Vocal Tract Adjustments of Dysphonic and Non-Dysphonic Women Pre- and Post-Flexible Resonance Tube in Water Exercise: A Quantitative MRI Study

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Summary: Objective. To compare vocal tract (VT) adjustments of dysphonic and non-dysphonic women before and after flexible resonance tube in water exercise (FRTWE) at rest and during phonation using magnetic resonance imaging.

Study Design. Prospective study.

Methods. Twenty women, aged 20–40 years, 10 dysphonic with vocal nodules (VNG) and 10 controls (CG), underwent four sets of sagittal VT MRI: two pre-FRTWE, at rest and during phonation, and two post-FRTWE, during phonation and at rest. The subjects performed 3 minutes of exercise. Nine parameters at rest and 21 during phonation were performed.

Results. Pre-FRTWE, eight significant differences were found, three at rest and five during phonation: at rest - laryngeal vestibule area, distance from epiglottis to pharyngeal posterior wall (PPW) and interarytenoid complex length were smaller in the VNG; during phonation - laryngeal vestibule area, angle between PPW and vocal fold (VF), epiglottis to PPW, and anterior commissure of the larynx to laryngeal posterior wall were smaller in the VNG; tongue area was larger in the VNG. Post-FRTWE, only three significant differences were found, two during phonation and one at rest: during phonation - angle between PPW and VF and the membranous portion of the VF length were smaller in the VNG; at rest - distance from epiglottis to PPW was smaller in the VNG.

Conclusions. Results suggest that the habitual VT adjustments of dysphonic and non-dysphonic women are different at rest and during phonation. The FRTWE promoted positive VT changes in the VNG, reducing the intergroup differences.

Key Words: Dysphonia–Vocal nodules–Vocal tract–Flexible resonance tube in water exercise–MRI measurements.

INTRODUCTION

The vocal tract (VT) has great plasticity and can take different configurations because of the rapid, precise, and highly coordinated movements of articulators such as lips, tongue, jaw, soft palate, and larynx.[1,2] The VT configuration can be modified by short- and long-term adjustments. Short-term adjustments enable the production of speech sounds and specific vocal qualities, whether in the spoken or singing voice.[2–4] Long-term adjustments are related to the way individuals usually use their articulators. Each individual tends to use specific muscle adjustments as part of their usual speech style,[5] which may or may not be healthy.

The vocal trauma because of inadequate phonatory pattern and excessive vocal effort can lead to the development of benign vocal fold (VF) lesions and change the VT morphology.[6–8] Vocal nodules are injuries that occur highly in children and young women;[9] its most usual etiology is VF tissue trauma.[7,10,11] Because of laryngeal imbalance or increased muscle tension, vocal hyperfunction is a common manifestation in patients with vocal nodules.[7,10,12] Yamasaki et al[6] compared the VT morphometry of normal and dysphonic young women with vocal nodules using magnetic resonance imaging (MRI); they found that women with vocal nodules presented regions of VT constriction, especially on the laryngeal vestibule, even when at rest position.

Voice therapy is the first choice for treatment of vocal nodules, and it aims to reduce muscle tension, optimize vocal behavior, and decrease the phonotrauma between the VFs.[7,13,14] Exercises with semi-occluded VT such as lips and tongue trills, fricative sounds, nasal sounds, and phonation into a glass tube or phonation into a straw gives a better interaction between the VF and the VT.[15]

More specifically, these exercises increase the inertive reactance of the VT and thereby facilitate sustained VF oscillation.[16] Phonation into a glass tube, also called resonance tube method, has long been used in voice therapy in Finland,[17] and it is now commonly used in other countries.[18] The description and practical implementations of this method was carried out by Simberg and Laine.[17] Resonance tube phonation in water has been used to treat patients with hyperfunctional voice, vocal nodules, and VF paralysis.[19] The position of the tube under the surface of the water changes depending on the therapy goal. In cases of hyperfunctional voice and vocal nodules, the free end of the tube

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is submerged 1–2 cm below the water surface; in cases of hypofunctional voice, the tube is set up deeper in the water.[17] The bubbles produced during resonance tube phonation in water exercise causes a back pressure which modulates the oral pressure with a possible "massage" effect on the VF.[19] The effects of resonance tube phonation was verified by using a setting of analysis such as subglottal pressure, electroglottography and perceptual evaluation,[18] high-speed imaging,[19] vertical laryngeal position and oral pressure variations,[20] and self-assessment, auditory-perceptual analysis, and acoustic evaluation.[21]

In 2007, Sihvo and Denizoglu[22] proposed the Lax Vox Voice Therapy Technique, which is similar to the resonance tube in water exercise, but it is performed using a silicon tube. According to the authors, the technique lowers the larynx position, expands the VT, and reduces the force collision between the VFs, which makes it good for cases of vocal nodules. However, these benefits were not established experimentally, except by two studies of Andrade et al.[23,24] In the first one,[23] the authors investigated changes in voice production pattern for seven semi-occluded VT exercises (SOVTEs) using electroglottography, and they verified that the exercises with a secondary source of vibration such as lip-trills, tongue-trills, and Lax Vox produced larger contact quotient range values that was caused by changes in oral pressure. In the second study,[24] the authors investigated the back pressure vs flow relationship for different tubes. They found that the resonance tube and silicone tubes submerged into water produced an almost constant back pressure determined by the depth of the water.

Computed tomography has been used to verify the effects of SOVTEs on VT configuration of normal and dysphonic subjects.[25–27] MRI is an important imaging method to investigate the VT anatomy[28–30] and the voice physiology.[1,31] The acquisition of multiplanar and volumetric images without the use of ionizing radiation is an important advantage of this method. High-resolution MRI allows detailed visualization of the laryngeal, pharyngeal and oral cavities, and the VT articulators.[32] Therefore, it is an interesting method to be used in the VT morphometric studies and for analysis of vocal techniques' immediate effects.

The study of glottis and supraglottic adjustments of dysphonic and non-dysphonic women, before and after vocal exercise, can bring important contributions about morphologic and functional characteristics of these individuals and information about vocal techniques' immediate effects. The goal of this research was to compare the VT adjustments of dysphonic and non-dysphonic women before and after flexible resonance tube in water exercise (FRTWE) at rest position and during phonation using high-resolution MRI.

We formulated two hypotheses for this study: (1) Habitual VT adjustments of the vocal nodules group (VNG) differ from the vocally healthy group at rest position and during phonation. (2) After FRTWE, the VT adjustments of the dysphonic group are similar to the control group (CG). In the first hypothesis we expect to find differences between the groups with lower values in the dysphonic group on the vertical, horizontal, and area measurements. In the second hypothesis we expect to observe few differences between the groups after FRTWE.

METHODS

This research was approved by the Comissão de Ética para Análise de Projetos de Pesquisa, under number 188.183. All participants read and signed an informed consent.

Delineation research

This prospective study used two independent variables and one dependent variable. The two independent variables were the VF nodules and FRTWE; the dependent variables were the VT morphometric measurements. Thus, the study design allowed two important comparisons between the groups of dysphonic and non-dysphonic women: one of their habitual VT settings, verified pre-FRTWE, and the other one of the immediate effects of the exercise on their glottic and supraglottic configurations, verified post-FRTWE.

Sample

The sample consisted of 10 young women without vocal complaints (CG) and 10 young dysphonic women with vocal nodules (VNG). The age range of the sample was 18–40 years old, with an average of 26.6 years old for the CG and 27.8 for the VNG. Statistical analysis showed that both VNG and CG were not different with respect to age range and weight. The sample from both groups was obtained at the same hospital where the research was conducted. The sample of the CG comprised undergraduate and graduate students, without vocal complaints or history of dysphonia. The VNG consisted of patients seeking vocal therapy at the ENT Department of the Universidade de Sao Paulo. All participants underwent a structured interview, auditory-perceptual evaluation, and laryngeal examination. A voice specialist speech-language pathologist with experience in clinical assessment performed the vocal auditory-perceptual evaluation. A voice deviation scale (VDS) was used to perform this analysis and the parameter G was considered.[33] According to the VDS, deviations below 35.5 mm were considered normal variability of vocal quality, and deviations superior to 50.5 mm were considered moderate deviations.

To maintain homogeneity within each group, exclusion and inclusion criteria were considered. Exclusion criteria were presence of pacemaker; claustrophobia; previously diagnosed disorder of vertebral column in the cervical region; neurologic or psychiatric conditions; previous vocal rehabilitation or training; presence of dental implants; subjects below 18 years of age or above 45 years old; and subjects of oriental descent.

Inclusion criteria for the VNG were vocal complaint and history of dysphonia related to vocal use; G above 50.5 mm on the VDS verified by auditory-perceptual evaluation; laryngeal diagnosis of vocal nodule, characterized by bilateral tissue thickening, symmetrically positioned in the membranous portion of both VFs, and medium-posterior triangular chink.

Inclusion criteria for the CG were absence of vocal complaint or previous history of dysphonia; G below 35.5 mm on the VDS; and normal laryngological examination seen by videolaryngostroboscopy.

Initially, 33 participants were selected, 17 for the VNG and 16 for the CG. Based on the exclusion and inclusion criteria,

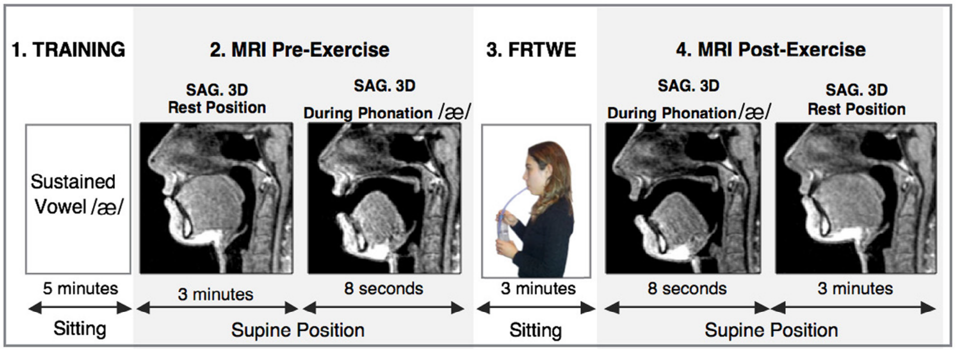

FIGURE 1. Protocol of MRI acquisition and phonatory task: (1) 5 minutes training of the sustained vowel /æ/ at comfortable frequency and intensity; (2) MRI scan pre-exercise at rest position and during phonation of the vowel /æ/; (3) 3 minutes of FRTWE; (4) MRI scan post-FRTWE during phonation of the vowel /æ/ and at rest position.

11 participants were able to take part in the VNG, and 10 were able to take part in the CG. The presence of minor laryngeal alterations was the main reason for exclusion. A subject from the VNG failed to produce the sustained vowel for the period of time necessary during the MRI and was excluded from the research. Thus, 10 dysphonic women with vocal nodules were part of the VNG. One participant from the CG was using a dental bar on the lower jaw, which caused distortion of the anterior oral cavity image. Because only a few measurements were affected, it was decided to keep this sample; thus, 10 non-dysphonic women formed the CG.

FRTWE

The exercise was performed with the use of a flexible silicone tube, similar to the one used on the Lax Vox Vocal Technique. The exercise was based on phonation into a silicone tube with one end immersed into water using a 500-mL bottle with 13 cm of water column. The tube had specific measures of length and diameter, 35 cm and 9 mm, respectively. To be included in the study, the participant had to be naïve for the FRTWE; the exercise was taught in-between the MRI scans. Participants were asked to phonate the vowel /u/ into the tube at comfortable frequency and intensity, with the free end submerged 2 cm below the water surface. They were also asked to blow with similar intensity. The same speech-language pathologist instructed all participants.

Protocol of MRI

MRI examinations were performed at the Department of Radiology—HC-FMUSP, with the 1.5T GE equipment (Signa HDxt, GE Healthcare, Chalfont St. Giles, UK). A pilot examination of a volunteer with vocal nodules was performed to develop the MRI protocol. All parameters were tested and set in this pilot examination. Sagittal plane 3D acquisition was chosen to obtain images at rest position and during phonation. The parameters used for imaging acquisition were spoiled gradient recalled echo (SPGR sequence), overlap of 0 mm, TR: 5,066 ms, TE: 1,016 ms, matrix of 192×160, NEX of 0.50, field of view of 22, slice thickness of 3 mm. During phonation the acquisition was about 8 seconds long. The acquisition was performed using a neurovascular array coil. Participants were placed in supine position.

Thereby, the protocol of MRI acquisition and phonatory task were (1) 5 minutes training of the sustained vowel /æ/, at comfortable frequency and intensity; (2) MRI scan pre-exercise at rest position and during sustained phonation of the vowel /æ/, in supine position; (3) 3 minutes of FRTWE—participants were led out of the MRI machine and then performed the exercise while sitting on a chair; (4) MRI scan post-FRTWE during phonation of the vowel /æ/ and at rest position, in supine position—participants were placed into the MRI machine immediately after exercise. The interval between finishing the exercise and image acquisition was approximately 3 minutes. Figure 1 shows the protocol of MRI acquisition and phonatory task.

Morphologic measurements

Nine measurements were performed at rest position and 21 during phonation. All measurements were performed using *OsiriX MD Software* (Pixmeo SARL, Geneva, Switzerland). At rest position three vertical, five horizontal, and one area measurements were performed: V1 - palate (level of the posterior nasal spine) to the lowermost edge of the hyoid bone; V2 - hyoid bone to the VF; V3 - palate to the VF; H1 - the lowermost edge of the jaw to the hyoid bone; H2 - hyoid bone to the pharyngeal posterior wall (PPW); H3 - anterior commissure of the larynx to the laryngeal posterior wall (LPW); H4 - epiglottis (above the arytenoid complex) to the PPW; H5 - length of the arytenoid complex; A1 - laryngeal vestibule area superiorly limited at the level of epiglottis apex and inferiorly limited by VF. Figure 2 shows the measurements and anatomic landmarks at rest position, in median sagittal plane, pre- and post-FRTWE.

Six vertical, six horizontal, two of length, four of area, one of volume, and two of angle measures were performed during phonation: V1 - distance between lips; V2 - palate to the lowermost edge of the jaw; V3 - palate to the lowermost edge of the hyoid bone; V4 - hyoid bone to the VF; V5 - palate to the VF; V6 - floor of mouth to the uppermost of the tongue; H1 - jaw to the hyoid bone; H2 - hyoid bone to the PPW; H3 - anterior commissure of the larynx to the LPW; H4 - epiglottis (above the arytenoid complex) to the PPW; H5 - length of the arytenoid complex; H6 - length of the membranous portion of the VF; L1 - length of the tongue measured as the distance of the tip of the tongue to the

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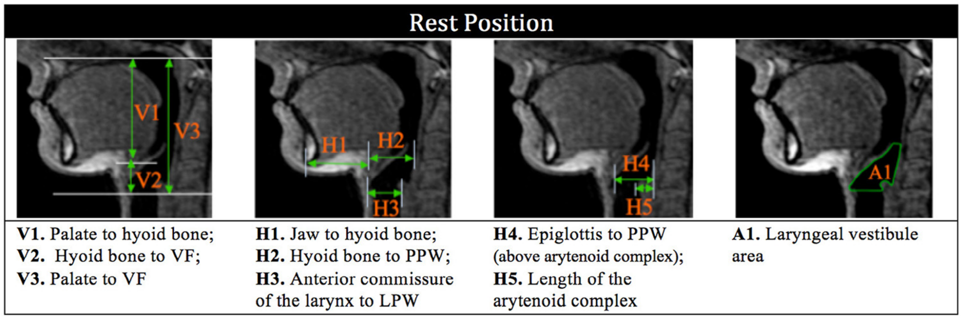


FIGURE 2. MRI scan from a representative participant of the CG. Anatomic landmarks at rest position, in median sagittal plane, pre- and post-FRTWE.

valeculla; L2 - length of the VT from the VF to the lips; A1 - laryngeal vestibule area; A2 - laryngeal and pharyngeal area, superiorly limited at the level of soft palate and inferiorly limited by VF; A3 - tongue area; A4 - buccal and pharyngeal area; Vol 1 - laryngeal vestibule and hypopharynx volume; Ang 1 - angle formed by PPW and VF; Ang 2 - angle formed by palate and PPW. The Ang 2 measurement was performed to ensure the participants' positioning were accurate pre- and post-exercise. Figure 3 presents the anatomic landmarks during phonation, in median sagittal plane, pre- and post-FRTWE.

The measurements were performed by a speech-language pathologist specializing in voice who has experience in doing VT analysis using MRI. Twenty percent of the measurements were retested by another experiment professional to verify the confidence level. There was no difference between the measurements.

Statistical analysis

The Mann-Whitney test was used for intergroup comparisons. The significance level was of 5%.

RESULTS

A total of nine morphologic measurements were carried out at rest position and 21 during phonation. The habitual long-term adjustments of the VT used by the VNG and the CG were verified through the MRI acquired pre-FRTWE. The VT configuration after the vocal exercise shows the immediate effect of the FRTWE. Statistically significant differences were found between the groups in the four moments: (1) rest position pre-FRTWE; (2) during phonation pre-FRTWE; (3) during phonation post-FRTWE; (4) rest position post-FRTWE.

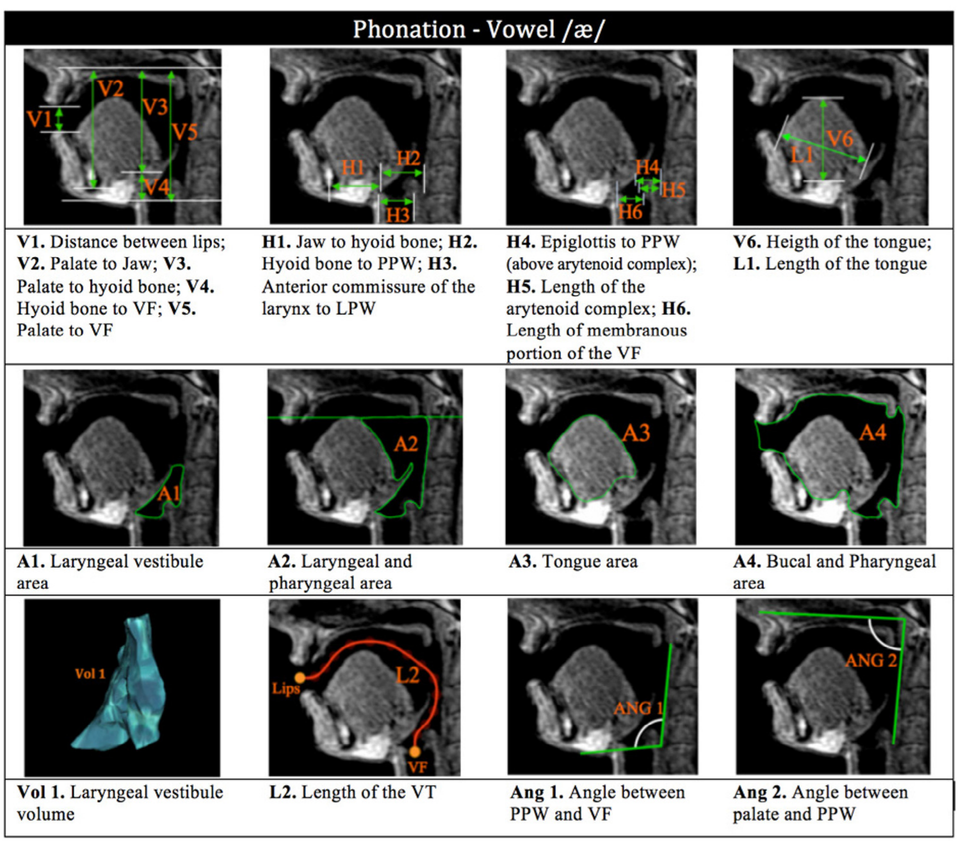
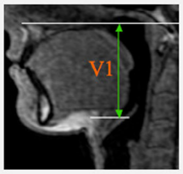
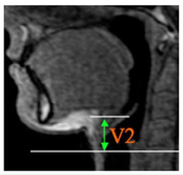
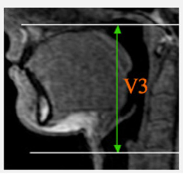
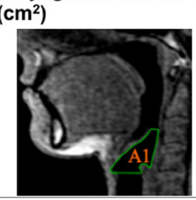


FIGURE 3. MRI scan from a representative participant of the CG. Anatomic landmarks during phonation, in median sagittal plane, pre- and post-FRTWE.

TABLE 1.
Values of the Vertical and Area Measurements at Rest Position, in Median Sagittal Plane, Pre- and Post-FRTWE

	MEASUREMENTS		PRE-FRTWE		POST-FRTWE	
			DYSPHONIC	CONTROL	DYSPHONIC	CONTROL
V1	**Palate to hyoid bone (cm)**	Mean	6,11	6,17	5,94	6,06
		SD	0,53	0,35	0,46	0,40
		Min value	5,48	5,69	5,30	5,44
		Max value	7,21	6,90	6,83	6,59
		P Value	0,520		0,473	
V2	**Hyoid bone to VF (cm)**	Mean	1,90	1,89	1,91	1,94
		SD	0,28	0,23	0,20	0,31
		Min value	1,25	1,45	1,58	1,33
		Max value	2,30	2,18	2,18	2,33
		P Value	0,880		0,545	
V3	**Palate to VF (cm)**	Mean	8,02	8,06	7,85	8,00
		SD	0,55	0,50	0,43	0,51
		Min value	7,18	7,57	7,29	7,48
		Max value	9,13	9,07	8,68	8,81
		P Value	1,000		0,496	
A1	**Laryngeal vestibule area (cm^2)**	Mean	4,10	4,79	4,50	4,80
		SD	0,59	0,60	0,71	0,62
		Min value	3,42	3,77	3,54	3,56
		Max value	5,12	5,88	6,30	5,78
		P Value	0,026		0,112	

Sample: 10 VNG and 10 CG
Legend: VF: Vocal fold

Rest position pre-FRTWE

There were three significant differences found between groups: two horizontal measurements and one area measurement: distance from the epiglottis to the PPW (above the arytenoid complex), the arytenoid complex length, and the laryngeal vestibule area. All these measurements were significantly lower in the VNG (Tables 1 and 2). The vertical measurements did not differ between groups.

Phonation pre-FRTWE

Five measurements differed between the groups: two were horizontal measurements, two were area measurements, and one was an angle measurement. The horizontal measurements that differed were the distance from the anterior commissure of the larynx to the LPW and the distance from the epiglottis to the PPW (above the arytenoid complex; Table 3). The area measurements that differed between the VNG and CG were the laryngeal vestibule area and the tongue area (Table 4). The angle between the PPW and VF differed between the groups (Table 5). All these measurements were significantly lower in the dysphonic group, with the exception of the tongue area that was statistically lower in the CG (Table 4). The vertical measurements did not differ between the groups (Table 6).

Phonation post-FRTWE

After the vocal exercise, only two significant differences were found between the groups during phonation: one horizontal measurement and one angle measurement. The membranous portion of the VF and the angle between the PPW and VF were both smaller in the VNG (Tables 3 and 5).

Rest position post-FRTWE

At rest position post-FRTWE, only the distance from the epiglottis to the PPW was statistically smaller in the VNG (Table 2).

DISCUSSION

The constant use of hyperfunctional muscle adjustments can lead to the development of laryngeal lesions, generate glottis and supraglottic constriction, and therefore, change the shape and size of the VT.[34,35] Vocal nodules are benign laryngeal lesions that occur

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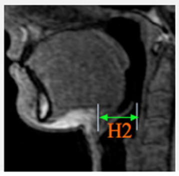
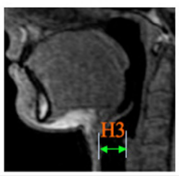
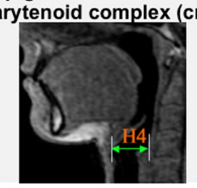
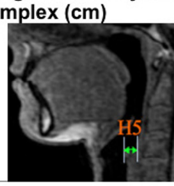
TABLE 2.
Values of the Horizontal Measurements at Rest Position, in Median Sagittal Plane, Pre- and Post-FRTWE

	MEASUREMENTS		PRE-FRTWE		POST-FRTWE	
			DYSPHONIC	CONTROL	DYSPHONIC	CONTROL
H1	Jaw to hyoid bone (cm)	Mean	4,28	4,30	4,37	4,65
		SD	0,50	0,36	0,53	0,45
		Min value	3,50	3,68	3,71	3,95
		Max value	5,11	4,98	5,15	5,21
		P Value	0,940		0,212	
H2	Hyoid bone to PPW (cm)	Mean	2,55	2,77	2,62	2,80
		SD	0,28	0,26	0,31	0,30
		Min value	2,22	2,23	2,22	2,35
		Max value	3,04	3,15	3,16	3,27
		P Value	0,082		0,162	
H3	AC of the larynx to LPW (cm)	Mean	1,85	2,02	1,87	2,02
		SD	0,20	0,15	0,22	0,21
		Min value	1,59	1,82	1,51	1,59
		Max value	2,18	2,23	2,18	2,25
		P Value	0,064		0,082	
H4	Epiglottis to PPW - above arytenoid complex (cm)	Mean	1,57	1,96	1,67	1,96
		SD	0,26	0,25	0,32	0,24
		Min value	1,24	1,62	1,16	1,62
		Max value	1,93	2,41	2,22	2,38
		P Value	0,011		0,028	
H5	Length of the arytenoid complex (cm)	Mean	0,63	0,77	0,72	0,85
		SD	0,05	0,08	0,08	0,24
		Min value	0,56	0,66	0,61	0,66
		Max value	0,68	0,89	0,88	1,46
		P Value	0,000		0,211	

Sample: 10 VNG and 10 CG
Legend: AC: Anterior commissure; PPW: Pharyngeal posterior wall; LPW: Laryngeal posterior wall

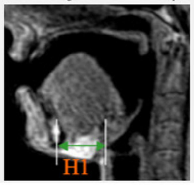
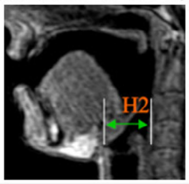
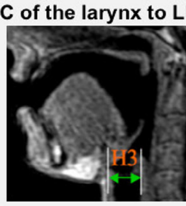
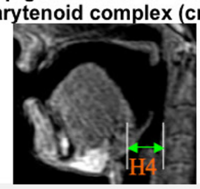
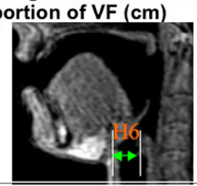
highly in children and dysphonic women. According to a retrospective study that examined the larynx of 4447 dysphonic patients, vocal nodules are one of the three most common diseases in the dysphonic population.[9] Voice therapy is usually the first treatment option, and it aims to reduce muscle tension and the collision force of the VFs.[7,13,14] SOVTEs are traditionally used in voice rehabilitation.[15] Although there are many variations in the exercises, they all have the same physiological basis.

Phonation into resonance tube made of glass with one end immersed in water has been indicated for treatment of patients with vocal nodules to promote positive changes in the glottic and supraglottic configuration and provide comfortable phonation.[15,19,21,23] Sihvo and Denizoglu[22] proposed the Lax Vox Voice Therapy Technique that consists of phonation in a silicone tube with one end immersed into the water. The silicone tube is made of resistant material and is easy to be used. Thus, this study used a silicone tube similar to the one described for Lax Vox Voice Therapy.

The imaging method chosen for this research was high-resolution MRI that offers anatomic images with excellent discrimination of the soft tissues,[32] without ionizing radiation. The main articulators of the VT such as lips, tongue, soft palate, jaw, and larynx could be seen and analyzed. The habitual glottic and supraglottic adjustments were observed pre-FRTWE, and the immediate effect on the VT configuration was observed post-FRTWE for both groups.

MRIs were obtained at four different moments: two at pre-exercise (at rest position and during phonation) and two at post-exercise (during phonation and at rest position). The qualities of MRIs at rest position were very similar between groups with

TABLE 3.
Values of the Horizontal Measurements During Phonation, in Median Sagittal Plane, Pre- and Post-FRTWE

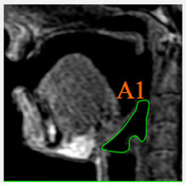
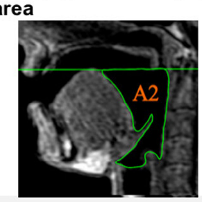
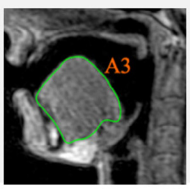
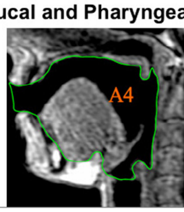
	MEASUREMENTS		PRE-FRTWE		POST-FRTWE	
			DYSPHONIC	CONTROL	DYSPHONIC	CONTROL
H1	Jaw to Hyoid bone (cm)	Mean	4,07	4,25	3,97	4,22
		SD	0,50	0,51	0,50	0,53
		Min value	3,17	3,28	3,27	3,24
		Max value	4,73	4,95	4,69	5,01
		P Value	0,38		0,36	
H2	Hyoid bone to PPW (cm)	Mean	2,72	2,83	2,87	2,90
		SD	0,26	0,35	0,30	0,34
		Min value	2,17	2,26	2,48	2,40
		Max value	2,99	3,38	3,37	3,51
		P Value	0,45		0,82	
H3	AC of the larynx to LPW (cm)	Mean	1,92	2,13	1,95	2,10
		SD	0,15	0,14	0,17	0,21
		Min value	1,75	1,82	1,76	1,87
		Max value	2,26	2,35	2,25	2,41
		P Value	0,009		0,088	
H4	Epiglottis to PPW - above arytenoid complex (cm)	Mean	1,56	1,75	1,66	1,80
		SD	0,17	0,19	0,23	0,19
		Min value	1,34	1,52	1,30	1,43
		Max value	1,87	2,13	2,01	1,98
		P Value	0,034		0,272	
H5	Lenght of the arytenoid complex (cm)	Mean	1,07	1,19	1,11	1,23
		SD	0,15	0,11	0,23	0,10
		Min value	0,89	0,98	0,65	1,10
		Max value	1,30	1,42	1,49	1,44
		P Value	0,058		0,211	
H6	Length of the membranous portion of VF (cm)	Mean	1,11	1,25	1,14	1,32
		SD	0,16	0,17	0,14	0,14
		Min value	0,90	1,01	0,92	1,01
		Max value	1,38	1,49	1,40	1,53
		P Value	0,069		0,008	

Sample: 10 VNG and 10 CG
Legend: AC: Anterior commissure; PPW: Pharyngeal posterior wall; LPW: Laryngeal posterior wall; VF: Vocal fold

well-defined anatomic points. A challenge of this research was to obtain MRIs with good quality during phonation because of reduced maximum phonation time in the VNG and of the presence of artifacts caused by the VFs' vibration. The quality of images during phonation was higher for the CG when compared with the VNG. However, the sagittal images of the VNG allowed adequate visualization of anatomic structures with good definition. Only one participant with vocal nodules could not keep the phonation as long as necessary and was excluded from the research. The reconstruction quality of the images in coronal and transverse planes in the VNG was not satisfactory; therefore, only sagittal plane images were considered.

The VT morphometric study of the dysphonic group and the CG showed significant differences in glottic and supraglottic

TABLE 4.
Values of the Area Measurements During Phonation, in Median Sagittal Plane, Pre- and Post-FRTWE

MEASUREMENTS (cm^2)			PRE-FRTWE		POST-FRTWE	
			DYSPHONIC	CONTROL	DYSPHONIC	CONTROL
A1	Laryngeal vestibule area	Mean	3,71	4,32	4,15	4,63
		SD	0,41	0,53	0,79	0,63
		Min value	3,08	3,07	3,27	3,30
		Max value	4,28	5,00	5,60	5,33
		P Value	0,010		0,162	
A2	Pharyngeal and laryngeal area	Mean	8,65	10,07	8,82	10,41
		SD	1,14	2,31	1,26	2,04
		Min value	6,61	6,83	6,62	7,74
		Max value	10,52	13,33	10,52	13,50
		P Value	0,186		0,112	
A3	Tongue area	Mean	22,72	20,70	22,33	21,07
		SD	1,79	1,74	1,69	1,98
		Min value	19,66	17,80	20,05	17,31
		Max value	25,30	23,00	24,49	23,46
		P Value	0,028		0,130	
A4	Bucal and Pharyngeal area	Mean	45,16	44,92	44,89	44,54
		SD	3,96	3,81	3,77	3,77
		Min value	39,17	38,74	39,42	37,95
		Max value	49,22	50,85	50,78	50,55
		P Value	0,870		0,935	

Sample: 10 VNG and 10 CG. Except for **A3** and **A4** measurements: 10 VNG and 9 CG

settings. There were 9 measurements carried out with participants at rest position and 21 during phonation of the sustained vowel /æ/. Eight significant differences between groups were found pre-FRTWE: three at rest position and five during phonation, suggesting that the habitual VT settings are different between the VNG and the CG. Post-FRTWE, only three significant differences were found between groups: two during phonation and one at rest position. The VT shape of a dysphonic patient was more similar to the VT shape of the nondysphonic group after the exercise. Therefore, FRTWE seems to produce positive effects on the VT configuration in the VNG.

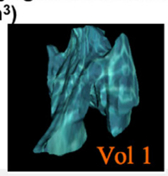
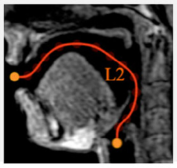
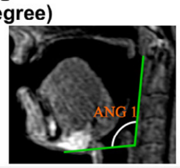
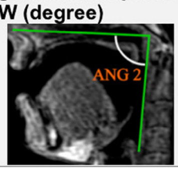
Patients with vocal nodules commonly have increased tension of the laryngeal and paralaryngeal muscles, which are often classified as secondary muscle tension dysphonia.[36] In these cases, the imbalance of the extrinsic muscles can modify the laryngeal position in the neck and change the inclination of important structures such as the hyoid bone, thyroid, cricoids, and arytenoid cartilages, affecting the function of the intrinsic laryngeal muscles.[36] A high larynx vertical position in the neck is one of the clinical characteristics of patients with muscular tension dysphonia.[13,34,36] In this research, vertical measurements were obtained with the participants at rest position and during phonation. Surprisingly, vertical measurements were very similar between groups in the four moments. Differences near the larynx were found for horizontal, area, and angle measurements between the VNG and CG.

Rest position—before FRTWE

At rest position, three measurements—two horizontal and one area—differed in the groups. The distance from the epiglottis to PPW (above the arytenoid complex) and the length of the arytenoid complex were statistically smaller in the VNG. The laryngeal vestibule area was also smaller in the dysphonic group. These results are suggestive of anteroposterior (AP) supraglottic constriction that is often observed in the larynx examination of dysphonic patients with muscular tension.[36–38]

The length measurement of the arytenoid complex was established because, during the MRI observation of both groups, this structure appeared visually smaller in the VNG, and indeed, it was found to be smaller in the dysphonic group. The VNG

TABLE 5.
Values of the Volume, Length, and Angle Measurements During Phonation, in Median Sagittal Plane, Pre- and Post-FRTWE

MEASUREMENTS			PRE-FRTWE		POST-FRTWE	
			DYSPHONIC	CONTROL	DYSPHONIC	CONTROL
VOL1	Laryngeal vestibule volume (cm^3)	Mean	6,09	6,53	6,30	6,79
		SD	1,21	1,21	1,61	1,11
		Min value	4,08	4,30	3,80	4,86
		Max value	7,92	8,64	9,22	8,08
		P Value	0,450		0,290	
L2	Length of the VT (cm)	Mean	14,62	14,51	14,73	14,66
		SD	0,39	0,57	0,44	0,47
		Min value	14,16	13,91	14,16	14,20
		Max value	15,31	14,07	15,39	15,51
		P Value	0,324		0,734	
ANG1	Angle between PPW and VF (degree)	Mean	80,76	90,42	85,87	90,94
		SD	3,04	6,73	4,27	4,82
		Min value	76,69	80,79	80,30	82,88
		Max value	84,43	99,33	94,74	96,66
		P Value	0,002		0,028	
ANG2	Angle between palate and PPW (degree)	Mean	97,25	97,56	97,99	97,59
		SD	6,20	7,30	5,98	6,35
		Min value	85,71	84,51	86,15	85,25
		Max value	104,20	109,01	103,98	105,42
		P Value	0,762		0,705	

Sample: 10 VNG and 10 CG. Except for **L2** measurement: 10 VNG and 9 CG
Legend: PPW: Pharyngeal posterior wall; VF: Vocal fold

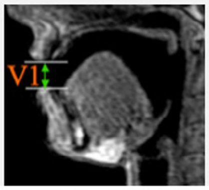
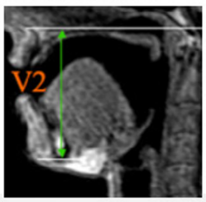
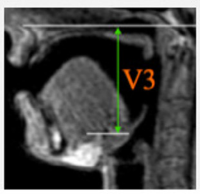
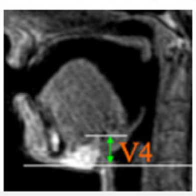
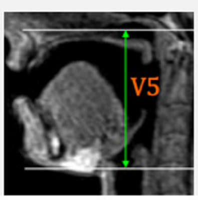
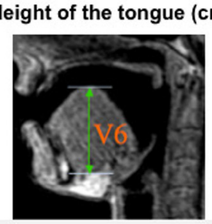
was composed of dysphonic women with bilateral lesions and medium-posterior triangular chink. We hypothesize that the arytenoid complex length reduction may be due to the lower activation of the interarytenoid muscle, which is responsible for the glottis posterior adduction.[12,39–41]

The laryngeal vestibule area was significantly smaller in the VNG, suggesting a reduction of the AP dimension of the laryngeal vestibule. Yamasaki et al[6] compared the VT of dysphonic and non-dysphonic women at rest position using MRI. For the authors, the reduced anterior-posterior dimension of the larynx may be a morphological characteristic of patients with vocal nodules.

Phonation—before FRTWE

Most morphologic differences between groups were found during phonation pre-FRTWE. Five morphologic measures differed between groups, two horizontal measurements, two area measurements, and one angle measurement. The distance from the anterior commissure of the larynx to the LPW and the distance from the epiglottis to the PPW (above the arytenoid complex) were significantly lower in the VNG. The laryngeal vestibule area was also lower in the dysphonic group. The reduction of the horizontal measurements and of the laryngeal vestibule area suggests the VNG presented smaller AP dimension of the supraglottic space during phonation. Partially, the larger tongue area observed in the dysphonic group (Table 4) can justify the presence of this reduced distance. The tongue is a structure composed of soft tissue that independently changes areas of the oral cavity and pharynx. The tongue is considered a muscular hydrostat with essentially constant volume. Thus, any change in one dimension will cause a compensatory change in the other dimensions.[42] Additionally, the tongue comprises interdigitated fibers that contribute to produce several deformation possibilities.[43] The VNG tongue area was larger in the AP dimension and probably narrowed in the lateral dimension. This configuration may contribute to reduced AP dimension of the supraglottic space. The posterior displacement of the tongue is considered a hyperfunctional posture.[44] According to Colton and Casper,[45] laryngeal AP constriction may be observed in patients who have a tense laryngeal posture. The value of the buccal and pharynx area was very similar between groups (Table 4—A4 measurement), hence, the larger tongue area observed in the VNG may be related to muscle adjustment used by dysphonic women.

TABLE 6.
Values of the Vertical and Length Measurements During Phonation, in Median Sagittal Plane, Pre- and Post-FRTWE

MEASUREMENTS			PRE-FRTWE		POST-FRTWE	
			DYSPHONIC	CONTROL	DYSPHONIC	CONTROL
V1	Distance between lips (cm)	Mean	1,19	1,07	1,25	0,94
		SD	0,43	0,29	0,59	0,24
		Min value	0,66	0,61	0,56	0,60
		Max value	1,92	1,54	2,27	1,36
		P Value	0,65		0,32	
V2	Palate to Jaw (cm)	Mean	7,16	7,01	7,13	6,93
		SD	0,50	0,45	0,55	0,44
		Min value	6,23	6,18	6,15	6,16
		Max value	7,85	7,71	7,96	7,48
		P Value	0,49		0,54	
V3	Palate to Hyoid bone (cm)	Mean	6,44	6,59	6,44	6,51
		SD	0,69	0,55	0,64	0,61
		Min value	5,13	5,91	5,40	5,45
		Max value	7,19	7,58	7,46	7,56
		P Value	0,85		0,65	
V4	Hyoid bone to VF (cm)	Mean	1,31	1,27	1,36	1,36
		SD	0,58	0,45	0,51	0,46
		Min value	0,64	0,58	0,66	0,58
		Max value	2,55	1,97	2,49	1,96
		P Value	0,85		0,70	
V5	Palate to VF (cm)	Mean	7,74	7,86	7,80	7,87
		SD	0,41	0,45	0,35	0,42
		Min value	7,08	7,37	7,40	7,24
		Max value	8,48	8,83	8,65	8,68
		P Value	0,94		0,44	
V6	Height of the tongue (cm)	Mean	5,26	5,29	5,15	5,24
		SD	0,54	0,20	0,50	0,24
		Min value	4,48	4,97	4,47	4,90
		Max value	6,23	5.60	6,13	5,64
		P Value	0,650		0,290	
L1	Length of the tongue (cm)	Mean	6,62	6,42	6,64	6,44
		SD	0,57	0,34	0,41	0,41
		Min value	5,63	5,71	6,08	5,88
		Max value	7,61	6,97	7,56	7,10
		P Value	0,821		0,290	

Sample: 10 VNG and 10 CG. Except for **V1** and **L1** measurements: 10 VNG and 9 CG
Legend: VF: Vocal fold

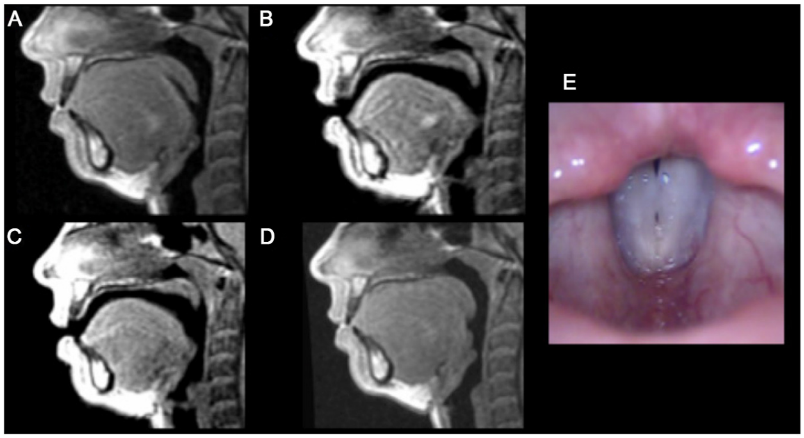


FIGURE 4. MRIs, sagittal plane, and larynx examination from a participant of the VNG. **(A)** Pre-FRTWE at rest position; **(B)** pre-FRTWE during phonation—note the inclination of the VF with elevation of the anterior commissure of the larynx; **(C)** post-FRTWE during phonation—note that the inclination of the vocal fold was reduced; there is a more regular contour of the laryngeal vestibule; and the tongue is more compacted; **(D)** post-FRTWE at rest position; **(E)** larynx examination: vocal nodules and medium-posterior triangular chink—note that the arytenoids apex are far from each other.

The measurement of the angle formed by the PPW and the VF turned out to be quite interesting. This angle was significantly lower in the VNG which presented a different inclination of the VF characterized by elevation of the anterior commissure of the larynx (Table 5—ANG 1). Figure 4 shows the VT of a participant with vocal nodules in four moments of MRI acquisition. In Figure 4B we can observe the inclination of the VF with elevation of the anterior commissure of the larynx. Post-exercise the inclination of the VF was reduced, Figure 4C. On the other hand, this angle was more obtuse for the CG with more rectified VF posture (Figures 5B and 5C). The measurements from the palate to the hyoid bone (Figure 3—V3) and from the jaw to the hyoid bone (Figure 3—H1) did not differ between groups; thus, it seems that the inclination of the VF observed in the VNG—with elevation of the anterior commissure of the larynx—may occur due to the larynx's intrinsic muscles imbalance. Dysphonic patients with muscle tension may present a different angle between laryngeal cartilages.[35] In this research, the VNG presented more inclination of VF, and we hypothesize that these data may be a signal of the change in the angle between the thyroid and cricoid cartilages.

The value of the angle between the palate and PPW was very similar between groups, pre- and post-FRTWE (Table 5—ANG 2). This measurement showed that there was no difference between the positioning and the repositioning of the participants in the MRI machine during the imaging acquisition sequence.

Phonation—after FRTWE

The VT morphometric analysis for both groups during phonation post-FRTWE showed similar values between groups; in other words, the groups were more alike. Only two measurements differed, the length of membranous portion of the VFs and the angle between the PPW and the VFs. Both measures were significantly lower in the VNG. The median value of membranous portion of the VFs increased in the CG post-FRTWE, which

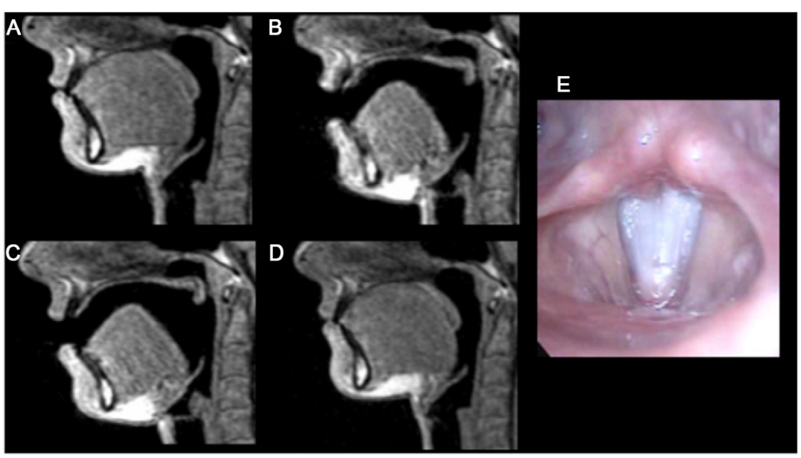


FIGURE 5. MRIs, sagittal plane, and larynx examination from a participant of the CG. **(A)** Pre-FRTWE at rest position; **(B)** pre-FRTWE during phonation—note the vocal folds are parallel to the ground; **(C)** post-FRTWE during phonation—note the vocal folds rectification; **(D)** post-FRTWE at rest position; **(E)** larynx examination: no lesions and complete glottal closure—note that the arytenoids are closer to each other.

probably contributed to the difference between groups, from 1.25 cm pre-exercise to 1.32 cm post-exercise.

The measurement of the angle between the PPW and VF increased in the VNG from 80.76° pre-FRTWE to 85.87° post-FRTWE. However, this angle was significantly lower in the dysphonic group post-exercise. These data suggest that the effect of exercise in the posture of VF (observed in sagittal plane) may be more evident in the long term.

Overall, after the FRTWE, there was a significant enlargement of the AP dimension of the larynx in the VNG.

Rest position—after FRTWE

At rest position post-FRTWE, one single difference was found between the groups. The distance from the epiglottis to PPW (above the arytenoid complex) was smaller in the dysphonic group. These data suggest that this anterior-posterior dimension of the laryngeal vestibule may represent a region of constriction in patients with vocal nodules.

CONCLUSION

The results of this research suggest that the habitual adjustments of dysphonic and non-dysphonic women's VT are different at rest position and during phonation. Vocal effort may change the position of the vocal tract articulators of patients with vocal nodules. VT adjustments in the VNG were characterized by the reduced AP dimension of the larynx, a larger area of the tongue, and inclined posture of the VFs with elevation of the anterior commissure of the larynx viewed in sagittal plane. The FRTWE promoted positive VT changes in the VNG, thus reducing intergroup differences. The inclination of the VF decreased in the dysphonic group immediately after the vocal exercise, but differences between the groups still exist. Probably FRTWE allows changes in the VF posture in the long term. This study provides understanding of VT adjustments in speakers with dysphonia relative to a normal CG and adds to the evidence base for VT adjustments associated with SOVTE.

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