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Original Research Article

Laryngeal Dimorphism: A Quantitative Analysis of Thyroid and Cricoid Cartilage in Relation to Vocal Cord Length in Indian Cadavers

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ABSTRACT

Background: "Laryngeal dimorphism" means structural and functional differences in the larynx between males and females, which are primarily influenced by variations in cartilage dimensions and vocal cord length of the larynx. Studying laryngeal dimorphism enhances diagnostic precision and therapeutic approaches in otolaryngology and phono-surgery**.**

Objective: To understand laryngeal dimorphism with examination of thyroid and cricoid cartilage morphology with variations in relation to vocal cord length in adult Indian cadavers.

Materials and Methods: Fifty embalmed adult laryngeal specimens (40 male, 10 female) aged 60–75 years were dissected using standard anatomical protocols. Specimens with deformities were excluded. Parameters measured included thyroid lamina height and width, internal angle, cornua distances, vocal fold length and width, cricoid diameters, and inter-arytenoid distance. Tools included a divider, scale, wire loop, and protractor. Statistical analyses involved mean, standard deviation, p-values, and linear regression.

Results: Significant sexual dimorphism was observed in internal thyroid angle ($p < 0.001$), lamina width, and cornua distances. Males exhibited longer and wider vocal folds ($p < 0.05$), though the membranous/cartilaginous ratio remained consistent across sexes. Cricoid sagittal diameter and inter-arytenoid distances were significantly greater in males. Thyroid lamina height was a strong predictor of vocal fold length ($p < 0.001$).

Conclusion: This study gives detailed morphological parameters of important laryngeal cartilages, such as thyroid cartilage and cricoid cartilage, with vocal folds, contributing to a better understanding of laryngeal anatomy with gender differences in the Indian population, with further application to surgical approaches.

KEYWORDS: Laryngeal dimorphism, Thyroid cartilage, Cricoid cartilage, Vocal folds, Sexual dimorphism, Indian cadavers, Laryngology, Forensic anatomy.

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INTRODUCTION

"Laryngeal dimorphism" means structural and functional differences in the larynx between males and females, which are primarily influenced by variations in cartilage dimensions and vocal cord length of the larynx. The human larynx, extends from the third to the sixth cervical vertebra, is a complex organ responsible for various functions like respiration, phonation and airway protection. The laryngeal wall framework consists of a mucosal lining, a fibroelastic membrane, cartilaginous structures, and an intrinsic muscular system. The thyroid and cricoid cartilages are the key anatomical components that contribute to vocal characteristics and sexual dimorphism [1].

According to evolutionary history, the larynx has undergone significant modifications to accommodate phonation as a secondary function. In early vertebrates, it primarily acted as a sphincter to prevent any foreign material from entering the airway passage. Over time, particularly in mammals, the development of the crico-arytenoid complex has increased respiratory efficiency, and improved cartilaginous structure has enabled a complex vocalization process. In humans, these adaptations have resulted in marked differences between male and female laryngeal anatomy, which influence voice pitch, resonance, and phonation.

The fundamental function of the larynx remains the same: that of protecting the airway passage with the help of sphincteric action during deglutition. Reflex inhibition of respiration with glottic closure and laryngeal elevation works in coordination to prevent aspiration of food and water. The role of intrinsic laryngeal muscle and extrinsic muscles like thyrohyoid with pharyngeal muscles is crucial in these movements [2]. Also, the Valsalva manoeuvre highlights the larynx's role in regulating intrathoracic and intra-abdominal pressures, demonstrating its multiple roles of physiological significance [3].

Phonation is the most specialized function of the larynx, which is influenced by morphological dimensions and variations in the thyroid and cricoid cartilages. The vibration of the vocal cords, governed by the Bernoulli Effect, determines pitch and sound modulation. The vocal fold length and its tension differ between males and females, leading to variations in voice frequency and sound quality. Different patterns of vocal fold vibrations, such as modal, falsetto, and glottal fry, reveal the complexity of vocal production, along with male and female differences contributing to distinct acoustic properties [4].

From a clinical point of view, the location of the larynx and its unavoidable exposure to external environmental agents have made this organ extremely vulnerable to trauma and various other infectious diseases. Many congenital anomalies related to the larynx are also reported. Cancer is another threat to which the larynx is very susceptible, and it bears a lot of importance due to its close association with tobacco smoking. Vocal cord paralysis and its proper management are still great challenges for researchers. Along with that morphological difference in thyroid and cricoid cartilage size, vocal cord length and tension are seen in males and females. For various types of surgical approaches for the larynx, such as laryngeal framework surgery in laryngeal paralysis, laryngeal reconstruction after partial or complete laryngectomy in carcinoma, Vocal rehabilitation according to the gender is required. So, studying laryngeal dimorphism enhances diagnostic precision and therapeutic approaches in otolaryngology and phono-surgery [5].

Understanding laryngeal dimorphism requires a detailed examination of thyroid and cricoid cartilage variations in relation to vocal cord length. This study aims to provide a quantitative analysis of these structures, which will enhance knowledge on vocal function, sexual dimorphism, and clinical applications in the human larynx.

MATERIALS AND METHODS

This study was conducted on 50 laryngeal specimens obtained from 55 embalmed cadavers of the age group 60-75 years from different regional medical colleges after approval of the Institutional Ethics Committee in the years 2023 to 2025. Standard dissection techniques were employed to meticulously examine the morphology and measurements of the laryngeal cartilages. Five specimens were excluded due to gross deformities or pathological conditions. Out of 50 laryngeal specimens, 40 were of males and 10 were of females.

Specimen Collection and Dissection: - Cadavers used for medical student dissections were selected after completion of facial and neck region dissections. In each cadaver, the dissection started from the Ventral side. The sternothyroid muscle was separated from the thyroid cartilage after cutting the sternohyoid muscle on both sides. The omohyoid muscle was also cut at its attachment to the hyoid bone. The mandible (jawbone) was cut on both sides using a saw, hammer, and chisel. Then, the palatoglossus and styloglossus muscles were cut. A cut was also made across the mylohyoid and anterior belly of the digastric muscle along the mandible. Next, the tongue was lifted, and the geniohyoid and genioglossus muscles were cut. The tongue was then pulled down, cutting the pharyngeal constrictor muscles, which helped separate the trachea (windpipe) from the esophagus (food pipe). The trachea was cut between the fifth and sixth rings, and the larynx (voice box), tongue, hyoid bone, and upper trachea were removed. Finally, the thyroid gland was taken out. Afterward, the thyrohyoid muscle was cut on both sides, and the thyrohyoid membrane was carefully cut to avoid damaging the thyroid cartilage. The trachea was transacted between the fifth and sixth tracheal rings, and the laryngeal specimen was recovered intact.

Measurement Protocol: The specimens were thoroughly cleaned to remove extraneous soft tissue, ensuring clear visualization of the anatomical landmarks. Measurements were performed using a divider, protractor, scale, and wire loop.

The key parameters recorded included:

Thyroid Cartilage: Height and width of lamina, distance between superior and inferior cornua, and internal thyroid angle as shown in Fig. 1.

Vocal Cords: Total length and membranous part length, measured using a divider placed from the anterior commissure to the posterior end of the vocal folds. Also, the width of the vocal folds was measured as shown in Figure 2.

Cricoid Cartilage: Internal sagittal and transverse diameters at both cranial and caudal ends, along with distances between arytenoid facets as shown in Figure 3.

The distance between the lower edge of the thyroid cartilage to the lower edge of the cricoid cartilage in the midline was measured

Fig. 1: Showing the various morphological measurements of thyroid cartilage.

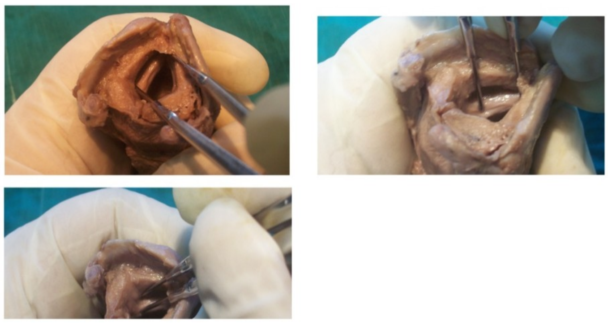

Fig. 2: Showing the various morphological measurements of vocal cords.

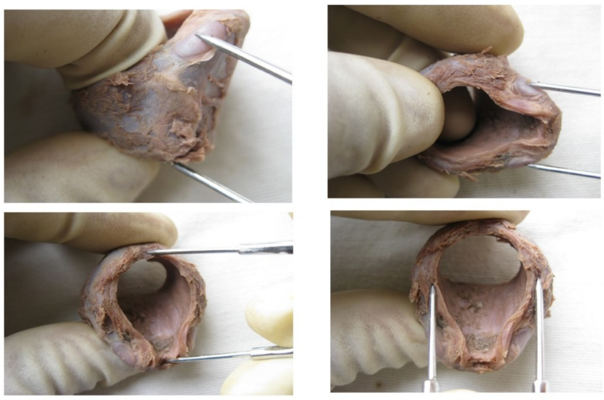

Fig. 3: Showing the various morphological measurements of cricoid cartilage.

Data Analysis: All recorded measurements were compiled systematically and analyzed statistically. The Mean and Standard Deviation

(SD) were calculated to assess variations in laryngeal dimorphism, and a p-value was calculated using SPSS software version 16. Simple linear regression analysis was done for predicting vocal cord length from the height of the thyroid lamina, the internal angle of the thyroid cartilage, and the distance between the thyroid and the cricoid cartilage in the midline. The regression analysis performed in this study was conducted using Python (version 3.x) with the Statistics' models library for statistical modelling. The findings were compared to existing literature to evaluate sexual dimorphism and anatomical differences in laryngeal structures.

RESULTS

Various measurements of the Thyroid cartilage, Vocal cords, and Cricoid cartilage obtained from forty male and ten female cadavers were obtained. The following observations were made:

Morphometric measurement of thyroid cartilage, including Height and width of lamina on both right and left sides, distance between superior and inferior cornua, and internal thyroid angle, with mean and standard deviation in both sexes, is shown in Table 1.

Table 1: Showing the Morphometric measurements of thyroid cartilage.

Parameter	Male Mean ± SD	Female Mean ± SD	p-value	Significance
Superior Cornua Distance (mm)	33.90 ± 6.83	34.60 ± 6.65	0.796	Not significant
Inferior Cornua Distance (mm)	29.10 ± 3.09	27.70 ± 3.3	0.282	Not significant
Superior to Inferior Cornua Distance (Right) (mm)	42.5 ± 5.3	37.36 ± 3.87	**0.007**	Significant (p < 0.05)
Superior to Inferior Cornua Distance (Left) (mm)	42.60 ± 5.53	36.40 ± 3.98	**0.015**	Significant (p < 0.05)
Max Height of Thyroid Lamina (Right) (mm)	27.50 ± 2.88	24.5 ± 3.89	0.053	Borderline significant
Max Height of Thyroid Lamina (Left) (mm)	27.3 ± 2.84	24.10 ± 3.89	0.055	Borderline significant
Width of Thyroid Lamina (Right) (mm)	38.10 ± 3.6	32.50± 3.69	**0.003**	Significant (p < 0.05)
Width of Thyroid Lamina (Left) (mm)	38.55 ± 3.67	32.60 ± 3.69	**0.002**	Significant (p < 0.05)
Internal Angle (Degrees)	76.50 ± 8.21	91.86 ± 6.63	**0.0001**	Highly significant (p < 0.001)

Table 2: Showing the Morphometric measurements of the vocal cords.

Parameter	Male Mean ± SD	Female Mean ± SD	p-value	Significance
Total Length of Vocal Folds (mm)	16.50 ± 2.52	14.5 ± 1.64	**0.021**	Significant (p < 0.05)
Width of Vocal Folds (mm)	4.50 ± 0.78	3.80 ± 0.71	**0.047**	Significant (p < 0.05)
Length of Membranous Part (mm)	12.60 ± 1.96	10.80 ± 1.51	**0.039**	Significant (p < 0.05)
Ratio of Membranous to Cartilaginous Part	3.23 ± 1.02	2.91 ± 0.63	0.821	Not significant

Table 3: Showing the Morphometric measurements of cricoid cartilage.

Parameter	Male Mean ± SD	Female Mean ± SD	p-value	Significance
Distance between lower border of cricoid and arytenoid facet (mm)	22.52 ± 2.36	19.88 ± 2.64	**0.018**	Significant (p < 0.05)
Distance between arytenoid facets (mm)	16.91 ± 1.81	15.38 ± 2.45	**0.045**	Significant (p < 0.05)
Internal sagittal diameter (Cranial end) (mm)	24.41 ± 3.05	20.38 ± 4.66	**0.011**	Significant (p < 0.05)
Maximum internal transverse diameter (Cranial end) (mm)	14.11 ± 2.64	14.00 ± 1.51	0.891	Not significant
Internal sagittal diameter (Caudal end) (mm)	17.5 ± 2.05	14.75 ± 2.92	**0.027**	Significant (p < 0.05)
Internal transverse diameter (Caudal end) (mm)	18.13 ± 2.16	16.5 ± 1.69	0.076	Not significant

The findings are that there was a statistically significant difference ($p<0.001$) in the internal angle between thyroid laminae between males and females. Also, statistically significant differences ($p<0.05$) were observed in the distance measured from the superior to the inferior cornua of thyroid cartilage, and also the width of thyroid lamina, suggesting its importance in different genders. Borderline significance was observed in the maximum height of the thyroid lamina. No significant differences were found with other measurements.

Morphometric measurement of Vocal cords, measuring Total length, membranous length, width, and ratio of membranous to cartilaginous part, with their mean and standard deviation in both sexes, are shown in Table 2.

The findings are that there was a statistically significant difference ($p<0.05$) in the various vocal cord measurements between males and females. It was observed that males had longer and wider vocal cords compared to females. The membranous part of the vocal cord was also significantly longer in males. Despite the difference between the morphology of the vocal cords, the ratio of the membranous to cartilaginous part showed no significant difference ($p = 0.821$) in both sexes. This suggests that while the overall dimensions of the vocal folds vary but their proportionality remains constant among sexes.

Morphometric measurement of Cricoid cartilage, measuring Internal sagittal and transverse diameters at both cranial and caudal ends, along with distances between arytenoid facets, with mean and standard deviation in both sexes, is shown in Table 3.

The findings are that there was a statistically significant difference ($p<0.05$) in several anatomical measurements of the Cricoid framework between males and females. Males showed a greater distance between the lower border of the cricoid cartilage and the arytenoid facet, a wider distance between the arytenoid facets, and larger internal sagittal diameters at both the cranial and caudal ends compared to females. The internal transverse diameter at the caudal end showed borderline significance ($p = 0.076$). No significant differences were found with other measurements.

Simple linear regression analysis was done for predicting vocal cord length from the height of the thyroid lamina, the internal angle of the thyroid cartilage, and the distance between the thyroid and the cricoid cartilage in the midline. The key results found were that the height of thyroid lamina was a significant predictor of vocal cord length with a p-value less than 0.001, and the regression equation was

Vocal Fold Length = 3.7795 + 0.4497 × (Height)

DISCUSSION

In the present study, we have done a detailed analysis of various morphological dimensions of the thyroid cartilage, vocal folds, and cricoid cartilage along with the differences between males and females in the Indian cadavers. Aside from pure anthropometry, such information has potential application to studies in laryngeal physiology, advanced methods of laryngeal imaging, and surgery of the laryngeal framework.

Thyroid Cartilage Dimensions: In the present study, the distances measured between both sides of the superior cornua and the distance between both sides of the inferior cornua of the thyroid cartilage were generally lower than those documented earlier. Further, measurements in our male specimens closely corresponded to those reported by Tayama et al. (2001) [6], while female values were more consistent with findings by Zieliñski (2001) [7]. Despite these variations, statistical analysis revealed no significant differences between sexes in this parameter, so it remains the same in both sexes. However, the distances between the tips of the superior and inferior cornua showed statistically significant sexual dimorphism. This observation supports previous reports by Wysocki et al. (2008) [8] and is further validated by studies of Ahmed et al. (2016) [9] and Kim et al. (2020) [10], which emphasize sex-based structural differences in the larynx that may influence voice production and airway function. Additionally, variations were observed in the height and width of the thyroid lamina between male and female specimens, but the width of the thyroid lamina had a statistically significant difference. Thus it proves that males generally possess larger laryngeal cartilages, which are associated with deeper voice pitch and a more prominent laryngeal contour, as highlighted in the findings of Kirchner et al. (2019) [11].

Internal Angle of the Thyroid Laminae: In the present study, a highly statistically significant difference was observed in the internal angle of the thyroid laminae between males and females, with females generally exhibiting wider angles. Such findings are already reported by Eckel and Sittel (1995) [12] and

Jotz et al. (2007) [13]. Other studies, like those of Arens et al. (2014) [14] and Kim et al. (2021) [15], have revealed the importance of the internal angle of the thyroid lamina in relation to vocal characteristics. A wider internal angle is associated with a less prominent laryngeal prominence and may contribute to the typically higher fundamental frequency of the female voice.

Vocal Fold Measurements: The present study showed that there are differences in the total length, width, and membranous portion of the vocal folds, in both sexes, consistent with the widely recognized anatomical dimorphism of the laryngeal framework. Although our recorded values were generally lower than those described by Eckel and Sittel (1995) [12], such differences may be due to variations in population characteristics, anatomical preservation, or measurement method. Nevertheless, findings from different studies consistently point to the inherent sex-related differences in vocal fold anatomy, suggesting a strong biological basis for these variations.

A particularly notable finding was that the cartilaginous segment of the vocal folds accounted for roughly 25% of their total length in both males and females. This contrasts with the proportions reported by Friedrich et al. (1999) [16], who found that this region comprised approximately 37% in males and 42% in females. More recent investigations, including those by Honjo and Isshiki (2009)[17] as well as Xue et al. (2017) [18], have similarly reported variability in these measurements, suggesting that technical factors—such as imaging modality, sample size, and anatomical definitions—can significantly affect outcomes. These discrepancies underline the necessity of establishing consistent measurement criteria and protocols in future anatomical studies to improve comparability and accuracy.

Cricoid Cartilage and Arytenoid Measurements: The dimensions of the cricoid cartilage, particularly the sagittal diameter at both the cranial and caudal ends, demonstrated significant gender differences, with males exhibiting larger values. These findings are in agreement with prior research and underscore the importance of considering sex-specific differences in airway management and intubation procedures. In the present study, there is a statistically significant difference seen in the inter-arytenoid facet distance between male and female specimens, with consistently smaller values observed in females. While our measurements were lower than those published by Eckel et al. (1994) [19] and Wysocki et al. (2008) [8], the trend aligns with findings from other anatomical studies. Notably, Maue et al. (2015) [20] and Kim et al. (2020) [10] also reported reduced inter-arytenoid distances in females, which they associated with smaller overall laryngeal dimensions. Differences in measurement outcomes across studies may be attributed to factors such as ethnic variation, specimen condition, or differences in methodology. Despite these minor variations, the consistent observation of sex-based differences in this parameter across diverse populations supports its role as a reliable indicator of laryngeal dimorphism.

Regression Analysis and Predictive Models: Regression analysis identified that thyroid ala height is a significant predictor of vocal fold length, explaining about 32.7% of the variance. However, thyroid-cricoid distance and the internal angle between the thyroid laminae were weak predictors. This suggests that there are multiple anatomical and physiological factors contributing to the length of the vocal fold. So, a combination of genetic, developmental, environmental, and functional factors influences the length of vocal folds, not just the cartilage dimensions.

Despite many differences in materials, methods, and the number of investigated specimens, some data from our study were quite similar to those reported earlier. Considerable gender-related differences in many of the geometric measurements of the laryngeal framework were also observed in the present study, e.g. distance between the right and left superior cornua of thyroid cartilage being more in females and between right and left inferior cornua of thyroid cartilage being more in males, greater distance between the tips of the superior and inferior cornua of thyroid cartilage in males, greater height and width of thyroid lamina in males, about 20% greater angle of thyroid lamina in females, greater diameters of cricoid cartilage in males, greater length and width of vocal folds in males and the membranous part of the vocal folds being almost three times that of the cartilaginous part in both the genders. Not only are such gender-related differences essential for biomechanical modelling, but they also have many clinical implications, such as placement of electromyography electrodes, determining tube size for intubation, and understanding gender-specific variations in thyroid cartilage and vocal fold structure, which can enhance surgical precision and optimize patient outcomes. The purpose of this study was to present detailed laryngeal cartilage dimensions for furthering biomechanical models of the larynx. Similarly, forensic identification efforts may benefit from these anatomical markers when determining sex from skeletal remains. Additionally, our findings highlight the need for tailored approaches in voice therapy, considering how structural differences influence vocal characteristics. Our study would also provide specific data on the morphometry of various laryngeal cartilages in Indian subjects, which were lacking so far, that can be useful for planning laryngeal surgeries.

Limitations and Future Directions: The present study provides valuable insight into the laryngeal morphology with emphasis on thyroid cartilage, cricoid cartilage, and vocal folds. The limitation of our study is the specific demographics of our study group, and the sample size can be increased to generalise the results to a broader population.

Further investigations should be expanded using resolution imaging techniques and including broader, more diverse sample populations to validate the anatomical trends observed. In addition, examining how these structural differences influence physiological functions such as phonation, respiration, and airway control should be studied to provide more valuable insight.

CONCLUSION

The present study, with a detailed analysis of various dimensions of thyroid cartilage, vocal folds, and cricoid cartilage, shows that the internal angle of thyroid cartilage, the distance between the superior and inferior cornu on one side of thyroid cartilage, the length and width of vocal folds, sagittal diameter of cricoid cartilage at both ends are statistically significant for gender dimorphism. Also, the present study's significant finding is that the height of thyroid lamina was a significant predictor of vocal cord length with a p-value less than 0.001, and the regression equation is

Vocal Fold Length = 3.7795 + 0.4497 × (Height)

Thus, our study gives detailed morphological parameters of important laryngeal cartilage contributing to a better understanding of laryngeal anatomy with gender differences in the Indian population, with further application to surgical approaches.

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Author Contributions

Jitendra Rawal: Conceptualized the study design, supervised data collection, conducted statistical analysis, and performed critical revision of the manuscript for important intellectual content. **Rutvi Baldha:** literature review, methodology refinement. **Maulik Patel:** Carried out data acquisition, conducted statistical analysis, and reviewed the final manuscript. **DhavalKumar Patel:** Carried out data acquisition, contributed to literature review, and managed ethical approvals.

Conflicts of Interests: None

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