Correlation of spheno-occipital synchondrosis and mandibular condylar cortication with chronological age using computed tomography in Indian population– A cross-sectional study

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KEYWORDS

Occipital Bone;
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ABSTRACT

Background: Forensic age estimation is a procedure which utilises many methods to estimate the age of both living and deceased individuals, including those who have died in natural disasters or man-made catastrophes. The pattern and closure of spheno-occipital synchondrosis (SOS) fusion, along with subchondral ossification of the mandibular condyle, can be used to estimate age.

Aim and objectives: This study aims to estimate age using computed tomographic (CT) images of spheno-occipital synchondrosis fusion (SOS) and mandibular condylar cortication (MCC), and to correlate these findings with chronological age.

Materials and methods: The present study included 435 CT images of individuals aged 10-25 years. SOS fusion was assessed using a four-stage system, and MCC was assessed bilaterally using a three-stage system on the sagittal plane. Data on fusion stages and cortication types were entered along with chronological age, and then statistically analysed.

Results: SOS fusion stage 2 occurred at similar age in males (19.82 ± 2.67 years) and females (19.23 ± 2.93 years). Earlier fusion of other stages was observed in females by a mean age of 2 years. MCC was completed 1 year earlier in females, with statistically significant differences ($p \leq 0.001$). When comparing cortication types and different fusion stages, only type II cortication showed statistically significant differences compared to different fusion stages ($p \leq 0.001$).

Conclusion: Mandibular condylar cortication (MCC) and spheno-occipital synchondrosis (SOS) fusion were positively correlated with chronological age, suggesting that these parameters can be used as an adjunct method for age estimation.

INTRODUCTION

Forensic personal identification (FPI) is a core area of forensic sciences and technologies. It deals with the development and implementation of appropriate techniques to identify live and recently deceased subjects, and decomposed human remains at a crime scene for criminal investigation.[1] Despite significant advances in diagnostic methods, FPI remains a challenging task, especially when dealing with skeletal remnants or decomposing body parts. The identification of human remains becomes progressively challenging with increasing postmortem interval (PMI) due to degradation of physical characteristics, further complicated by the influence of both biotic and abiotic factors on the decomposition process.[2, 3] Primary FPI methods include fingerprint analysis, DNA profiling, and dental comparisons.[4] However, these methods have limitations when analysing decomposed skeletal remains or when antemortem and post-mortem records are unavailable.[4,5] In these scenarios, anthropological techniques can be employed for the estimation of population characteristics including age, sex, stature, and ancestry, along with individual identifiers such as moles and cicatrices scars. [6] Accurate estimation of any of these biological profiles is crucial for personal identification, as it narrows down the search for a missing person. [7]

Bone age estimation is a reliable forensic tool, as demonstrated by both quantitative and qualitative studies. [8] Previous studies have used cranial suture closure, dentition, epiphysis and ossification centres, and the articulating surfaces of the ox coxae (pubic symphyses and auricular surface). [9] Methods for evaluating these indicators have evolved, with computed tomography (CT) and magnetic resonance imaging (MRI) now being used in addition to other macroscopic and conventional radiographic examinations. [10]

The spheno-occipital synchondrosis (SOS), also known as the basilar suture, is a growth center between the occipital and sphenoid bones that plays a role in the development of the craniofacial region. Due to its late ossification phase, it is a valuable source of both therapeutic and forensic data. [11] Forensic age estimation by considering the pattern and timing of SOS fusion can provide an upper and lower age limit in adolescents and aids in adult age estimation. [12]

Age estimation using a single bone is found unreliable in previous studies. [13-14] Therefore, this study investigated the use of cortication around the condyle, another reliable factor, to estimate age. The development of the mandibular condyle is closely related to the development and growth of the mandible, with morphological changes in size and remodeling occurring at specific ages. [15] A recent study demonstrated that the displacement of condylar cartilage by bony tissue is not observed until the attainment of adult skeletal maturity. [16] Assessment of the aforementioned parameters can be performed using macroscopic examinations involving a cadaver or radiographic examinations such as CT, MRI, CBCT, or a combination of any of these. [17-20] However, CT scans provide the most precise and accurate images of these factors. Bayrak et al., [21] evaluated the relationship between mandibular condylar cortication (MCC), spheno-occipital synchondrosis (SOS), and chronological age. As there can be variations among different populations and ethnic groups, this study proposed to assess the correlation between chronological age, SOS, MCC using computed tomography in the Indian population.

MATERIALS AND METHODS

This was a retrospective cross-sectional study of 435 individuals aged 10 to 25 years. CT scans were collected from the archives of a private medical institution between January 2023 till July 2023. CT scans were acquired using a 256-slice GE Revolution Evo® CT machine with the following protocol: 120kVp; 280 mAs; window level of 4000 AU; scan time of 12 s.

Continuous sagittal sections of thickness 0.1 mm with a field of view of 20-25 cm, showing the skull base and mandibular condyle, were included for assessment. The scans were exported in a tagged image file format (*tiff), blinding the patients' demographic details, such as name, age, and sex, revealing the area of interest for assessment by two observers. This study was conducted in accordance with the ethical standards of Declaration of Helsinki, including all amendments and revisions. [22]

This study included CT scans of patients with no evidence of congenital or developmental deformities involving the skull base and mandible; no history of previous trauma or treatment; and no technical errors, motion blur, or artifacts. The CT scans of patients with systemic diseases or temporomandibular joint disorders were excluded. Demographic characteristics of the included subjects are described in the Table 1.

Measurement of parameters

Sagittal sections were selected as they reveal the complete visibility of the mandibular condyle and provide insight into its cortication status. The degree of SOS fusion was assessed in the midsagittal plane because it was clearly visible in that section. Two dentomaxillofacial radiologists

Table 1. Demographic details of the participants described in terms of number and percentage.

Category			n	%
Gender		Male	284	65.3
		Female	151	34.7
		Total	435	100
Age Group (years)	Male	10-14	28	9.9
		15-20	71	25.0
		21-25	185	65.1
		Total	284	100
	Female	10-14	16	10.6
		15-20	42	27.8
		21-25	93	61.6
		Total	151	100
Mandibular Condylar Cortication	Right	Type I	46	10.6
		Type II	143	32.9
		Type III	246	56.6
		Total	435	100
	Left	Type I	48	11.0
		Type II	140	32.2
		Type III	247	56.8
		Total	435	100
Spheno-occipital synchondrosis		Stage 0	41	9.4
		Stage 1	14	3.2
		Stage 2	68	15.6
		Stage 3	312	71.7
		Total	435	100

evaluated the SOS fusion and MCC based on the staging systems described by Franklin and Flavel et al., [23] and Bayrak et al., [24], respectively. To assess intra-observer reliability, one observer randomly assessed a sample of 100 CT images after a period of one month. MCC was assessed based on three stage grading system as depicted in Figure 2

Type I: Absence of cortication observed on mandibular condyle.

Type II: Bone on the mandibular condylar surface appears at a lower density than structure around condyle (cortical areas).

Type III: The surface of mandibular condyle appears at higher or similar density than surrounding cortical areas.
Four stages of Spheno-occipital synchondrosis fusion assessment as depicted in Figure 1.

Statistical analysis:
The stages of SOS fusion and MCC with respect to sex and chronological age were entered into Microsoft Excel® software (Microsoft, Redmond, WA, USA). The chronological age was calculated by subtracting the date of birth from the date of exposure. Statistical Package for the Social Sciences (SPSS) software (version 22.0, SPSS Inc., Chicago, IL, USA) was used to perform the statistical analysis. Quantitative variables were represented using mean and standard deviation whereas qualitative variables were expressed as numbers and percentages.
The Kolmogorov-Smirnov test was used to assess the distribution of the data and its normality. One-way ANOVA with post hoc Tukey's test was performed to determine the difference between the stage of SOS fusion and MCC and sex in accordance with chronological age. Linear regression analysis and Pearson correlation tests were used to determine the relationship between chronological age, sex, SOS fusion, and MCC. Inter-examiner and intra-examiner reliability was assessed using Cohen's kappa statistics. The level of significance was set at 5% ($p \leq 0.05$).

RESULTS

Cohen's kappa coefficient demonstrated substantial inter- and intra-examiner agreement in assessing mandibular condylar cortication (MCC) and spheno-occipital synchondrosis (SOS) (k = 0.78 and 0.81, respectively).
No sex- or side-specific differences were observed in the minimum age for type I MCC, which was 10 years. Type II MCC began at 14 years in both sexes, with the exemption of the right side in males, where it began as early as12 years.
Females exhibited Type III MCC onset 3 years earlier (16 years) compared to males (19 years). Statistically significant differences were noticed for MCC across all types and sides, as detailed in the Table 2.
The minimum age for stage 0 and 2 fusion was identical for both males and females. However, stage 1 fusion occurred significantly earlier in females compared to males, with a mean difference of 5 years ($p \leq 0.001$). Notably, stage 3 fusion occurred significantly earlier in males by 3 years than females ($p \leq 0.001$), as shown in Table 3. These findings suggest the existence of distinct and sex-specific timing of SOS fusion across various stages as depicted in Table 3.
This study examined the relationship between the different stages of SOS and MCC in both the male and female subjects on both the sides. On right side of MCC, statistically significant differences were observed in both males and females for Type II MCC and across all stages of SOS. ($p \leq 0.001$ and $p = 0.029$, respectively). Notably, females lacked Stage 0 SOS with Type II and III MCC, while those with Type I MCC lacked Stage 2 SOS. Both males and females with Type III MCC on right side did not present with Stage 1 SOS. Table 4 describes the mean values, along with minimum and maximum age limits, for different stages of MCC and SOS. Similarly, on the left side, statistically significant differences were observed in both sexes for Type II MCC and across all stages of SOS. ($p \leq 0.001$ and $p = 0.018$, respectively). Additionally, Type I MCC and Stages of SOS (Stage 0, 1, and 3) revealed a statistically significant difference ($p = 0.002$) in females. Notably, females showed an absence of Stage 0 SOS in Type I and II MCC, while those with Type I MCC lacked Stage 2 SOS. Stage 1 SOS was absent in both males and females with Type III MCC. The mean values, along with minimum and maximum age limits, for different stages of MCC and SOS are described in Table 5. A very strong positive correlation was observed between MCC on the right and left sides for both genders ($p \leq 0.05$). Other assessed parameters also exhibited a strong positive correlation between them for both genders (see Table 6).
This study evaluated the variation in the type of MCC on both sides in 246 images. Type I MCC was observed on both sides in all but one image, where type II MCC was noted on the left side. In 9 of the 246 images with type III MCC, type II MCC was noted on the left side. Other possible variations in the types of MCC between the right and left sides are described in Table 7.

Figure 1. Stage 0: Completely open. Stage 1: Closed superior border. Stage 2: Complete fusion with visible fusion scar. Stage 3: Complete fusion with no visible scar.
Stage assessment system of Spheno-occipital synchondrosis devised by Franklin and Flavel.et al.[23]

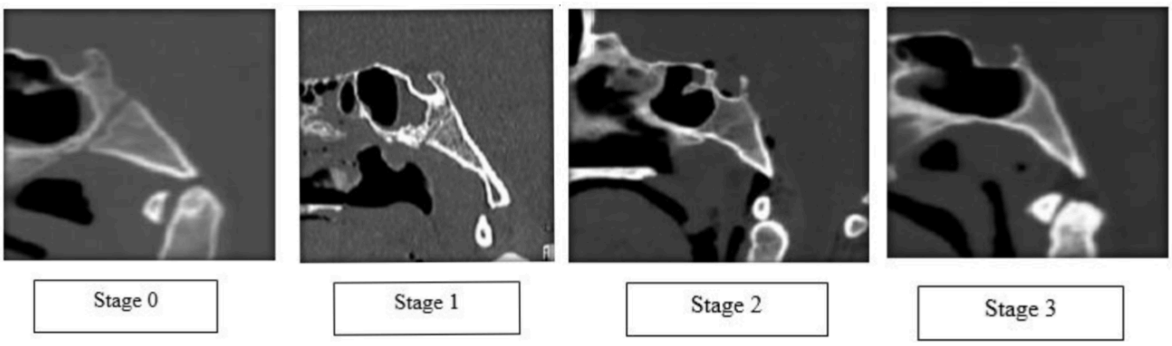

Figure 2. Mandibular condylar cortication assessment based on 3-stage system devised by Bayrak et al. [24]

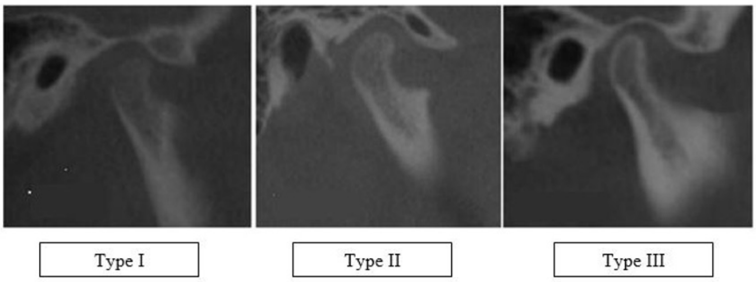

Table 2. Types of MCC with respect to the sides and gender. Superscript a, b, and c represent type I, II, and III MCC, respectively Superscript ab, ac, and bc denotes association between type I, II, and III MCC based on post hoc analysis n - number of patients SD - Standard deviation Min - minimum, Max – maximum. ** denotes highly statistically significant difference (p ≤ 0.001) Statistical test used: One-way ANOVA with post hoc Tukey test.

Sex	Mandibular Condylar Cortication	Right					Left					p
		n	Mean	SD	Min	Max	n	Mean	SD	Min	Max	
Males	Type I $^{ab, ac}$	32	12.84	3.18	10	24	33	12.76	3.09	10	24	≤0.001**
	Type II ^{bc}	91	19.63	2.67	12	25	87	19.71	2.55	14	25	
	Type III	161	23.14	1.53	19	25	164	23.09	1.57	19	25	
	Total	284	20.85	3.93	10	25	284	20.85	3.92	10	25	
Females	Type I $^{ab, ac}$	14	10.93	1.07	10	13	15	11.47	2.37	10	19	≤0.001**
	Type II ^{bc}	52	18.54	2.39	14	24	53	18.72	2.41	14	24	
	Type III	85	22.69	1.72	16	25	83	22.67	1.86	16	25	
	Total	151	20.17	4.03	10	25	151	20.17	4.03	10	25	
Total	Type I $^{ab, ac}$	46	12.26	2.85	10	24	48	12.35	2.91	10	24	≤0.001**
	Type II ^{bc}	143	19.23	2.62	12	25	140	19.34	2.54	14	25	
	Type III	246	22.98	1.61	16	25	247	22.95	1.68	16	25	
	Total	435	20.62	3.97	10	25	435	20.62	3.97	10	25	

Table 3. Stages of SOS with respect to sex for included studies. n - number of patients. SD - Standard deviation. Min - minimum, Max – maximum. ** denotes highly statistically significant difference ($p \leq 0.001$) Statistical test used: One-way ANOVA

Spheno-occipital synchondrosis		n	Mean	SD	Min	Max	p
Male	Stage 0	29	12.62	3.34	10	24	≤0.001**
	Stage 1	12	16.67	1.44	15	19	
	Stage 2	33	19.82	2.68	14	25	
	Stage 3	210	22.39	2.28	10	25	
	Total	284	20.85	3.93	10	25	
Female	Stage 0	12	10.83	0.94	10	13	≤0.001**
	Stage 1	2	14.50	6.36	10	19	
	Stage 2	35	19.23	2.93	14	25	
	Stage 3	102	21.71	2.64	13	25	
	Total	151	20.17	4.03	10	25	
Overall	Stage 0	41	12.10	2.96	10	24	≤0.001**
	Stage 1	14	16.36	2.34	10	19	
	Stage 2	68	19.51	2.81	14	25	
	Stage 3	312	22.17	2.42	10	25	
	Total	435	20.62	3.97	10	25	

Table 4. SOS stages and its corresponding types of MCC on the right side. n - number of patients. SD - Standard deviation. Min - minimum, Max – maximum. * stands for statistically significant values at p ≤ 0.05. ** denotes highly statistically significant difference (p ≤ 0.001) Statistical test used: One-way ANOVA.

Mandibular Condylar Cortication	Spheno-occipital synchondrosis	Males					P
		N	Mean	SD	Min	Max	
Type I	Stage 0	25	12.16	3.00	10	24	0,137
	Stage 1	4	15.50	1.00	15	17	
	Stage 2	1	16.00	-	16	16	
	Stage 3	2	14.50	6.36	10	19	
Type II	Stage 0	3	13.33	1.16	12	14	≤0.001**
	Stage 1	8	17.25	1.28	16	19	
	Stage 2	23	19.00	2.34	14	23	
	Stage 3	57	20.54	2.27	15	25	
Type III	Stage 0	1	22.00	-	22	22	0,200
	Stage 2	9	22.33	1.66	19	25	
	Stage 3	151	23.19	1.52	20	25	
Mandibular Condylar Cortication	**Spheno-occipital synchondrosis**	**Female**					**p**
		n	**Mean**	**SD**	**Min**	**Max**	
Type I	Stage 0	12	10.83	0.94	10	13	0,092
	Stage 1	1	10.00	-	10	10	
	Stage 2	-					
	Stage 3	1	13	-	13	13	
Type II	Stage 0	-					0.029*
	Stage 1	1	19.00		19	19	
	Stage 2	23	17.57	1.85	14	21	
	Stage 3	28	19.32	2.55	14	24	
Type III	Stage 0	-					0,549
	Stage 2	12	22.42	1.68	19	25	
	Stage 3	73	22.74	1.73	16	25	

Table 5. SOS stages and its corresponding types of MCC on the left side. n - number of patients. SD - Standard deviation. Min - minimum, Max – maximum. * stands for statistically significant values at p ≤ 0.05. ** denotes highly statistically significant difference (p ≤ 0.001) Statistical test used: One-way ANOVA.

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Mandibular Condylar Cortication	Spheno-occipital synchondrosis	Males					p
		N	Mean	SD	Min	Max	
Type I	Stage 0	27	12.22	2.90	10	24	98
	Stage 1	4	15.50	1.00	15	17	
	Stage 2	1	16.00	-	16	16	
	Stage 3	2	14.50	6.36	10	19	
Type II	Stage 0	1	14.00	-	14	14	≤0.001**
	Stage 1	8	17.25	1.28	16	19	
	Stage 2	25	19.04	2.46	14	23	
	Stage 3	53	20.51	2.31	15	25	
Type III	Stage 0	1	22.00	-	22	22	237
	Stage 2	8	22.25	1.75	19	25	
	Stage 3	155	23.14	1.56	20	25	
Mandibular Condylar Cortication	**Spheno-occipital synchondrosis**	**Female**					**p**
		n	**Mean**	**SD**	**Min**	**Max**	
Type I	Stage 0	12	10.83	0.94	10	13	0.002*
	Stage 1	1	10.00	-	10	10	
	Stage 2	-					
	Stage 3	2	16.00	4.24	13	19	
Type II	Stage 0	-					0.018*
	Stage 1	1	19.00	-	19	19	
	Stage 2	24	17.71	1.94	14	21	
	Stage 3	28	19.57	2.52	14	24	
Type III	Stage 0	-					806
	Stage 2	11	22.55	1.70	19	25	
	Stage 3	72	22.69	1.89	16	25	

Table 6. Correlation between the MCC on both sides, SOS, chronological age and gender. Statistical test used: Pearson Correlation. rp is Pearson correlation coefficient * denotes statistically significant values at $p \leq 0.05$

	MCC Right (r_p)		MCC Left (r_p)		SOS (r_p)		Chronological age (r_p)	
	Male	Female	Male	Female	Male	Female	Male	Female
MCC Right (r_p)	1	1	.934*	.963*	.723*	.709*	.815*	.861*
MCC Left (r_p)			1	1	.754*	.694*	.821*	.836*
SOS (r_p)					1	1	.785*	.746*
Chronological age (r_p)							1	1

Table 7. Variations in the types of MCC on right and left sides.

		MCC Left Side			
	Cortication type	Type I (%)	Type II (%)	Type III (%)	Total
MCC Right Side	Type I	45 (10.3)	1 (0.2)	0	46 (10.5)
	Type II	3 (0.7)	130 (29.9)	10 (2.3)	143 (32.9)
	Type III	0	9 (2.1)	237 (54.5)	246 (56.6)
	Total	48 (11)	140 (32.2)	247 (56.8)	435 (100)

DISCUSSION

Establishing an individual's identity is essential in cases of catastrophic events, such as manmade or natural disasters. [25] Age estimation in living individuals is of extreme importance in living or dead individuals for various purposes, such as identification, obtaining civil rights and benefits from society, and medico-legal purposes. [26] Hence, forensic age estimation (FAE) has become an integral part of the forensic medicine field that focuses on utilizing an accurate method of estimating the chronological age of the person. [27] This helps in the identification of both living and deceased individuals and can be used to create a biological profile that can be compared to missing persons for the latter. [28]

With the recent surge in the need for identification and age estimation in living individuals for legal purposes, forensic anthropology has been extended to include this area of study. [29] Age estimation procedures are implemented to accurately categorize individuals as adults or children with protected legal status, ensuring transparency through reproducible methodologies and verifiable results for expert review and evaluation of clinical interpretations. [30]

A variety of methods can be used to estimate chronological age, including height and weight measurements, pubertal status, dentition, and dental findings. [31] While these methods offer valuable insights, no single approach can definitively ascertain chronological age with complete accuracy. [27] This highlights the need for novel approaches and improved accuracy in age estimation techniques.

The expanding role of computed tomography (CT) in forensic medicine extends beyond post-mortem examinations, finding application in anthropological studies and age estimation of living individuals. [32] Notably, integrating skeletal changes revealed by CT scans with other age-related indicators, such as dental development, enhances the accuracy and confidence in age estimation compared to relying solely on traditional methods. [33]

Kadesjö et al., [34] compared the effective dose of cone-beam computed tomography (CBCT) and multislice CT (MSCT) for temporomandibular joint (TMJ) examinations using thermoluminescent dosimetry (TLD) measurements. Before dose optimization, the bilateral effective dose was 184 µSv for CBCT and 113 µSv for MSCT. Following optimization, the CBCT dose was reduced by 50% compared to MSCT, resulting in effective doses of 92 µSv and 124 µSv, respectively. This suggests that optimization strategies demonstrate considerable potential for significantly reducing radiation doses associated with both dentomaxillofacial CT and CBCT examinations.

Considerable variation in the closure of SOS among males, females, and different ethnicities has provoked interest in the research field to further assess the fusion degree as an accurate age estimation method. [10] Also, the mandibular condyle, an integral component of the mandible varies according to sex with respect to its growth, development, shape, or morphological appearance. [35] Developmental changes, such as cortication can be detected on radiographs, and the assessment of these changes can be used to correlate with the age of the individual.

Assessment of SOS fusion was performed using a four-stage system devised by Franklin and Flavel et al., [23] utilizing CT in 312 Australian individuals. In males, the SOS was open (Stage 0) at a mean age of 10.28 ± 3.30 years and complete fusion (Stage 3) occurred at mean age of 19.83 ± 2.94 years. In females, the SOS was open at a mean age of 8.62 ± 2.40 years, and complete fusion (Stage 3) occurred at a mean age of 18.62 ± 3.55 years. Other fusion stages (stages 1 and 2) also occurred earlier in females than in males.

Hisham et al., [36] assessed fusion of SOS using a four-stage system in a CT scans of 500 Malaysian individuals. Stage 0 fusion occurred earlier in females (9.33 ± 2.69 years) than in males (10.26 ± 2.45 years). Stages 1 and 2 also occurred earlier in females than in males, by approximately 2 years and 1 year, respectively. Stage 3 fusion occurred at similar ages in both sexes, with mean age of 20.84 ± 2.84 years in males and 19.78 ± 3.35 years in females.

Two Turkish studies assessed the SOS using a four-stage system on CT scans. [18, 37] Sinanoglu et al., [18] found that stage 0 and stage 2 fused at similar age in males and females, whereas stage 1 and stage 3 fused 1-2 years earlier in females. Kocasrac et al [37] found out that all fused earlier in females, except for stage 0, which fused earlier in males.

In this study, the SOS fusion stages were generally earlier in females than in males. Stage 0 fusion occurred approximately 2 years earlier in females (10.83 ± 0.94 years) than males (12.62 ± 3.34) years. [23] Stage 1 and 3 fusion also occurred earlier in females, by 1-2 years. Stage 2 fusion occurred at similar ages in males and females (19.82 ± 2.68 years and 19.23 ± 2.93 years, respectively). Complete fusion (Stage 3) occurred at the age of 22.39 ± 2.28 years in males and 21.71 ± 2.64 years in females. The results in this study correspond to previously published studies [18, 23, 36, 37] that showed earlier fusion of SOS in females, suggesting that females attain skeletal maturity earlier than males do.

Lei et al., [38] were the first to classify the formation of cortical bone around mandibular condyle using CBCT based on presence of a bony layer in the periphery of the mandibular condyle. They found that the initial signs of subchondral bone formation were seen at 12-13 years for girls and 13-14 years for boys, with complete cortical bone formation by 21 years for females and 20 years for males.

Bayrak et al., [24] developed a novel method of mandibular condylar cortication (MCC) classification, which identified three stages based on the density difference of cortical bone surrounding the mandibular condyle and areas adjacent to condyle. Type I cortication was seen at a mean age of 14.14 years for males and 13.01 years for females, suggesting that there is no evidence of cortical bone formation below this age category. They concluded that the type of MCC may vary for the same individual when the right and left sides are considered, and that the cortication process occurs later in males than in females.

Ma et al., [39] investigated the morphology and cortication of the mandibular condyle using cone-beam computed tomography (CBCT) from 1010 temporomandibular joints (TMJ). They found that the majority of mandibular condyles exhibited a planar morphology anteriorly, while a convex morphology was more prevalent posteriorly. The mean age for males and females with no evidence of cortication was 15.11 ± 2.71 and 14.25 ± 2.60 years, respectively. Complete cortication of the mandibular condyle was observed at a mean age of 23.63 ± 3.36 years for males and 23.86 ± 3.73 years for females.

MCC was assessed on both sides in this study. Irrespective of the side, Type I cortication was seen at a mean age of 12-13 years in males and 10-11 years in females. MCC was complete at a mean age of 23 years in males and 22 years in females. These results are consistent with those reported by Lei et al., [38], Bayrak et al., [24], and Ma et al. [39]

Seo et al., [40] assessed the cortication of the mandibular condyle using Cone Beam Computed Tomographic (CBCT) images of 829 Korean individuals. The prevalence of no cortication was higher in males (30.84%) compared to females (19.74%). Conversely, females exhibited a higher prevalence of complete cortication (35.59%) compared to males (26.48%). These findings suggest sex-based differences in mandibular condyle cortication patterns, potentially influencing susceptibility to temporomandibular joint disorders.

Bayrak et al., [21] were the first to assess the relationship between SOS fusion stages and different types of MCC using CBCT. They found a positive correlation between these parameters, with statistically significant differences for both males and females. Similarly, in this study, a very strong positive correlation was seen for both sexes between right- and left-side MCC and SOS, as well as between chronological age, sex, and the measured parameters. This suggests that MCC, along with SOS fusion, can be used as a reliable method for estimating age.

The findings from this study converge with the previous study [41] on the promising use of these parameters in forensic settings, with a key strength being their consistent results across observers. The authors acknowledge that the health, nutrition, growth, and developmental status of bones, as well as ethnicity, can influence the closure of the SOS. This can impart variability with respect to age; hence, this method should be used as an adjunct to other more accurate age estimation methods. Additionally, the limited sample size and uneven distribution of age groups among ethnicities may limit the generalizability of the findings.

Future studies should include an equal number of individuals in both groups to accurately compare the differences in age for closure of spheno-occipital synchondrosis as well as mandibular condylar cortication. Additionally, an improved sample size with more data from studies that utilized computed tomography for the assessment of both parameters in the Indian population is needed to create a population-specific dataset for future forensic purposes.

CONCLUSION

This study evaluated the reliability of the SOS and MCC for age estimation which was demonstrated by the positive correlation between chronological age, sex, and assessed parameters, thereby revealing it to be used reliably for age estimation. Calculating an age range of the included individuals for various stages of MCC and SOS based on maximum and minimum ages can be considered. To assess the generalizability of these findings and explore potential population-specific variations, further research is warranted comparing these observations across diverse demographic subsets. Additionally, future studies should investigate the potential of cone-beam computed tomography (CBCT) as a comprehensive imaging modality for evaluating the mandibular condyle and middle cranial fossa.

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