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The morphometry of the laryngeal phonatory system – base of the anatomical study of the voice aptitudes

MARIUS VALERIU HÎNGANU[1)], ROMICĂ SEBASTIAN COZMA[2)], PAULA CIOCHINĂ[3)], IRINA-ANDREEA SCUTARIU[4)], CRISTINA ASIMIONOAIEI-SIMIONESCU[3)], DELIA HÎNGANU[1)]

[1)] *Department of Morpho-Functional Sciences I, Faculty of Medicine, "Grigore T. Popa" University of Medicine and Pharmacy, Iaşi, Romania*

[2)] *Department of Otorhinolaryngology, Faculty of Medicine, "Grigore T. Popa" University of Medicine and Pharmacy, Iaşi, Romania*

[3)] *2nd Department Wind Instruments Percution and Singing, Faculty of Performance, Composition and Music Theory Studies, "George Enescu" University of Arts, Iaşi, Romania*

[4)] *4th Department, Faculty of Theatre, "George Enescu" University of Arts, Iaşi, Romania*

Abstract

Speaking is one of the characteristics of the human race and the main factor that has marked our progress over time. The singing voice is the crowning of the speech act and the main component of the lyrical manifestation of personality. Doctors in various fields, but especially anatomists have been concerned about discovering how the voice and the substrate of its variability are formed, but these aspects have not yet been fully deciphered. This study is the starting point in our research on the phonation system, organized on three levels: laryngeal, oral, palatinal, pharyngeal, epiglottal and nasal. We performed the dissection of seven embalmed anatomical parts, on which, we made measurements of the anatomical elements involved in the phonation. We performed the same measurements on a batch of seven adults investigated by magnetic resonance imaging (MRI). The results were entered into the statistical calculation formulas and compared with each other and with the literature. The results of the study show that certain values resulting from the calculation formulas remain constant and others vary greatly from each individuals and gender.

***Keywords*:** phonation, singing voice, laryngeal system, morphometry.

Introduction

Speaking characterizes the human race and explains the possibility of communication and transmission of information presented in most people. The singing voice is the artistic form of speech and a peculiarity of individual expression. This is addressed to 'talented' people who can do it in a pleasant way for the general public. This study is intended to be the beginning of a research of this type of talent and a modality of qualitative and quantitative appreciation of it. The origin of the sound is found at the specialized structures of the laryngeal glottal floor. The fundamental frequency of a voice is conditioned, first of all, by the individual anatomical features of the phonator laryngeal system. In this study, we highlighted the anatomical variations, but also the constants of the laryngeal phonator system by using modern imaging methods.

Communication is an essential process of maintaining human relations, being the foundation of social organization. The branch of medicine dealing with the study of voice, illness and voice disorders is phoniatry. The *European Union of Medical Specialists* (UEMS) classified it, in 2010, as one of the seven subspecialties of otorhinolaryngology [1].

Phonation requires precise coordination of breathing, control of the specialized laryngeal structures involved in this process, as well as a control regarding the positioning of the tongue, lips and mandible [2].

Speech is based on the formation of complex sounds, a combination of fundamental sound and a rich system of harmonics [3].

The main objectives of our study are:

- identification of a spectrum of anatomical variations of the laryngeal phonator system from different individuals;
- the relation between the anatomical structures and their morphometry on the fundamental frequency of the voice;
- highlighting the particularities of the structures responsible for the mechanism of laryngeal sound production.

The first step in this direction is exploring the laryngeal floor of the phonator system.

Materials and Methods

The study was conducted on a number of seven anatomical parts preserved by formolization, at the "Ion Iancu" Institute of Anatomy of the "Grigore T. Popa" University of Medicine and Pharmacy, Iaşi, Romania. On a group of seven adults, the laryngoscopical examination was first performed. We followed the macroscopic appearance of the larynx and the dynamics of the vocal cords, in order to exclude the persons with associated pathology of phonator apparatus. The subjects stated that they do not know having a laryngeal pathology and do not accuse dysphonia or other voice changes. At the same time, they

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deny smoking, a habit that affects the larynx, influencing the results. In the second step, accurate measurements were performed on magnetic resonance imaging (MRI) images, which were used in different formulas.

We dissected and highlighted the cartilaginous, muscular, and ligamentous structures of the larynx, then we made measurements at this level. The values obtained were used in statistical calculation formulas.

In the macroscopic, clinical and radiological anatomy study, a statistic was performed by using the metric values of the laryngeal ligamentous apparatus involved in the phonation and the volumetric values of the infraglottal filter (volume of the infraglottal floor).

Results

Measurements were made on: DAP: Anteroposterior diameter of glottis; GMD: Glottal maximum diameter; VCL: Vocal cords length before and after mucosal removal; DC: Maximum distance between vocal cords; ITL: Interarytenoidian distance. HIG: Height of infraglottal floor; VIG: Volume of infraglottal floor, and MIG: The length between the voice processes (Figures 1–4) on anatomical specimens and also on MRI images (Figures 5 and 6).

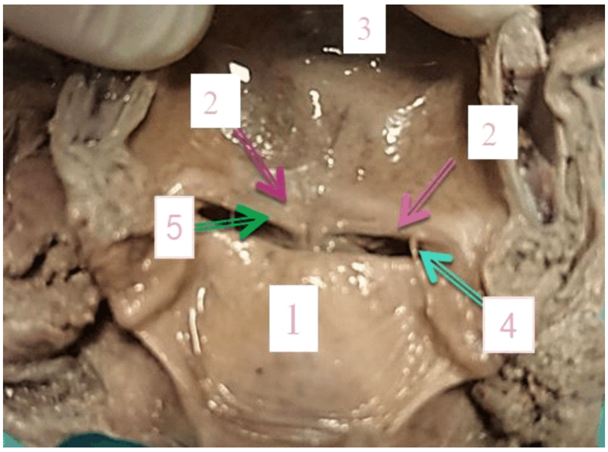

Figure 1 – ***Dissection piece. 1: Supraglottal floor; 2: True vocal folds; 3: Infraglottal floor; 4: False vocal folds; 5: Laryngeal vestibule.***

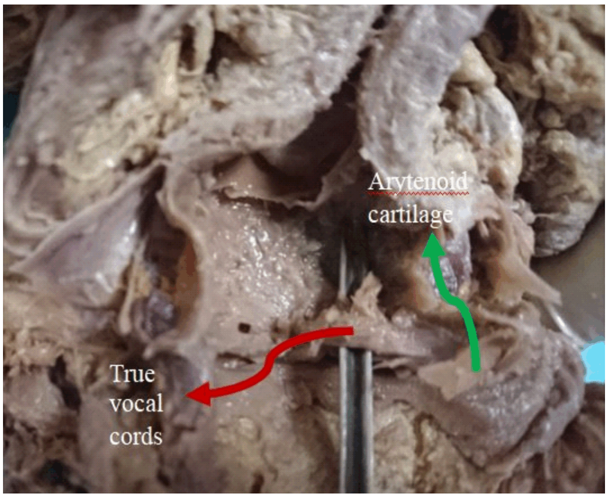

Figure 2 – ***With red arrow, true vocal cords; with green arrow, arytenoid cartilage.***

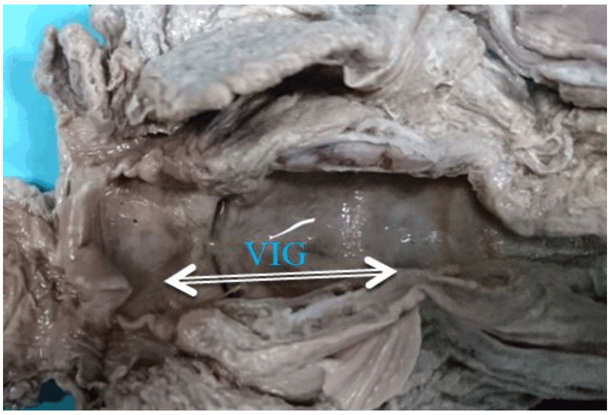

Figure 3 – ***Dissection specimen: measurement of infraglottal volume.***

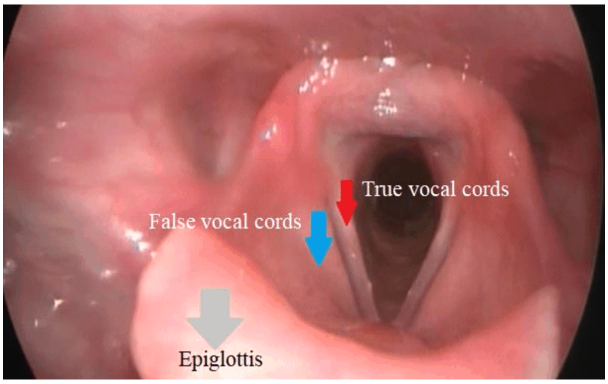

Figure 4 – ***Laryngoscopic examination: normal, no pathological changes.***

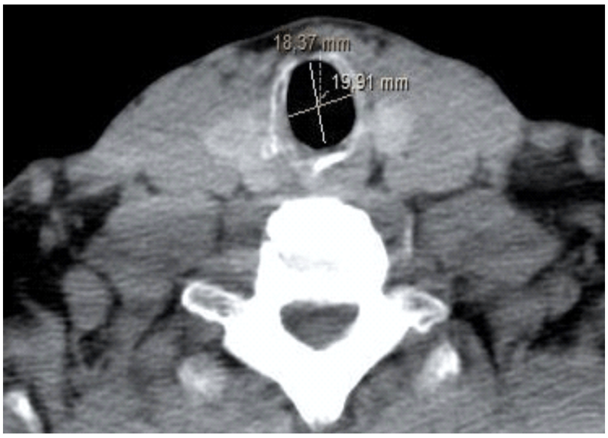

Figure 5 – ***Forced exhale: vocal cords are getting closer and arytenoid cartilage can be recognized. MRI image.***

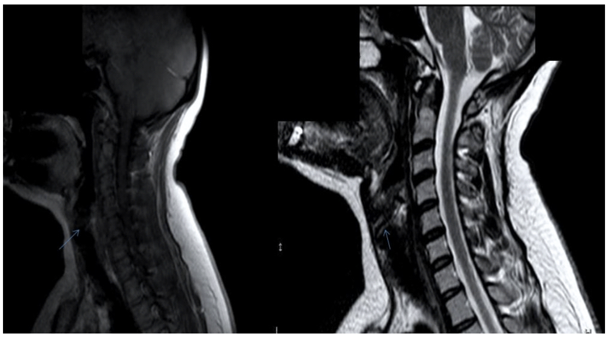

Figure 6 – ***MRI highlighting of false vocal cords (left) and true vocal cords (right).***

Taking as a reference the average size measured for each structure, we obtained different variations, which for a better understanding we expressed as a percentage.

For measurements on dissection specimens, the DC/VCL ratio has an average value of 2.53 with a variation range of 24.05%. DAP/VCL has an average value of 2.4, with a variation of 11.27%. DAP/ITL has an average of 2.4 and a variation range of 6.4%.

Between male and female gender, the highest morphometric differences were found in the VIG (20%), HIG (50%) and the GMD/HIG (3.2%).

The same measurements made by the imaging technique are shown in Tables 1 and 2.

Table 1 – *The results of the measurements on MRI images*

Measured parameters	Female subjects		Male subjects	
VCL (lengths of vocal cords) [cm]	*Right* 1.49 ±0.11	*Left* 1.46 ±0.07	*Right* 1.68 ±0.08	*Left* 1.64 ±0.1
GCV (thickness of vocal cords) [cm]	*Right* 0.866 ±0.29	*Left* 0.867 ±0.23	*Right* 0.897 ±0.46	*Left* 0.804 ±0.11
HVC (height of vocal cords) [cm]	*Right* 0.5 ±0.32	*Left* 0.502 ±0.28	*Right* 0.735 ±0.32	*Left* 0.608 ±0.45
DAT (arytenoid diameter) [cm]	*Right* 0.346 ±0.14	*Left* 0.307 ±0.23	*Right* 0.62 ±0.4	*Left* 0.69 ±0.65
DAP/GMD (anterior-posterior glottal diameter) [cm]	1.863±1.5		2.55±4.33	
ITL (interarytenoidian distance) [cm]	1.64±0.67		1.33±0.98	
MIG (the length of voice processes) [cm]	1.114±0.84		0.99±1.05	
Cricoid ring diameter [cm]	1.47±1.19		1.99±1.23	
HI (height of infraglottal floor) [cm]	0.996±0.12		1.24±0.85	
Volume of infraglottal floor [mL]	0.988±0.54		1.167±0.8	

Table 2 – *The results of the measurements on MRI images*

Ratios	Female subjects	Male subjects
VCL/ITL	0.9	0.125
VCL/VIG	0.014	0.0014
DAP/VCL	1.25	0.154
DAP/ITL	1.13	0.149
GMD/MIG	1.67	2.31
GMD/VIG	0.018	0.016

The ratios obtained between these values are as follows: LCV/VIG=10.48–19.1%; DAP/VCL=4.16–9.38%; DAP/ITL=8.34–12.16%; VCL/VIG=1.9–27.27%; DAP/VCL=9.09–11.03%; DAP/ITL=10.49–13.37%; VCL/ITL=12.3–16.29%; GMD/MIG=15.91–30.92%; GMD/VIG=12.72–25.04%; VCL/ITL=16.8–29.6%; GMD/MIG=12.12–67.09%; GMD/VIG=6.25–31.25%.

Relatively constant ratios between vocal folds and interarytenoid distance, as well as between vocal folds and the maximum opening of vocal processes demonstrate that at the glottis level the measured dimensions increase directly proportional.

A large interarytenoid distance results in longer vocal folds and a larger antero-posterior glottal diameter.

These findings indicate a complete functional specialization of the glottal structures, from the phonatory point of view.

We have obtained ratios whose results are significantly higher than average, such as VCL/VIG, with a variation of up to 131.57%, where we have a VCL of about 3 cm, given by the fact that the female VCL is about 1.1–1.5 cm. In this case, an inverse proportional variation is observed, as the VCL increases, the VIG decreases, so the amplitude of a sound is not given by VCL, but by its tension.

The GMD/VIG ratio also has high variations of up to 121.42%, but due to the increased VIG. VIG gives us a certain amount of air that we can release gradually or not during phonation, and the bigger it is, the lower is the voice quality – especially for singers. Narrow GMD and a small VCL determine the production of a sound with acute, high, timbre, characteristic of female gender.

A large GMD and an increase in LCV characterize male gender with baritone voice production and the fundamental frequency decreases.

The phonatory adaptation of the glottis is different from that of the height and volume of the infraglottal floor. This can influence the harmonic vibrations of a certain fundamental frequency with a constant infraglottal pressure.

Infraglottal pressure has a modulating role in voice timbre (it influences the pharyngeal-buccal harmonic of the voice) and depends on the infraglottal volume and the type of breathing.

An increased infraglottal volume can be compensated by adequate respiration.

As a result of the measurements, there was a greater variation in a set of ratios. Therefore, there is an inversely proportional relationship between the parameters of each increased ratio. Those values with a variation of less than 5% suggest a direct proportionality relationship (Figure 7).

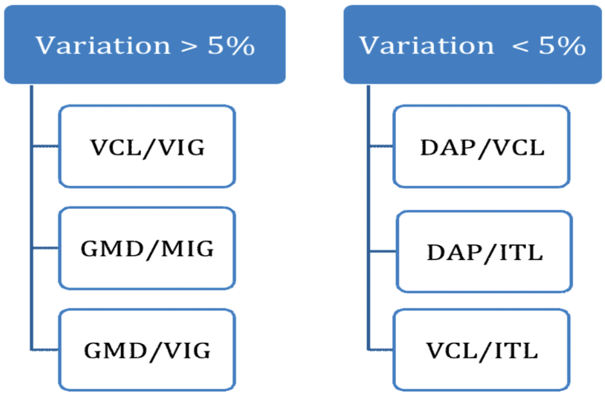

Figure 7 – *Values with a variation of less than 5%.*

The results obtained were compared with the results of similar measurements made on embalmed pieces. The ratios where major numerical differences were reported are:

- VCL/VIG (18.42–131.57%) – this difference is mainly based on the existence of 3 cm of vocal cords at the level of an embalmed piece;
- GMD/VIG (28.57–121.42%) – the percentage varies due to the high value of VIG (9.55), which may indirectly indicate an anomaly of the phonator apparatus or the fact that the piece belonged to a person which performed in musical field (increased infraglottal volume allows to maintain musical effort).

This study highlighted the fact that the fundamental frequency is governed by many parameters that can be studied and reported in various forms. These fractions are aimed at identifying constant or non-constant parameters from physiological point of view, with conclusions being drawn from current anatomical functional knowledge. Also, the morphometric study of the normal phonator system is important for differentiation from the pathology associated with it.

Discussion

"Sounds are perceived as human vocalizations when they are produced by a vocal system that follows the simple relationship between the size of the vocal folds and vocal tracts. We have found that these anatomical parameters encode the perceptual vocal identity (man, woman, child) and show that brain areas that respond to human speech also encode vocal identity" [4].

The data collected by direct laryngeal morphometry on dissected pieces are very close to those in the literature [5–7] and confirm the substrate of the fundamental differences between the two genders regarding the particularities of phonation in adults.

The literature describes three major vocal subsystems that interact with each other: non-linear source-filter interactions, airflow control by glottal adduction, and tracheal-induced vocal tract elongation [8]. The three vocal formants are the infraglottal filter that determines the amount and pressure of the air column coming from the lungs, the glottal floor of the larynx that produces what is called the fundamental frequency of the voice, and the ensemble formed by the supraglottal, oro-velo-pharyngeal and nasal formations, which modulates the voice [9–12].

Measurements performed on MRI images are also very close to those obtained by direct measurements and in accordance with literature data [13–15]. However, we have not found in the literature another study to correlate the values obtained from these measurements (direct and imaging) and to produce statistical formulas based on these.

The ratios that we made characterize the so-called vocal quality (a parameter studied in phoniatry, which involves voice control, being defined by a number of factors: vocal cord configuration, laryngeal anatomy, voice control capability. VCL/VIG is highly varied. So, VCL varies inversely proportional with VIG. An increased infraglottal volume is associated with a low vocal cord length, in order to allow the support of the vocal cords vibration, in a single expiration, during the phonation or during the musical act [16, 17].

GMD/MIG – there is a relationship of inverse proportionality between the two parameters, both anatomically (the vocal processes have an internal oblique distribution, the distance between them *versus* the maximum diameter of the glottis being lower), and functionally. The distance between the vocal processes, the vocal muscles, can be controlled in the idea of producing and supporting notes of low or high intensity. GMD/VIG – the infraglottal volume value is increased, as compared to the maximum glottal diameter, to allow the passage of fragmented air through the glottal slit in a single expiration. DAP/VCL-DAP is directly proportional to VCL.

The dynamics of the vocal cords follow the anterior-posterior diameter of the glottal slit, these two laryngeal components functioning in harmony for the adduction, respectively the abduction of the vocal cords. DAP/ITL, VCL/ITL – the distance between the vocal processes of the arytenoid cartilage and the anterior-posterior diameter must be symmetrical for aligning the midline of the vocal cords and for completing the phoning process. Increasing the length of the interarytenoid distance is associated with an increase in DAP and VCL, respectively, to maintain a phonator or musical effort.

Conclusions

The quality (amplitude and penetrance) and the timbre of a voice vary inversely with the dimensions of the vocal cords and GMD. Their low values are characterized by an acute timbre, and their high values by a gravely timbre. The laryngeal filter, the infraglottal floor, and the sphincter of true vocal folds are responsible for the fundamental frequency with which a sound is produced. We will be able to use these formulas on patients for an indirectly determining of the fundamental frequency of voice in those individuals. The obtained statistical results encourage us to believe that we have laid the foundations for creating an imaging protocol by which we can determine the characteristics of the fundamental frequency of an individual. Quantification of the anatomical variations of the phonator system is essential in understanding the personality of an individual. Its morphometry is the starting point for studying the harmonic capacities of each individual's voice.

Conflict of interests

The authors declare that they have no conflict of interests.

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Corresponding author
Romică Sebastian Cozma, Lecturer, MD, PhD, Department of Otorhinolaryngology, Faculty of Medicine, "Grigore T. Popa" University of Medicine and Pharmacy, 16 University Street, 700115 Iaşi, Romania; Phone +40748–167 030, e-mail: scozma2005@yahoo.com

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