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Radiographic assessment of sella turcica morphology and dimensions using digital lateral cephalometry

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Abstract:
Sella turcica morphology varies across populations, yet region-specific morphometric data for the Central Indian population remain limited despite its importance in orthodontic and craniofacial assessment. Therefore, it is of interest to evaluate the morphology and linear dimensions of the Sella turcica in 180 digital lateral cephalometric radiographs from individuals aged 12-65 years, with morphology classified using the Axelsson system. The mean anteroposterior diameter (10.73 ± 1.56 mm) was greater than Sellar length (8.97 ± 1.64 mm) and depth (7.29 ± 1.49 mm), while normal morphology was observed in 40.0% of cases, followed by oblique anterior wall (21.1%) and pyramidal dorsum sellae (18.3%), with no significant sex differences ($p > 0.05$). Increasing age was associated with dimensional remodeling during adolescence and relative morphometric stability in adulthood, whereas sexual dimorphism remained minimal. These findings establish region-specific reference values for the Central Indian population and provide clinically relevant data for orthodontic diagnosis, cephalometric analysis, craniofacial surgery and radiological evaluation.

Keywords: Sella Turcica (ST), cephalometric analysis, digital lateral cephalogram, morphometric analysis, craniofacial growth, orthodontic radiology

Background:
The sella turcica (ST) is a saddle-shaped depression located atop the sphenoid bone, which contains the pituitary gland (also known as the hypophysis or hypophyseal body) in the hypophyseal fossa. Due to the anatomical proximity to the pituitary gland, the optic chiasm, cavernous sinus and internal carotid arteries, the morphology of the sella turcica is a vital landmark for dealing with many skull based issues and lesions in imaging and neuroendocrine evaluation of the skull **[1, 2].** The significance of the ST lies not only in its anatomical value, but also as a valuable tool for craniofacial growth and developmental evaluation and hence also as an area of great interest in anatomy, orthodontics, oral radiology and maxillofacial diagnostics. The close embryological association of the sella turcica and the pituitary gland occurs during the development of the craniofacial structures, are formed from different germ layers and their anterior and posterior have different embryologic origins. Thus, abnormalities in the migration of neural crest cells, development of the cranial base or the development of the pituitary could lead to changes in the dimensions and morphology of the sellar **[2, 3].** Therefore, disorders of the ST have been linked to craniofacial syndromes, skeletal discrepancies, dental aberration and endocrine diseases which have all made the ST a potential indicator of developmental disturbance **[3, 4].** The center of sella turcica or "S point" is one of the most useful cephalometric landmarks and is part of various craniofacial analyses **[5]** that are used in orthodontic and dentofacial orthopedics. With the increasing frequency of digital cephalometry and the progress of computerization of cephalometric tracing systems, the clinical significance of the accurate identification and interpretation of sellar anatomy in diagnosis and treatment planning has also increased **[5, 6].** There is inter-individual variation both in size, shape and structure of the sella turcica. Other variations, including Sella turcica bridging, oblique anterior wall, pyramidal dorsum sellae, irregularity of the dorsum sellae and double contour of the sellar floor have been reported as common in both normal individuals and patients with craniofacial abnormalities **[7, 8].** There are several studies that have shown associations between these variations of the sellar morphology and impacted teeth, cleft lip and palate and a variety of genetic syndromes, indicating that the sellar morphology is related to underlying craniofacial developmental mechanisms **[4, 7 and 9].** Lateral cephalometric radiographs (LCR), computed tomography (CT) and cone-beam computed tomography (CBCT) are useful lateral imaging tools for accurately assessing linear sellar dimension: sellar length, depth, or anteroposterior diameter. These dimensions change with age, gender and racial differences as well as with pituitary diseases and pathology of the bones **[10-12].** Pituitary adenoma or pituitary hyperplasia may be detected by an increased size of sellar turcica, while sellar hypoplasia or abnormal sellar shape may be seen in developmental disorders or in endocrine disorders **[1].** Hence, in addition to its contribution to the diagnosis of the ST in the orthodontic field, systematic radiographic examination of the ST can also help to recognize areas of pathological involvement in the pituitary region. However, the recent investigations in various populations have shown that there is a significant ethnic and geographical difference in the size and shape of sellar in different individuals. Significant differences have been found in the incidence of sellar variants and in the normative morphometric value in various studies conducted in India, Saudi Arabia, Yemen, Eastern Asia and Europe **[8, 10, 11 and 13-16]** which suggests that morphometric norms must be particular to the different ethnic groups and cannot be taken as universal. This variance could be mediated by genetic background, environmental influences, growth of faces and image acquisition. Although several studies have been conducted in recent years with almost all being of international origin, little information is available in the literature about sella turcica morphology and dimensions in Indian population has been available which has got geographical inequalities, with the majority from Northern or Southern India **[13, 17]**. Therefore, it is of interest to improve the applicability of cephalometric

assessment in orthodontic, radiographic and craniofacial clinical practice and to help develop regional normative standards.

Materials and Methods:

Study design and setting:

This hospital based cross-sectional study was done in the Dept. of Anatomy, M.G.M. Medical College and M.Y. Hospital, Indore, in association with Dept of Oral Medicine and Radiology, Government College of Dentistry Indore.

Study duration and ethical approval:

It was done in one year after approval by Institutional Scientific Review Committee and Institutional Ethics Committee. Ethical clearance applied before data collection started. All participants were asked about the objectives and nature of the study and written informed consent was obtained in Hindi and English from everyone who participated. Confidentially and anonymity of all the X-rays were ensured during the process of investigation.

Study population and sampling:

A total of 180 populations (Central Indian) aged 12 to 65 years irrespective of sex were recruited. This period allowed for the evaluation of development and ageing related alterations of sellar shape and size during adolescence and adulthood. Sample size was deemed suitable for previously published cephalometric morphometric studies that examined the dimensions of the sella turcica in similar populations as this sample and the number of subjects allowed for these subsamples according to their age and sex distribution. The methods used were a retrospective convenience sampling. The digital lateral cephalograms that were saved in the Departmental archives under Oral Medicine and Radiology were screened sequentially based on their first author's ID numbers and according to the inclusion/exclusion criteria of the study.

Eligibility criteria:

The criteria for inclusion of radiographs were age between 12-65 years in the Central Indian population with normal digital lateral cephalometric appearances without signs of craniofacial trauma and radiographs that were well exposed to show the sella turcica. To ensure good visualization of sellar margins that might bias morphometric measurements, X-rays were omitted when there was a history of craniofacial trauma, surgery, congenital craniofacial deformities or syndromic conditions.

Radiographic equipment and imaging protocol:

All lateral cephalometrics were taken with the Castellini X-Radius Trio Plus imaging system and evaluated with the iRYS digital imaging software, complete with integrated digital measuring scale. Standard exposure parameters were used to obtain radiographs, while uniform standardization of radiographic images ensured uniformity of image quality and avoiding magnification error. The imaging system worked well with high spatial resolution ranging from 5.6–5.7 line pairs/mm and still maintained adequate contrast resolution which allowed an accurate visualization of the craniofacial landmarks and sellar boundaries. Subjects were seated with their natural head posture while the Frankfort flat lying parallel to the floor plane when the images were acquired. Images were obtained with a fixed imaging protocol in order to obtain the same geometry throughout and eliminate radiographic distortion as far as possible.

Cephalometric standardization and measurements:

The analyses of cephalometric data were made digitally under standardized viewing conditions, using calibrated imaging software. Anatomical landmarks were located and followed before measuring. A midsagittal reference line and Frankfort horizontal plane were used for standardization of measurements according to the methods described by Silverman and Kisling. Three linear dimensions of sella turcica were examined: antero-posterior diameter, sellar depth and sellar length. The distance between tuberculum sellae and the tip of the dorsum sellae was considered to be Sellar length. The depth of sellar was calculated as the distance from a line drawn between tuberculum sellae and dorsum sellae to the deepest part of the sellar floor, in a perpendicular direction. The AP diameter was determined between the highest point of the tuberculum sellae and the most posterior point on the posteroinferior border of hypophyseal fossa.

Morphological classification:

Morphological analysis of the sella turcica was carried out, using the system suggested by Axelsson *et al.* The X-rays were classified into 6 morphotypes, namely, normal morphotype, oblique anterior wall, sella turcica bridging out of the sellar floor, double contour of the sellar floor, irregularity, or notching out of the sellar dorsum and pyramidal sellar dorsum. The five predominant morphological categories found during assessment were assigned to each radiograph.

Calibration and reliability of observers:

Observers were first calibrated prior to the study to ensure that the identification and measurement of landmarks was consistent across the observers. Intra-observer reliability was ensured by a second evaluation of a portion of these photographs after two weeks to reduce the possibility of measurement bias. High reproducibility and consistency of the cephalometric tracing protocol was found with repeated measurements.

Statistical analysis:

All the data were entered in Microsoft Excel and analyzed with SPSS version 29.0 (IBM Corp., Armonk, NY, USA). All study variables were subjected to descriptive statistical analysis, which included mean, standard deviation, minimum and Maximum, frequencies and percentages calculation. An independent sample t-test was used for the comparisons between males and females in the case of continuous variables and chi-square test was used for the comparisons in the case of categorical variables. To assess age-wise differences in sellar dimensions, one way analysis of variance (ANOVA) was used and the Pearson's correlation

coefficient was used to assess correlations among sellar dimensions. All analyses were statistically significant at p-value of < 0.05.

Results:

The study included 180 digital lateral cephalometric radiographs of subjects aged 12–65 years from the Central Indian population. Equal numbers of males and females were included to assess sex-related differences in the morphology and dimensions of the sella turcica. **Table 1** shows the demographic distribution. The study comprised 90 males (50.0%) and 90 females (50.0%). The largest proportion belonged to the 12–25-year age group (92; 51.1%), followed by >25–45 years (58; 32.2%) and >45–65 years (30; 16.7%). The overall linear dimensions are presented in **Table 2**. The mean sellar length was 8.97 ± 1.64 mm (range: 4.8–12.9 mm), depth was 7.29 ± 1.49 mm (range: 3.2–11.2 mm) and AP diameter was 10.73 ± 1.56 mm (range: 5.9–15.7 mm). Thus, the dimensions followed the order AP diameter > length > depth. **Table 3** compares the sellar dimensions between males and females. Mean length was slightly higher in males (9.06 ± 1.55 vs. 8.87 ± 1.71 mm; p = 0.446). Mean depth (7.16 ± 1.62 vs. 7.42 ± 1.33 mm) and AP diameter (10.59 ± 1.54 vs. 10.87 ± 1.57 mm) were slightly higher in females, but these differences were not statistically significant (p > 0.05). Thus, none of the measured dimensions showed a significant sex-related difference. The sex-wise ranges are shown in **Table 4**. Length ranged from 4.8–12.2 mm in males and 5.6–12.9 mm in females; depth from 3.2–11.2 mm and 4.3–11.0 mm, respectively; and AP diameter from 7.4–15.7 mm and 5.9–15.5 mm, respectively. Considerable overlap was observed between the two sexes. The distribution of sellar morphologies is presented in **Table 5**. Normal morphology was most common (72; 40.0%), followed by oblique anterior wall (38; 21.1%), pyramidal dorsum sellae (33; 18.3%) and irregularity/notching (29; 16.1%). Double contour of the sellar floor was observed in 6 subjects (3.3%), while bridging was least frequent (2; 1.1%). **Table 6** shows the morphological configurations associated with the extreme sellar dimensions. The minimum length was 4.8 mm in a notching morphology, while the maximum length was 12.9 mm in normal morphology. The minimum depth (3.2 mm) and AP diameter (5.9 mm) were associated with pyramidal morphology, whereas the maximum depth (11.2 mm) occurred in normal morphology and the maximum AP diameter (15.7 mm) in the oblique anterior wall type. Among subjects younger than 25 years, **Table 7** shows a weak but significant negative correlation between length and depth (r = −0.22, p = 0.007). Length and AP diameter showed a weak, non-significant positive correlation (r = 0.159, p = 0.051), whereas depth and AP diameter demonstrated a moderate positive correlation (r = 0.511, p < 0.001). Among subjects older than 25 years, **Table 8** demonstrated a significant moderate positive correlation between length and AP diameter. Correlations between length and depth and between depth and AP diameter were weak and non-significant. **Figure 1** presents the age distribution of the study population. **Figure 2** graphically demonstrates that AP diameter was the largest mean sellar dimension, followed by length and depth. **Figure 3** shows broadly comparable sellar dimensions between males and females, consistent with the non-significant sex-wise comparisons. **Figure 4** illustrates the predominance of normal sellar morphology, followed by oblique anterior wall and pyramidal dorsum sellae. **Figure 5** presents a representative lateral cephalometric radiograph showing the anatomical landmarks and linear measurements used for assessment of the sella turcica.

Table 1: Demographic distribution of study population

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	90	50.0
	Female	90	50.0
Age Group (years)	12–25	92	51.1
	>25–45	58	32.2
	>45–65	30	16.7
Total		180	100

Table 2: Overall Linear dimensions of the sella turcica

Parameter	Mean ± SD (mm)	Minimum (mm)	Maximum (mm)
Length	8.97 ± 1.64	4.8	12.9
Depth	7.29 ± 1.49	3.2	11.2
AP Diameter	10.73 ± 1.56	5.9	15.7

Table 3: Comparison of linear dimensions of the sella turcica between male and female subjects

Parameter	Male Mean ± SD (mm)	Female Mean ± SD (mm)	p-value
Length	9.06 ± 1.55	8.87 ± 1.71	0.446
Depth	7.16 ± 1.62	7.42 ± 1.33	>0.05
AP Diameter	10.59 ± 1.54	10.87 ± 1.57	>0.05

Table 4: Range of Linear dimensions according to gender

Parameter	Male Range (mm)	Female Range (mm)
Length	4.8–12.2	5.6–12.9
Depth	3.2–11.2	4.3–11.0
AP Diameter	7.4–15.7	5.9–15.5

Table 5: Distribution of morphological variants of the sella turcica

Morphological Variant	Frequency (n)	Percentage (%)
Normal morphology	72	40.0
Oblique anterior wall	38	21.1
Pyramidal dorsum sellae	33	18.3
Irregularity/notching	29	16.1
Double contour of sellar floor	6	3.3
Sella turcica bridging	2	1.1

Table 6: Association of morphological variants with extreme sellar dimensions

Parameter	Minimum Value	Associated Morphology	Maximum Value	Associated Morphology
Length	4.8 mm	Notching	12.9 mm	Normal morphology
Depth	3.2 mm	Pyramidal type	11.2 mm	Normal morphology
AP Diameter	5.9 mm	Pyramidal type	15.7 mm	Oblique anterior wall

Table 7: Correlation between sellar dimensions in subjects <25 years

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Comparison	Correlation Coefficient (r)	p-value	Interpretation
Length vs Depth	-0.22	0.007	Weak negative correlation
Length vs Diameter	0.159	0.051	Not significant
Depth vs Diameter	0.511	<0.001	Moderate positive correlation

Table 8: Correlation between sellar dimensions in subjects >25 years

Comparison	Correlation Pattern	Statistical Significance
Length vs Diameter	Moderate positive correlation	Significant
Length vs Depth	Weak correlation	Not significant
Depth vs Diameter	Weak correlation	Not significant

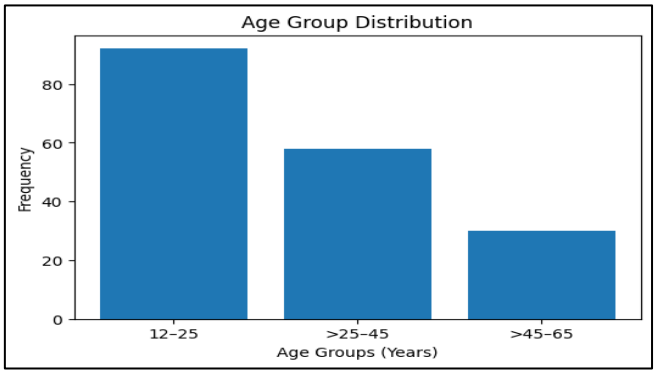


Figure 1: Age-wise distribution of study participants

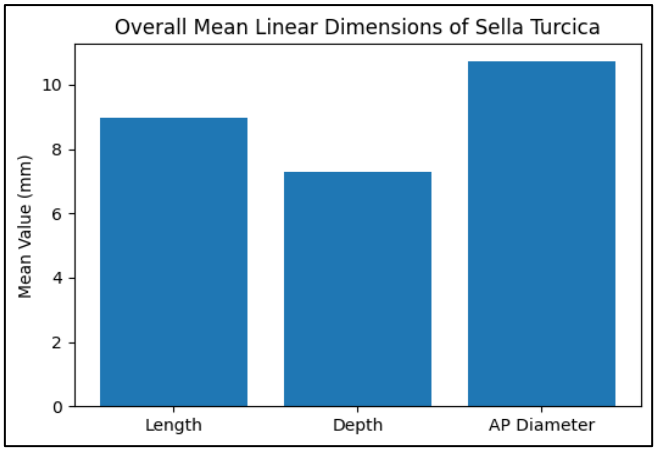


Figure 2: Overall mean linear dimensions of the sella turcica

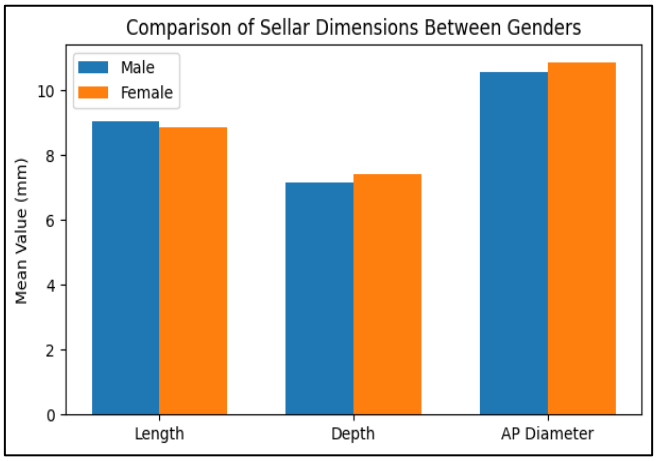


Figure 3: Comparison of linear dimensions between male and female subjects.

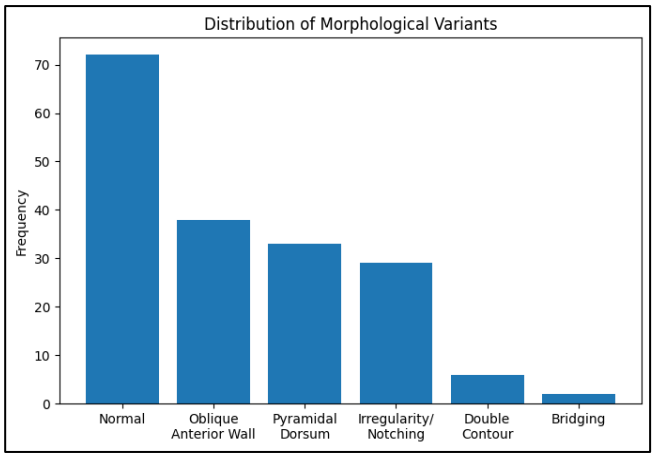


Figure 4: Distribution of morphological variants of the sella turcica

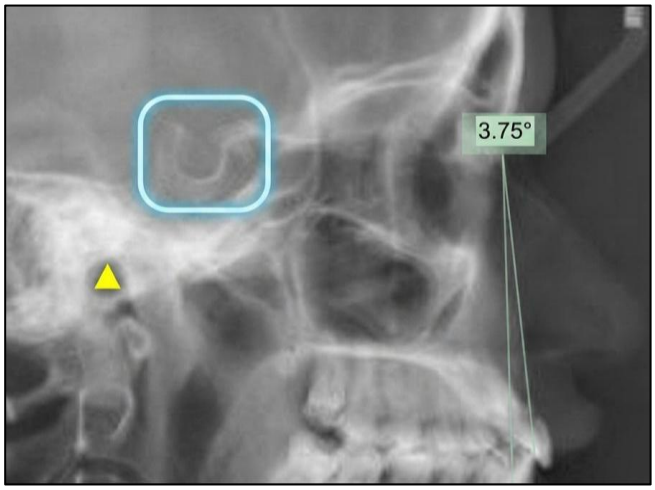


Figure 5: Digital lateral cephalometric radiograph of the sella turcica

Discussion:

The present study aims to analyze the morphology and linear dimensions of the sella turcica in a population from Central India obtained from standardized digital laterals cephalometric radiograph. The findings showed that AP diameter was the largest sellar dimension with sellar length being the second largest and sellar depth being the third largest. The most

common radiological pattern was normal morphology and the most common morphological variants were obliqueness of the anterior wall of the sella turcica and the presence of a pyramidal dorsum sellae. No significant sexual differences were found in sella dimensions and an age difference found in dimensional correlation indicated continuing developmental remodelling in the craniofacial system of the sella turcica throughout the period of craniofacial maturation. The results are important normative information for the Central Indian population and will help the evidence of population variability in the morphology of sellar. The sella turcica is always viewed and seen in relation to the pituitary gland and adjacent cranio central base structures and therefore is one of the most important cephalometric landmarks. Anatomical and radiological studies have focused recently on the variation in sellar morphology as being indicators of developmental processes involving migration of the neural crest cells, growth of the cranial base and pituitary morphogenesis. Therefore, assessment procedure of the sella turcica has become more and more important in the field of orthodontic diagnosis, oral radiology, craniofacial diagnosis and neuroendocrine assessment **[15, 18].** The average sellar length, depth and anteroposterior diameter in this study were 8.97 ± 1.64 mm, 7.29 ± 1.49 mm and 10.73 ± 1.56 mm, respectively. The AP diameter was the widest diameter recorded from the sellar plane, depicting a greater degree of horizontal than of vertical growth. The dimensional changes observed in this study are also observed by Surana *et al.* and Khaitan *et al.* in Indian population, who reported that the APD generally is greater than other linear measurement of the skull on cephalometric analysis **[1, 9].** Identical pattern of funicular closure was reported in several other populations, such as the Romanians, the Saudi people and Eastern Asia, but the exact timings varied between studies due to the inter-ethnic variability, differences in the skeletons and imaging techniques used **[5, 7, 11].** The results of these investigations suggest the notion of population-specific reference values over the concept of universal cephalometric values. An Indian radiological survey by Goyal and Nagapurkar also showed age-related variation in sellar dimensions. Among 300 subjects, normal sellar morphology was observed in 66.7%, while several sellar dimensions increased up to the fifth or sixth decade before declining thereafter **[19]**. There were no significant sex differences in the present study. Males were slightly longer in sellar length (SLL) and females were slightly deeper in depth (SD) but the differences between the sexes were not statistically significant in anteroposterior diameter (APD). The findings of the present study are similar to the study conducted by others such as Arthisri *et al.*, Chou *et al.* and Surana *et al.* which also reported on a slight or inconsistent sexual difference in sellar size **[1, 3, 7].** Other reports, however, have reported as sexually dimorphic a much greater sellar size in males, which may be related to differences in cranial base size and in overall skeletal growth patterns **[5, 11].** The differences between studies could be due to factors such as the variety in sample size, age distribution, ethnic differences, skeletal classification and imaging modality. The present results imply that setting a specific normative standard for males and females may not be justified for the Central Indian population with regards to their weight-for-height (WFH) characteristics. All of the radiographs were analyzed morphologically and out of the total number of radiographs, the normal morphology was the most common and it comprised 40%. More recently, in the Indian, Saudi Arabia (SA) and Eastern Asia it has been reported that there was no significant deviation from normal morphology in healthy populations **[3, 5, 7].** The percentage of normal morphology found in the present study was a little less than in some international studies and indicates a high morphological variability in Central Indian population. This variation can be interpreted in terms of the variability in gene frequencies among various regions of the country and the variation in the timing of the occurrence of different elements of the craniofacial development. The most common morphological variants were found to be the oblique anterior wall morphology, the pyramidal dorsum sellae and an irregularity or notching of the dorsum sellae. The clinical significance of these observations is highlighted by several recent studies that have shown correlations between sellar morphological abnormalities and craniofacial developmental abnormalities. In a systematic review, Jankowski *et al.* found significant correlations between dental and sellar abnormalities and Antonarakis *et al.* showed relations between dental anomalies and craniofacial deviations in cleft lip and cleft palate sufferers **[4, 20].** Chou *et al.* also noted substantial associations between the morphology of the sellar region, presence of skeletal bridging and the patterns of skeletal malocclusion in an Eastern Asian population **[7].** More recently, Siddiqui *et al.* reported in a systematic review and meta-analysis that individuals with unilateral non-syndromic cleft lip and palate had smaller sellar length, depth and area and more than twice the odds of sella turcica bridging compared with non-cleft controls, although the certainty of evidence was limited by methodological concerns **[21]**. While sellar bridging was not seen in our current study, it should be remembered that its presence makes it important to have a critical examination of the radiographs in routine cephalometric studies. An interesting observation of the present study was that the percentage prevalence of pyramidal dory form of the sella turcica was comparatively higher when compared with several Indian studies reported earlier. The present observation may suggest some unique geographical anatomical features among the Central Indians. India is a very ethnically diverse country and when attempting to extrapolate morphometric standards from other parts of the world, representation of local craniofacial architecture must not be taken for granted. The results are thus a call for validation of region-specific normative datasets to enhance diagnosis and minimize misdiagnosis of normal anatomical variants as disease. The present study also showed that small dimension Sellars correlated with pyramidal and notching variants while large Sellars correlated with normal and oblique anterior wall variants. However, there was considerable overlap between the different morphological categories, indicating that on its own, morphology is not a reliable predictor of sellar size. In three-dimensional and volumetric evaluations of the correlation between the shape and dimensions of the sellar,

similar findings have been reported **[17].** A thorough examination of the sella turcica should thus include qualitative evaluation of its morphology and quantitative evaluation of its morphometry. The results of the age-correlation of dimensions obtained from the present study give further information about the developmental changes in the sella turcica. A strong negative correlation was seen between sellar length and depth among those less than 25 years and a moderate positive correlation was seen between depth and anteroposterior diameter. The results are probably due to adolescent and early adult remodeling of the cranial base and growth of the pituitary fossa. For the older individuals (those > 25 years old), however, the sellar length was positively associated with the anteroposterior diameter, but the sellar depth was relatively independent. The conclusions derived from these findings indicate that vertical growth stabilizes after skeletal maturity, while horizontal growth is continued in adulthood, coordinated with the movements of the vertical plate. Conclusions were drawn from these findings indicating that vertical growth slows after skeletal maturity, but horizontal growth persists and is coordinated with vertical movement. In longitudinal morphometric studies, which compared sellar development between various ages similar age-related changes have been noted **[1, 3 and 15].** Clinically, the present study provides implications for orthodontics, oral radiology and craniofacial diagnostics. The sella is one of the most important cephalometric landmarks and it is important to understand and recognize the normal anatomical variations to reduce the error of tracing and improve the reproducibility in cephalometric analysis. Comparison of normative data for different age groups and populations is further reinforced by the development of digital cephalometry and automated tracing techniques **[12, 13].** In this context, Shakya *et al.* showed the feasibility of deep-learning-based automated segmentation of the sella turcica on lateral cephalometric radiographs, with VGG19 and ResNet34 showing comparatively higher segmentation performance than the other evaluated architectures **[22]**. In addition, when the sellar morphology is atypical or sellar enlargement occurs, early recognition of pituitary pathologies, endocrine abnormalities and craniofacial developmental disorders is made easier **[15, 18].** The present study has a number of methodological merits: a well-standardized digital cephalometric analysis, equating the representation of males and females and the sampling of a wide age range from adolescence to late adulthood. However, there are some restrictions that should be recognized. As a cross-sectional design, this design did not allow for the growth of the individual participants over time to be examined. Two-dimensional lateral cephalometric radiographs also might not completely represent the complicated three dimensional characteristics of the sella turcica. Recent studies using the cone-beam computed tomography (CBCT) and volumetric assessment methods have shown their ability to visualize the sellar anatomy better and may enable future studies to acquire more precise assessments **[7, 17].** Additionally, multicentric studies with large and heterogeneous samples are needed to build the big Indian norms database. The present study concludes that there are significant morphometric and morphological variations in sella turcica in the Central Indian population along with different morphotype of sella turcica for the population of Central India. Results confirm the influence of the population-specific nature of the cephalometric rules and emphasize the significance of establishing a systematic assessment of the sellar in orthodontic and craniofacial diagnostics.

Conclusion:

Normal sella turcica morphology was the most frequent pattern, with the anteroposterior diameter being the largest dimension and no significant sexual dimorphism was observed. Age-related remodeling was evident during craniofacial growth, while the oblique anterior wall and pyramidal dorsum sellae were the most common morphological variants. These findings provide region-specific normative data for the Central Indian population and support routine evaluation of the sella turcica during cephalometric analysis for orthodontic and craniofacial assessment.

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