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Anatomical Characterization of the Upper Airway in the Indian Population: Implications for Laryngoscope Design

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Abstract

Purpose

This study highlights a key research gap in population-specific laryngoscope blade design, emphasising the lack of data on upper airway anatomy in the Indian population. The study aims to characterise the upper airway in the Indian population and evaluate the need for population-specific laryngoscope blade designs based on anatomical variations.

Methods

The upper airway profile, defined as the path traversed by the laryngoscope blade, was segmented into horizontal and vertical components. CT scans of 118 Indian adults were retrospectively collected from a tertiary-care institution, and analysed using four reproducible mid-sagittal landmarks. Comparative anatomical data from ten international populations were obtained from published literature. Independent t-tests with Holm–Bonferroni correction were used to evaluate differences in airway dimensions across populations, and Pearson's correlation was used to assess associations with age.

Results

The mean horizontal component was 77.8 mm and the mean vertical component was 50.95 mm, with males exhibiting larger dimensions than females for both components. The horizontal component differed significantly from the Austrian population, while the vertical component (upper airway length) was significantly shorter than all ten comparison populations. The vertical component showed a moderate positive correlation with age in both sexes, whereas the horizontal component did not. The measured lower incisor-to-vallecula working lengths for males (77.28 mm) and females (71.07 mm) were substantially shorter than the working lengths of standard C-MAC Mac 3 and C-MAC Mac 4.

Conclusion

This study demonstrates distinct gender-based and inter-population variations in the upper airway profile of the Indian population and highlights a mismatch with standard blade designs. These findings underscore the need for population-specific laryngoscope blade designs that account for anatomical diversity, particularly in terms of curvature and insertion length.

Highlights

• CT-based upper airway morphometry in 118 Indian adults using reproducible landmarks.

• Indian vertical airway length was shorter than in ten global populations.

• Males had significantly larger absolute airway dimensions than females.

• The vertical-to-horizontal ratio did not differ by sex.

• Airway working lengths fell short of standard Macintosh blade lengths.

1. Introduction

The upper airway is anatomically complex and highly variable between individuals and across populations, yet successful airway management depends on navigating this variability reliably. Endotracheal intubation (ETI), the definitive method of securing the airway in anesthesia, critical care, and trauma, requires direct exposure of the laryngeal inlet using a laryngoscope [1]. The geometry a laryngoscope must accommodate is therefore dictated by upper airway anatomy. Direct and video laryngoscopy (VL) are two general techniques of laryngoscopy. VL offers several advantages over the direct laryngoscope, including a better and magnified view of the larynx, no need for an eye line view for insertion, hence no space required behind the blade, and no need to align oral–pharyngeal––laryngeal axes, making intubation easier for beginners [2]. During ETI, the blade tip must engage the vallecula, and the inner surface should touch the upper incisors without using the teeth as leverage.

Anatomical variations may play a crucial role in shaping the design and dimensions of laryngoscopes, as there are significant differences in the upper airways of different populations. A comparison of the upper airway anatomy between European and Chinese populations revealed that the Chinese population exhibited a shorter total airway length and smaller retropalatal space than Europeans [3]. Similarly, a study conducted on the Mexican population identified that existing video laryngoscope blades were unsuitable for their specific anatomical characteristics [4]. The findings indicated a need for a redesigned blade to accommodate the anatomical variations in the Mexican population [4]. An evaluation of endotracheal tube placement in the Indian population demonstrated that the standard recommendations, i.e., 23 cm for males and 21 cm for females, may lead to over-insertion [5]. This could result in the endotracheal tube entering the cricoid ring, potentially increasing the risk of complications during intubation in Indian patients, as the tube is not designed for the anatomy of the Indian population [5]. Another study conducted on nerve endings around the epiglottis discussed that nerve stimulation increases with an increase in the pressure applied to the vallecula [6], underscoring that ill-fitted or overly long blades may provoke exaggerated reflex responses in addition to mechanical difficulties. The guidelines for management of difficult airway by the American Society of Anesthesiologists highlight that anatomical variations are a key factor in difficult intubation and recommend that airway management strategies, including device selection, be individualized based on the patient's specific anatomy [7]. There are various reasons for a difficult airway, some based on anatomical features like protruding sternal region, anterior larynx, etc. So, if the anatomy changes, there is a chance that these features can cause difficulty in intubation. [8]. Despite the extensive research on upper airway anatomy across various populations, there remains a significant lack of literature specifically addressing the Indian population. To date, no comprehensive studies have compared the upper airway anatomy of the

Indian population with that of other nationalities for the anatomical features of the Indian population, considering the length and curvature.

Given this context and the absence of comprehensive anatomical data from the Indian population, this study aimed to characterize the upper airway anatomy of an adult Indian population using CT and to evaluate the compatibility of standard Macintosh laryngoscope blade dimensions with the measured anatomical working length. Specifically, CT derived upper airway measurements from the Indian population were compared with published data from ten other global populations, intra-population variation by age and sex was assessed, and the anatomical working length was compared against standard blade dimensions to evaluate clinical compatibility.

2. Materials and Methods

Study Design and Imaging Data

This retrospective cohort study was conducted at the Department of Radiodiagnosis and Interventional Radiology of a tertiary-care institution, and included imaging data acquired between August 6, 2015, and March 2, 2020. The study was approved by the institutional ethics committee (approval details withheld for blinded review), and, given the retrospective nature of the study and the use of computed tomography imaging data acquired as part of routine clinical care, the requirement for informed consent was waived. All methods were performed in accordance with relevant institutional guidelines and regulations, and in compliance with the ethical principles of the Declaration of Helsinki. Computed tomography (CT) images were acquired using Siemens SOMATOM Definition AS + and SOMATOM Definition Flash scanners. The slice thickness of the CT scans was 1 mm, and reconstruction increments were also set at 0.7 mm, ensuring overlapping slices capture detailed anatomical features. This setup provided high-resolution imaging for the study's analysis.

Patient positioning and coordinate frame

All measurements were taken in each CT scan's original coordinate frame, without rotating individual scans to match a standard anatomical reference plane. In this frame, the horizontal axis (x) runs front-to-back in the mid-sagittal view, and the vertical axis (y) runs top-to-bottom (head-to-neck). This was done for two reasons. First, all scans came from the same hospital protocol (supine, head in neutral position), so the starting positioning was already consistent. Second, the geometric measurements used in this study are defined relative to the image itself, not to a separate anatomical reference plane.

Image processing and measurement workflow

A custom Python measurement tool was developed using pydicom for DICOM parsing and the Matplotlib event-handling system for interactive landmark placement. For each scan, the processing pipeline proceeded as follows. Available CT phases were first filtered, and the series providing complete coverage from the oral cavity to the larynx at the smallest slice thickness was selected. The rater then

identified the mid-sagittal slice by scrolling through the sagittal stack and selecting the slice that showed continuous alignment of the nasal septum, vomer, and hard palate, confirming central midline anatomy. On this slice, the rater placed the four landmarks and landmark coordinates were stored in image-pixel space and converted to millimetres using the in-plane DICOM PixelSpacing attribute of the selected slice. Inter-landmark distances were then computed from the stored coordinates. All landmark placements were performed on the mid-sagittal slice using a fixed soft-tissue window/level appropriate for visualising upper airway anatomy.

Anatomical landmarks

Four reproducible anatomical landmarks were used (Fig. 1):

• L1: Tip of the lower incisor. The most caudal cusp of the lower central incisor as projected onto the mid-sagittal slice. When both central incisors were independently identifiable in adjacent sagittal slices, the mean position of the two tips was used.

• L2: Posterior pharyngeal wall. The point at which a horizontal line through L1 (parallel to the image x-axis) intersected the posterior pharyngeal wall in the mid-sagittal slice. This operational definition fixes the measurement level on the posterior pharyngeal wall surface, removing the ambiguity that would otherwise arise from the curvature of the wall.

• L3: Posterior nasal spine (PNS). The most posterior bony point of the hard palate as visualised on the mid-sagittal slice.

• L4: Vallecula. The deepest (most caudal) point of the vallecular trough between the base of the tongue anteriorly and the epiglottis posteriorly, as visualised on the mid-sagittal slice.

Definition and computation of measurements

Three measurements were derived from the four landmark coordinates:

• Horizontal component (H): the perpendicular straight-line distance between L1 and L2. Because L2 is defined as the intersection of a horizontal line through L1 with the posterior pharyngeal wall, H is geometrically equivalent to the anteroposterior extent of the airway.

• Vertical component (V): the axis-parallel cranio-caudal separation between L3 and L4, defined as the absolute difference in image y-coordinates: $V = |y(L4) - y(L3)|$. V was defined as an axis-parallel projection (rather than a Euclidean distance) to maintain comparability with the published anatomical literature used for inter-population comparison, in which upper airway vertical length is most commonly reported as an axis-parallel cranio-caudal measure.

• Anatomical working length (W): the straight-line distance between L1 and L4. W represents the total insertion distance traversed by a laryngoscope blade from the incisors to the point of vallecular engagement and is used for comparison with manufacturer-specified Macintosh blade working lengths.

Comparative Literature Data

Published studies reporting upper airway anatomical dimensions were used to obtain comparative data for inter-population analysis. Search was conducted in PubMed and Scopus up to December 31, 2024, using keywords related to upper airway length and the incisor-to-pharyngeal wall distance. Studies were included if they involved adult human subjects without major craniofacial deformities or significant obstructive sleep apnea. From the eligible literature, data from ten nationalities reporting upper airway length were identified, while only one study provided measurements corresponding to the horizontal component defined in this work. These literature-derived values were used solely as comparative benchmarks to contextualize the CT-based anatomical measurements obtained in the present study. This literature survey was intended to support anatomical comparison rather than to serve as a comprehensive systematic review.

Table 1
Literature data for horizontal component measurement for airway in the Austrian population

S. No.	Sample Size	Authors	Nationality	OSA	Horizontal component length	
					Mean (mm)	SD (mm)
1	20	[9]	Austria	No	81	6

The following data were extracted from the selected studies: sample size, nationality, obstructive sleep apnea (OSA) status and severity, mean upper airway length with standard deviation, and distance from the lower incisors to the pharyngeal wall, where available. Preference was given to datasets involving participants without OSA; when unavailable, data from cohorts with the lowest reported apnea–hypopnea index (AHI < 15, reported as mild OSA in various studies) were selected. The extracted comparative data are summarized in Table 1 and Table 2.

Table 2
Literature data for vertical component (UAL) measurement for airway in 10 nationalities

S. No.	Sample Size	Authors	Nationality	OSA	Upper Airway Length	
					Mean (mm)	SD (mm)
1	10	[10]	Netherlands	No	66.20	12.40
2	20	[11]	Turkey	AHI < 5	73.28	7.60
3	15	[12]	Taiwan	AHI < 7.8	70	7
4	17	[13]	US	No	66.30	10.10
5	11	[14]	Brazil	AHI < 15	64.80	7
6	20	[9]	Austria	No	57	10
7	14	[15]	South Korea	No	62	7.08
8	20	[16]	China	No	68.80	6.83
9	40	[17]	Portugal	No	62.93	8.05
10	28	[18]	Saudi Arabia	No	59.16	5.03

Reliability and Sample Size Estimation

Measurement reliability was assessed using a subset of 20 randomly selected patients. Nine anatomical parameters were independently measured by the primary investigator and by an anesthetist with over 20 years of clinical experience. Inter-rater reliability was evaluated using the intra-class correlation coefficient (ICC) based on a two-way mixed-effects model with single-rater consistency. Statistical analysis was performed using IBM SPSS software, yielding an ICC value of 0.994, indicating excellent measurement reliability.

Sample size was estimated using an independent t-test power analysis with unequal group sizes (comparison-group n fixed at published values) [19]. For the inter-population comparison of the vertical component (upper airway length), effect sizes were estimated from pilot data (vertical component mean = 51 mm, SD = 6.24 mm, n = 20) relative to the ten published populations, whose sample sizes were fixed. At α = 0.05 (two-sided) and 80% power, and accounting for the fixed comparison-group sizes, the most demanding comparison, against the Austrian cohort (the most anatomically similar population; Cohen's d = 0.83), required 69 participants; all other comparisons required substantially fewer (n = 2–15) owing to their larger effect sizes. For the sex comparison, in the absence of sex-stratified pilot data, a conventional large effect size (Cohen's d = 0.80) was assumed. Under the same criteria (α = 0.05, two-sided; 80% power), a minimum of 24 participants per group (48 total) was required.

Based on these analyses, the binding requirement was 69 participants (the Austrian inter-population comparison). To ensure adequacy, 125 subjects with no OSA or other upper airway abnormality were initially identified, of whom 118 (40 male, 78 female) were included in the final analysis after image-quality screening. The achieved sample therefore exceeded the requirement for all comparisons, providing high power (> 95%) for the observed sex-based differences (Cohen's d = 0.83–0.96) and adequate power across the inter-population comparisons.

Statistical Analysis and Comparisons

All anatomical measurements were obtained for all 118 subjects. Data distributions were assessed using the Shapiro–Wilk test and were found to be approximately normal. Comparisons between the Indian cohort and each published population were performed using two-sample t-tests based on summary statistics (mean, standard deviation, and sample size), with Holm–Bonferroni correction for multiple comparisons. Statistical significance was set at adjusted $p < 0.05$. A Pearson's correlation test was conducted to assess associations between airway parameters and age. To facilitate interpretation of age-related trends, analyses were performed using continuous age (actual patient age in years) and categorical age groups (10-year intervals: 15–25 (data from 18 onwards considered), 25–35, ..., 65–75 years). Correlation coefficients were calculated separately for both approaches to assess the consistency of findings. The anatomical working length was then compared to the blade working lengths of commonly used Macintosh blades 3 and 4 to evaluate clinical appropriateness. Macintosh blade working lengths typically range from 111 mm (size 3) to 137 mm (size 4), serving as reference points for evaluating the appropriateness of current clinical recommendations [20].The working lengths were measured for males and females, then compared with the Mac 3 and Mac 4.

The comparison was conducted for the following considerations:

• Comparison of the Indian population with others

• Variation in the parameter based on Gender and Age

• Comparison of the working length of the upper airway with existing blades

A t-test was selected for comparison with every other population for the parameters.

3. Results

The mean age of the sample (Indian population, n = 118; 78 females, 40 males) was 44.61 ± 14.74 years. Both horizontal and vertical components were measured for all 118 patients. The mean (SD) horizontal component measured 77.8 (7.14) mm, and the vertical component measured 50.95 (6.74) mm.

Table 3
Comparison of the Horizontal component between Austrian and Indian population

S. No.	Nationality	Horizontal component length		p-value	Cohen's d
		Mean (mm)	SD (mm)		
1	India	77.8	7.14	-	-
2	Austria	81	6	0.04*	0.46
$p < 0.05$ = significant difference (*), Cohen's conventions (small = 0.2, medium = 0.5, large = 0.8, very large = 1.3)					

For the horizontal component, no p-value correction was required as only one comparison was made. The horizontal component showed a statistically significant difference compared with the Austrian population ($p = 0.04$, Cohen's $d = 0.46$), as shown in Table 3. For the vertical component (upper airway length), comparisons were made against ten international populations; after Holm–Bonferroni correction, the Indian cohort remained significantly shorter than all ten populations (adjusted $p < 0.05$ for all comparisons), with very large effect sizes (Cohen's $d = 0.83–3.25$), as shown in Table 4. These findings indicate substantial population-specific differences in upper airway anatomy.

Table 4
Comparison of the vertical component between the Indian population and other nationalities

S. No.	Nationality	Upper Airway Length		p-value (raw)	p-value (adjusted)	Cohen's d
		Mean (mm)	SD (mm)			
1	India	50.95	6.74	-	-	-
2	Netherlands	66.2	12.4	< 0.01	< 0.01*	2.09
3	Turkey	73.28	7.6	< 0.01	< 0.01*	3.25
4	Taiwan	70	7	< 0.01	< 0.01*	2.81
5	US	66.3	10.1	< 0.01	< 0.01*	2.12
6	Brazil	64.8	7	< 0.01	< 0.01*	2.04
7	Austria	57	10	0.01	0.01*	0.83
8	South Korea	62	7.08	< 0.01	< 0.01*	1.63
9	China	68.8	6.83	< 0.01	< 0.01*	2.64
10	Portugal	62.93	8.05	< 0.01	< 0.01*	1.69
11	Saudi Arabia	59.16	5.03	< 0.01	< 0.01*	1.27

p-values adjusted using Holm–Bonferroni correction. $p < 0.05$ indicates statistical significance. Cohen's conventions: small = 0.2, medium = 0.5, large = 0.8, very large = 1.3.

Comparison of the vertical component against ten international populations is presented in Fig. 2. The Indian cohort mean (50.95 mm, 95% CI 49.72–52.18) was lower than every comparison population, with no overlap between the Indian confidence interval and that of any other cohort. Effect sizes ranged from large to very large (Cohen's d = 0.83–3.25), with the smallest difference against the Austrian population and the largest against the Turkish population. All ten comparisons remained statistically significant after Holm–Bonferroni correction (adjusted $p < 0.05$).

Table 5
Upper airway morphometry by sex

Component	Male median (IQR)	Female median (IQR)	p-value	Cohen's d
Horizontal	82.00 (76.06–85.62)	76.33 (72.41–79.62)	< 0.01	0.83
Vertical	55.00 (50.31–58.51)	48.81 (45.39–52.29)	< 0.01	0.87
V/H ratio	0.67 (0.62–0.74)	0.64 (0.58–0.69)	0.12	0.17

Both the horizontal and vertical components were significantly greater in males than in females ($p < 0.001$), with large effect sizes (Cohen's d = 0.83 and 0.87 respectively), as shown in Table 5. In contrast, the V/H ratio did not differ significantly between sexes (0.67 vs 0.64; $p = 0.12$, $d = 0.17$), indicating that the proportional relationship between the two components is preserved despite differences in absolute size.

The total dataset for the vertical and horizontal components was divided by gender and plotted as shown in Fig. 3. For the horizontal component, male 10-year averages ranged from approximately 77 mm at age 20 to 84 mm at age 60, while female averages ranged from approximately 74 mm to 78 mm without a consistent directional trend. For the vertical component, male averages increased from approximately 48 mm at age 20 to 59 mm at age 60, while female averages remained relatively stable at approximately 46 to 50 mm. Across all age groups, males exceeded females in both components, with a clear age-related increase evident only in the male vertical component.

Pearson's correlation tests were conducted to assess associations between airway parameters and continuous age. Moderate positive correlations were observed between age and the vertical component in both males ($r = 0.40$, $p = 0.013$) and females ($r = 0.32$, $p = 0.006$), indicating a positive association between age and vertical component in this cross-sectional sample. The horizontal component showed no statistically significant association with age in either sex, despite a slight upward trend in the male average ($r = 0.19$, $p = 0.256$; females $r = 0.02$, $p = 0.836$). Age-related trends are visualized in Fig. 3 using 10-year age group categories to facilitate interpretation; however, these grouped averages are intended for visual clarity only, and the statistical inference reported above is based on the individual-level continuous data.

The measured lower incisor-to-vallecula working lengths were significantly greater in males (77.28 ± 6.62 mm) than in females (71.07 ± 6.35 mm; $p < 0.001$, Cohen's $d = 0.96$). Both values were modestly higher than those reported by Jha et al. in a North Indian cohort (70.5 ± 5.1 mm and 66.6 ± 5.0 mm respectively) [20], a difference of approximately 7 mm in males and 4 mm in females that may reflect differences in landmark definition, imaging position, or regional sampling within India.

The difference between the anatomical working length and the standard Macintosh blade lengths was quantified for both blade sizes and stratified by gender (Fig. 4). In males, the difference against the C-MAC Mac 3 blade showed a median of 33 mm (IQR 29–39 mm), which increased substantially against the longer C-MAC Mac 4 blade to a median of 60 mm (IQR 55–66 mm). A similar pattern was observed in females, with a median difference of 39 mm (IQR 36–44 mm) for the C-MAC Mac 3 blade and 66 mm (IQR 63–71 mm) for the C-MAC Mac 4 blade. Across both sexes, the consistently positive differences indicate that the standard blade lengths exceed the anatomical working length by a considerable margin, with the mismatch being most pronounced for the C-MAC Mac 4 blade. These findings reinforce the potential risk of over-insertion when using standard Macintosh blades in the Indian population and highlight the need for anatomically appropriate blade dimensions.

4. Discussion

This study provides a comprehensive quantitative analysis of upper airway anatomy in an Indian adult population and demonstrates significant inter-population and intra-population variability. Using CT-based morphometric measurements and standardized anatomical landmarks, the study characterizes differences in upper airway geometry across populations and examines variation within the Indian cohort based on age and gender. It further compares the measured anatomical working length against the blade working length of standard Macintosh blades, highlighting a mismatch relevant to laryngoscope selection and design.

Inter-Population Variation

Inter-population comparisons revealed statistically significant differences in both components of the upper airway. The horizontal component differed significantly between the Indian and Austrian populations ($p = 0.04$), while the vertical component (upper airway length) was significantly shorter in the Indian cohort than in all ten comparison populations, differences that were substantial in magnitude rather than marginal. Consistent with prior reports of regional variation in upper airway morphology, including documented differences between East Asian and European populations [3], these findings reinforce that airway dimensions should not be assumed uniform across populations when designing airway management devices.

Intra-Population Variation: Gender and Age

Within the Indian population, males exhibited significantly larger upper airway dimensions than females across both the horizontal and vertical components (both $p < 0.001$), with large effect sizes. This is

consistent with the established sexual dimorphism of craniofacial and pharyngeal anatomy, whereby males exhibit greater overall skeletal and soft-tissue dimensions than females [9]. Notably, while absolute dimensions differed markedly by sex, the V/H ratio was comparable between males and females, indicating that the proportional configuration of the upper airway is largely independent of sex even as its absolute scale is not. This distinction is directly relevant to device design: blade curvature, which reflects proportional airway geometry, may generalise across sexes, whereas blade length must account for sex-based differences in absolute dimensions.

Age-related analysis demonstrated similar patterns between sexes. The horizontal component showed no statistically significant association with age in either males ($r = 0.19$, $p = 0.256$) or females ($r = 0.02$, $p = 0.836$), despite a slight upward drift in the male average. In contrast, the vertical component exhibited a statistically significant, moderate positive correlation with age in both males ($r = 0.40$, $p = 0.013$) and females ($r = 0.32$, $p = 0.006$). While this is consistent with a possible age-associated increase in upper airway length, the finding should be interpreted with caution: the cross-sectional design cannot establish elongation over time, and it contrasts with earlier studies reporting age-related changes predominantly in females or describing a reduction in upper airway dimensions with advancing age due to soft-tissue remodeling [21].

Component-Based Representation of Airway Geometry

An important contribution of this study is its representation of upper airway anatomy using reproducible horizontal and vertical components. Because airway curvature is sensitive to head position, mouth opening, and imaging conditions, decomposing the airway into two orthogonal dimensions provides a more stable and reproducible description of its spatial configuration. This component-based framework enables standardized reporting and meaningful comparison across populations without reliance on curvature metrics that vary with posture, imaging, or methodology.

Comparison with Existing Blade Sizes

The measured anatomical WL (lower incisor-to-vallecula length) was 77.28 mm for males and 71.07 mm for females, modestly higher than the corresponding values of 70.5 mm and 66.6 mm reported previously [20]. Despite the difference in magnitude, both datasets consistently show a shorter anatomical WL in females than in males, and in both sexes an anatomical WL considerably shorter than the blade WL of commonly used Mac 3 and Mac 4 blades, indicating a potential mismatch between blade dimensions and anatomical reach.

Current clinical practice in India typically employs C-MAC Mac 3 blades for females and C-MAC Mac 4 for males [20]. However, the present data show that the anatomical WL is substantially shorter than the blade WL in both sexes. While this study does not prescribe specific blade sizes, this mismatch highlights the importance of revisiting the ergonomic compatibility of currently used devices, and motivates clinical investigation into whether current blade sizes are optimally suited for Indian patients and whether device design should be adapted accordingly.

Limitations

Despite its contributions, this study has certain limitations. First, the data were acquired with the mouth closed, which may differ from open-mouth anatomy during device use; however, the closed-mouth position provides a consistent and reproducible reference for comparative anatomical measurement. Second, the smaller number of male participants may have reduced the robustness of the age-related findings for the male vertical component. Third, as the data were obtained from a single tertiary-care centre, the findings may not fully capture the anatomical diversity of the broader Indian population.

5. Conclusion

This study provides a comprehensive CT-based morphometric assessment of the upper airway in an Indian adult population, establishing normative values for its horizontal and vertical components and demonstrating significant intra-population variation by gender and age alongside marked inter-population differences.

A notable finding is the relatively shorter vertical component (anatomical WL) in the Indian population compared with ten other nationalities, indicating a distinct, possibly steeper, airway configuration. Because the anatomical WL reflects the total insertion distance during laryngoscopy, its being considerably shorter than the blade WL of standard size 3 and size 4 Macintosh blades suggests a risk of over-insertion and reduced intubation efficiency with currently used devices. The shorter vertical component may further imply a steeper curvature, pointing to the need to reconsider not only blade length but also blade curvature to better match the airway's natural profile.

These findings underscore the value of population-specific reference data over assumed uniform anatomy, and the need for laryngoscope blades anatomically compatible with the Indian population. Although limited by closed-mouth CT imaging and a region-specific sample, the study offers a robust dataset from reproducible landmarks. Future work should compare existing blades against the measured airway profile to assess their suitability for this population and, if required, design and evaluate better-matched blades, while incorporating open-mouth imaging and broader geographic and ethnic representation.

Declarations

Funding Declarations

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Conflict of Interest Declarations

The authors have no competing interests to declare that are relevant to the content of this article.

Ethics Approval Statement

This retrospective cohort study was approved by the Institutional Ethics Committee of the All India Institute of Medical Sciences (AIIMS), New Delhi (IEC-09/07.02.2020, RP-01/2020). Given the retrospective nature of the study and the use of computed tomography data acquired as part of routine clinical care, the requirement for informed consent was waived by the Committee. All methods were performed in accordance with relevant institutional guidelines and regulations and in compliance with the ethical principles of the Declaration of Helsinki. This study did not involve cadaveric specimens and was conducted exclusively using computed tomography imaging of living adult subjects.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Harshit Mourya: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing. **Jay Dhariwal:** Conceptualization, Methodology, Formal analysis, Supervision, Writing – review & editing. **Anju Gupta:** Resources, Investigation, Formal analysis, Writing – review & editing. **Kaushik Mukherjee:** Conceptualization, Methodology, Formal analysis, Writing – review & editing. **Devasenathipathy Kandasamy:** Resources, Investigation, Writing – review & editing. **Nishkarsh Gupta:** Conceptualization, Methodology, Formal analysis, Supervision, Project administration, Writing – review & editing.

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Figures

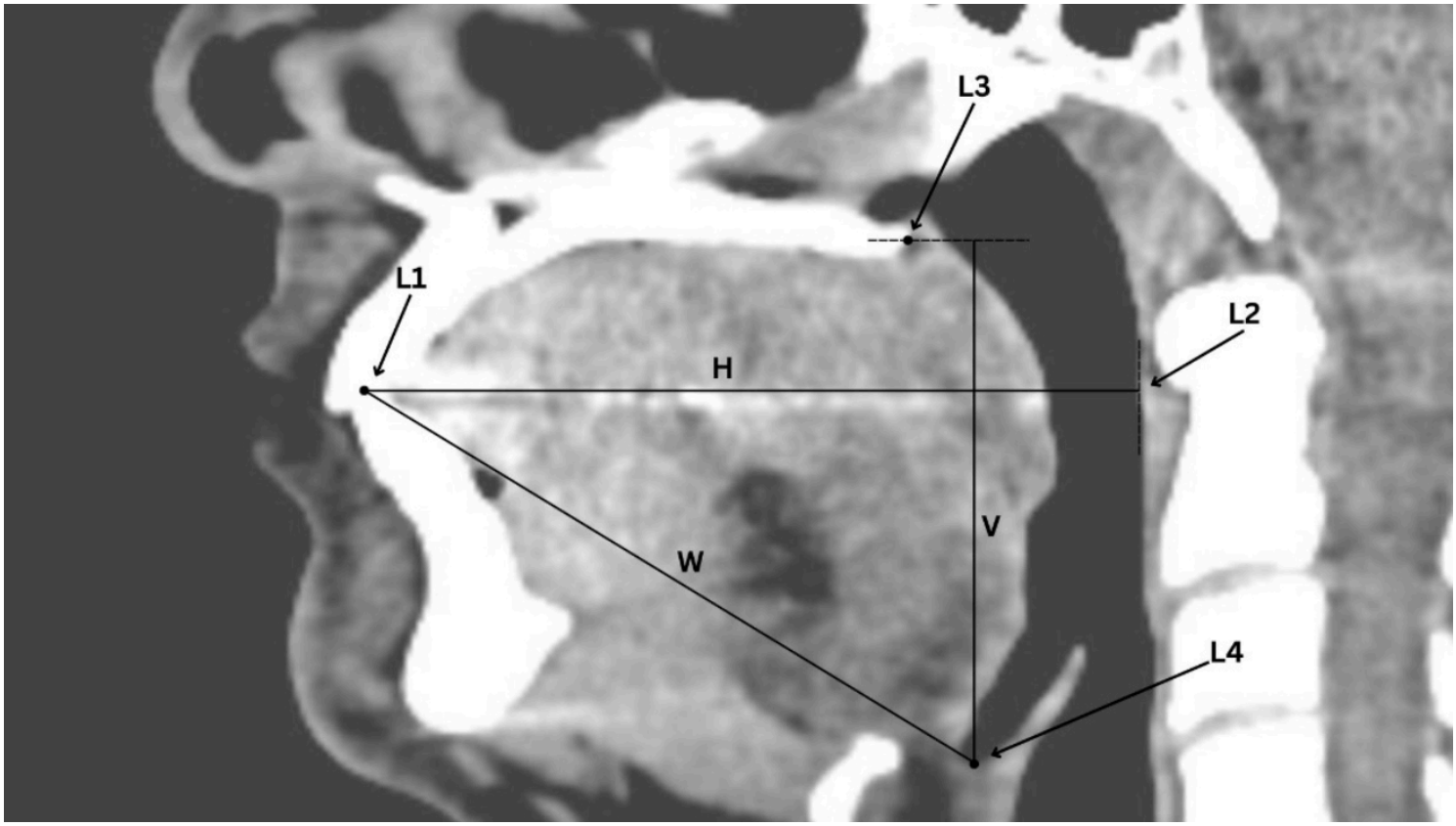


Figure 1

Mid-sagittal CT schematic illustrating the four anatomical landmarks (L1–L4) used to define the horizontal component (L1–L2), vertical component (L3–L4), and incisor-to-vallecula distance (L1–L4)

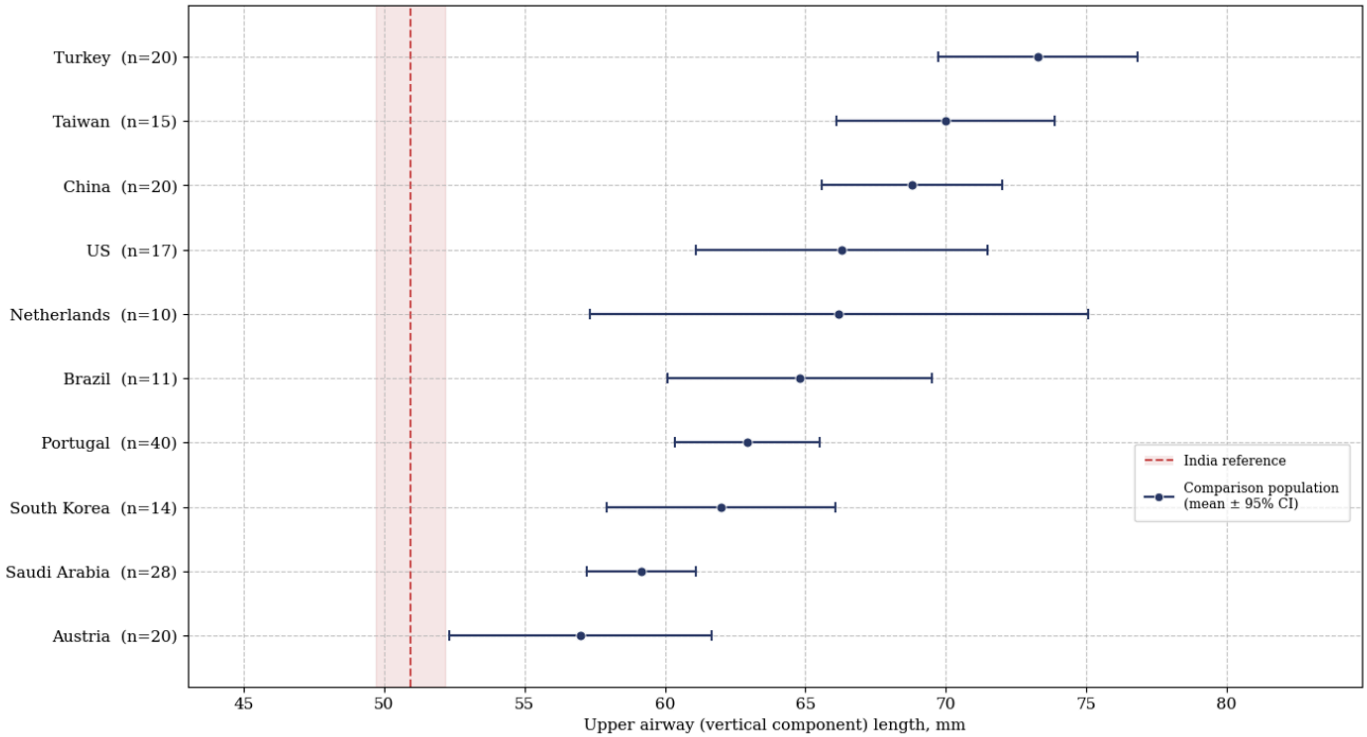


Figure 2

Comparison of the Vertical component of the Indian population with other nationalities

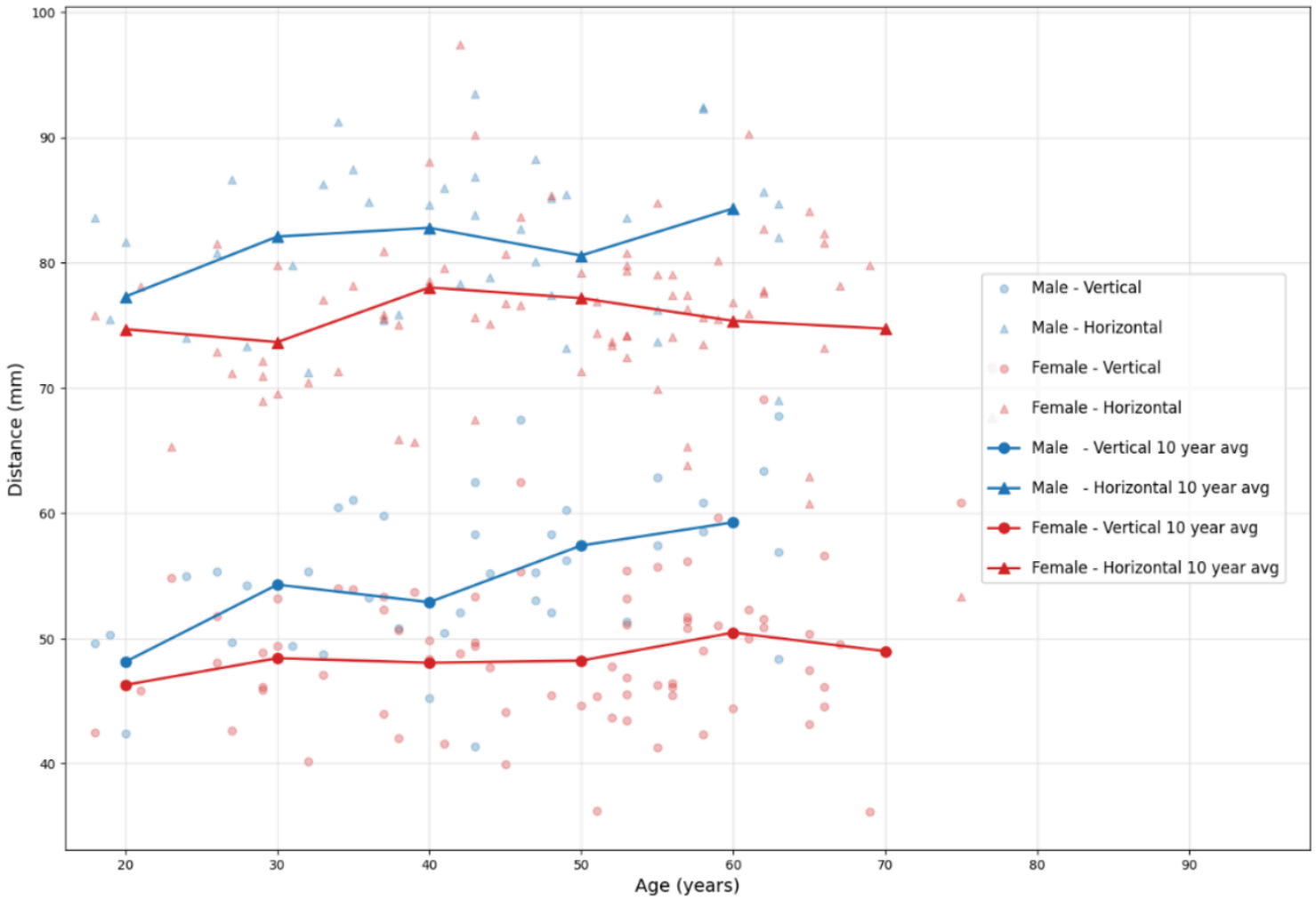


Figure 3

Change in horizontal and vertical components with respect to age in the male & female population

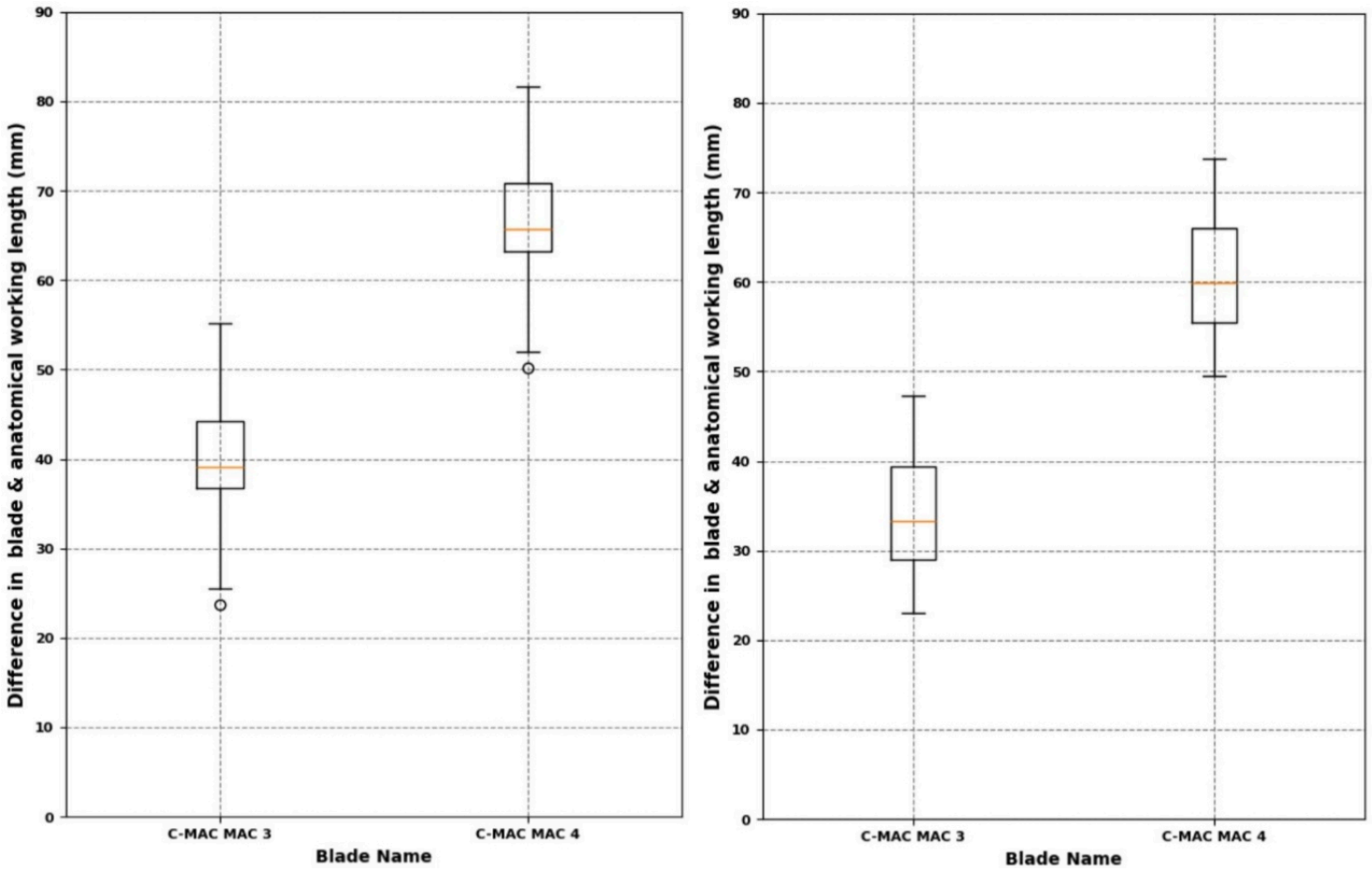


Figure 4

Difference of working length with Mac 3 and Mac 4 blades. Females in left and Males in right