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ORIGINAL ARTICLE

Application of Volumetric Assessment of the Maxillary Sinus for Facial Profile Determination in Forensic Odontology

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ABSTRACT

Introduction: Forensic odontology relies on craniofacial features for identification when traditional methods fail. The maxillary sinus, with its variable dimensions, offers potential for profiling, yet its link to facial profiles remains under explored. This study aims to assess whether CBCT-derived maxillary sinus dimensional ratios can reliably distinguish frontal and lateral facial profile types in a living population.

Methodology: This cross-sectional study enrolled 50 adults (18–60 years) at Kothiwal Dental College, Moradabad, with no craniofacial trauma or sinus pathology. Standardized frontal and lateral photographs categorized profiles (Oval, Square, Round; Convex, Straight, Concave) using anthropometric guidelines. CBCT scans measured bilateral sinus height, width, and depth, calculating ratios (H/W, H/D, W/D, left-right asymmetry). Two blinded observers assessed data, with reliability confirmed by ICC (>0.75). Spearman's correlation, Kruskal-Wallis, and linear discriminant analysis evaluated associations, using SPSS with $p<0.05$ significance.

Results: Analysis revealed significant gender differences in the Height-to-Width (H/W) ratio (males: 1.95±0.21, females: 1.82±0.24, p=0.033). Frontal profiles showed significant variations in H/W (oval: 1.98±0.43, p=0.047), H/D (round: 1.12±0.36, p=0.001), and W/D (round: 0.56±0.12, p=0.008). Side profiles exhibited significant differences in H/W (straight: 2.05±0.58, p=0.041), H/D (concave: 1.15±0.26, p=0.018), and W/D (concave: 0.58±0.18, p=0.021), suggesting sinus ratios as potential profile markers.

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Conclusion: Maxillary sinus ratios, particularly H/W, correlate with gender and facial profiles, enhancing forensic identification. CBCT provides a precise tool, though larger, diverse samples are needed to validate findings and address limitations like post-mortem applicability, advancing individualized profiling in forensic odontology.

KEYWORDS

• Facial profile • Maxillary sinus • Gender • CBCT • Morphometry

INTRODUCTION

Forensic odontology plays a pivotal role in human identification, particularly when traditional methods like fingerprints or DNA are unavailable, relying heavily on craniofacial features and dental structures.[1] The maxillary sinus, a prominent anatomical landmark, exhibits significant variability in size and shape, making it a potential candidate for forensic profiling.[2] Recent advancements in cone-beam computed tomography (CBCT) have enhanced the precision of sinus measurements, offering a non-invasive tool to explore its dimensions height, width, and depth in three-dimensional detail.[3] Studies have suggested that maxillary sinus characteristics may correlate with demographic factors like age and gender, yet their association with facial profiles remains underexplored.[4] Facial profiles, categorized as frontal (e.g., oval, square) and lateral (e.g., convex, straight), are critical in forensic reconstruction and identification, often assessed through anthropometric or photographic analysis.[5] The differential ratios of sinus dimensions (e.g., height-to-width, left-to-right asymmetry) could provide unique identifiers, bridging internal anatomy with external morphology, an area with limited research.[6] This study, "Front and Side Facial Profile Identification Using Differential Ratios of Maxillary Sinus Dimensions," aims to investigate whether CBCT-derived sinus ratios can reliably distinguish facial profile types in a living population. By integrating radiographic precision with observable facial traits, it seeks to enhance forensic identification techniques, particularly in cases involving skeletal remains or mass disasters where soft tissue is absent. Building on prior work that validates CBCT for sinus analysis and its forensic utility, this research addresses a gap in linking sinus morphometry to facial typology, potentially offering a novel, reproducible method for individualization in forensic odontology.

METHODOLOGY

Study Design

This observational cross-sectional study aims to evaluate the association between front and side facial profiles and differential ratios of maxillary sinus dimensions. Data will be collected at a single time point from a living population to establish correlations and potential individualizing features.

Study Population

The study will include adults aged 18–60 years who have no history of craniofacial trauma, surgery, or sinus pathology, ensuring that maxillary sinus morphology remains unaffected by external factors. Participants must have high-quality cone-beam computed tomography (CBCT) scans encompassing the maxillofacial region, allowing precise measurement of sinus dimensions. Additionally, they must provide informed consent to participate and supply standardized facial photographs in frontal and lateral views for profile assessment. Individuals with congenital craniofacial anomalies, such as cleft palate, chronic sinusitis, or orthodontic appliances that could alter sinus anatomy, will be excluded to maintain measurement consistency. Similarly, participants with poor-quality CBCT scans (e.g., those exhibiting motion artifacts) or incomplete photographic data will be excluded to ensure data reliability and validity for correlating sinus dimensions with facial profiles in this forensic odontology investigation.

Sample Size Calculation: Assuming a moderate correlation (r=0.4) between sinus ratios and facial profiles, with α=0.05 and power=80%, a minimum of 45 participants is required (calculated via G*Power). To account for

variability and subgroup analysis, a target of 50 participants will be enrolled.

Setting

The study will be conducted at a Kothiwal Dental College, Moradabad in the department of Orthodontics with access to CBCT facilities and photographic equipment. Ethical approval will be obtained from the institutional ethics committee, and informed consent will be secured from all participants.

Data collection for this study will encompass facial profile assessment and CBCT measurement of maxillary sinus dimensions. Standardized photographs will capture each participant's frontal (full face) and lateral (right-side profile) views using a digital camera (e.g., Canon EOS 80D) with a 50 mm fixed focal length and consistent softbox lighting. Participants will be positioned 1 meter from the camera, maintaining a neutral expression and head alignment via a cephalometric holder, with a ruler included for scale. Two trained observers will categorize profiles into predefined types lateral (convex, straight, concave) and frontal (oval, square, round) based on anthropometric guidelines, with inter-observer agreement evaluated using Cohen's kappa. Concurrently, maxillary sinus dimensions will be measured bilaterally using a CBCT scanner (e.g., Planmeca ProMax 3D) set at 90 kVp, 5 mA, and 0.15 mm voxel size, focusing on the maxillofacial region. Scans will be analyzed with software (e.g., Romexis Viewer) to record height (*Figure 1*) (vertical distance, coronal view), width (*Figure 2*) (mediolateral distance, axial view), and depth (*Figure 3*) (anteroposterior distance, sagittal view). Differential ratios, including Height-to-Width (H/W), Height-to-Depth (H/D), Width-to-Depth (W/D), and left-to-right asymmetry (e.g., Left Height/Right Height), will be calculated. Two radiologists, blinded to facial profile data, will independently measure dimensions, with averages taken and reliability assessed via the Intra-class Correlation Coefficient (ICC). Recorded variables will include demographics (age, gender), facial profile types, sinus dimensions (mm), differential ratios, and the primary outcome: correlation between sinus ratios and facial profile types, facilitating forensic identification analysis.

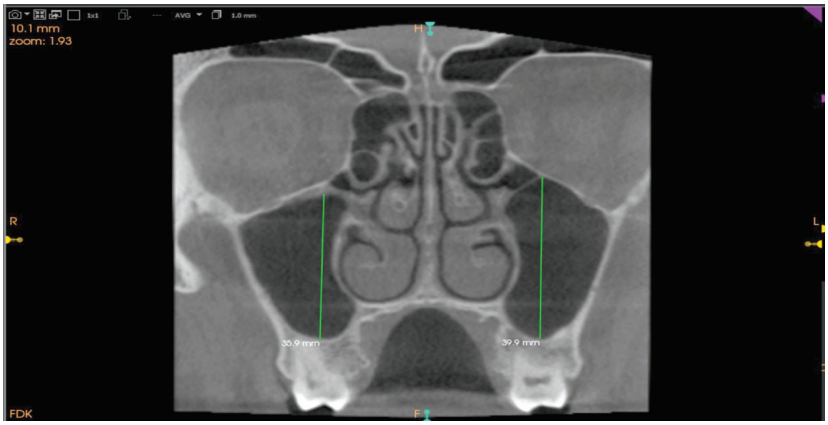

Figure 1: CBCT image of maxillary sinus measuring height (in mm)

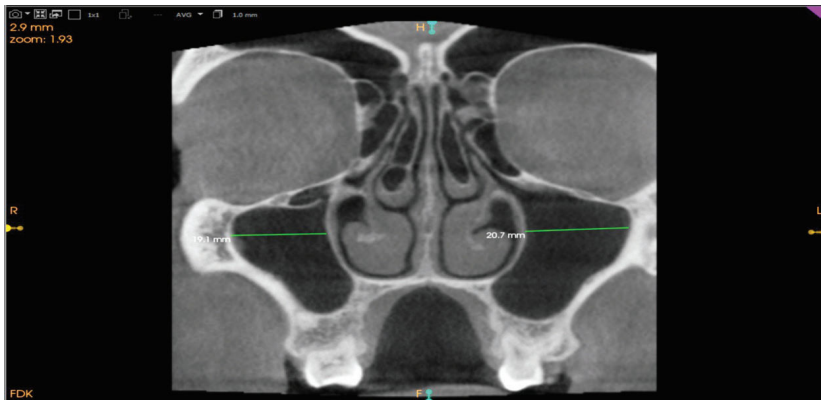

Figure 2: CBCT image of maxillary sinus measuring width (in mm)

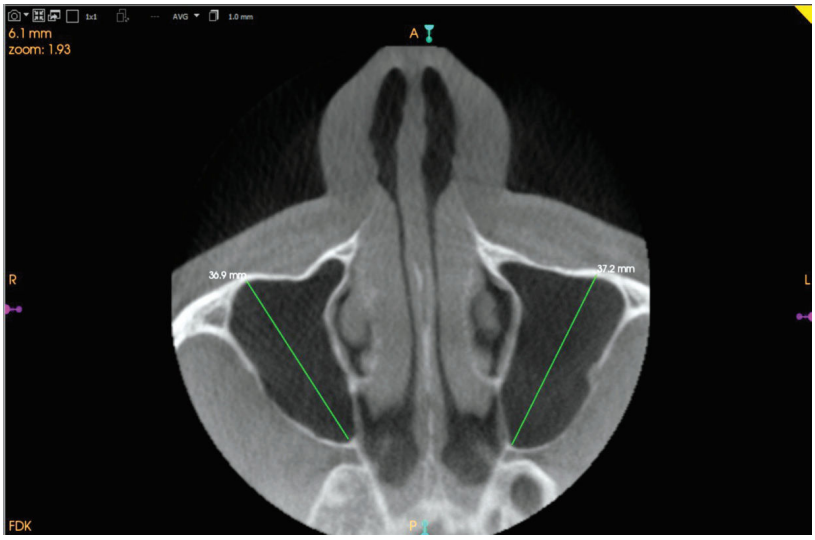

Figure 3: CBCT image of maxillary sinus measuring depth (in mm)

Data Analysis

Descriptive statistics will summarize the mean, standard deviation, and range of sinus dimensions (height, width, depth) and their differential ratios (e.g., H/W, H/D, W/D), alongside the frequency and percentage of facial profile types (e.g., % convex, % oval). Spearman's Rank Correlation will assess relationships between continuous sinus ratios and either ordinal profile classifications or continuous anthropometric measures derived from photographs. For comparative analysis, the Kruskal-Wallis Test will examine differences in sinus ratios across facial profile types (e.g., convex vs. straight vs. concave) if data is non-normal, as determined by the Shapiro-Wilk test, while the Mann-Whitney U Test will compare ratios between genders and assess left-right asymmetry. Linear discriminant analysis will explore whether sinus ratios can predict facial profile categories, with classification accuracy reported as a percentage. Reliability of measurements will be evaluated using the Intra-class Correlation Coefficient (ICC), with values exceeding 0.75 considered acceptable for inter-observer agreement. A significance level of $p<0.05$ will be adopted to determine statistical significance. All analyses will be conducted using SPSS software, ensuring robust handling of the dataset and reliable interpretation of results for forensic identification purposes.

Quality Control

To ensure the integrity and reliability of the study, rigorous quality control measures will be implemented. Blinding will be employed, with radiologists measuring CBCT scans kept unaware of the photographic facial profile data, and profile assessors blinded to the CBCT results, minimizing bias in the assessment of maxillary sinus dimensions and facial classifications. Calibration will involve pre-study training for all investigators to standardize photographic techniques and CBCT measurement protocols, aiming for an Intra-class Correlation Coefficient (ICC) greater than 0.8 to confirm high inter-observer reliability. Additionally, data validation will be conducted by rechecking 10% of all measurements both photographic and CBCT-derived to ensure consistency and accuracy across the dataset, addressing potential errors and reinforcing the study's reproducibility for forensic odontology applications.

RESULTS

The bivariate analysis of maxillary sinus parameters between males (n=25) and females (n=35) revealed a statistically significant difference in the Height-to-Width (H/W) ratio, with males showing a higher mean (1.95 ± 0.21) than females (1.82 ± 0.24, $p=0.033$) (*Table 1*). In contrast, the Height-to-Depth (H/D) ratio was slightly higher in females (1.05 ± 0.25) than males (0.92 ± 0.34), and the Width-to-Depth (W/D) ratio was lower in females (0.52 ± 0.15) than males (0.58 ± 0.11), but these differences were not significant ($p=0.093$ and $p=0.094$, respectively). These findings infer that the H/W ratio may serve as a gender-specific

Table 1: Comparison of outcome variables in male and females

Parameters of maxillary sinus	Male (n=25)	Female (n=35)	p-value
	Mean ± SD	Mean ± SD	
H/W	1.95 ± 0.21	1.82 ± 0.24	0.033*
H/D	0.92 ± 0.34	1.05 ± 0.25	0.093
W/D	0.58 ± 0.11	0.52 ± 0.15	0.094

Height-to-Width (H/W), Height-to-Dept h (H/D), Width-to-Depth (W/D)

The comparison of outcome variables among participants with different front profiles showed statistically significant differences across all parameters (*Table 2*). The Height-to-Width (H/W) ratio was highest in the oval group (1.98 ± 0.43), followed by square (1.85 ± 0.32) and round profiles (1.72 ± 0.16), with a *p*-value of 0.047. Height-to-Depth (H/D) ratio varied significantly ($p = 0.001$), being highest in the round group (1.12 ± 0.36). Width-to-Depth (W/D) ratio also differed significantly ($p = 0.008$), with the round profile showing the highest mean (0.56 ± 0.12). These results indicate a strong association between front profile type and sinus morphological dimensions.

Table 2: Comparison of outcome variables in participant with different front profiles

Parameters of maxillary sinus	Oval (n=15)	Square (n=25)	Round (n=20)	p-value
	Mean ± SD	Mean ± SD	Mean ± SD	
H/W	1.98 ± 0.43	1.85 ± 0.32	1.72 ± 0.16	0.047*
H/D	0.98 ± 0.24	0.78 ± 0.26	1.12 ± 0.36	0.001*
W/D	0.48 ± 0.18	0.42 ± 0.14	0.56 ± 0.12	0.008*

Height-to-Width (H/W), Height-to-Depth (H/D), Width-to-Depth (W/D)

Post hoc analysis using Tukey's test revealed significant differences in arch form comparisons (*Table 3*). oval vs round showed significant variation in height-to-width ratio (p=0.04), while square vs round demonstrated significant differences in both Height-to-Depth and Width-to-Depth ratios (p=0.00). No significant differences were found between oval and square forms across all dimensional ratios (p>0.05). These findings suggest distinct morphological characteristics between rounded and angular arch forms.

Table 3: Post Hoc analysis with Tukey test

Pairwise group	Oval vs Square	Oval vs Round	Square vs Round
	p-value	p-value	p-value
H/W	0.41	0.04*	0.35
H/D	0.10	0.34	0.00*
W/D	0.41	0.24	0.00*

Height-to-Width (H/W), Height-to-Depth (H/D), Width-to-Depth (W/D)

The comparison of maxillary sinus parameters among participants with different side profiles revealed statistically significant differences in all three ratios (*Table 4*). The Straight profile group showed the highest Height-to-Width (H/W) ratio (2.05 ± 0.58), followed by Convex (1.86 ± 0.32) and Concave (1.68 ± 0.36), with a *p*-value of 0.041. The Concave group had the highest Height-to-Depth (H/D) ratio (1.15 ± 0.26), while the Convex group had the lowest (0.82 ± 0.35), indicating a significant variation ($p = 0.018$). Width-to-Depth (W/D) ratio was also significantly different ($p = 0.021$), with the concave profile showing the highest value (*Table 5*). These findings suggest that side profile shapes influence sinus morphology.

Table 4: Comparison of outcome variables in participants with side profiles

Parameters of maxillary sinus	Convex (n=26)	Concave (n=14)	Straight (n=20)	p-value
	Mean ± SD	Mean ± SD	Mean ± SD	
H/W	1.86 ± 0.32	1.68 ± 0.36	2.05 ± 0.58	0.041*
H/D	0.82 ± 0.35	1.15 ± 0.26	0.98 ± 0.38	0.018*
W/D	0.45 ± 0.12	0.58 ± 0.18	0.52 ± 0.14	0.021*

Height-to-Width (H/W), Height-to-Depth (H/D), Width-to-Depth (W/D)

Tukey's post hoc analysis revealed significant differences in arch form comparisons (Table 5). Concave vs Straight forms showed significant variation in Height-to-Width ratio (p=0.04), while Convex vs Concave forms demonstrated significant differences in both Height-to-Depth and Width-to-Depth ratios (p=0.01 and p=0.02 respectively). No significant differences were found between Convex and Straight forms across all dimensional ratios (p>0.05).

Table 5: Post hoc analysis with Tukey test

Pairwise group	Convex vs Concave	Convex vs Straight	Concave vs Straight
	p-value	p-value	p-value
H/W	0.46	0.30	0.04*
H/D	0.01*	0.26	0.33
W/D	0.02*	0.23	0.45

Height-to-Width (H/W), Height-to-Depth (H/D), Width-to-Depth (W/D)

DISCUSSION

The study provides compelling evidence for the utility of maxillary sinus morphology in forensic odontology, revealing significant correlations with gender and facial profiles. Gender analysis indicated a statistically significant difference in the Height-to-Width (H/W) ratio (p=0.033), with males showing a higher mean than females, consistent with Deshpande,4 who identified gender dimorphism in sinus dimensions using CBCT. However, Height-to-Depth (H/D) and Width-to-Depth (W/D) ratios showed no significant differences, suggesting H/W as a more robust gender marker, aligning with Tambawala *et al.* on sinus width variations.[7,8] This partial dimorphism may reflect sex-specific craniofacial development, as noted by Krishan *et al.*[1]

Front profile comparisons revealed significant differences across all ratios. Oval profiles exhibited the highest H/W, while round profiles had the highest H/D, supporting previous study,[9] who linked sinus shape to facial typology via CBCT. The W/D ratio was highest in round profiles, suggesting profile-specific sinus adaptations, consistent with Sahlstrand-Johnson *et al.*,[2] who emphasized sinus volume variability. Side profile analysis further confirmed significant differences, with straight profiles showing the highest H/W and concave profiles the highest H/D. These findings align with Moustansir et al.,[3] who reported sinus morphology influencing lateral facial contours, and De Greef *et al.*,[4] who highlighted facial profile utility in forensic reconstruction.

The results extend prior research by Uthman *et al.*,[8] who validated CBCT for sinus measurements, suggesting that differential ratios could serve as unique identifiers in forensic contexts, such as mass disasters or skeletal remains identification. The significant associations observed here contrast with Jain *et al.*,[10] who found weaker sinus-profile links, possibly due to smaller sample sizes or 2D imaging limitations. According to Chen *et al* maxillary dimensions exhibited no significant difference among the 3 skeletal patterns.[11] This study's use of CBCT enhances precision, corroborating Maspero *et al.* on its forensic potential.[6] Hanafi *et al.* concluded that benefit of using orthodontic profiles for enhancing model accuracy beyond basic demographic predictors like age, sex and body mass index.[12]

Limitations include the sample size, which, while adequate for initial findings, may limit statistical power and generalizability, particularly across diverse ethnicities. Exclusion of pathological cases restricts applicability to real-world forensic scenarios, where sinus alterations may occur. Additionally, the study's focus on living subjects overlooks post-mortem changes, a gap also identified by Tambawala *et al.*[7]

Future perspectives in forensic odontology could involve larger, multi-ethnic cohorts to validate these findings, as suggested by De Greef *et al.*[4] Integrating machine learning, as proposed by Guo et al. could refine sinus-profile predictive models, enhancing accuracy.[13] Exploring soft tissue interactions or degraded remains, per Uthman *et al.*[8] could further broaden applicability, positioning this method as a reliable tool for victim identification and facial reconstruction in forensic practice.

CONCLUSION

The analysis of maxillary sinus ratios, especially the height-to-width (H/W) dimension, demonstrates significant correlations with both gender and facial profile characteristics, thereby improving forensic identification accuracy. Cone-beam computed tomography (CBCT) emerges as a reliable and precise imaging modality for such assessments. However, further research involving larger and more diverse population samples is necessary to strengthen these findings and overcome current limitations, including challenges in post-mortem applications.

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