.70	10.80	10.20	13.90	19.90
Confidence limit	0.11	0.11	0.09	0.10	4.01	5.41
P-value	0.036*		0.010*		0.157	







Abbreviation: LPW, Laryngeal posterior wall.
* Statistically significant difference.

development of VN,[5] it is possible that subjects with these lesions present a shorter anterior-posterior dimension of the larynx—from the anterior commissure of the glottis to the laryngeal posterior wall—compared with normal subjects. In other words, the presence of a reduced anterior-posterior dimension of the larynx may be a morphological predisposition in the development of such lesions. No statistical difference between the groups was obtained in what concerns the angle between both vocal folds (measure 12).

Surprisingly, from all vertical measurements (Table 1), only a tendency to statistically significant difference was observed, regarding the distance from PNS to the superior margin of the hyoid bone (measure 2), that was smaller in the VNG. This suggests that the hyoid bone is more likely to be raised as a result of the increase in the muscular tension than the vocal folds. This finding seems to be natural, because the suprahyoid muscular group is fixed to the hyoid bone.

By analyzing the three horizontal measurements performed (Table 2), no statistically significant differences were obtained. Nevertheless, it was possible to obtain a statistical tendency regarding measure 5, defined by the distance between the epiglottis and the posterior wall of the pharynx, which was smaller in the VNG. This finding would reinforce the rational of a possible hyperfunction of the suprahyoid muscles, which would bring the apex of the epiglottis closer to the posterior pharyngeal wall, in the VNG.[22,28] The other horizontal measurements presented no significant difference between the groups.

The results of this study show that, at rest position, the laryngeal vestibule may be the region of the vocal tract that seems to be more likely to indicate the long-term muscular adjustments used by patients with VN. Figure 5 displays the laryngeal images and MRI samples of a subject from the CG and those of a patient with VN. Observe, in the MRI, the reduced area of the laryngeal vestibule and the irregular contour displayed in the image of the VN patient compared with the control. It is important to highlight that this is an exploratory research, and therefore, the relationship between the results obtained and muscular adjustments by dysphonic patients should be carefully considered.

Traditionally, vocal rehabilitation of patients with VN should aim at the reduction of vocal abusive behaviors and the balance of the intrinsic and extrinsic laryngeal muscles. Moreover, based on these data, there might be some benefit from trying to adjust the vocal tract structures, but further study would be needed to determine if this would have an effect either on prevention or resolution of VN.

CONCLUSIONS

Significant differences were observed in the morphometry of the vocal tract of patients with VN, which suggested an anterior-posterior constriction of the laryngeal vestibule, a narrower distance between the vocal folds, and a reduced distance of the anterior-posterior dimension of the larynx. Results obtained from this study suggest that patients with VN may present a constantly increased tension of the laryngeal muscles,

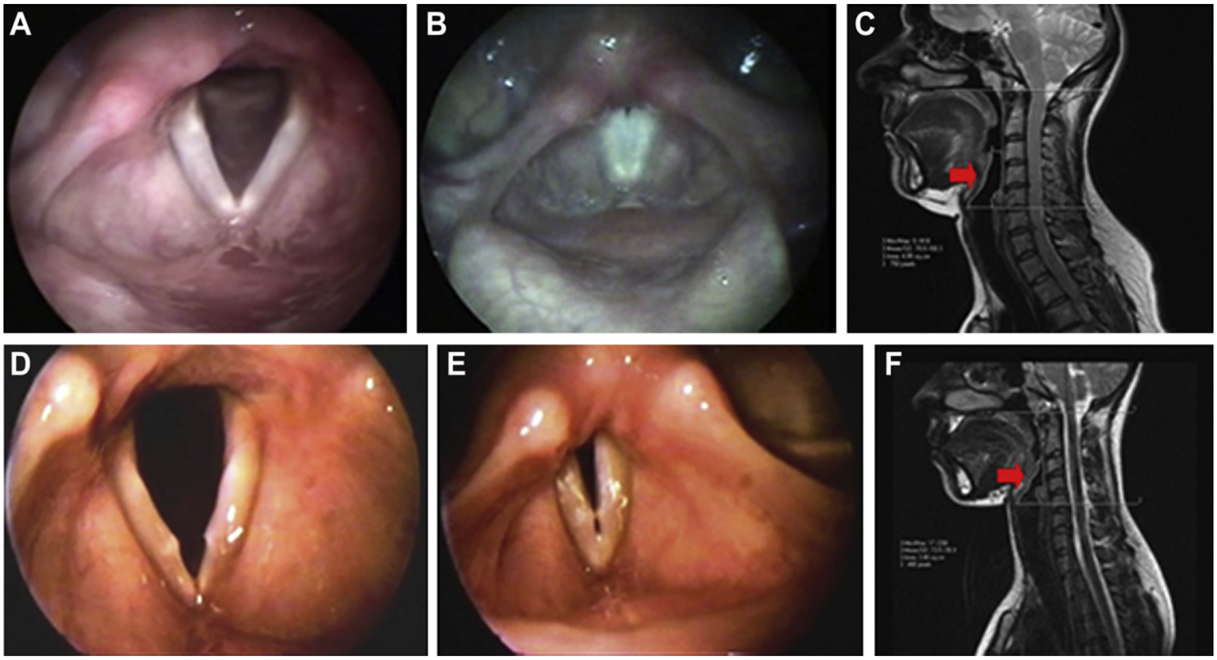


FIGURE 5. Telelaryngoscopic images obtained during respiration and phonation, and MRI of median sagittal plane showing the measurement of the laryngeal vestibule area of a subject from the control group and of a patient with vocal nodules. **A**. Control group: larynx image of a normal woman during respiration. **B**. Control group: larynx image of a normal woman during phonation. **C**. Control group: laryngeal vestibule area of 4.95 cm^2. Note the regularity of the vestibule contour. **D**. Vocal nodule group: larynx image obtained during respiration. Observe bilateral tissue thickening. **E**. Vocal nodule group: larynx image obtained during phonation. Observe bilateral tissue thickening and presence of glottic chink—medium-posterior triangular. **F**. Vocal nodule group: laryngeal vestibule area of 3.48 cm^2. Note the irregularity of the laryngeal vestibule contour and the narrowing at the apex of the epiglottis.

even at rest, and that reduced anterior-posterior dimension of the larynx may be a morphological characteristic of patients with VN.

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