A Computerized Tomography Study of Vocal Tract Setting in Hyperfunctional Dysphonia and in Belting

*Marcelo Saldias, †,‡,*Marco Guzman, §Gonzalo Miranda, and ||Anne-Maria Laukkanen, *§*Santiago, and* †*Chile,* ‡*, and* ||*Tampere, Finland*

Summary: Background: Vocal tract setting in hyperfunctional patients is characterized by a high larynx and narrowing of the epilaryngeal and pharyngeal region. Similar observations have been made for various singing styles, eg, belting. The voice quality in belting has been described to be loud, speech like, and high pitched. It is also often described as sounding “pressed” or “tense”. The above mentioned has led to the hypothesis that belting may be strenuous to the vocal folds. However, singers and teachers of belting do not regard belting as particularly strenuous.

Purpose: This study investigates possible similarities and differences between hyperfunctional voice production and belting. This study concerns vocal tract setting.

Methods: Four male patients with hyperfunctional dysphonia and one male contemporary commercial music singer were registered with computerized tomography while phonating on [a:] in their habitual speaking pitch. Additionally, the singer used the pitch G4 in belting. The scannings were studied in sagittal and transversal dimensions by measuring lengths, widths, and areas.

Results: Various similarities were found between belting and hyperfunction: high vertical larynx position, small hypopharyngeal width, and epilaryngeal outlet. On the other hand, belting differed from dysphonia (in addition to higher pitch) by a wider lip and jaw opening, and larger volumes of the oral cavity.

Conclusions: Belting takes advantage of “megaphone shape” of the vocal tract. Future studies should focus on modeling and simulation to address sound energy transfer. Also, they should consider aerodynamic variables and vocal fold vibration to evaluate the “price of decibels” in these phonation types.

Key Words: Nonclassical singing−Vocal loading−Vocal tract imaging−Computed tomography−Physiology of singing.

INTRODUCTION

According to clinical observations, typically made through laryngeal endoscopy, hyperfunctional dysphonia is characterized by an elevated larynx, a constricted pharynx and epilaryngeal outlet, *Aditus laryngis*, strongly adducted vocal folds, and usually also medialization of the ventricular folds.[1−6] Hyperfunctional dysphonia leads to complaints of inadequate vocal communication and vocal fatigue. According to experiments with excised larynges, increased adduction and higher pitch and loudness increase impact stress (pressure per unit area) during vocal fold collisions in phonation.[7] Thus, hyperfunctional phonation has been regarded as a risk for vocal fold trauma due to mechanical loading of the tissue.

Similar findings of the vocal tract as those listed for patients in hyperfunctional dysphonia have been made for contemporary commercial music (CCM) singers in belting (high pitched, loud yelling-like singing), yet professional CCM singers and teachers of CCM do not regard belting as strenuous or harmful.[8−11] Typically, one adds to the statement “when it is produced correctly.” It has been hypothesized that the sphincters of the vocal tract (pharynx, epilarynx, and larynx, the latter including both vocal folds and ventricular folds) can be adjusted separately.[8] Thus, at least theoretically, it would be possible to produce stronger constrictions in the epilarynx and hypopharynx while using only moderate adduction, which would diminish vocal loading and yet increase the loudness of phonation. It is known that narrowing of the epilaryngeal tube may lower phonation threshold pressure and increase sound pressure level, the strength of harmonics, and the level at 2−4 kHz, where the human ear is most sensible.[12,13] Specifically, Titze and Story[12] stated that the source-filter interaction and the vocal tract inertance may be increased by narrowing the epilarynx tube in an anterior-posterior (A-P) direction. This may favorably affect the vocal fold vibration and may allow for an economic voice production.

Based on laryngeal imaging, operatic singers are known to take advantage of epilaryngeal narrowing[8,14] while apparently keeping the vocal fold adduction, and thus biomechanical loading, just moderate.[15] Nasoendoscopic registrations by Cookman and DeVore[16] showed, for instance, how a classically trained soprano singer uses a very tight epilaryngeal narrowing when singing an aria, that the vocal folds are not visible at all. Similar results were reported by Mayerhoff et al[14] in a group of healthy professional opera singers by using nasoendoscopy. High degrees of both A-P and medial supraglottic laryngeal compression were observed during singing.

So far, most studies of patients with hyperfunctional dysphonia have been carried out using endoscopy. Such a method visualizes the pharynx and larynx from above. The present study aimed to investigate the total vocal tract

Accepted for publication February 1, 2018.
Conflict of interest: The authors report no declarations of interest.
From the *University of Chile, Santiago, Chile; †Department of Communication Sciences, Universidad de los Andes, Chile; ‡Department of Otolaryngology, Clinica Las Condes; §University of Chile Hospital, Santiago, Chile; and the ||University of Tampere, Tampere, Finland.
Address correspondence and reprint requests to Marco Guzman, University of Chile, Avenida Independencia 1027, Santiago, Chile.
E-mail: guzmann.marcoa@gmail.com
Journal of Voice, Vol. 33, No. 4, pp. 412−419
0892-1997

https://doi.org/10.1016/j.jvoice.2018.02.001

setting in patients diagnosed with hyperfunctional dysphonia and in a singer while belting using computerized tomography. Based on previous laryngeal endoscopy data, we hypothesized that (1) laryngeal and pharyngeal settings would be similar when comparing dysphonic patients and belters, and (2) high vertical laryngeal position, narrow outlet of epilarynx tube, and constricted pharynx would be present in both dysphonic patients and belters.

MATERIAL AND METHODS

Subjects

The plan for this study was reviewed and approved by the University of Chile Hospital Review Board. Informed consent was obtained from five volunteer subjects: four vocally untrained male patients (average age 25 years) diagnosed with mild hyperfunctional dysphonia and a 32-year-old male CCM singer with no vocal complaints. All subjects underwent flexible laryngoscopy (with stroboscopy) assessment (Olympus ENF-P4; Olympus, Center Valley, PA) to confirm their vocal condition (functional dysphonia and/or normal voicing). Laryngoscopic assessment was performed by a laryngologist using intranasal topical anesthesia for all subjects. Inclusion criteria for dysphonic subjects were laryngoscopic diagnosis of mild hyperfunctional dysphonia without vocal fold lesions and no previous voice therapy or training. All subjects were assessed with the GRBAS scale, where all of them presented at least 1 for G, R, B, and S. For the normal-voiced singer, the inclusion criteria were laryngoscopic diagnosis of a normal larynx structure and function, no self-reported voice complaints at the moment of the experiment, and more than 3 years of voice training in CCM technique. The singer was assessed with GRBAS scale = 00000.

In the present study, hyperfunctional dysphonia diagnosis was made based on frequently occurring features found in the literature, ie, compression of the glottis and supraglottic structures during phonation, poor voice quality, and vocal complaints.[1–6]

Computed tomography (CT) study

Procedures and tasks

Computerized tomography was carried out at the University of Chile Hospital, Department of Imaging and Radiology. The images of the vocal tract were taken through a SOMATON Sensation 64 (Siemens Healthcare, Earlangen, Germany) CT machine, using 100 kV of voltage, 0.4 seconds of time of rotation, and 1.2 mm of slice thickness. All subjects were at supine position inside the CT machine, with their heads fixed through a frame. During image acquisition, dysphonic subjects were asked to produce a sustained vowel [a:] in a comfortable and habitual pitch and loudness. The singer was required to perform two different phonatory tasks: (1) a sustained vowel [a:] in a comfortable and habitual pitch and loudness (pitch B2) and (2) a sustained vowel [a:] at a high pitch and loudness, using a clear belting quality (pitch G4). Subjects' pitch was controlled by one of the experimenters using an electronic keyboard as a reference. As there is a maximum amount of radiation allowed, subjects were scanned only once during each phonatory task.

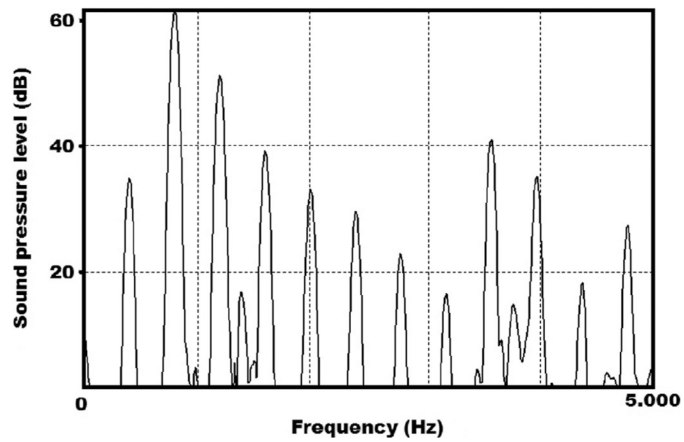

FIGURE 1. Spectrum of the belting sample recorded from the singer subject.

To ensure that the singer's belting performance was according to the musical genre, a second procedure was performed in which some audio samples were acoustically recorded for perceptual analysis. The recordings were made some days after CT acquisition in an acoustically treated room of the Voice Research Laboratory at the University of Chile using a professional condenser-omnidirectional microphone (model NT2-A; Rode, Long Beach, CA) at a distance of 30 cm from the mouth of the singer, who was in an upright position. Samples were digitally recorded in a WAV format (at 44 KHz of sampling rate; 16 bits) using a USB audio interface (Focusrite Scarlett 8i-6; Focusrite Audio Engineering, High Wycombe, UK) and the software *Pro Tools* 9.0 (Avid Corporation, Burbank, CA). The same three tasks used for the CT were recorded. Perceptual evaluation of the audio samples was made by five blinded judges (trained CCM teachers). Three of the evaluators were trained in the Complete Vocal Technique (CVT),[17] and they classified the sample as representing "overdrive," according to CVT terminology. "Overdrive" has been regarded as one subtype of the general term belting.[9,18] Figure 1 shows an example of the spectral structure of the belting sample of our singer. The spectrum with a strong second harmonic resembles those of the overdrive, obtained by McGlashan et al[9] and Sundberg et al.[18]

Audio and CT recordings were made in separate sessions. In order to ensure similar productions, each task was practiced by the singer several times before acquisition. Furthermore, one of the researchers controlled vocal productions for each task during both sessions.

Image analysis

CT images were analyzed by a radiologist specializing in head and neck imaging and by two speech-language pathologists specializing in vocology; the *OsiriX* software (version 5.0.2 64-bit, Pixmeo SARL, Bernex, Switzerland.) was used

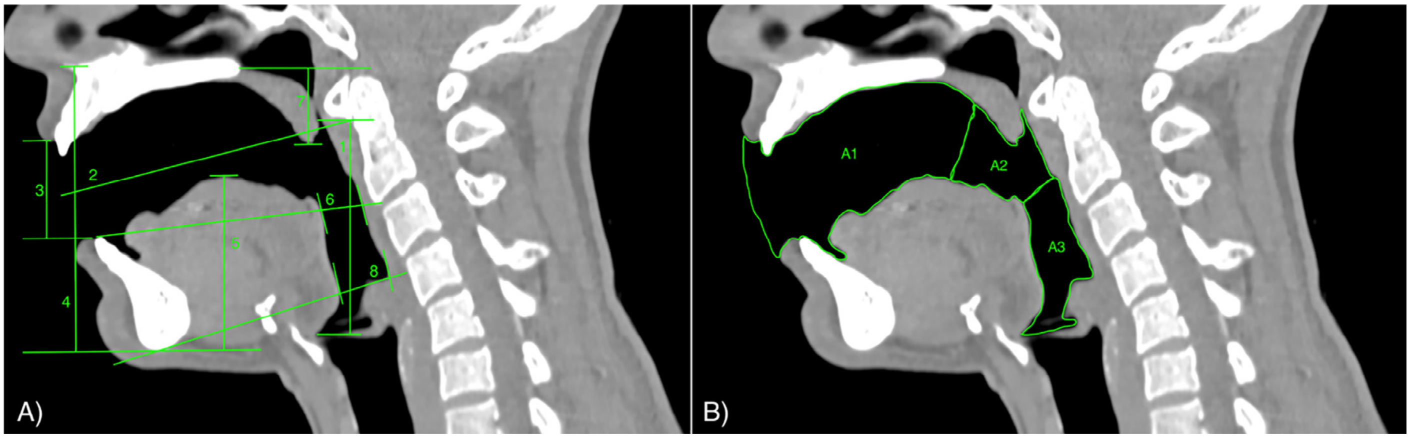

FIGURE 2. (**A**) To the left, measurement of sagittal distances: (1) vertical position of larynx; (2) horizontal length of vocal tract; (3) lip opening; (4) jaw opening; (5) tongue dorsum height; (6) oropharyngeal width; (7) velum elevation; and (8) hypopharyngeal width. (**B**) To the right, measurement of sagittal areas: A1, oral; A2, pharyngeal; and A3, epilaryngeal.

in the image analysis. Vocal tract distances were measured from midsagittal CT images, and cross-sectional areas were measured both from midsagittal and transversal images. Thirteen anatomic measurements were performed: eight distances (millimeters), three cross-sectional areas (square millimeters) on sagittal plane, and two cross-sectional areas on transversal plane (square millimeters). All these variables were based on previous CT[19,20] and MRI[21−25] studies:

a. Anatomic distances (Figure 2A): (1) the vertical length (VL) of the vocal tract (the distance between the lowest point of the odontoid process of the Atlas and the vocal folds, following a vertical line); (2) the horizontal length (HL) of the vocal tract (the distance between the lowest point of the Atlas and the narrowest point between the lips); (3) the lip opening (LO; the distance between the lower edge of the upper lip and the upper edge of the lower lip); 4) the jaw opening (JO; the distance between the lowermost edge of the jawbone contour and the anterior end of the hard palate); (5) tongue dorsum height (TDH; the distance between the lowermost edge of the jaw bone and the uppermost point of the tongue dorsum); (6) oropharynx width (OW; the distance between the lowest point of the second vertebra and the most posterior part of the tongue contour, following a straight line from the anterior uppermost edge of the jawbone contour to the anterior lowest point of the second vertebra); 7) velum elevation (VE; the distance between the posterior end of the hard palate and the anterior lowest point of the uvula); and (8) hypopharynx width (HW; the distance between the lowest point of the pharynx and the internal edge of the epiglottis, following a line from the anterior uppermost edge of the jawbone contour to the lower point of the pharynx).
b. Sagittal cross-sectional areas (Figure 2B): (1) A1—oral cavity (measured from the lips to the velum, up to the line connecting the lowermost edge of the jawbone contour and a break of declivity on the velum surface); (2) A2—the pharyngeal region (measured from the line ending A1, down to the horizontal line connecting the lower edge of the opisthion in the occipital bone, and the lowermost edge of the jawbone contour); and (3) A3—the epilaryngeal region (measured from the line ending A2, down to the vocal folds).
c. Transversal cross-sectional areas (Figure 3): (1) Ap—the inlet of the lower pharynx (the region just above the collar of the epiglottis, following a line just above the tip of arytenoids parallel to the bottom line of the CT image), and (2) Ae—the outlet of the epilaryngeal tube (the region just below the collar of the epiglottis, where the epilarynx and the piriform sinuses form three separate tubes, following a line from the backbone to the jawbone trough the tip of arytenoids, parallel to the bottom line of the CT image).

Given the small number of subjects and the great individual variability in the vocal tract length and configuration possible to find between humans,[26] the data were normalized in order to analyze similarities or differences between measures obtained from the singer and the dysphonic subjects. Sagittal distances were normalized toward the distance between the superior edge of the anterior arch of the first vertebra and the anterior inferior edge of the fifth vertebra of each subject (reference value), whereas sagittal areas were normalized considering the total sagittal area of each subject as the reference value. Normalization was made in order to express each measure as a percentage of the reference value, following the formula 100 x (measure to normalize/reference value). For each measure (sagittal distances and sagittal areas), the average was calculated in order to be compared with each corresponding individual normalized value.

As for transversal areas, the ratio between the inlet of the lower pharynx and the outlet of the epilarynx tube (Ap/Ae) was calculated for each task.

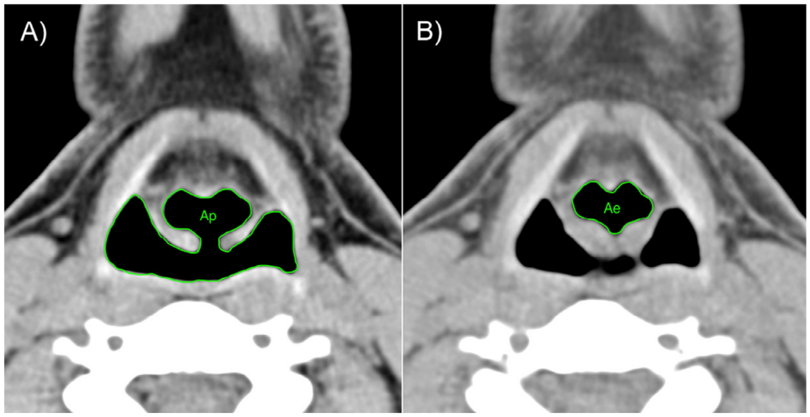

FIGURE 3. Transversal measurement of areas. (**A**) To the left: pharyngeal inlet (Ap). (**B**) To the right: epilaryngeal outlet (*Aditus laryngis*) (Ae).

RESULTS

Table 1 shows mean values and ranges for vocal tract distances and areas measured from the four hyperfunctional subjects (HS) and values obtained from single samples of the singer during speech (SS) and during belting (SB) productions. Table 1 shows that the laryngeal position in the hyperfunctional subjects (mean = 74.53 mm; range = 20.47) was somewhat lower than in the singer during speech (71.90 mm). During belting the singer had a higher laryngeal position than in speech (70.70 mm). No big differences were found either for oropharyngeal width (HS mean = 12.73 mm, range = 11.90; SS = 14.20 mm; SB = 16.50 mm) or for hypopharyngeal width (HS mean = 21.90 mm, range = 5.78; SS = 17.70 mm; SB = 21.20 mm). Other distances were also very similar between dysphonic subjects and belting except for the larger HL of the vocal tract (HS mean = 96.86 mm, range = 8.20; SB = 106.40 mm), wider JO (HS mean = 81.91 mm, range = 6.68; SB = 110.70 mm), and wider LO (HS mean = 9.80 mm, range = 5.84; SB = 39.00 mm) in the singer.

TABLE 1.
Mean Values and Range for Vocal Tract Distances and Areas Measured from the Four Patients, and Values Obtained from Single Samples from the Singer in Speech and in Belting

	Hyperfunctional Patients		Singer	Singer
Distances (mm)	Mean	Range	(Speech)	(Belting)
Vertical length	74.53	20.47	71.90	70.70
Horizontal	96.86	8.20	107.3	106.40
Lip opening	9.80	5.84	30.80	39.00
Jaw opening	81.91	6.68	105.00	110.70
Tongue dorsum height	57.36	22.46	72.80	62.50
Oropharynx width	12.73	11.09	14.20	16.50
Velum elevation	25.31	7.06	31.30	26.80
Hypopharynx width	21.90	5.78	17.70	21.20
Areas (mm^2)				
Ae	1.65	0.91	1.48	1.64
Ap	5.89	2.82	5.01	4.65
A1	12.85	5,89	23.74	30.53
A2	4.52	0.84	6.20	6.87
A3	7.15	4.01	8.79	9.60

Normalized data (Table 2) show similar results related to sagittal distances. To be considered a difference, an individual normalized value had to be higher or lower by at least 1 standard deviation of the mean normalized values of the hyperfunctional subjects. The VL of the vocal tract was found to be smaller for the singer (during speech and in belting) than hyperfunctional subjects, which suggests a slightly higher laryngeal position for the singer. A slightly higher laryngeal position was also observed in belting than in speech. Similar results were observed for hypopharyngeal width. No major differences were found between hyperfunctional subjects and the singer during speech and belting for the HL of the vocal tract, TDH, oropharyngeal width, and VE. LO and JO showed a tendency to be smaller for hyperfunctional subjects and wider for the singer during both speech and belting. Both LO and JO were wider during belting than in speech.

Sagittal cross-sectional areas seemed to be wider for belting than for hyperfunctional subjects (Table 1), such as A1 (HS mean = 12.85 mm^2, range = 5.89; SB = 30.53 mm^2), A2 (HS mean = 4.52 mm^2, range = 0.84; SB = 6.87 mm^2[22]), and A3 (HS mean = 7.15 mm^2, range = 4.01; SB = 9.60 mm^2). However, according to normalized data, only A1 was wider in the singer than in hyperfunctional subjects, whereas A2 and A3 were narrower. Differences found in A1, A2, and A3 were greater during belting (Table 3).

The transversal area of the epilaryngeal outlet (Ae) was similar between all subjects (HS mean = 1.65 mm^2, range = 0.91; SS = 1.48 mm^2; SB = 1.64 mm^2). Similar results were found for the transversal pharyngeal inlet area (Ap) (HS mean = 5.89 mm^2, range = 2.82; SS = 5.01 mm^2; SB = 4.65 mm^2) (Table 1). The Ap/Ae ratio also showed similar results. However, because Ap tended to be slightly smaller for the singer during belting than for speech and for dysphonic patients, the Ap/Ae ratio slightly decreased during belting (HS = 3.59; SS = 3.38; SB = 2.83) (Table 4).

TABLE 2.
Normalized Data for Sagittal Distances From Hyperfunctional Subjects and the Singer During Speech and Belting

	Sagittal Distances (mm)															
	VL		HL		LO		JO		TDH		OW		VE		HW	
Subjects	R (mm)	N (%)	R (mm)	N (%)	R (mm)	N (%)	R (mm)	N (%)	R (mm)	N (%)	R (mm)	N (%)	R (mm)	N (%)	R (mm)	N (%)
HS 1	65.26	69.05*	100.25	106.08	8.40	8.88	78.42	82.98	48.80	51.64*	18.89	19.98*	25.86	27.36	20.88	22.09
HS 2	75.12	90.72	99.80	120.53*	13.36	16.13*	84.38	101.90*	54.27	65.54	11.00	13.28	23.32	28.16	19.27	23.27
HS 3	72.00	83.91	92.05	107.15	9.90	11.52	85.10	99.06	71.26	82.95*	13.22	15.38	29.55	34.40*	25.05	29.16*
HS 4	85.73	88.38	95.32	98.26	7.52	7.75*	79.75	82.21*	55.09	56.79	7.80	8.04*	22.49	23.18*	22.38	23.07
Mean		83.015		108.005		11.07		91.537		64.23		14.17		28.275		24.397
SD		8.42		8.004		3.225		9.002		11.895		4.289		4.010		2.785
SS	71.90	67.38*	107.30	100.56	30.80	28.86*	105.00	98.40	72.80	68.22	14.20	13.30	31.30	29.33	17.70	16.58*
SB	70.70	66.63*	106.40	100.28	39.00	36.75*	110.70	104.33*	62.50	58.90	16.50	15.55	26.80	25.25	21.20	19.98*

Notes: To be considered a difference, the individual normalized value must be higher or lower by at least 1 SD of the normalized values from the hyperfunctional subjects (*).
Abbreviations: HL, horizontal length; HS, hyperfunctional subject; HW, hypopharyngeal width; JO, jaw opening; LO, lip opening; OW, oropharyngeal width; N, normalized values; R, real values; SB, singer in belting; SD, standard deviation; SS, singer in speech; TDH, tongue dorsum height; VE, velum elevation; VL, vertical length.

Figures 4–6 compare the CT registrations obtained from one patient (the most hyperfunctional one) and the singer in speech and in belting. A similar larynx position is noted for both subjects (at the level of the ffith vertebra approximately), slightly higher for the singer during belting compared with speech and hyperfunctional subjects. Similarly, it is possible to observe how the OW and HW were similar between the subjects even though the patient had a slightly smaller OW. The JO and LO, and the HL, were larger for the singer (both in speech and in belting), and consequently also the oral (A1), pharyngeal (A2), and epilaryngeal regions (A3). Figure 5 shows that the pharyngeal inlet (Ap) tended to be smaller in the singer during belting, and similarly also the sinus piriformes. Figure 6 shows no particular differences in the epilaryngeal tube outlet (Ae) between a patient and the singer.

DISCUSSION AND CONCLUSIONS

According to the results, various similarities can be seen between the patients with hyperfunctional dysphonia and the singer while belting. These similarities include high vertical laryngeal position (in the singer of the present study and especially data form other studies concerning hyperfunctional patients), similar oropharyngeal width (distance between the posterior part of the tongue and the back wall of the pharynx) and hypopharyngeal width (distance between the epiglottis and the back wall of the pharynx), small epilaryngeal outlet (A-P or anterior-posterior aryepiglottic constriction), and small pharyngeal inlet. Thus, one may conclude that there were no particular differences between hyperfunctional patients and the singer as it comes to those vocal tract characteristics that have traditionally been considered as signs of vocal hyperfunction.

Regarding vocal tract setting in singers, concordant data were presented by Guzman et al[10] in a study that aimed to assess vocal tract setting through laryngoscopy in a group of healthy CCM singers while singing three different styles (pop, rock, and jazz). All styles showed a narrow aryepiglottic sphincter, constricted pharynx, and a high vertical laryngeal position compared with the resting position and the rock style showing the most prominent changes. The authors concluded that supraglottic activity is a common laryngoscopic feature in CCM singers and it may not necessarily be harmful, but it is a strategy to avoid vocal fold damage. Previously, Borch and Sundberg[27] found a high degree of supraglottic activity, including the aryepiglottic folds, anterior part of the arytenoid mucosa, and ventricular folds, in CCM singers.

As belting is defined as a high-pitched, loud yelling-like singing, it is suitable to speculate that high vocal intensity could contribute to vocal tract setting usually reported during belting (high vertical laryngeal position, narrow epilarynx tube outlet, and constricted pharynx). In fact, earlier studies have reported that vocal intensity is an independent variable affecting vocal tract shape.[10] In a study by Guzman et al,[10] carried out with CCM singers, statistically

TABLE 3.
Normalized Data for Sagittal Areas From Hyperfunctional Subjects and the Singer During Speech and Belting

	Sagittal Areas (mm^2)					
	A1		A2		A3	
Subjects	R (mm^2)	N (%)	R (mm^2)	N (%)	R (mm^2)	N (%)
HS 1	12.92	52.45	4.80	19.48	6.91	28.05
HS 2	16.11	58.53*	4.22	15.33*	7.19	26.12
HS 3	10.22	52.19	4.11	20.99*	5.25	26.81
HS 4	12.14	46.07*	4.95	18.78	9.26	35.14*
Mean		52.31		18.645		29.03
SD		4.406		2.073		3.594
SS	23.74	61.29*	6.20	16.00*	8.79	22.69*
SB	30.53	64.95*	6.87	14.61*	9.60	20.42*

Notes: To be considered a difference, the individual normalized value must be higher or lower by at least 1 SD of the normalized values from the hyperfunctional subjects (*).
Abbreviations: A1, oral cavity; A2, pharyngeal region; A3, epilaryngeal region; HS, hyperfunctional subject; N, normalized values; R, real values; SB, singer in belting; SD, standard deviation; SS, singer in speech.

TABLE 4.
Transversal Areas and Ap/Ae Ratio From Hyperfunctional Subjects and the Singer During Speech and Belting

Transversal Areas (mm^2)			
Subjects	Ap	Ae	Ap/Ae
HS 1	7.39*	2.26*	3.26*
HS 2	5.82	1.43	4.06*
HS 3	4.57*	1.35	3.38
HS 4	5.80	1.57	3.69
Mean	5.89	1.65	3.59
SD	1.00	0.35	0.30
SS	5.01	1.48	3.38
SB	4.65*	1.64	2.83*

Notes: To be considered a difference, the individual normalized value must be higher or lower by at least 1 SD of the mean values from the hyperfunctional subjects (*).
Abbreviations: Ae, outlet of the epilaryngeal tube; Ap, inlet of the lower pharynx; HS, hyperfunctional subject; SB, singer in belting; SD, standard deviation; SS, singer in speech.

significant differences were found for all laryngoscopic parameters between three intensity levels studied. High intensity produced the highest degree of A-P epilaryngeal compression, medial laryngeal compression, and pharyngeal compression.[10] These outcomes are in agreement with those observed by Mayerhoff et al.[14] The degree of both medial and A-P compression of the epilarynx was greater during loud phonation. Likewise, in a study assessing supraglottic configuration in different singing voice qualities, greater A-P epilaryngeal compression was found when subjects performed loud phonation and during the three loudest voice qualities: belting, twang, and opera.[8] Association between vocal loudness and epilaryngeal activity has also been found in vocally trained actors.[28]

As was mentioned before, a small epilaryngeal outlet (Ae) and pharyngeal inlet (Ap) areas were found for hyperfunctional subjects and the singer during belting. However, because Ap tended to be smaller during belting, the Ap/Ae ratio was found to be slightly lower. This configuration is in concordance with other studies related to belting, where a

FIGURE 4. Sagittal images from one male patient with hyperfunctional dysphonia (**A**) and a singer in a speech task (**B**) and in belting (**C**).

FIGURE 5. Pharyngeal inlet (Ap) in a patient with hyperfunctional dysphonia (**A**) and in singer in a speech task (**B**) and in belting (**C**).

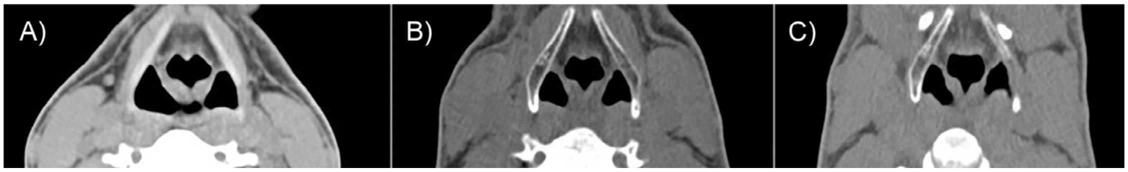

FIGURE 6. Epilaryngeal outlet (Ae) and sinus pyriformis in a patient with hyperfunctional dysphonia (**A**) and in a singer in a speech task (**B**) and in belting (**C**).

narrower pharynx has been found in the context of a stretched epilarynx tube,[9,10] which would contribute to the characteristic metallic and bright voice quality of belting.[9,29,30]

The fact that our patients and the singer showed a similar tendency to a higher laryngeal position should be analyzed carefully. It has been shown previously that there is a great individual variability in the vocal tract length.[26] The four hyperfunctional subjects from the present study showed a VL of the vocal tract between 65.26 and 85.73 mm (mean = 74.53 mm). Also, we compared this mean length with only one vocally normal CCM singer (SS = 71.9 mm; SB = 70.7 mm). Considering the possible individual variability between humans, it would be necessary to count with a larger number of subjects for an accuracy analysis. However, the glottis was located approximately at the level of the fifth vertebra both in the patients and in the singer. According to literature, the rest position of the larynx is between the fourth and sixth vertebra,[31] and the glottis is located between the fifth and sixth vertebra,[32] which may suggest that our patients and the singer showed a normal larynx position during phonation.

It has also been proposed that a higher laryngeal position would be associated with a hyperfunctional dysphonia.[2,3] Nevertheless, it is possible that the mild form of hyperfunctionality that our patients showed may not affect the vertical laryngeal position significantly. In other words, this grade of hyperfunction may not be necessarily characterized by an excessively high vertical laryngeal position. Moreover, there is some evidence that speech type (ie, sustained vowel versus connected speech) may affect the type of voice production and detectability of vocal pathologies.[33−35]

The supine position during CT registration may also affect the results even though earlier results (in normal voiced subjects) have shown that supine and upright positions do not cause any particular differences in the formant frequencies of phonation, which seems to suggest that no remarkable differences exist in vocal tract setting either.[24] However, in an MRI study Traser et al[36] observed some gravitational effects on the vocal tract of untrained subjects during singing. According to their results, the vertical laryngeal position was significantly affected by gravity, resulting in a higher larynx elevation during the supine position than for an upright position. Similar findings were found by Kitamura et al[37] and Traser et al[38] In the same study by Traser et al,[36] it was also reported that the supine position did not significantly affect either the epilaryngeal region or the OW in untrained subjects.

Although several similarities were found when comparing dysphonic subjects and the singer, there were also some differences. The singer had a wider JO and LO (both in speech and in belting, being greater in the latter) and larger volumes of the oral cavity (including larger HL) compared with the patients. Already based on facial expression, it is possible to see the wide JO and LO and a frontal and flat tongue positioning in belting, which has been described to take advantage of a "megaphone shape" of the vocal tract.[39] Classical singers, in turn, tend to use an inverse megaphone shape, characterized by a smaller LO and a wider pharyngeal cavity. The results of the present study are in agreement with an earlier MRI study by Echternach et al,[11] where a greater LO and JO were found in a single female singer during belting compared with head voice production. The differences described are related to such acoustic features found in belting, in which both the fundamental frequency and the second harmonic are located below the first formant.[39]

Because of the small number of subjects, data presented in this study should be interpreted with caution. Also, a limitation of the present study is the fact that no resting situation was assessed during CT (eg, rest expiratory lung volume), which makes it difficult to establish a better comparison due to the individual variability of the vocal tract structures. Finally, on the basis of the vocal tract setting, as such, it is not possible to draw conclusions of how taxing the voice production is in belting compared with hyperfunctional speech. A future study will apply computerized modeling, based on the CT images, to shed light on the vocal tract transfer characteristics. Through this study it might be possible to estimate the voice source needed to establish such an acoustic output as is typically seen and heard in the patients and in belting. This, in addition to further aerodynamic and electroglottographic and inverse filtering results, will give further information on the price of decibels in hyperfunction and belting.

Acknowledgments

The authors thank the participants for their contribution to the study.

REFERENCES

1. Wendler J, Seidner W, Eysholdt U. Chapter: Klinik. In: *Lehrbuch der Phoniatrie*. 4th ed Leipzig: VEB George Thieme; 2005:139–191.
2. Morrison MD. Pattern recognition in muscle misuse voice disorders: how I do it. *J Voice*. 1997;11:108–114.

3. Morrison MD, Rammage LA, Belisle GM, et al. Muscular tension dysphonia. *J Otolaryngol*. 1983;12:302–306.
4. Behrman A, Dahl L, Abramson A, et al. Anterior-posterior and medial compression of the supraglottis: signs of nonorganic dysphonia or normal postures? *J Voice*. 2003;17:403–410.
5. Rubin A, Praneetvatakul V, Gherson S, et al. Laryngeal hyperfunction during whispering: reality or myth? *J Voice*. 2006;20:121–127.
6. Stemple JC, Galze LE, Klaben B. Chapter 4: pathologies of the laryngeal mechanism. *Clinical Voice Pathology: Theory and Management*. 4th ed San Diego, CA: Plural Publishing Inc; 2010:71–112.
7. Jiang JJ, Titze IR. Measurement of vocal fold intraglottal pressure and impact stress. *J Voice*. 1994;8:132–144.
8. Yanagisawa E, Estill J, Kmucha ST, et al. The contribution of aryepiglottic constriction to "ringing" voice quality: a videolaryngoscopic study with acoustic analysis. *J Voice*. 1989;3:342–350.
9. McGlashan J, Thuesen MA, Sadolin C. Overdrive and edge as refiners of "belting". *J Voice*. 2017;31:385 e11-385.e22.
10. Guzman M, Lanas A, Olavarria C, et al. Laryngoscopic and spectral analysis of laryngeal and pharyngeal configuration in non-classical singing styles. *J Voice*. 2015;29:130 e21-28.
11. Echternach M, Popeil L, Traser L, et al. Vocal tract shapes in different singing functions used in musical theater singing—a pilot study. *J Voice*. 2014;28:653 e1-653.e7.
12. Titze I, Story B. Acoustic interactions of the voice source with the lower vocal tract. *J Acoust Soc Am*. 1997;101:2234–2243.
13. Vampola T, Laukkanen A-M, Horacek J, et al. Vocal tract changes caused by phonation into a tube: a case study using computer tomography and finite-element modeling. *J Acoust Soc Am*. 2011;129:310–315.
14. Mayerhoff RM, Guzman M, Jackson-Menaldi C, et al. Analysis of supraglottic activity during vocalization in healthy singers. *Laryngoscope*. 2014;124:504–509.
15. Sundberg J. Articulatory interpretation of the singing formant. *J Acoust Soc Am*. 1974;55:838–844.
16. Cookman S, DeVore K. Inside the Voice, Inside the Scream, Inside the Singing Voice. *Laryngeal teaching series*. Vol. 4. Total Voice Inc; 2006 Compilation of vols. 1−3.
17. Sadolin C. Chapter 2: Vocal modes. *Complete Vocal Technique*. Copenhagen: Shout publishing; 2010:81–157.
18. Sundberg J, Bitelli M, Holmberg A, et al. The "Overdrive" mode in the "Complete Vocal Technique": a preliminary study. *J Voice*. 2017;31:528–535.
19. Guzman M, Miranda G, Olavarria C, et al. Computerized tomography measures during and after artificial lengthening of the vocal tract in subjects with voice disorders. *J Voice*. 2017;31:124 e1-124.e10.
20. Guzman M, Laukkanen AM, Krupa P, et al. Vocal tract and glottal function during and after vocal exercising with resonance tube and straw. *J Voice*. 2013;27:523 e19-523.e34.
21. Echternach M, Sundberg J, Markl M, et al. Professional opera tenors' vocal tract configurations in registers. *Folia Phoniatr Logop*. 2010; 62:278–287.
22. Echternach M, Sundbarg J, Arndt S, et al. Vocal tract in female registers—a dynamic real-time MRI study. *J Voice*. 2010;24:133–139.
23. Echternach M, Traser L, Richter B. Vocal tract configurations in tenors' passaggio in different vowel conditions—a real-time magnetic resonance imaging study. *J Voice*. 2014;28:262 e1-262.e8.
24. Laukkanen AM, Horacek J, Havlik R. Case-study magnetic resonance imaging and acoustic investigation of the effects of vocal warm-up on two voice professionals. *Logoped Phoniatr Vocol*. 2012;37:75–82.
25. Laukkanen A-M, Horacek J, Krupa P, et al. The effect of phonation into a straw on the vocal tract adjustments and formant frequencies. A preliminary MRI study on a single subject completed with acoustic results. *Biomed Signal Process Control*. 2012;7:50–57.
26. Roers F, Mürbe D, Sundberg J. Voice classification and vocal tract of singers: a study of x-ray images and morphology. *J Acoust Soc Am*. 2009;125:503–512.
27. Borch DZ, Sundberg J. Some phonatory and resonatory characteristics of the rock, pop, soul, and Swedish dance band styles of singing. *J Voice*. 2011;25:532–537.
28. Guzman M, Ortega A, Olavarria C, et al. Comparison of supraglottic activity and spectral slope between theater actors and vocally untrained subjects. *J Voice*. 2015;30:767 e1-767.e8.
29. Bestebreurtje ME, Schutte HK. Resonance strategies for the belting style: results of a single female subject study. *J Voice*. 2000;14:194–204.
30. LeBorgne WD, Lee L, Stemple JC, et al. Perceptual findings on the Broadway belt voice. *J Voice*. 2010;24:678–689.
31. Romanes GJ. *Cunningham's textbook of anatomy*. 12th ed Oxford University Press; 1981.
32. KenHub. (n.d). Article—Larynx. [online]. Available at https://www.kenhub.com/en/library/anatomy/larynx. [Accessed 29 December 2017].
33. Wolfe V, Cornell R, Fitch J. Sentence/vowel correlation in the evaluation of dysphonia. *J Voice*. 1995;9:297–303.
34. Zraick RI, Wendel K, Smith-Olinde L. The effect of speaking task on perceptual judgment of the severity of dysphonic voice. *J Voice*. 2005;19:574–581.
35. Parsa V, Jamieson DG. Acoustic discrimination of pathological voice: sustained vowels versus continuous speech. *J Speech Lang Hear Res*. 2001;44:327–339.
36. Traser L, Burdumy M, Ritcher B, et al. Weight-bearing MR imaging as an option in the study of gravitational effects on the vocal tract of untrained subjects in singing phonation. *PLoS ONE*. 2014;9 e112405.
37. Kitamura T, Takemoto H, Honda K, et al. Difference in vocal tract shape between upright and supine postures: observations by an open-type MRI scanner. *Acoust Sci Tech*. 2005;26:465–468.
38. Traser L, Burdumy M, Ritcher B, et al. The effect of supine and upright position on vocal tract configurations during singing—a comparative study in professional tenors. *J Voice*. 2013;27:141–148.
39. Titze IR, Worley AS. Modeling source-filter interaction in belting and high-pitched operatic male singing. *J Acoust Soc Am*. 2009;126:1530–1540.