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## Correlations between oropharyngeal and laryngeal anatomy and the frequency of singing voice: A population-based study, in Greece

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### Abstract

The aim of this study is to explore if there is correlation between the typical voice classification and oropharyngeal anatomy, using cervical posterior-anterior radiography on professional singers in Epirus, Greece. Methods: 70 professional singers, 35 men and 35 women, were recruited for this study. All participants underwent a cervical posterior-anterior radiographic imaging of their oral pharyngeal and laryngeal area. Results: A statistically significant difference of mean distance was observed for the CI-MHP area ( $p=0,004$ ), the MHP- SCV area ( $F=2,62$ ,  $p=0,032$ ), as well as SCV-AI area ( $F=11,82$ ,  $p=0,000$ ). For the average length measured in mm of the phonetic area PA, statistically significant differences were computed among all the singers in the group ( $F [5] = 5.368$ ,  $p = 0.001$ ), as well as the OPC area ( $F = 6,48$ ,  $p = 0,000$ ). Conclusions: The cervical posteroanterior radiography provided new correlations of the voice category of professional singers with their Oropharyngeal and Laryngeal Anatomy.

**Keywords:** Voice; Cervical radiography; Professional singers; Greece; Laryngeal anatomy

### 1. Introduction

The larynx is a resistant segment of the respiratory tract and plays a vital role allowing the passage of air from the upper to the lower respiratory system. The larynx also receives attention because is the most sensitive and expressive component of the vocal mechanism [1]. The vocal system consists of the bellows or lungs, the vibrating organ or larynx, and the resonating cavities of the head and neck [2-5]. In voice production, both the internal and external mechanism of the larynx are involved and influenced by many functions, that shape the final sound effect. Except larynx, the final voice production is affected by many other factors, such as hormonal changes, age, gender differences, body size, anatomical structures of the larynx and psychological conditions. All these factors play important role in shaping the final "phenotype" of the voice [6-10]. Singing voice, as well as the voice of speech is considered a type of human expression and a complicated procedure that can be influenced by physical, psychological, environmental, social and cultural factors [11-15]. Several researchers have attempted to quantify the conditions that influence the production of singing voice [16, 17]. Most of the studies correlate the classical singing voice with body type, claiming that low-tone voices, such as basso singers, tend to match with taller people, while high-tone voices, such as tenor and soprano,

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correlate with shorter people [18]. Furthermore, many studies have suggested that there is a relationship between laryngeal anatomical parts and qualitative vocal characteristics, as they are observed through special imaging techniques [19-25].

When the vocal coach classify professional singers into groups, takes into account several parameters. The most important vocal characteristic is the vocal tone and its frequency while singing, both in male and female singers. This usually reaches two octaves, rarely extending to three or more. In accordance with the above, male and female singers have been categorized into the following groups, based on the classical voice classification: soprano, mezzo-soprano, contralto, tenor, baritone and bass [23, 26-32]. Exarchakos in his work, suggested a way to determine the oropharyngeal and laryngeal anatomy, measuring the distances between the structures involved in the procedure of singing. These distances extend from the cervical incisor to the medulla of the hard palate (CI-MHP), from the medulla of the hard palate to the second cervical vertebra (MHP-SCV) and from the second cervical vertebra to the anterior incision (SCV-AI) [23, 33].

Considering the above, the purpose of this study is to provide evidence, using cervical posteroanterior radiography, that there is a good correlation between the voice classification of professional singers and their oral pharyngeal and laryngeal anatomy. Our aim is to analyze and compare the results of our research with the results of a previous research, so to end up in useful conclusions [34].

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## 2. Material and methods

### 2.1. Participants

Seventy (70) healthy singers (male: 35; female: 35), aged from 18 to 70, were included in this study. All of the participants were professional singers that practice voice in specialized centers, in Ioannina, Greece. 16 of the 35 male singers were classified into the voice category basso, 11 were classified as baritones and 8 male singers were tenors. Likewise, the thirty-five females were classified as: 1) 7 contraltos, 2) 12 mezzo-sopranos and 3) 16 sopranos. An experienced vocal coach classified the professional singers into groups. We used specific included and excluded criteria to determine the final sample. Singers with a medical history of head and neck surgery, voice disorders in the past or neck radiation, singers who take drugs, drink alcohol or smoke were excluded from the study. Additionally, who had presented during the previous weeks laryngeal/vocal complaints, symptoms of gastro re-flux (GERD), or laryngopharyngeal reflux (LRP) disease, were excluded this study [35-46]. Female participants that were pregnant were not included in the study, because their receiving any radioactive substance would have been impermissible [47, 48]. The above data were obtained through a specific history form used in the ENT clinic of our hospital. This study was approved by the Ethical Committee of the Medical School, University of Ioannina.

### 2.2. Collection of Data

The sample was evaluated at the ENT clinic of our hospital. Each subject was informed of the research purposes and gave their written consent. For each participant, a cervical posteroanterior radiography was performed.

### 2.3. Cervical Posteroanterior Radiography

Cervical Posteroanterior Radiography is in fact a lateral cervical radiography in a posteroanterior (PA) position. This imaging method was first used as chest radiography for pulmonary diseases. In order to achieve the lateral cervical radiography in (PA) position, we collaborated with a specialist from the radiology department of our hospital. The X-ray results were performed in the radiological laboratory of our hospital. X-ray contrast agent was not used, according to the standard protocol procedure. Women were allowed to participate in the X-ray examination only after a negative urine pregnancy test [49-52].

As proposed to the literature, in order to achieve this imaging technique, each participant was positioned 180 - 200 cm away from the image receptors, erect and with a head inclination of 14°. During the imaging procedure, the singer was again asked to open the mouth and were sat in a neutral position, with head straight. We strictly excluded any participants who did not fulfill the anatomic criteria. The head position, as well as the object position, in this technique does not change the image contouring. As the radiation dose is much lower than that of the standard AR projection in cervical radiography, PA projection was preferred to the traditional anteroposterior (AP) radiogram [49-54].

The measurements were obtained by extending a line drawn along the cervical incisor to the medulla of the hard palate (CI-MHP), from the medulla of the hard palate to the second cervical vertebra (MHP-SCV) and from the second cervical vertebra to the anterior incision (SCV-AI). We measured the phonetic area (PA), which was the sum of all distances, CI-

MHP, the MHP- SCV and the SCV-AI (PA = CI-MHP + MHP-SCV + SCV-AI), as well as the oral-pharyngeal cavity [OPC] distance, which shows the mean length of the oral-pharyngeal cavity (OPC = CI-MHP + MHP-SCV). X-rays with foreign bodies, false positive findings, calcifications and/or soft tissue and osseous masses were excluded from our study. The above-mentioned dimensions were measured using electronic tools provided by the IMPAX program.

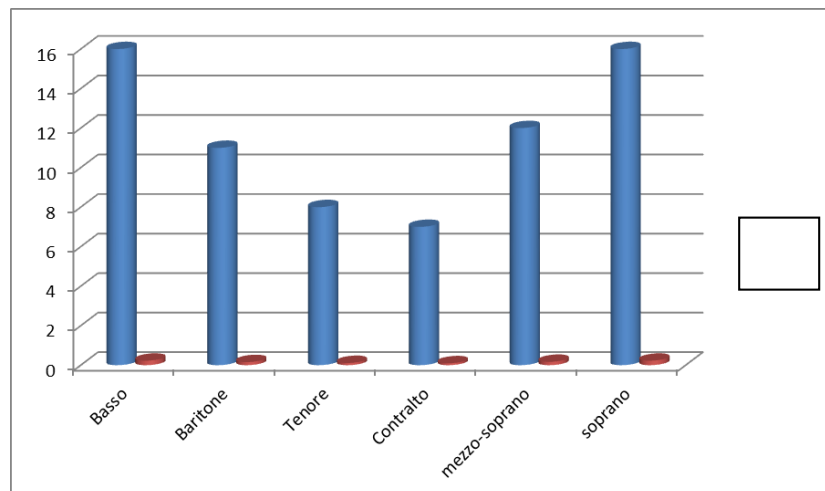
Although MRI technique could probably offer more precise data, we found the limitations of this technique stronger than its efficacy. Firstly, because of the deficient equipment, we did not have easy access to this technique in our hospital. Secondly, MRI excludes participants who are anxious, claustrophobic or are overweight, people with metal in their body, kidney or liver diseases. Finally, MRI scans need much time and cost more than other imaging tests such as a CT scan or X-ray. These were the stronger reasons to choose the x-ray instead of the MRI technique [55-57].

## 2.4. Statistical Analysis

The distribution of variables was tested using the Kolmogorov-Smirnov and Shapiro-Wilk tests. All skewed variables are expressed as the medians and the interquartile range, and all normally distributed variables are expressed as the means and standard deviations (SD). A repeated measures ANOVA model was used for the comparison of the study groups and the Cervical Posteroanterior Radiography findings. Additionally, ETA statistics were calculated. The Pearson rank correlation coefficient was used to correlate the vocal category of the participants with the PA and OPC. All reported p-values were two-tailed, and the statistical significance was set at the value of  $p < 0.05$ . The analysis was performed with SPSS statistical software (19.0, Armonk, NY, USA).

## 3. Results

Through the examination of gender percentages, the participants are divided into: 50% men (35 men) and 50% women (35 women). Regarding the voice category to which the participants belong, the analysis showed that 16 singers (22.9%) belong in the bass category, 11 singers (15.7%) are baritones and 8 (11.4%) are tenors. 7 singers [10%] are contralto, 12 (17.1%) are mezzo-soprano and 16 singers (22.9%) are soprano (Figure 1). The mean age of the total sample was 38.64 years (SD= 16.52). The mean age of males at 36.51 (SD = 14.34) and the mean age of females at 40.77 years (SD = 18.41). The mean height of the total sample was 1.73 meters (SD = 0.08). The mean height of male singers was 1.76 (SD = 0.06) and for females was 1.70 SD = 0.08]. The mean body weight of the total sample was 72.46 kg (SD = 10.88) with male mean body weight of 76.71 (SD = 9.96) and female mean body weight 68.20 kg (SD = 10.19). The mean years of vocal training for the total sample was 9.26 years (SD = 7.13) with mean male vocal training at 9.63 (SD = 7.74) and female mean vocal training at 8.89 years (SD = 6.95) (Table 1).



**Figure 1** Diagram with the number and percentage of participants, based on the voice category. X-axis: voice category (male and female), Y-axis: number and percentage of participants

As regards the comparison of the mean distances in millimeters for the CI-MHP among all singers in the group, a statistically significant difference was observed ( $p=0,004$ ). Statistically significant difference of mean distances for the MHP- SCV was calculated ( $F=2,62$ ,  $p=0,032$ ) among all the singers in the group. Likewise, statistically significant differences was observed among all the singing groups for the SCV-AI ( $F=11,82$ ,  $p=0,000$ ). For the average length measured in mm of the phonetic area PA, statistically significant differences were computed among all the singers in

the group ( $F(5) = 5.368, p = 0.001$ ). Statistically significant differences were also observed in the average distance which represents the mean length of the OPC for all the singers in the group ( $F = 6,48, p = 0,000$ ) [Table 2].

**Table 1** Mean values and Standard Deviation [ S.D.] of the variables; age, weight, height, years of vocal training, both in male and female singers

	<b>Sample N= 70</b>	<b>Male N= 35</b>	<b>Female N= 35</b>
Age [years], Mean [S.D.]	38.64 [16.52]	36.51 [14.34]	40.77 [18.41]
Weight [kg], Mean [S.D.]	72.46 [10.88]	76.71 [9.96]	68.20 [10.19]
Height [m], Mean [S.D.]	1.73 [0.08]	1.76 [0.06]	1.70 [0.08]
Years of vocal training, Mean [S.D.]	9.26 [7.13]	9.63 [7.74]	8.89 [6.95]

**Table 2** Comparison of mean distances using cervical posteroanterior radiography among all singers

	<b>CI-MHP</b>	<b>MHP-SCV</b>	<b>SCV-AI</b>	<b>PA</b>	<b>OPC</b>
	<b>Mean [S.D.]</b>	<b>Mean [S.D.]</b>	<b>Mean [S.D.]</b>	<b>Mean [S.D.]</b>	<b>Mean [S.D.]</b>
Bass	57.50 [9.07]	95.98 [11.31]	85.53 [11.28]	239.02 [12.36]	153.48 [10.88]
Baritone	51.10 [5.14]	89.13 [7.97]	73.01 [8.40]	213.44 [3.99]	140.42 [7.68]
Tenor	49.05 [8.66]	85.97 [7.76]	62.91 [17.02]	197.93 [19.53]	135.02 [1378]
Contralto	55.94 [10.04]	85.78 [6.93]	72.51 [6,97]	220.12 [13.04]	147.61 [18.35]
Mezzo-soprano	47.47 [4.02]	87.16 [9.88]	69.70 [7.68]	204.35 [9.06]	134.64 [8.28]
Soprano	48.52 [4.86]	85.66 [9.86]	57.42 [11.21]	191.61 [10.21]	134.19 [11.36]
<i>F</i>		2.62	11.82		6.48
p-level	0.004	0.032	0.000	0.000	0.000

**Table 3** Comparison of mean distances using cervical posteroanterior radiography among all singers

	<b>CI-MHP</b>	<b>MHO-SCV</b>	<b>SCV-AI</b>	<b>PA</b>	<b>OPC</b>
	<b>Mean [S.D.]</b>	<b>Mean [S.D.]</b>	<b>Mean [S.D.]</b>	<b>Mean [S.D.]</b>	<b>Mean [S.D.]</b>
Bass	57.50 [9.07]	95.98 [11,31]	85.53 [11.28]	239.02 [12.36]	153.48 [10.88]
Baritone	51.10 [5.14]	89.13 [7.97]	73.01 [8.40]	213.44 [3.99]	140.42 [7.68]
Tenore	49.05 [8.66]	85.97 [7.76]	62.91 [17.02]	197.93 [19.53]	135.02 [13.78]
<i>F</i>		3.32	10.04	31.43	9.41
p-level	0.042	0.049	0.000	0.000	0.001

Specifically, it was controlled if there were differences between bass, baritone, tenor and between contralto, mezzo-soprano and soprano. Statistically significant differences was observed in the mean distance in millimeters of the CI-MHP area ( $p=0,042$ ), with the difference between the bass and the tenore ( $p= 0,023$ ). Statistically significant difference also observed for the mean distance of the MHP-SCV area ( $F=3,32, p=0,049$ ). The mean distance of the area SCV-AI was statistically significant different ( $F=10,04, p = .0,000$ ) and the difference was between bass and baritone ( $p = 0,042$ ) and between bass and tenore ( $p =0,001$ ). It was also calculated statistically significant difference for the mean length measured in mm of the PA area ( $F = 31,43, p = 0,000$ ) with the difference found between bass and baritone ( $p = 0,000$ ),

between bass and tenore ( $p = 0,000$ ) and between baritone and tenore ( $p = 0,043$ ). Statistically significant differences were observed between the mean distance of the OPC area ( $F = 9,41$ ,  $p = 0,000$ ) the difference between bass and baritone ( $p = 0,015$ ) and between bass and tenore ( $p = 0,002$ ) (Table 3-4).

**Table 4** Comparison between the category's bass, baritone and tenore

	Voice category	Voice category	p-level
CI-MHP	Bass	Baritone	0.065
		Tenore	0.023
	Baritone	Bass	0.065
		Tenore	0.576
	Tenore	Bass	0.023
		Baritone	0.576
MHP-SCV	Bass	Baritone	0.226
		Tenore	0.071
	Baritone	Bass	0.226
		Tenore	0.759
	Tenore	Bass	0.071
		Baritone	0.759
SCV-AI	Bass	Baritone	0.042
		Tenore	0.001
	Baritone	Bass	0.042
		Tenore	0.212
	Tenore	Bass	0.001
		Baritone	0.212
PA	Bass	Baritone	0.000
		Tenore	0.000
	Baritone	Bass	0.000
		Tenore	0.043
	Tenore	Bass	0.000
		Baritone	0.043
OPC	Bass	Baritone	0.015
		Tenore	0.002
	Baritone	Bass	0.015
		Tenore	0.563
	Tenore	Bass	0.002
		Baritone	0.563

A statistical analysis was also prepared for the female singers. Non- statistically significant difference was observed for the mean distance in mm of the CI-MHP area ( $p = 0,112$ ) and the mean distance of the MHP-SCV ( $F = 0,128$ ,  $p = 0,880$ ). The mean distance of the area SCV-AI is statistically significant different ( $F = 8,89$ ,  $p = .0,001$ ) with the difference between contralto and soprano ( $p = 0,005$ ) and between mezzo-soprano and soprano ( $p = 0,007$ ). About the mean length of the area PA, measured in mm, was observed statistically significant difference ( $p = 0,000$ ) with the difference between contralto and soprano ( $p = 0,000$ ) and mezzo-soprano and soprano ( $p = 0,026$ ). Non statistically significant differences were observed between the mean distance of the OPC area ( $F = 3,28$ ,  $p = 0,051$ ) (Table 4-5).

**Table 5** Comparison between the categories contralto, mezzo-soprano and soprano

	CI-MHP	MHP-SCV	SCV-AI	PA	OPC
	Mean [S.D.]	Mean [S.D.]	Mean [S.D.]	Mean [S.D.]	Mean [S.D.]
Contralto	55.94 [10.04]	85.78 [6.93]	72.51 [6.97]	220.12 [13.04]	147.61 [18.35]
Mezzo-soprano	47.47 [4.02]	87.16 [9.88]	69.70 [7.68]	204.35 [9.06]	134.64 [8.28]
Soprano	48.52 [4.86]	85.66 [9.86]	57.42 [11.21]	191.61 [10.21]	134.19 [11.36]

**Table 6** Comparison between the categories contralto, mezzo-soprano and soprano

	Voice category	Voice category	p-level
SCV-AI	Contralto	Mezzo-soprano	0.816
		Soprano	0.005
	Mezzo-soprano	Contralto	0.816
		Soprano	0.007
	Soprano	Contralto	0.005
		Mezzo-soprano	0.007
PA	Contralto	Mezzo-soprano	0.200
		Soprano	0.000
	Mezzo-soprano	Contralto	0.200
		Soprano	0.026
	Soprano	Contralto	0.000
		Mezzo-soprano	0.026

#### 4. Discussion

The aim of this study was to justify the relation between the voice classification based on frequency and the oropharyngeal anatomy, on professional singers. Specifically, it was controlled if there were differences between the different voice categories: bass, baritone, tenor and between contralto, mezzo-soprano and soprano. For the CI-MHP distance in male singers, we found statistically significant difference between bass and tenore ( $p = 0,023$ ). We observed that the mean distance of the area CI-MHP is longer in low- frequency voices and shorter in high- frequency voices. Particularly, the longest mean distance of the area CI-MHP appears the bass singer, followed by baritone and tenore. On the contrary, we did not end up in same conclusion, through correlation between the mean distance CI-MHP in female singers. The longest mean distance was observed contralto, followed by soprano and finally by mezzo-soprano. Non statistically significant difference observed for the mean distance of the CI-MHP area, measured in mm, in female singers ( $p = 0,112$ ).

The correlation between the mean distance MHP-SCV and the voice categories in male singers approved a statistically significant difference ( $F = 3,32$ ,  $p = 0,049$ ), without clarifying specific differences between the three voice categories. As the frequency of the male voice increase, the mean distance of the MHP-SCV area decrease. Bass singers appear the biggest mean value of the distance MHP-SCV, followed by baritone. The shortest mean value of the MHP-SCV distance appears the tenore. Non statistically significant difference for the same distance observed in female singers ( $F = 0,128$ ,  $p = 0,880$ ).

The mean distance of the SCV-AI in men singers appeared statistically significant difference ( $F = 10,04$ ,  $p = .0,000$ ), with the difference between bass and baritone ( $p = 0,042$ ) and between bass and tenore ( $p = 0,001$ ). So, as the frequency of the male voice categories increase, the mean distance SCV-AI decrease. Likewise, the mean distance of the SCV-AI area in female singers appeared statistically significant difference ( $F = 8,89$ ,  $p = .0,001$ ). So, the biggest the mean value of this distance is, the lower the frequency of the female singing voice does.

The mean distance for the PA area both in male ( $F = 31,43$ ,  $p = 0,000$ ) and female ( $p = 0,000$ ) singers appeared statistically significant difference, correlated with voice categories. We noticed that the mean PA distance is longer in low frequency singing voices and shorter in high frequency voices, both in male and female singers.

Statistically significant differences also observed for the mean distance OPC ( $F = 9,41$ ,  $p = 0,000$ ) in male singing voices. Nevertheless, non-statistically significant differences observed between the mean OPC distance, in female singers ( $F = 3,28$ ,  $p = 0,051$ ). The OPC distance represents the length of oropharynx correlated to voice category. Our study included 70 professional singers and ends up to similar conclusions with our previous study that included 55 professional singers [34]. But, we observed differences in the mean distances PA and OPC. To our previous study, the phonetic area PA that represents the sum of all distances appeared to have the longest length in singers with middle frequencies, both in men and women. Through this study was improved that singers with low frequency voices appear the longer PA distance while singers with high frequency voices appear the shorter PA distance. Additionally, in our previous study, we found that OPC distance was inversely proportional to the voice frequency in both male and female singers, result that concerns only male singers in this study. Considering the sample size as a limitation of our previous study, we believe that the participants of this study increase the validity of the results.

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## 5. Conclusion

Many researchers in the past investigated and improve relations between the voice categories and several features, such as anatomical parts of the vocal tract, in singers. Gutzmann claims that singers with a high hard palate are categorized into singing groups with high frequency vocal range, such as tenors and soprano. In addition, the role of resonance and vibration of the hard palate in singing has already been discussed by many researchers and using various methods Gates in 1998 noticed that lifting on the opening between soft and hard palate and extended the ribs, influences the vocal pitch. Similar results are reported by Lammert et al., suggesting that the palatal concavity is a major source of morphological variation that effects speech, articulation and acoustics. The larynx position influences the singing voice production. This was a field of research in many studies. Shipp observed that the larynx is raised while singing, the laryngeal muscles move and change vocal pitch. Wang suggested that, although a singer's high formant is associated with different larynx position, lowering the larynx does not explain the extra formant production, the singer's formant and voice quality. [60-66]. Based on Cleveland's observations, the larynx can rise in certain tenors and certain female voices. Sonninen, Hurme and Laukkanen used radiographic imagining methods and observed a female singer while singing. They noted that singing voice production involves complex movements of the laryngeal structures.

This study attempted to correlate the vocal category of professional singers with their oropharyngeal and laryngeal anatomy, through the use of cervical posteroanterior radiography. This was achieved through the collection of data on 70 healthy singers. The male singers included basses, baritones and tenors and the female singers were contraltos, mezzo-sopranos and sopranos. The statistical analysis of the data included the determination of mean distances, measured in millimeters [mm], and the correlations of the voice categories of the professional singers, that were before classified into groups by a vocal coach. The results showed statistically significant differences among all the singers for all distances.

We conclude that male singers with a low voice category, such as basses, exhibit the longest length of oropharynx, while singers with high frequency voice such as tenores have the shortest length of oropharynx. The main finding of Roers' investigation was that sopranos tended to have the shortest vocal tract and basses the longest and this effect is more dependent on the length of the pharynx cavity than on the length of the mouth cavity. Our conclusions about OPC distance led us to a similar consideration.

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## Compliance with ethical standards

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### *Disclosure of conflict of interest*

The authors declare no conflicts of interest regarding the publication of this paper.

### *Statement of ethical approval*

This study was approved by the Ethical Committee of the Medical School, University of Ioannina.

### *Statement of informed consent*

Informed consent was obtained from all individual participants included in the study.

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