ORIGINAL RESEARCH

# Evaluation of Spheno-occipital Synchondrosis Fusion in Chinese Population Using CBCT: A Cross-sectional Study

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## Abstract

**Aim:** This study sought to assess the fusion of spheno-occipital synchondrosis (SOS) in Chinese population using cone-beam computed tomography (CBCT).

**Materials and methods:** This is a cross-sectional study in which data were randomly collected based on the pre-existing institutional records. Following selection criteria, the CBCT images of 500 patients aged 6–25 years (226 males and 274 females) were analyzed. Three-dimensional virtual models were oriented at a standardized position, then adjusted to the median sagittal plane (MSP) view. A four-stage scoring system was used; completely open, partially fused, semi-fused, or completely fused. The student's *t*-test, one-way ANOVA, Pearson correlation, and linear regression analysis were used and the significant level was set at $\leq 0.05$.

**Results:** The mean age of closure of stages 1, 2, 3, and 4 were 7.44, 9.62, 12.94, and 19.03 years in females, and 8.79, 11.13, 14.82, and 20.18 years in males, respectively. There was significantly strong positive correlation between spheno-occipital fusion and age (female: $r = 0.853$, male: $r = 0.879$; $p < 0.001$), with $1.47 \pm 0.33$ years earlier fusion in females. All inter- and intra-stages mean ages were statistically significant in both genders. The transition age model demonstrated a mean age (in years) between stages 1–2 (10.1), stages 2–3 (12.79), and stage 3–4 (17.93) for males, and stages 1–2 (8.96), stages 2–3 (11.45), and stage 3–4 (16.69) for females.

**Conclusions:** The present findings of SOS stages of fusion in both genders could guide age estimation and assessment of normal skeletal growth patterns and active skeletal growth period in the Chinese population.

**Clinical significance:** There is still controversy about the time to closure of the SOS because of population and assessment technique variations. This study could be used as a reference for the specific examined population during planning for dentofacial orthopedic and/or orthognathic surgery and dental implant prosthesis for both genders. Moreover, these finding may be useful for medical purposes.

**Keywords:** Chinese population, Cone-beam computed tomography, Skeletal growth, Spheno-occipital synchondrosis, Stages of fusion.

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## Introduction

The spheno-occipital synchondrosis is a cartilaginous craniofacial development center between the sphenoid and occipital bones in the skull base. It is active during the growing phase and ossifies during skeletal maturation, the last growing site in the skull. The fusion starts endocranially and advances ectocranially until completed.[1]

Craniofacial growth and orthodontics studies[2–4] showed that the SOS is critical in developing the craniofacial complex. It helps to define the final shape of the cranial base and its relationship to the maxilla and mandible.[2,3] Several skeletal and biological markers have been investigated in comparison with SOS for potential application in assessing growth status and age estimation, including the analysis of third molar mineralization (TMM),[5] chronological age,[5] hand-wrist maturation,[6] cervical vertebrae maturation (CVM),[7] mid-palatal suture (MPS), and the zygomaticomaxillary suture (ZMS) maturation,[8] condyle cortication,[9] menarche onset,[10] mandible growth spurt,[4] and developmental puberty.[10] Thus, they consider the SOS a reliable biological growth indicator or a skeletal maturation indicator.

Based on previous growth and age estimation researches,[10,11–20] the fusion time of spheno-occipital fusion varied greatly among and within populations. Madeline et al.[3] used conventional CT scans of American patients, and they found that the SOS complete fusion was 18 years in males and 16 years in females. However, Okamoto et al.[21] observed the SOS's fusion in males at 13 and females at 12 years in a

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Japanese population. Can et al.[22] also concluded that the complete fusion was 20.34 (3.4) years for men and 18.17 (3.5) years for women in a Turkish population. Bassed et al.[23] investigated Australians and reported that both males and girls had completed closure by 17 years. Franklin and Flavel studied Western Australians and found that complete fusion occurred at an average age of 19.83 (2.94) years in males and 18.62 (3.55) years in females.[14] Lottering et al.[15] found that Queensland, Australian males >16.3 years of age, and females 13.8 years of age had a complete fusion in their investigation. On the other hand, Sinanoglu et al.[17] used the CBCT scans of the Turkish population and found the total fusion of the SOS at mean ages of 20.02 and 18.21 years in males and females, respectively. Another study in Turkish[5] reported that 18.92 years (3.63) for males and 18.02 years (3.63) for females for complete SOS closure. In the same way, Alhazmi et al.[6] concluded that the SOS was entirely fused in Americans at the ages of 16.41 and 15.25 for males and females, respectively.

This variety may be due to the usage of different SOS closure analysis methods[24] and other factors, such as age, gender, racial, ecological, geographical, and biological factors.[25] Moreover, environmental factors like nutrition, climate, and weather substantially impact stature and craniofacial parameters.[26] This essential database is required for any population. Therefore, this study aimed to evaluate the fusion of SOS in Chinese population using CBCT for normal skeletal maturation and forensic medicine purposes.

# Methods

## Sample Selection

This cross-sectional, comparative study was approved by the Ethics Committee of the Hospital of stomatology at Lanzhou University's school, China (No: LZUKQ-2019-042). The sample size was calculated using the G*power 3.0.10 software with an alpha value of 0.05 and a power of 80% and a two-sided test comparing two independent samples based on a study conducted by Fortanely;[27] the minimum sample size required was 39 subjects per SOS stage group. The collected number in the present study was 48 subjects for each group (six groups).

Data were randomly collected based on the pre-existing records between January 2016 and July 2021 according to a known patient age, gender, dental and medical history, and CBCT scan. Exclusion criteria included: (1) patients with reported cleft lip or cleft palate, (2) craniofacial syndromes, (3) head trauma and/or deformity, (4) gross asymmetry, (5) previous orthodontic or orthopedic treatment, or (6) inadequate diagnostic quality radiographs. Written informed consent was obtained from each participant or his/her guardian. Five hundred subjects, 274 females and 226 males, were included in this study. The age range was from 6 to 25 years with a mean age of 13.9 ± 5.6 years, in which the upper and the lower limit was chosen according to previous studies.[14,17,18]

## CBCT Evaluation

CBCT images were acquired using I-CAT Imaging System (Imaging Sciences International Inc. Hatfield, USA). Each patient was scanned using a standard protocol that included a standardized head position, maximal intercuspation, and the Frankfort horizontal plane parallel to the floor with a crossing laser guide. According to the imaging protocol, the patient was instructed not to swallow or move during the scanning process. The following acquisition parameters were used: 16 × 13 cm field of view, 120 kV, 18.54 mAs, and 8.9 seconds exposure time. The selected voxel dimension was 0.3 mm, and the slice thickness was 2 mm.

Digital Imaging and Communications in Medicine (DICOM) files of the CBCT images were obtained and then imported into *in vivo* 6.0.3 software (Anatomage, San Jose, California, USA). All 3D virtual models were oriented at a standardized position, and then adjusted to the median sagittal plane (MSP) view.[8,10,14] The view of the CBCT has changed to the slice thickness of 1 mm, "mild sharpening," and "bone" algorithm.[10,11,27]

## The Spheno-occipital Scoring

For evaluating the fusion degree of SOS, the four-stage system of Franklin and Flavell[14] (Table 1 and Fig. 1)was followed. The scoring was somewhat changed; instead of a score of zero, the unfused was given a score of stage "1." All scoring was evaluated blindly without knowing the patient's demographic data and recorded in a separate sheet. Two well-trained observers, WA and RA, independently scored the entire sample. Separated by a 1-month interval, both observers randomly selected 100 images and re-evaluated for intraobserver agreement. In the cases of disagreement, the axial view was used to assess the synchondrosis to reach a consensus as recommended by Okamoto et al.[28] Moreover, the first observer (WA) scored the whole sample for more reliability assessment.

## Statistical Analysis

IBM SPSS Statistics for Windows, Version 26.0 (Armonk, New York: IBM Corp.), was used. The sample distribution, means, median, minimum and maximum ages, and standard deviations of the mean ages for the SOS stages were computed using descriptive statistics. Pearson correlation analysis was used to analyze the association between chronological age and fusion stage. The student's *t*-test used to compare the age and gender according to the fusion stages. One-way ANOVA analysis determined the differences in mean ages among fusion stages of both genders.

Linear regression analysis produced a regression model for age prediction based on the fusion stages of SOS. Moreover, the average

**Table 1:** Description the fusion of the spheno-occipital synchondrosis scoring

| *Stage* | *Status* | *Description* |
|---|---|---|
| 1 | Unfused | Opened entirely with no sign of closure or presence of bone in the gap between the endocranial and ectocranial borders. |
| 2 | Partial-fused | Fused endocranially but not more than half the length of the synchondrosis (fusing endocranially, ≤50%). |
| 3 | Semi-fused | Fusing ectocranially with more than half the length of the synchondrosis but without fusing of the inferior (ectocranial) border (fusing ectocranially >50% and less than 100% fusion). |
| 4 | Complete fusion | Fused entirely with normal bone appearance throughout the synchondrosis, but a fusion scar may be existing. |

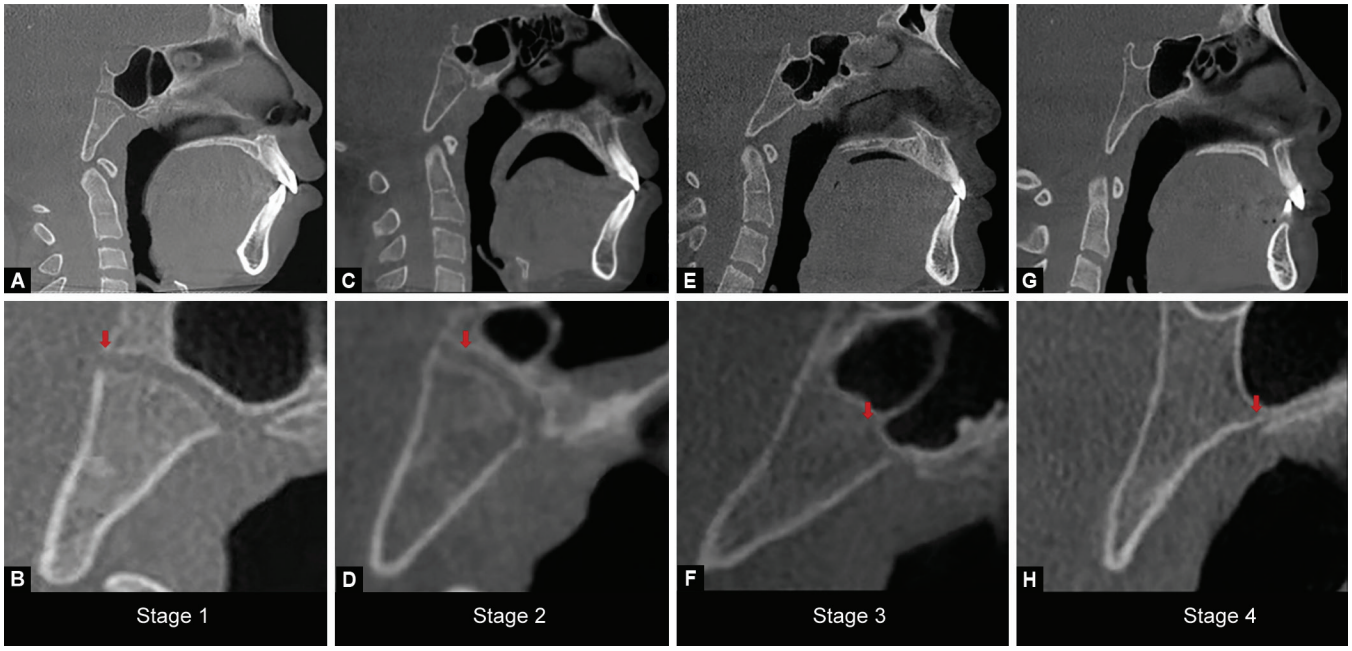
ages for transitions between fusion phases were calculated using linear regression parameters. For each gender separately, regression analysis was performed with age as the dependent variable and the stage of spheno-occipital fusion as the independent variable. Inter- and intraobserver reliability was calculated using Cohen's Kappa coefficient.

## Results

Following an investigation of the CBCT scans of 500 cases (aged from 6 to 25 years; with a mean age of 13.89 ± 1.13 years), which consisted of 274 females and 226 males with mean ages of 13.68 ± 5.30 and 14.14 ± 4.99 years, respectively. The distribution of SOS fusion stages by age and gender was shown in Table 2 and Figure 2. The descriptive analysis features of the study were presented in Table 3. The mean age for closure of stages 1, 2, 3, and 4 were 7.44, 9.62, 12.94, and 19.03 in females and 8.79, 11.13, 14.82, and 20.18 years in males, respectively. The early age of complete closure (stage 3) was 14.00 years with a mean age of 20.18 years in males and 13.20 years with an age of 19.03 years in females. The latest age of incomplete closure (stage 2) was 18.30 years with a mean age of 14.82 years in males and 16.90 years with a mean age of 12.94 years in females. The early age of incomplete closure (stage 1) was 7.60 years with a mean age of 9.20 years in females and 7.80 years with a mean of 11.13 years in males, respectively.

Pearson correlations analysis revealed a strong positive association between age and spheno-occipital closure stages (for all: $r = 0.853$, female: $r = 0.853$, male: $r = 0.879$; $p < 0.001$). Regarding the age range, there was a significant difference detected between males and females in all stages ($p < 0.05$), with a mean difference of about 1.47 ± 0.33 years earlier SOS fusion in females. One-way ANOVA analysis with *post-hoc* Bonferroni adjustment showed males and females established significant differences ($p < 0.001$) among and within the mean ages of all closure stages.

The simple linear regression was accomplished with age as the dependent variable and the stage of spheno-occipital fusion as the independent variable. It was used for performing a regression




**Figs 1A to H:** 3D MPR reconstruction representing the stages of SOS fusion in the mid-sagittal plane: (A and B) Stage 1; (C and D) Stage 2; (E and F) Stage 3; (G and H) Stage 4 with red arrow pointing the different stages of SOS fusion on the section/slice… on similar grounds

**Table 2:** Distribution of spheno-occipital synchondrosis fusion stages by age and genders

| | | *Age-group* | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Stage* | *Gender* | *6* | *7* | *8* | *9* | *10* | *11* | *12* | *13* | *14* | *15* | *16* | *17* | *18* | *19* | *20* | *21* | *22* | *23* | *24* | *25* |
| 1 | Male | 6 | 8 | 18 | 8 | 4 | 3 | 2 | | | | | | | | | | | | | |
| | Female | 20 | 16 | 8 | 2 | 1 | 1 | 0 | | | | | | | | | | | | | |
| 2 | Male | | 1 | 6 | 11 | 6 | 15 | 11 | 10 | | | | | | | | | | | | |
| | Female | | 4 | 14 | 15 | 12 | 7 | 2 | 0 | | | | | | | | | | | | |
| 3 | Male | | | | 0 | 0 | 1 | 5 | 9 | 13 | 9 | 6 | 4 | 2 | | | | | | | |
| | Female | | | | 2 | 6 | 9 | 17 | 16 | 6 | 4 | 6 | 0 | 0 | | | | | | | |
| 4 | Male | | | | | | | | 0 | 3 | 3 | 9 | 6 | 4 | 8 | 6 | 6 | 5 | 6 | 6 | 6 |
| | Female | | | | | | | | 7 | 11 | 11 | 13 | 6 | 8 | 7 | 9 | 6 | 5 | 7 | 8 | 8 |
| | ∑ Male | 6 | 9 | 24 | 19 | 10 | 19 | 18 | 19 | 16 | 12 | 15 | 10 | 6 | 8 | 6 | 6 | 5 | 6 | 6 | 6 |
| | ∑ Female | 20 | 20 | 22 | 19 | 19 | 17 | 19 | 23 | 17 | 15 | 19 | 6 | 8 | 7 | 9 | 6 | 5 | 7 | 8 | 8 |
| | ∑*n* | 26 | 29 | 46 | 38 | 29 | 36 | 37 | 42 | 33 | 27 | 34 | 16 | 14 | 15 | 15 | 12 | 10 | 13 | 14 | 14 |

**Table 3:** Descriptive features for fusion stages of spheno-occipital synchondrosis

| | *n* | *Mean age (years)* | *SD* | *95% CI* | *Median age* | *Min-max* |
|---|---|---|---|---|---|---|
| Females | 274 | | | | | |
| Stage 1 | 48 | 7.44 | 1.18 | 7.10–7.79 | 7.30 | 6.00–11.60 |
| Stage 2 | 54 | 9.62 | 1.25 | 9.28–9.96 | 9.50 | 7.60–12.20 |
| Stage 3 | 66 | 12.94 | 1.75 | 12.51–13.37 | 12.75 | 9.50–16.90 |
| Stage 4 | 106 | 19.03 | 3.78 | 18.30–19.76 | 18.75 | 13.20–25.90 |
| Males | 226 | | | | | |
| Stage 1 | 49 | 8.79 | 1.49 | 8.36–9.22 | 8.50 | 6.10–12.30 |
| Stage 2 | 60 | 11.13 | 1.64 | 10.71–11.55 | 11.50 | 7.80–13.90 |
| Stage 3 | 49 | 14.82 | 1.72 | 14.32–15.31 | 14.80 | 11.70–18.30 |
| Stage 4 | 68 | 20.18 | 3.33 | 19.37–20.98 | 20.20 | 14.00–25.50 |
| Total | 500 | | | | | |

CI, confidence interval; SD, standard deviation

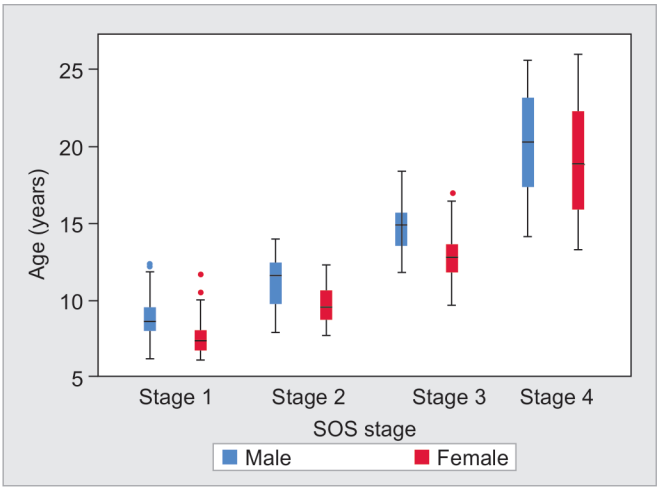



**Fig. 2:** The age, gender, and spheno-occipital synchondrosis closure stages distribution

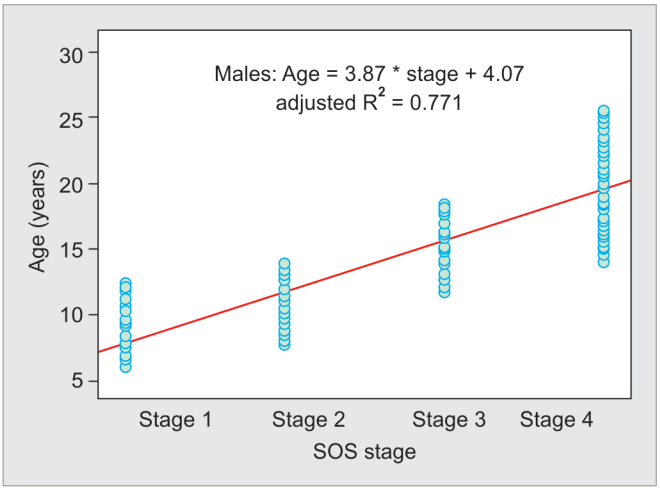



**Fig. 4:** Scatter plot display the correlation between the spheno-occipital synchondrosis stages and age of male participants

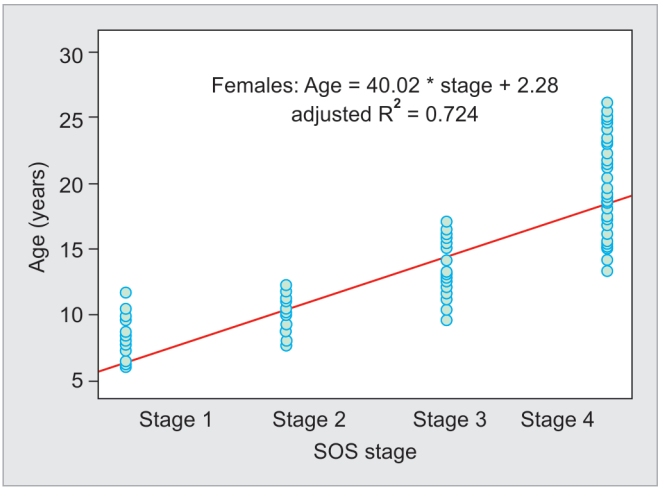



**Fig. 3:** Scatter plot display the correlation between the spheno-occipital synchondrosis stages and age of female participants

model for age prediction by using the SOS stages (Figs 3 and 4). For males, the used regression equation was (Age = 3.87 * Stage + 4.07 with adjusted $R^2$ = 0.771) in which the slope coefficient was 3.87, and the intercept was 4.07 while the coefficient of determination (adjusted $R^2$) was 0.772, indicating that this regression model in males explained nearly 77% of the variation in data. For females, the used regression equation was (Age = 4.02 * Stage + 2.28 with adjusted $R^2$ = 0.724) in which the slope coefficient was 4.02, and the intercept was 2.28 while the coefficient of determination (adjusted $R^2$) was 0.725, indicating that nearly 72% of the variation in data were explained by this regression model in females.

Table 4 shows the transition age estimation model (stages 1–2, stages 2–3, and stages 3–4). The upper bound of the unfused fusing transitioning stage was calculated using the 1.217 and 1.572 standard errors for females and males, respectively, to determine the latest age at which an individual is expected to be unfused. Similarly, the "fused" age limit was derived from the lower bound of the fusing-fused transition stage using the 3.163 and 2.771 standard errors, respectively, to determine the earliest age at which a subject is expected to be fused.

For intraobserver reliability, 20% of the entire sample (100 cases) was reassessed. The Weighted Kappa agreement measures were 0.922 for each observer separately. At the same time, the interobserver reliability depended on the entire sample assessment between observers (Table 5). The strength of intra- and interobserver agreement was rated as "almost perfect."[29]

**Table 4:** Results of linear regression analysis for transition ages of spheno-occipital synchondrosis stages in both genders

| | *Female* | | | *Male* | | |
|---|---|---|---|---|---|---|
| *Transition stages* | *Estimate age* | *Min-max* | *Std. error* | *Estimate age* | *Min-max* | *Std. error* |
| 1–2 | 8.96 | 7.44–9.62 | 1.217 | 10.08 | 8.79–11.13 | 1.572 |
| 2–3 | 11.45 | 9.62–12.94 | 1.541 | 12.79 | 11.13–14.82 | 1.674 |
| 3–4 | 16.69 | 12.94–19.03 | 3.163 | 17.93 | 14.82–20.18 | 2.771 |

**Table 5:** Inter and intraobserver reliability

| | *Intraobservers* | | *Interobservers* |
|---|---|---|---|
| | *W.A.* | *R.A.* | *Both* |
| Number of cases | 100 | 100 | 500 |
| Weighted kappa (κ) | 0.922 | 0.922 | 0.900 |
| Significance | $p < 0.001$ | $p < 0.001$ | $p < 0.001$ |

These results may be helpful in assessing the normal craniofacial skeletal maturity for orthodontic, orthopedic, and orthognathic goals or in age estimation for forensic purposes in the Chinese population of both genders.

## Discussion

The objective was to analyze CBCT to assess the timing and pattern of SOS fusion in Chinese population of both genders. Previous studies have shown SOS fusion consider a biological growth indicator that is important in evaluating the craniofacial growth in orthodontics and dentofacial orthopedics.[4,10,27] In contrast, other studies consider it as a skeletal maturation indicator that can evaluate skeletal maturity during orthognathic surgery or dental implant prosthesis treatment planning.[30,31] Moreover, it is used for age estimation in the forensic field.[17,18] SOS's early and late normal fusing time also has a crucial role in medical diagnosis if the skull base development has an abnormality or a post-traumatic injury from a normal variant.[32–34]

For the present study, CBCT was the modality of choice as it provides the benefits of low-cost, high-resolution, accurate three-dimensional imaging (3D) without the risk of increased radiation exposure to the patient, easy visualization of superimposed bony structures, and the highly using in dental field.[35]

The results of this study demonstrated a significant positive correlation between chronological age and spheno-occipital fusion stages (for all: $r = 0.853$, female: $r = 0.853$, male: $r = 0.879$; $p < 0.001$). Our findings are comparable to those of Frankel et al.[32] (male: $r = 0.821$) and Alhazmi et al.[10] (female: $r = 0.834$, male: $r = 0.844$), who employed a similar 4-stage scoring using CT and CBCT image, respectively.

The early age of complete fusion (stage 4) was 14 years with a mean age of 20.18 years in males, while it was 13.20 years with a mean age of 19.03 years in females. The latest age of incomplete fusion (stage 3) was 18.30 years with a mean age of 14.82 years in males and 16.90 years with a mean age of 12.94 years in females. The early age of incomplete fusion (stage 1) was 7.80 years with a mean age of 11.13 years in males and 7.60 years with a mean age of 9.20 years in females. This finding accords with previous studies that used the same scoring system (four-stages) and same techniques,[9,16,18,19] but still differ in the SOS fusion time from 2 to 3 years, which supported the assumption of the growth variations between populations in previous studies.[24,26]

Based on previous research, the SOS fuses earlier in females than in males.[10,14,18] This study corroborates with past studies since each SOS fusion stage appeared earlier in females than in males. This sexual dimorphism demonstrates that the females are always ahead of the males by about 1.47 ± 0.33 years.

In the American population, a study reported no statistically significant differences in the mean ages for SOS fusion stages 1 and 0, 1 and 2, and 0 and 2 for females.[11] The nonstatistically significant differences in the mean age between initial and intermediate fusion phases are inferred from previous investigations, which could have suggested that females' SOS fused at a faster rate and in a shorter period frame than males.[3,10,11] Still, in our study, the differences in the mean age between all stages were statistically significant in both genders, which indicates the fusion of SOS synchondrosis for males and females was logically has a closer rate and periods.

In the current study, the regression model's coefficient of determination (adjusted $R^2$) was 0.771 for males and 0.724 for females. These values are higher than those reported in studies in the four SOS stages system with CBCT,[9,31] indicating that more fitness in the age estimation of this study regression model depends on the SOS stage for both genders. Furthermore, this study model fitness was slightly higher in males than females, a finding that has been presented in other studies.[16,19,20,36] In contrast to the studies mentioned above, others suggested a better model fit for females than males.[10,37]

The results of Table 4 were used to construct statistically quantified age estimation models based on fusion status as shown in CBCT scans (i.e., age-at-transition standards and lower and higher developmental bounds), which was used in the same way of Sinanoglu et al.[17] Compared with Hisham et al.,[18] the present study shows that the transition age between Stages 2 and 3 in females is around 9.62–12.94 years. This age was concordance to the average age of starting of menarche in Chinese females (12.3 years; 12.1–12.4 years) that was conducted in Lei et al. ($n$ = 344,230).[38] This finding supports the proposal that SOS begins to fuse around puberty.[10,12]

The current study has some limitations; the racial, socioeconomic differences between participants were not considered. Further studies of SOS with more attention to ecological, biological, geographical, and racial factors are to be considered in future studies.

## Conclusions

Based on the current finding, a four-stage scoring system viewed from the mid-sagittal plane using CBCT is reliable and reproducible in Chinese population aged 6–25-years-old of both genders. The spheno-occipital synchondrosis was found to be an important skeletal indicator of age estimation and suggested to be a biological indicator of the normal pattern of skeletal growth, the active skeletal growth period, and the maturation period in a Chinese population of both genders.

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