"CORRELATION OF SPHENO-OCCIPITAL SYNCHONDROSIS AND CONDYLAR CORTICATION WITH CHRONOLOGICAL AGE USING COMPUTED TOMOGRAPHY – A CROSS-SECTIONAL STUDY"

By

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LIST OF ABBREVIATIONS

ABBREVIATION	FULL FORM
SOS	Spheno-occipital synchondrosis
DNA	Deoxyribonucleic acid
CT	Computed Tomography
MRI	Magnetic Resonance Imaging
CBCT	Cone Beam Computed Tomography
DICOM	Digital Imaging and Communications in Medicine
tiff	Tag Image File Format
kVp	Kilovoltage peak
mAs	Milliampere-seconds
AU	Active pharmaceutical ingredient
mm	Millimeter
cm	Centimeter
SPSS	Statistical Package for the Social Sciences
ANOVA	Analysis of Variance
MDCT	Multi Detector Computed Tomography
3D	3 Dimensional
CVM	Cervical Vertebrae Maturation
TMM	Third Molar Maturation

OPG	Orthopantomogram
AEC	Articular Eminence Cortication
MCC	Mandibular Condyle Cortication
MCI	Mandibular Cortical Index
TMJ	Temporomandibular Joint
FAE	Forensic Age Estimation
MSCT	Multi Slice Computed Tomography

ABSTRACT

BACKGROUND:

Forensic age estimation is an entity that aids in estimating age in living individuals as well as dead individuals in cases of natural calamities and man-made disasters. Pattern and closure of spheno-occipital synchondrosis fusion (SOS) along with subchondral ossification of condyle can be used for age estimation.

AIM AND OBJECTIVES:

To estimate age based on the computed tomographic (CT) images of SOS fusion and condylar cortication and correlating it with chronological age.

MATERIALS AND METHODS:

435 CT images belonging to individuals aged between 10 to 25 years were included in this study. SOS was assessed using four stage system and condylar cortication on both sides using three stage system on sagittal plane. Data regarding the fusion stages and cortication types were entered with respective chronological age and then statistically analyzed.

RESULTS:

Stage 2 SOS was found to fuse at similar age between males (19.82 ± 2.67 years) and females (19.23 ± 2.93 years). Earlier fusion was noted for other stage in females compared to males by a mean age of 2 years. Condylar cortication was completed earlier in females than in males by 1 year with statistically significant differences (p=0.000). On comparing cortication types and different fusion stages, only Type II cortication had statistically significant differences when compared to different fusion stages (p = 0.000).

CONCLUSION:

Condylar cortication and SOS fusion had a significant positive correlation with respect to chronological age and hence these parameters can be used as an auxiliary method for age estimation.

KEY WORDS: Occipital Bone; Sphenoid Bone; Age Determination by Skeleton; Mandibular Condyle; Multidetector Computed Tomography; Forensic Anthropology.

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INTRODUCTION

The process of establishing the identification of an individual is often needed in natural disasters like earthquakes, tsunamis, floods, etc., or in cases of man-made disasters like mass murders, terrorist attacks, or any situation where a body is purposely dismembered in a manner that hinders personal identification. Forensic personal identification, a primary area of focus in forensic sciences and technologies, deals with appropriate techniques that are utilized to identify live subjects, recently deceased bodies, and human remains at a crime scene [1]. Regardless of swift advancement in diagnostic methods, the identification process remains a challenging task as skeletal remnants or decomposing body parts make the individual identification process more difficult [2, 3].

Methods of identification include fingerprint analysis, DNA profiling, and dental comparisons. However, these methods have pitfalls when decomposed skeletal remains are analyzed or when there are no comparisons available, like antemortem and post-mortem records of the same individual [4, 5]. As a result, other techniques, such as radiological or anthropological methods, can be used to determine an unknown individual's sex, age, and ethnicity [6].

Precise estimation of any one of the above-mentioned biological components in skeletal remains is critical because it helps in personal identification by narrowing down the search for a missing person [7].

Bone, a component of the skeletal system, is resistant to putrefaction and destruction [8]. Bones contain many important age markers, which aid in forensic identification. Many quantitative and qualitative studies for estimating bone age have shown that bone can be used as a reliable source in forensic determination [9].

Previous studies used cranial suture closure, dentition, epiphysis, and ossification centers, as well as the articulating surface of the ox coxae (pubic symphyses and auricular surface) [10]. Methods for evaluating these indicators have evolved from the past, when computed tomography (CT), and magnetic resonance imaging (MRI) were implemented in addition to other macroscopic and conventional radiographic examinations. For example, CT evaluation of third molar teeth, clavicle ossification degree, macroscopic and CT evaluation of spheno-occipital synchondrosis, canine tooth volume, sagittal suture analysis, and MRI evaluation of tibial epiphysis and calcaneum are some of the applications in forensics for estimation of age [11-16].

A cartilaginous joint between two hard bones is known as synchondrosis. At the midline of the base of the skull, three synchondroses are present. They are spheno-ethmoidal synchondrosis, inter-sphenoidal synchondrosis, and spheno-occipital synchondrosis. Spheno-occipital synchondrosis (SOS) is one of these three synchondroses, and because of its role in the development of the craniofacial region and its late ossification phase, it has therapeutic and forensic uses [17]. The basilar suture, also known as spheno-occipital synchondrosis, is a growth center between the occipital and sphenoid bones. It increases the facial height by pulling the maxilla upwards and forwards, thereby increasing the facial depth and height and aiding in cranial flexion [18, 19].

Forensic age estimation by considering the pattern and timing of SOS fusion provides an upper and lower age limit in an adolescent [20]. However, the technique using the assessment of single bones for age estimation is not so dependable [21-23]. So, another reliable factor that can be assessed to derive an age estimation, namely cortication around the condyle, was considered.

The development of the mandibular condyle is a process that begins with endochondral ossification and chondrogenesis [24]. This process of development is closely related to the development and growth of the mandible as morphological changes in the form of size and remodeling take place at a certain age [25].

The deposition of secondary cartilage on the osseous surface of the condyle takes place during the 12th week of intrauterine life [26]. Remodeling causes changes in the mineralization of cortical bone between the cortical regions of the mandibular condyle. Research states that condylar cartilage is not displaced by bony texture until the age of 20-25 years [27].

For the former, radiographs (conventional, CT, MRI, Cone beam CT (CBCT), or a combination of any of these) or macroscopic examinations involving a cadaver or deceased individual can be used to assess spheno-occipital synchondrosis and condylar cortication. CT scans provide precise or accurate images of the abovementioned factors [28-31].

The literature review shows only one study has evaluated condylar cortication and correlated it with chronological age to find any association [32] and only one study evaluated the relationship between condylar cortication, spheno-occipital synchondrosis and chronological age [33].

As a result, our study suggested estimating age based on computed tomographic images of the spheno-occipital synchondrosis and condylar cortication and correlating it with chronological age.

HYPOTHESIS:

NULL HYPOTHESIS:

There will be no correlation between spheno-occipital synchondrosis and condylar cortication with chronological age to be used as an age estimating factor in forensic identification.

ALTERNATIVE HYPOTHESIS:

There will be a correlation between spheno-occipital synchondrosis and condylar cortication with chronological age to be used in age estimation for forensic identification of an individual.

AIM OF THE STUDY

This study estimates age based on the computer tomographic images of spheno-occipital synchondrosis fusion and condylar cortication and correlates it with chronological age.

OBJECTIVES

1. To estimate age, based on fusion degree of spheno-occipital synchondrosis in the sagittal view of computed tomography.
2. To estimate age, based on the cortication of condyle assessed bilaterally in the sagittal view of computed tomography.
3. To correlate the age obtained by assessment of spheno-occipital synchondrosis and condylar cortication with chronological age.

REVIEW OF LITERATURE

Forensic anthropology:

Application of anthropological methods and theory that stays within the medico-legal context, that relates to the recovery and analysis of the skeleton and forms a basis for understanding and interpretation of variations among humans, the biology of skeleton etc. is called Forensic anthropology [34]. It involves the estimation of the biological profile that comprises sex, ancestry, age, and stature from unknown skeletal remains. This helps in generating information that can be used in the identification of a person wherein forensic anthropologists specialize as they are aware of osteology, growth and development, and pathologies involving the skeletal system [35].

History of forensic anthropology:

Initially, forensic anthropology was restricted only to anatomists and a few physical anthropologists that were consulted for law enforcement on skeletonized remains due to their employment in museums and universities which lead to little or sparse information regarding the possible application of biological anthropology. In 1878, a Harvard anatomy professor named Thomas Dwight laid the foundation for forensic anthropology with his extensive work on establishing methods of estimating age, sex, and stature from the skeleton in his essay, *The Identification of the Human Skeleton: A Medicolegal study* [35]. His work helped him to earn the title of “Father of Forensic Anthropology in the United States”.

The utility of forensic anthropology gathered attention during the 2nd World War and the Korean war where the identification of deceased service members was needed for medicolegal and military purposes. Wilton Marion Krogman developed forensic anthropological methods based on the skeletal remains of deceased soldiers which he published in two works namely *Guide to the Identification of Human Skeletal Material* [37] and *The Human Skeleton in Forensic Medicine* [17]. Later this field became more professionalized with the establishment of the physical anthropology section of the American Academy of Forensic Sciences [38] (AAFS) in 1972 and the American Board of Forensic Anthropology (ABFA) [39] in 1977. Apart from establishing the biological profile, this field has increased its scope to personal identification, trauma, and taphonomic analysis, and investigation of mass disasters and violations of international law with investigations limited not only to the deceased individuals but also involves living individual to determine whether the individual has attained a particular age or not [38, 39].

Age estimation in forensic anthropology:

Among the four biological profile factors, knowing the age at death is a critical characteristic in identifying the missing person since it is one of the most essential parts of analysis in forensic anthropology that aids in limiting the list of likely missing individuals [40]. This age can be either *skeletal age* which is based on skeletal maturity; *biological age* which corresponds to physiological age; or *chronological age* which is the time duration that elapsed from the time of birth till the person is alive.

Methods to determine age depend on what the skeletal remnants present and it also varies between an immature individual (fetal, infant, child, and adolescent) and a mature individual. Hence, if the preliminary assessment reveals completely fused third molar apices; epiphyses of the sternal clavicle and iliac crest; fused basilar synchondrosis, then techniques involving assessment for mature individuals should be employed [41].

Age estimation of the immature can be accurately established based on dental formation when the teeth are present for examination. Evaluation of individual teeth for age assessment should be carried out for age estimation keeping in mind the variations in gender and population differences [42]. Also, ossification of long bones can be used for age estimation but, dental development is highly correlated with chronological age and hence the most accurate and reliable method should be used whenever possible as bone development is more susceptible to environmental influences like nutrition, health status, etc. [43].

Skull base development and Spheno-occipital synchondrosis:

Growth of bone takes by the deposition of bone matrix on a precursor by a process called osteogenesis. Formation of bone can be of two types; one where the ossification process occurs within a mesenchyme that is known as intramembranous ossification; secondly the ossification process takes place from cartilage known to be endochondral ossification. The development of bones has two or more centers of ossification [19]. The first one that occurs in long bones (diaphysis or shaft) is the primary ossification center. Secondary ossification centers appear late after birth and are referred to as epiphyses. Between diaphysis and epiphysis, a cartilaginous layer exists that helps the bone to grow in length known as metaphysis or growth plate [19].

The cranial base develops from cartilage that is continuous with nasal cartilage that is later replaced by bone during embryogenesis. Primary ossification centers undergo osteogenesis beginning from the third month in utero till the first year of birth leading to the formation of cranial base bones. Sphenoid and occipital bones that are formed from 25 separate ossification center, 19 of which is for the former, lays down the cranial base [45]. All these primary ossification centers fuse to form basioccipital, presphenoid, basisphenoid, and ethmoid bones which are illustrated in Figure 1.

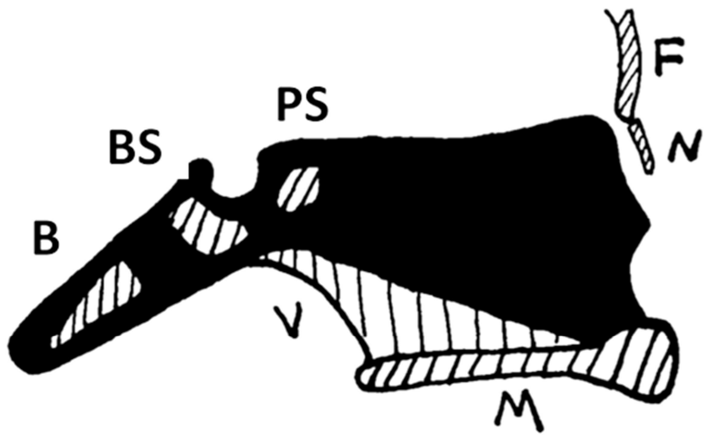


Figure 1: ***Midsagittal view of Fetal Cartilaginous Skull. Solid represents cartilage and hashed fill represents primary ossification centers of the basioccipital (B), basisphenoid (BS), presphenoid (PS), vomer (V), maxillary (M), frontal (F), and nasal (N).*** **Modified figure adapted from Scott,1958**

Synchondrosis known as bands of cartilage exists between ossified bone and acts as a growth center until the fusion of the bone is completely achieved. These synchondroses play a major role in prenatal and postnatal growth of the skeleton where the growth is exhibited in either direction denoted by bipolar nature involving the cranium and face as the timing of the closure of these can indicate the onset of skeletal development or maturation [46].

Three midline cranial base synchondroses that are primarily related to the growth of the skull base which is depicted in Figure 2.

1. Intersphenoid synchondrosis
2. Spheno-ethmoidal synchondrosis
3. Spheno-occipital synchondrosis

Synchondrosis that separates presphenoid and basisphenoid bones until fusion is called ***intersphenoid synchondrosis***. This synchondrosis is not related to postnatal growth of the cranial base as the fusion takes place near the [47, 48].

Synchondrosis that separates presphenoid and ethmoid bones until fusion is ***spheno-ethmoidal synchondrosis***. It is related to post-natal growth of the cranial base until its fusion when the growth of the anterior cranial base is complete i.e. 6-8 years of age [49].

The third synchondrosis that separates basioccipital and basisphenoid bones is ***spheno-occipital synchondrosis***. Since it is the last cranial base synchondrosis to ossify, it represents a major postnatal growth mechanism of the cranial base as the fusion takes place from the endocranial surface to the ectocranial surface [50].

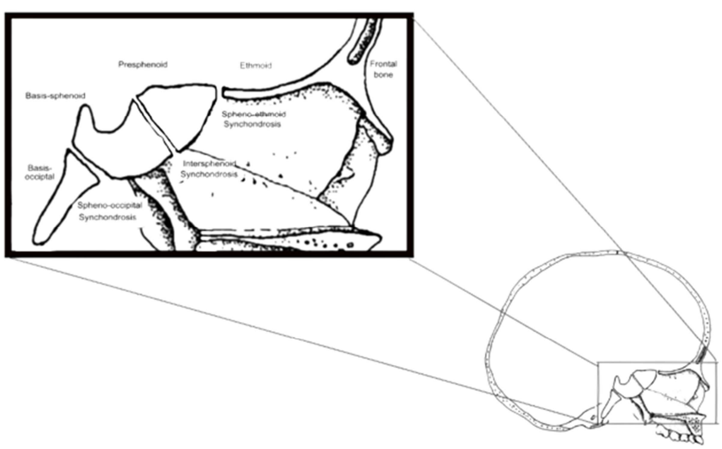


Figure 2: ***Midsagittal view of Cranial Base Synchondrosis.*** **Modified figure adapted from Scott,1958**

Mandible and Condylar growth:

Initially, the condyle was thought to be the primary and principal growth center of the mandible which controlled the growth of the mandible [51]. Later, it was proved that condyle alone does not determine mandibular growth but it occurs as a growth site needed for development controlled by intrinsic and extrinsic factors [52]. Condylar cartilage which is approximately 1.5 mm in thickness reduces to 0.5mm by 6 months of age due to a decrease in the zone of hyaline cartilage. This thickness further decreases by 0.2 mm to attain a diameter of 0.3 mm once the primary teeth erupt into the oral cavity till the age of 7 years [53].

The shape of the condyle remains constant with an increase in size during mixed dentition where the growth cartilage area diminishes and gets replaced by immature bone. This transition is supported by the formation of fibrocartilage which is then replaced ossification of bone [54]. It was stated that deposition of subchondral compact bone takes place until 30 years of age which correlates with the reduction in endochondral ossification [55].

Growth of the condyle takes place due to simultaneous deposition and resorption on the periosteal and endosteal surfaces. The posterolateral region of the region has periosteal deposition and endosteal resorption whereas the anteromedial region has endosteal deposition and periosteal resorption [56]. This process helps in the superior and lateral growth of the condyle.

Radiographic evaluation reveals the formation of small focal areas of mineralization in the first year of life that coalesce and form a continuous layer that increases in thickness as age progresses [57]. Variation in mineralization of the condyle is noted during growth with compact, cortical bone forming around the neck of the condyle around the first 6 years of age till 20 years of age following a superior pattern [57].

Radiology in forensics:

Schuller in the year 1921 utilized radiographs initially for dental identification and stated that they can be used for comparative and reconstructive purposes [58]. Comparative radiograph uses two radiographs one that is taken before death and the other that is taken after death. Reconstructive identification is one where the biological profile is generated for an unidentified person with the help of radiographs and other aids [58].

The use of radiographs in forensic dentistry is considered with the identification of teeth, presence of anatomical structures, associated pathologies, and other features like the presence of foreign objects, restorations, etc. as these features vary among individuals and hence can be used for comparative identification [59].

Radiographs can help to ease the identification process as they give information simpler and quickly in a non-invasive manner both in living and dead individuals [60]. Radiographs can help in the analysis of a tooth and its surrounding structures like coronal shape and size, anatomy of pulp, various dental treatments, etc. which can be compared in both antemortem and postmortem radiographs [61, 62].

Owing to the evolution in the field of radiology, conventional radiographs are replaced by advanced digital three-dimensional imaging systems which can be used for facial reconstruction in addition to that of comparative purpose [63]. The manner of death in medico-legal cases can be determined by a virtual autopsy technique named "virtopsy" where multi-detector computed tomography, magnetic resonance imaging, ultrasonography, and other advanced imaging modalities are implicated [64].

Computed tomography and forensics:

The word "tomography" is derived from the Greek word "tomos" referring to the x-ray technique where a single plane is photographed while eliminating the outline of structures in other planes [65]. This explains the working principle of conventional radiography which has a limitation of superimposition due to overlapping structures and improper detailing of the 3-dimensional volume of the human body that is represented as the 2-dimensional images.

To overcome the disadvantage of conventional radiography, Computed tomography (CT) was introduced in the year 1967 by Godfrey N. Hounsfield where x-ray measurements of a body were taken from different directions which allowed the reconstruction of internal structure [66]. This imaging has evolved since its inception in terms of generation based on the source of the x-ray beam, collimation used, and the type of detector that detects the x-ray beam [67].

CT helps in the segmentation of images and it helps to avoid the superimposition of anatomical planes that is beyond the plane of interest with increased accuracy and reliability for the observer where computer-assisted analysis can be carried out for various purposes [68].

CT helps in the identification of individuals where the autopsy has not consented to or cannot be performed in cases of mass disasters like an explosion, fire, or natural calamities and also in cases where the body is purposefully dismembered in cases like murder. CT guided autopsy (Virtopsy) can be performed wherein visualization of complex internal anatomical structure with possible superimposition of images [64].

Apart from the above-mentioned potential applications, CT can be used in determining the skeletal maturity, gender of the unknown individual, and dental or skeletal age of a living or dead individual [68].

Assessment of Spheno-occipital synchondrosis:

Direct assessment of SOS fusion:

Akhlaghi *et al* (2008) macroscopically assessed the fusion of SOS based on calcification along the length of the cartilaginous part of the suture [69]. They classified fusion into three various stages as shown in Figure 3.

1. Open: Calcification has not begun or less than 1/4th of the suture had been calcified
2. Semi-closed: The calcification of the cartilage had been more than 1/4th but less than 3/4th of the length of the suture.
3. Closed: Calcification of more than 3/4th of the suture.

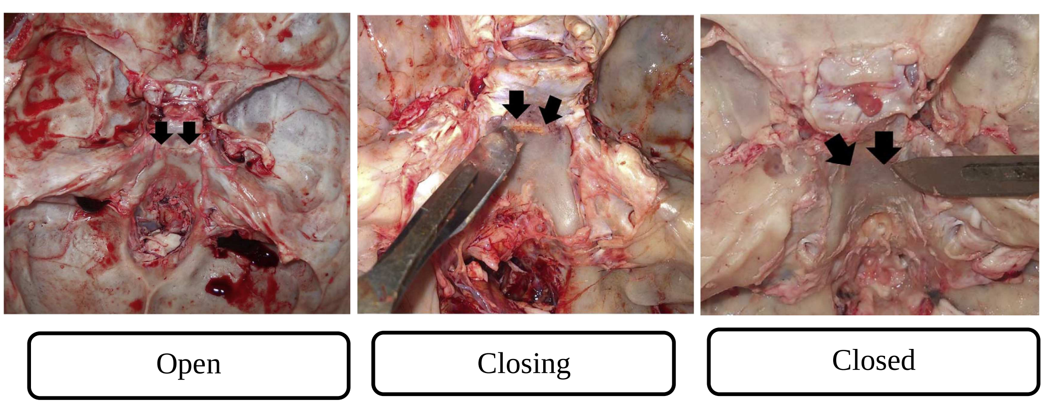


Figure 3: Three stages of SOS assessed through the direct method.

Mahon *et al* (2017) [70] adapted a non-invasive direct evaluation of SOS fusion as shown in Figure 4 based on three stage system devised by **Shirley and Jantz *et al*** [71] where numerical values corresponding to each of the three stages were substituted.

1. Spheno-occipital synchondrosis remains open with noticeable space between the occipital bone and sphenoid bone
2. The basilar portion of the occipital bone and the body of the sphenoid bone has an active fusion with mild spacing noticeable on the ectocranial aspect.
3. Complete fusion with the absence of spaces or openings with or without fusion scar.

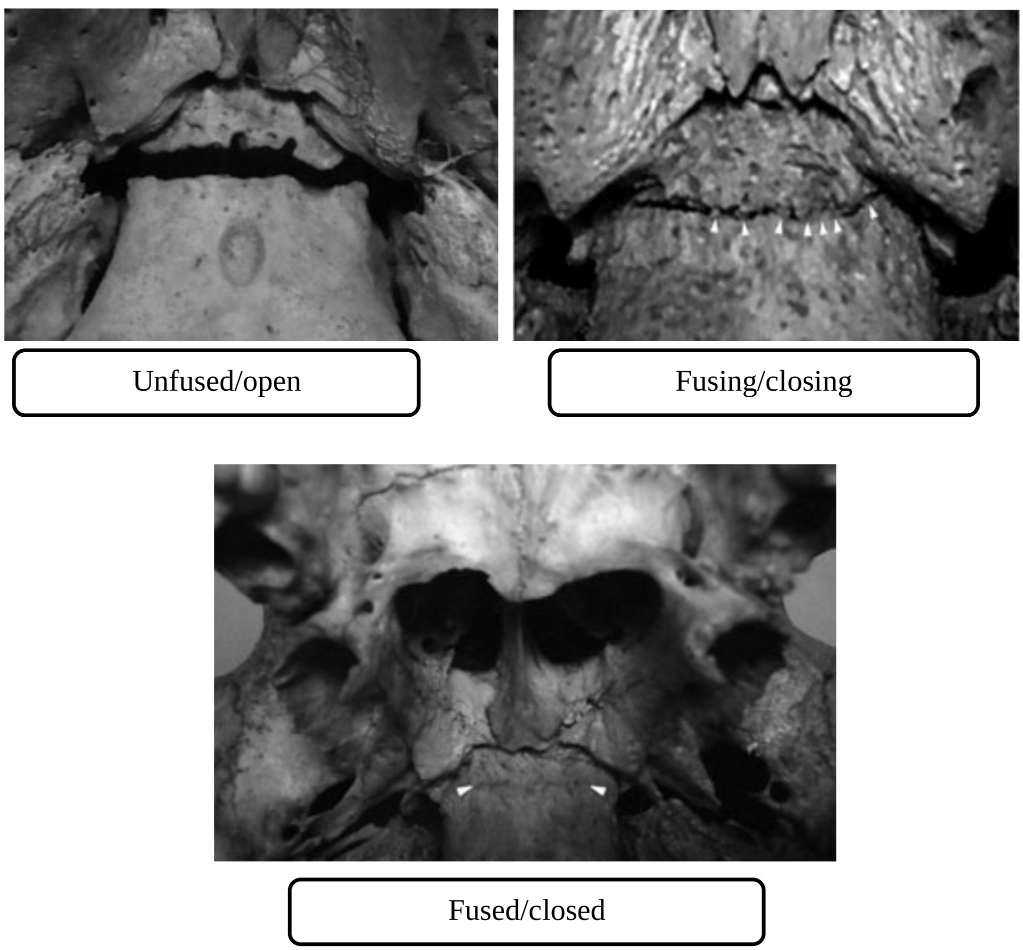


Figure 4: Direct assessment of Spheno-occipital synchondrosis revealing different stages of fusion

Radiographic method of SOS assessment:

Radiographic assessment of SOS fusion was initially assessed by **Bassed *et al*** [10] where the fusion stages were based on the ossification status. Five stages were proposed where the visibility of the scar was also taken into consideration as shown in Figure 5.

1) Stage 1: The suture appears to open completely.
2) Stage 2: Closure occurs only in the superior border.
3) Stage 3: Half of the superior border is closed.
4) Stage 4: Fusion scar is noted with complete fusion.
5) Stage 5: Complete fusion of suture with no scar.

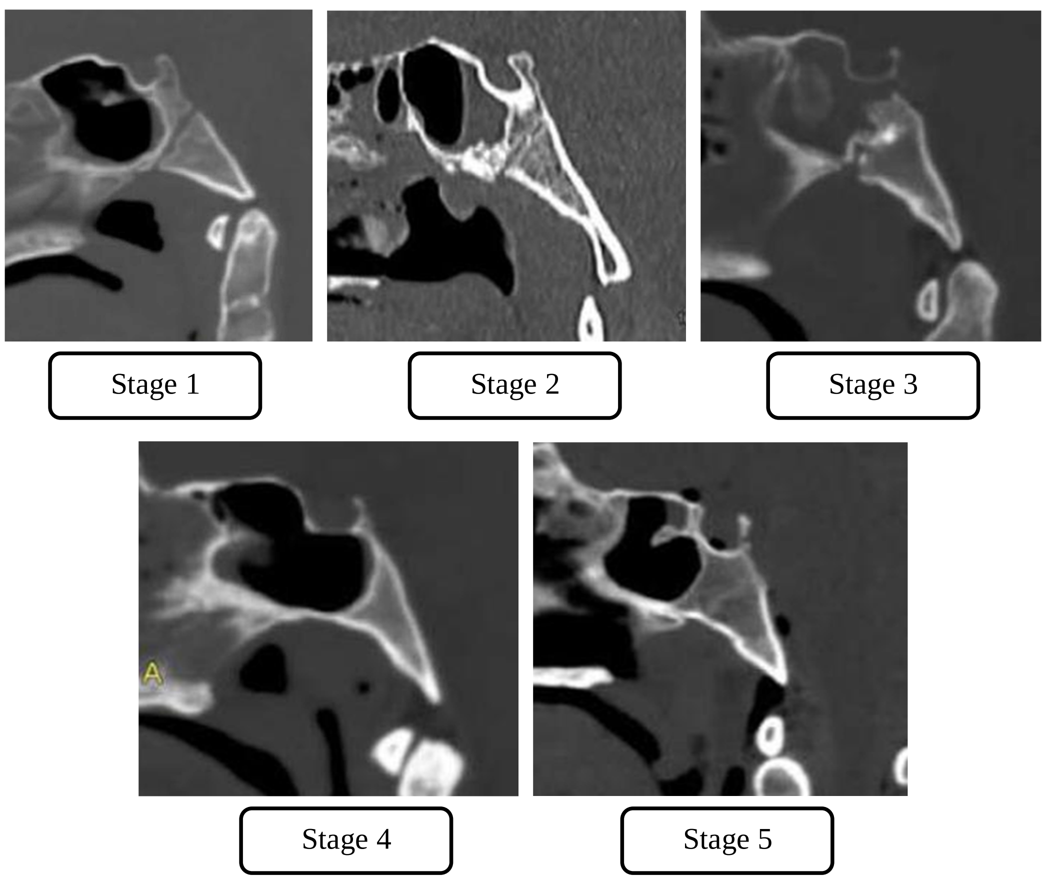


Figure 5: Radiographic assessment of Spheno-occipital synchondrosis showing 5 stages of fusion.

Later, **Franklin *et al*** (2013) [72] modified five stage-systems given by **Bassed *et al*** [10] into a four-stage system where the fusion scar was not separately considered for classification (Figure 6).

1) Stage 0: Basilar portion of the occipital and the sphenoid bone remains completely open with no signs of fusion or bone deposition.
2) Stage 1: Fusion proceeds from the endocranium to the ectocranium, where the fusion is not more than half the length of the synchondrosis.
3) Stage 2: Ectocranium remains unfused with more than half the length of the synchondrosis being fused.
4) Stage 3: Fusion is complete with the appearance of normal bone with or without a fusion scar.

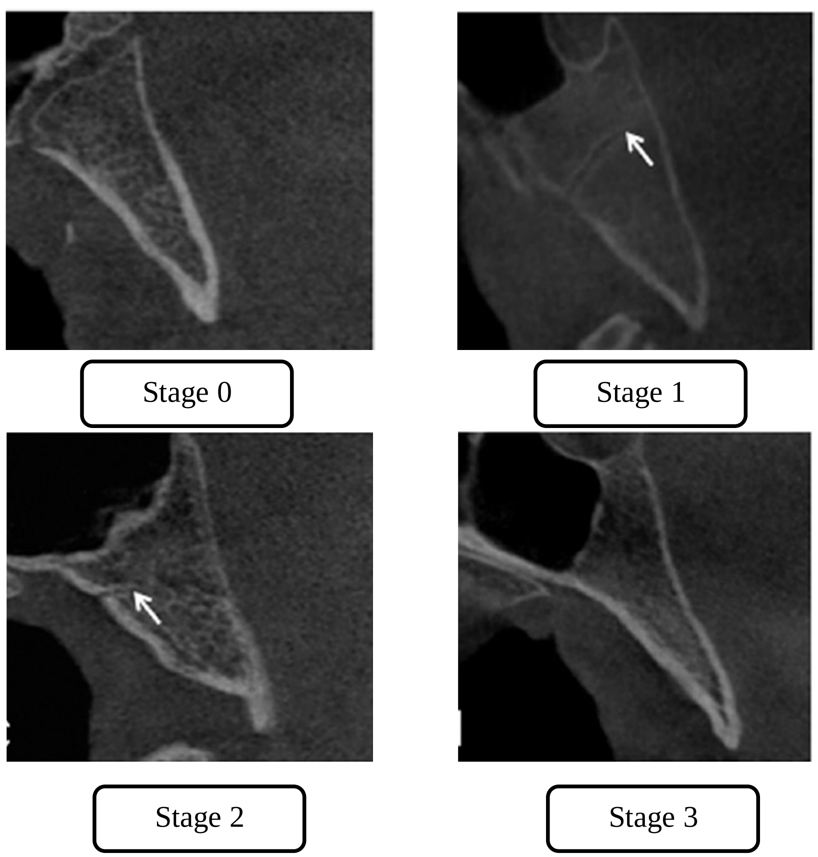


Figure 6: Radiographic assessment of Spheno-occipital synchondrosis using 4 stage system

LITERATURE SEARCH:

Spheno-occipital synchondrosis and age estimation

Conventional radiological methods:

Powell *et al* (1963) utilized laminography, where tracing was performed with the marking of anatomical landmarks. All x-rays taken for orthodontic treatment planning of age groups 6 to 21 years, belonging to 205 males and 193 females, were assessed for spheno-occipital closure using 6-stage systems. Initial closure of the suture was noted at 10 years of age for males, whereas 8 years was the earliest age at which initial closure was noted for females. Complete closure of SOS was found between 13 and 16 years in males and between 11 and 14 years in females. Obliteration of sutures was earlier in females when compared to males by 2 to 3 years [73].

Konie *et al* (1964) assessed skeletal age based on the closure of SOS and skeletal maturity using laminograms and hand-wrist radiographs respectively. 314 patients (162 females & 152 males) belonging to age groups 7 years to 24 years were evaluated for the fusion of SOS and the atlas of skeletal maturation was followed by hand-wrist assessment. Initial fusion of the spheno-occipital junction was noted in the age range of 10–11 years for females and 13–14 years for males. Complete ossification was noted after the ages of 13 years and 6 months in females and 16 years in males [27].

Histological methods:

Melsen *et al* (1972) performed a histological examination of SOS closure on sections of 100 individuals of both genders aged 0–20 years who had died due to long-standing illness, violence, or accidents. Three-stage systems were utilized in which open denoted open suture; closing when there was a formation of an osseous bridge between the occipital and sphenoid bones, and closed when cartilage had been replaced by bone. It was concluded that the age group for closing synchondrosis ranged from 13 years and 6 months to 18 years and 7 months for males, whereas it ranged from 12 years and 3 months to 16 years and 1 month for females [74].

Ingervall *et al* (1972) carried out a postmortem investigation where toluidine blue staining of SOS and clivus was carried out in 32 males and 21 females aged 2 days to 24 years and 11 months. SOS was either closed or closing in the age group of over 16 years in males and above 13 years and 9 months in females. Suture closure occurred earlier by 2 years in females when compared to males and irrespective of gender, small cartilaginous areas were seen among the subjects aged 17 years or older [75].

Direct inspection :

A sample of autopsied Northwest Indian population was carried out by **Sahni *et al*** (1998) to estimate the timing of fusion of the basisphenoid with the basilar section of the sphenoid bone. Skulls from 50 males and 34 females belonging to ages of 10 to 20 were removed from the calvarium and examined which was then macerated after computed tomographic assessment. Three stages of fusion were used to describe the union between the two bones. Complete fusion was seen in boys at the age of 15 years or above and at or above 13 years for girls [76].

Coqueugniot *et al* (2007) devised new aging standards based on the fusion of infracranial epiphyses and SOS on 132 skeletons of individuals aged between 7 to 29 years. Their study concluded that the direct macroscopic examination of ossifications of the SOS and other bones like the pelvic girdle, the shoulder, and the upper and lower limbs can be utilized for age determination when there is an absence of dental remains [77].

The closure of the spheno-occipital suture in male cadavers that were sent to an Iranian legal medical organization was examined by **Akhlaghi *et al*** in 2008. 106 Cadavers belonging to age 8 to 26 years were examined directly after autopsy for the suture closure according to three stage system. The open suture was found at the mean age of 12.78 ± 3.00 years; Semi closed suture was found at the mean age of 16.86 ± 2.69 years; Closed suture was found at the mean age of 21.36 ± 3.22 years. They also carried out regression analysis to predict whether closure of the suture can be used for age determination. Analysis revealed that the male cadavers can be grouped above or below 16 years with a sensitivity of 88.31% and specificity of 79.31% [69].

Similarly, **Akhlaghi *et al* (2010)** examined the closure of SOS through a direct visual examination and correlated it with chronological age in the Legal Medical Organization of Tehran (LMO). 376 cadavers belonging to 180 males and 170 females of age group 8 to 26 years were evaluated according to three staging systems. The open suture was found in the mean age of 12.27 ± 2.73 years for boys and 9.04 ± 1.15 years for girls; Semi closed suture was found in the mean age of 16.12 ± 2.85 years for boys and 12.38 ± 0.52 years for girls; Closed suture was found in the mean age of 21.17 ± 3.14 years for boys and 19.44 ± 3.59 years for girls. The age limit was set in their study that when the suture is closed the age of the boys was 15 years or above and in girls, it was 12 years or above. When the suture remains open or semi-closed, the age of the boys is below 21 years whereas, in girls, the age was 13 years or below [78].

By performing a direct examination of the ectocranial site of the suture, **Shirley *et al***. (2011) evaluated SOS fusion in 162 modern American individuals aged 5 to 25 (100 females and 62 males). Three stage scoring system was utilized and age transition between different stages of suture closure was derived using 68% and 95% prediction intervals. When the suture is unfused, the age probability that a male could be was less than 21.6 years whereas it was less than 16.8 years in females. The suture was fusing in the age range of 12.6-22.8 years in males and 7.8-20.1 years in females. Closed sutures had an age probability of more than 13.3 years in males and more than 9.3 years in females [71].

Mahon *et al* (2017) estimated the repeatability of the three-stage scoring method of SOS on a sample of South African Black skeletal sample. A total of 147 randomly selected skeletons (74 males and 73 females) of the age of 12-30 years were inspected for the degree of fusion. The Mean age of the sample where the SOS was unfused was 14.3 ± 1.9 years (6.1% of the sample). Fused SOS was found at the mean age of 16.5 ± 1.8 years (11.6% of the sample) and fused SOS was found at the mean age of 24.3 ± 4.0 years (82.3% of the sample) [70].

Pate *et al* (2018) evaluated the utility of the SOS fusion in the estimation of age among the Central Indian population. 198 cadavers (117 males and 81 females) belonging to the age group 8 to 26 years were macroscopically examined using a digital Vernier caliper utilizing the Mitra-Akhlaghi scale to grade the fusion degree. The mean age at which the suture was open in males was 11.11 ± 2.12 years and in females was 9.25 ± 1.58. Mean age where the semi-closed suture was noted in males was at 16.80 ± 1.16 years, whereas in females it was at 12.6 ± 1.14 years. A closed suture was found at the mean age of 21.48 ± 2.05 years in males and 20.27 ± 2.65

years in females. They concluded that there was a significant linear correlation existed between the age of the individual and the closure of SOS for both genders [79].

Computed tomography:

Okamoto *et al*. (1996) retrospectively evaluated the development of the SOS using high-resolution thin-section CT of 253 patients aged 1 to 77 years of old. Patients aged between 8 to 13 years had a midline ossification center. Additional symmetrical ossification centers on both sides of the midline were noted for 6 girls whereas it was not seen in boys. SOS did not persist after 13 years of age in any patient. They concluded that high-resolution CT images can be used to predict the progressive calcification of SOS [28].

Bassed *et al*. (2011) utilized a multi-factorial approach where age estimation was carried out with CT imaging of the medial clavicular epiphysis, the third molar tooth, and the spheno-occipital synchondrosis. A sample of the Australian population consisting of 605 individuals that included 421 males and 184 females belonging to the age group 15-25 years were assessed for spheno-occipital synchondrosis, third molar development based on Demirjian staging, and external end of the clavicle for epiphysis. Linear regression analysis performed to assess the correlation of each variable with age revealed that there was no significant correlation of SOS with chronological age thereby indicating that it cannot be used for the age estimation model [10].

Franklin *et al*. (2014) developed a quantified age estimation standard based on the scoring of the degree of SOS fusion in a high-resolution multislice CT. Cranial CT scans of 312 individuals of the contemporary Western Australian population aged 5 to

25 years were assessed for SOS fusion utilizing 4 stage system. The mean age for Stage 0 was found to be 10.28 ± 3.30 years in males and 8.62 ± 2.40 years in females. Stage 1 was found in the mean age of 14.30±1.44 years in males and 12.65 ± 1.86 years in females. Stage 2 was found in the mean age of 16.38 ± 0.48 years in males and 13.53 ± 1.13 years in females. Stage 3 was found in the mean age of 19.83 ± 2.94 years in males and 18.62 ± 3.55 years in females. They concluded that the SOS fusion degree has a potential value in an indication of skeletal age [72].

Can *et al.* (2014) investigated the fusion degree of SOS for estimating age in the Turkish population with the help of MDCT. A total of 638 individuals of age 10 to 25 years (399 men and 139 women) were evaluated for SOS fusion utilizing the five-stage system proposed by **Bassed *et al*** [32] SOS was open at the mean age of 11.5 ± 1.5 years for males and 10.7 ± 0.8 years for females. Fusion was found to start earlier in women than in men by 2 years and this process completes in both gender at the age of 17 years. A positive correlation was noted between age and degree of fusion of SOS and they concluded that CT assessment of SOS was helpful for estimating the age of the individuals between 11 and 17 years of age [80].

Barrany *et al*. (2015) determined the pattern of fusion of SOS using a CT scan among the Yemen population to assess whether the fusion of SOS can be used as a reliable age estimation marker. They investigated SOS fusion in a sample of 217 subjects (121 males and 96 females) belonging to the age group 15 to 25 years. Four stage system by **Flavel *et al.*** [72] was used for staging the fusion degree of SOS. Stage 0-1 was found in the age less than or equal to 23 years in males and 22 years in females. Stage 2-3 was found in the age less than or equal to 16 years in males and less than or equal to 15 years in females [81].

Guillaume *et al* (2016) evaluated the foramen magnum area and the posterior cranial fossa with the degree of cranial base synchondrosis ossification. 6 stage system was utilized to retrospectively analyzed 235 healthy children. SOS fusion began at approximately 10 years whereas grade II was observed at age 10.14 years. Grade III was seen approximately at 13.5 years. They concluded that earlier closure of SOS and other sutures of the skull base closed earlier in girls when compared to boys [82].

Hisham *et al* (2018) quantified the timing of the closure of SOS in Malaysian individuals with the help of MDCT and formulated an age estimation model based on its closure status. Anonymous CT scans of 500 individuals (336 males and 164 females) aged 5-25 years were analyzed based on four stage system. The age in which transition from stage 0-1 occurred in males was found to be 12.52 years, whereas in females it was found to be 10.47 years. The transition of stages 1-2 occurred at the age of 13.98 years in males and the age of 12.26 years in females. Stage 2-3 transition was seen in the age 15.52 years in males and 13.80 years in females. Fusion of SOS was complete in all the included subjects above 18 years of age [83].

Magnetic resonance imaging:

Ekizoglu *et al* (2016) investigated the utility of MRI in the evaluation of the SOS degree of fusion for estimating the age. 1078 subjects (455 males and 623 females) of age 7 to 21 years were subjected to MRI evaluation of SOS according to five stage method. SOS fusion was found to start 2 years earlier in females than in males. Complete fusion was noted in the mean age of 18.43±1.84 years for males and 17.78±2.20 years for females. They concluded that MRI can be used efficiently in estimating age as it is non-invasive and had reduced radiation exposure when compared to CT [30].

Cone beam computed tomography:

Kocasarac *et al* (2015) developed a regression model based on the radiographic evaluation of SOS and third molar in a Turkish subpopulation. CBCT and OPG of 349 individuals (182 males and 167 females) aged 8 to 25 years were assessed for SOS fusion using the four-stage system and Demirjian system for third molar development assessment respectively. For males, stage 0 was found at the mean age of 9.92±1.19 years; stage 1 was found at the mean age of 11 ± 1.67 years; stage 2 was found at 17.12 ± 3.72 years; stage 3 was found at the mean age of 18.5±4.07 years. For females, stage 0 was seen in the mean age of 10.13 ± 1.58 years; stage 1 was seen in the mean age of 12.3 ± 2.12 years; stage 2 was seen in 15.42 ± 2.86 years; stage 3 was seen in the mean age of 20.56 ± 3.43 years. They concluded that a positive correlation between the age and SOS fusion was noted for females and also between the age and third molar calcification in both sexes [84].

Sinanoglu *et al* (2016) evaluated the reliability and reproducibility of CBCT in assessing SOS synchondrosis development for determining the age in a sample of the Turkish population. CT images belonging to 238 subjects (90 males and 148 females) aged 7 to 25 years. 4 stage system was used to assess the SOS fusion. The transition of age from stage 0 to stage 1 was seen in the mean age of 11.37 years for males and 10.56 years for females. The transition from stage 1 to stage 2 is seen at a mean age of 14.48 years for males and 15.75 years for females. Stage 2 to stage 3 is noted at a mean age of 18.36 years for males and 18.29 years for females. They concluded that SOS fusion can be used reliably as an age estimation marker in the Turkish population [29].

Alhazmi *et al* (2016) examined the relationship between SOS closure and puberty onset in a sample of the American population. 3D CBCT scans of 741 subjects (361 males and 380 females) of age 6 to 20 years were assessed for SOS fusion using a four-stage system. Significant relation between SOS fusion and the beginning of puberty was noted for males and females. The mean age for various degrees of fusion for males was 11.07 years, 12.95 years, 14.44 years, and 16.41 years for stages 0, 1, 2, and 3 respectively. Similarly, in females, mean ages of 9.75 years, 11.67 years, 13.25 years, and 15.25 years for stages 0, 1, 2, and 3 respectively were noted. It was proved that SOS closure occurs at an earlier age and at a faster rate in females when compared to males [85].

Kocasarac *et al* (2017) assessed the correlation between SOS fusion, cervical vertebrae maturation (CVM), and mandibular third molar maturation (TMM) with chronological age in a Turkish population. 116 individuals (43 males and 73 females) of age ranged 8-28 years who possessed CBCT, lateral cephalogram, and OPG were evaluated for SOS fusion using the four-stage system, cervical vertebrae maturation using Lamparski criteria, and third molar maturation using Demirjian system respectively. Statistical analysis revealed that there was a strong correlation between chronological age with SOS, CVM, and TMM among males (r = .810, r = .812, and r = .802 respectively). Also, a strong correlation between chronological age with SOS and TMM among females (r = .643 and r = .842 respectively). Their results suggested that there can be a new approach to assess skeletal maturity from SOS when CBCT is available [86].

Sharma *et al* (2020) ascertained the probability of estimation of age in a sample of the Indian population with the help of CBCT. 271 subjects aged 10-25 years (145 males and 126 females) were assessed for SOS closure based on six stage system. The youngest age at which the SOS was completely fused in males was 15 years whereas in females it was 13 years. Complete fusion was noted in all the individuals irrespective of gender above 16 years and females attained suture closure earlier than males. They depicted that closure of SOS had a linear relationship with age and it is reliable to determine age in the central Indian population [87].

Belgin *et al* (2021) evaluated the relationship between SOS, CVM, and clivus with chronological age on CBCT images of the Turkish population and compared the above-mentioned methods for age estimation. 200 CBCT images (98 males and 102 females) were assessed for SOS fusion using 4 stage system, CVM was assessed using Hassel and Farman staging and Clivus length and width were measured. Accuracy rate when all the above-measured parameters were considered for age estimation resulted in 80% after multiple regression analysis. They concluded that use of SOS and CVM can be used reliably for age estimation [88].

Cone beam computed tomography and Computed tomography:

Dalli kajan *et al* (2021) assessed the fusion patterns of SOS in a sample of the Iranian population where they utilized Spiral CT and CBCT scans of 763 subjects (459 males and 304 females). 5 stage system was utilized and the most frequent stages at different age groups were analyzed. In males, stage 1 was noted in 9-13 years, stage 2 in 14-15 years, stage 4 in 16 years, and stage 5 in the 17-22-year group. In females, stage 1 was noted in 9 years, stage 2 in 10-12 years, stage 3 in 13-14 years, and stage 4 and 5 in the age 15-17 years. It was concluded that fusion of SOS occurs 2 years earlier in females than in males and there was a positive correlation between different stages of fusion and the chronological age [89].

Condylar cortication and age estimation:

Bayrak *et al* (2018) evaluated the relationship between the mandibular condylar cortication with chronological age utilizing CBCT and also investigated whether condylar cortication can be used for the estimation of age. 433 Turkish subjects (173 males and 260 females) aged 8 to 31 years were assessed for condylar cortication on both sides based on three stage system. Type I was seen in the mean age of 14.14 ± 2.30 years for males for both the condyles and 13.01 ± 2.19 years for females; Type II was seen in the mean age of 16.11 ± 3.18 years for males and 15.48 ± 2.70 years for females. Type III was observed in the mean age of 19.39 ± 3.96 years for males and 17.95 ± 3.13 years for females. They stated that the type of condylar cortication may vary for the same individual when the right and left side are considered and the cortication process in males occur at a later time when compared to females [32].

Yalcin *et al* (2020) used cone beam computed tomography (CBCT) to measure articular eminence cortication (AEC), mandibular condyle cortication (MCC), and mandibular cortical index (MCI) in a Turkish population. 520 CBCT scans belonging to 312 males and 208 females aged 7 to 84 were investigated for the MCC and AEC, MCI in the sagittal section, and panoramic reformatted image of CBCT respectively. A significant relationship between MCC, AEC, and MCI was noted ($p<0.05$) and also for the measured parameters with age ($p < 0.05$). They concluded that cortication that occurs in the TMJ region should be known for diagnosing TMJ disorders and also for detecting osteoporotic changes [90].

Spheno-occipital synchondrosis, condylar cortication, and age estimation

Bayrak *et al* (2020) assessed the relationship between MCC, SOS, and chronological age utilizing CBCT images. 253 patients (94 males and 159 females) aged ranged from 10 to 28 years were assessed for MCC using Bayrak *et al* [32] three-staging system and SOS fusion according to four stage system. SOS stage 0 fusion was noted to be 12.97 ± 1.37 for males and 11.75 ± 1.35 years for females. The mean age for stage 1, stage 2, and stage 3 was approximately 2 years and 1 year respectively earlier for females when compared to males. Also, a positive correlation between MCC, SOS fusion, and chronological age was noted therefore they concluded that these factors can be used reliably for age estimation [33].

Table 1: Studies in which four stage system devised by Franklin et al. was used for staging the closure of SOS

Study	Age range (years)	Population	Method of assessment	Sample size		Staging system							
						Stage 0		Stage 1		Stage 2		Stage 3	
				M	F	M	F	M	F	M	F	M	F
Franklin et al. (2013)	May-25	Australia	CT	**169**	**143**	10.28±3.30	8.62±2.40	14.30±1.44	12.65±1.86	16.38±0.48	13.53±1.13	19.83±2.94	18.62±3.55
Kocasrac et al. (2015)	Aug-25	Turkey	CT	**182**	**167**	9.92±1.19	10.13±1.58	11±1.67	12.3±2.12	17.12±3.72	15.42±2.86	18.5±4.07	20.56±3.43
Sinanoglu et al (2016)	Jul-25	Turkey	CT	**90**	**148**	10±1.95	10±1.15	13±2.23	12±1.97	17±2.82	17±3.76	20±4.10	18±3.77
Kocasrac et al. (2017)	Aug-27	Turkey	CBCT	**43**	**73**	10.55±2.12	9.75±1.70	12.38±2.06	12.62±0.74	18.62±4.50	15.00±3.11	18.92±3.90	18.02±3.63
Alhazmi et al. (2017)	Oct-18	USA	CBCT	**361**	**380**	11.07±1.91	9.75±1.30	12.95±1.38	11.67±0.93	14.44±1.06	13.25±1.19	16.41±1.40	15.25±1.89
Hisham et al. (2018)	May-25	Malaysia	CT	**336**	**164**	10.26±2.45	9.33±2.69	13.74±1.48	10.82±2.36	14.75±1.45	13.60±1.07	20.84±2.84	19.78±3.35
Bayrak et al. (2020)	Oct-28	Turkey	CBCT	**94**	**159**	12.97±1.37	11.75±1.35	14.17±0.98	12.08±1.25	14.92±1.08	13.38±1.61	16.38±1.56	15.55±1.61

Table 2: Studies in which five stage system devised by Bassed et al. was used for staging the closure of SOS

Study		**Can et al (2014)**		**Ekizoglu et al (2016)**		**Elbarrany et al (2015)**		**Dallikajan et al (2021)**	
Age range (years)		15-25		Jul-21		15-25		Sep-22	
Population		Australia		Turkey		Egypt		Iran	
Method		CT		MRI		CT		CT and CBCT	
Sample size (N)		**638** (390 and 239)		**1078** (455 and 623)		**217** (121 and 96)		**763** (459 and 304)	
Gender		**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Fusion Stages	**Stage 1**	11.54±1.53	10.68±0.82	10.70±2.24	9.71±1.94	16.0±1.53	15±0	10.33	10.11
	Stage 2	14.00±1.65	12.69±1.93	13.78±1.82	13.08±1.98	18.50±2.54	20±2.35	13.55	11.12
	Stage 3	14.95±2.19	14.00±2.45	14.41±1.82	13.29±2.14	21.32±2.21	21.56±2.30	16.43	15.14
	Stage 4	20.34±3.46	18.17±3.55	17.51±1.88	17.51±2.20	21.78± 2.93	20.41±3.24	18.68	18.31
	Stage 5	20.88±2.72	21.21±2.87	18.43±1.84	17.78±2.20	20.52±3.25	20.4±3.14	19.62	19.23

METHODOLOGY

STUDY DESIGN:

This was a retrospective cross-sectional study, where CT assessment of SOS and condylar cortication of 435 individuals aged 10 to 25 years fulfilling inclusion and exclusion criteria was carried out. This study was conducted based on the ethical standards set by the Declaration of Helsinki, including all amendments and revisions.

SOURCE OF DATA:

CT scans taken as a part of routine investigation obtained from archives of the Department of Radio-diagnosis, KLE's Dr. Prabhakar Kore Hospital and Medical Research Centre, KLE Academy of Higher Education and Research (KAHER), Belagavi.

ARMAMENTARIUM:

1. 128 slices, GE Evolution Evo ® CT machine with 0.6mm slice thickness.
2. DICOM viewer software to view CT scans.
3. Adobe Photoshop to interpret converted scans in *tiff format.
4. Guideline sheet showing Spheno-occipital synchondrosis stage of fusion and the type of condylar cortication.
5. Scoring sheet for recording the observations.

SELECTION CRITERIA:

Inclusion criteria:

1. CT scans of patients of age groups from 10 years to 25 years.
2. CT scans show no evidence of congenital or developmental deformities involving the skull base and mandible.
3. CT scans reveal no evidence of a history of previous trauma or treatment.

Exclusion criteria:

1. CT scans reveal trauma or fracture potentially affecting the site of interest.
2. CT scans of patients affected by temporomandibular joint disorders (systemic, inflammatory, degenerative joint disease).
3. CT scans of patients with endocrine, metabolic, nutritional disorder, systemic diseases that may influence the cranial base development.
4. CT scans show motion blur or artifacts with no technical error.

METHOD:

CT scans collected from the archives were taken by 128 slices, GE Revolution Evo® CT machine. The protocol set during exposure was 120kVp, 280 mAs with a window level of 4000 AU and scan time of 12 seconds as shown in Figure 7. Continuous sagittal sections of the thickness of 0.6mm with a field of view of 20-25cm, showing the skull base and mandibular condyle were included for assessment. The scans were exported in tagged image file format (*tiff) blinding the patients' demographic details like name, age, and gender revealing only the area of interest for assessment by two observers.

Measurement of parameters:

The sagittal section was selected as it reveals the complete visibility of the condyle with insight regarding its cortication status. Spheno-occipital synchondrosis fusion degree was assessed in the mid-sagittal plane as it was visible in that section. Two dentomaxillofacial radiologists performed the evaluation of SOS fusion and cortication of condyle based on the staging system given by **Franklin and Flavel *et al*** [72] and **Bayrak *et al*** [32] respectively. One observer assessed a sample of 100 CT images randomly after one month.

Four stages of SOS fusion assessment are depicted in Figure 8

1. Stage I: Completely open.
2. Stage II: Closed superior border.
3. Stage III: Complete fusion with visible fusion scar.
4. Stage IV: Complete fusion with no visible scar.

Condylar cortication was assessed based on three stage grading system as depicted in Figure 9

1. Type I: Absence of cortication observed on condyle.
2. Type II: Bone on the condylar surface appears at a lower density than the structure around the condyle (cortical areas).
3. Type III: The surface of the condyle appears at a higher or similar density than surrounding cortical areas.

STATISTICAL ANALYSIS:

Stages of SOS fusion and condylar cortication for gender and chronological age were entered in Microsoft Excel® software. Chronological age was calculated by subtracting the date of birth from the date of exposure. Statistical Package for the Social Sciences (SPSS) 21.0 for Windows (SPSS Inc., Chicago, IL, USA) was utilized to perform statistical analysis. Quantitative variables were represented with the help of mean and standard deviation whereas qualitative variables were expressed in numbers and percentages. The distribution of the data and its normality were assessed using the Kolmogorov-Smirnov test. A one-way ANOVA test with post hoc Tukey was done to determine the difference between the stage of SOS fusion and condylar cortication on both sides with chronological age for both genders. Pearson correlation test was carried out to determine the relationship between chronological age with SOS fusion and cortication types on both sides. Inter-examiner and intra-examiner reliability were done by Cohen's kappa statistics. The level of significance for analysis was set at 5% ($p < 0.05$).

PHOTOGRAPHS

Figure 7: 256 Slice GE Revolution Evo® CT machine

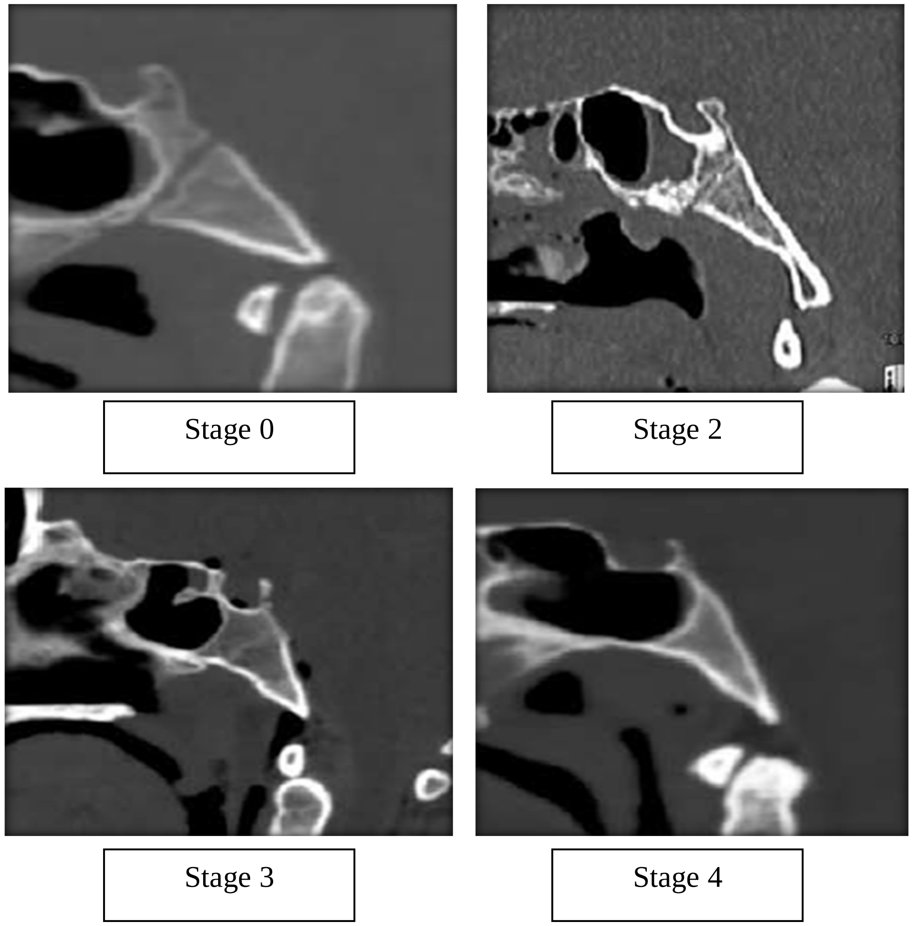


Figure 8: 4 Stage assessment system of Spheno-occipital synchondrosis by Flavel et al

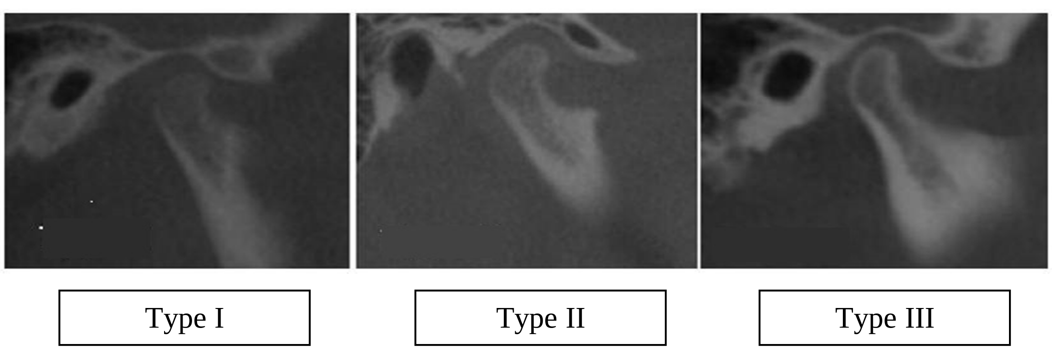


Figure 9: Condylar cortication assessment based on 3-stage system by Bayrak et al

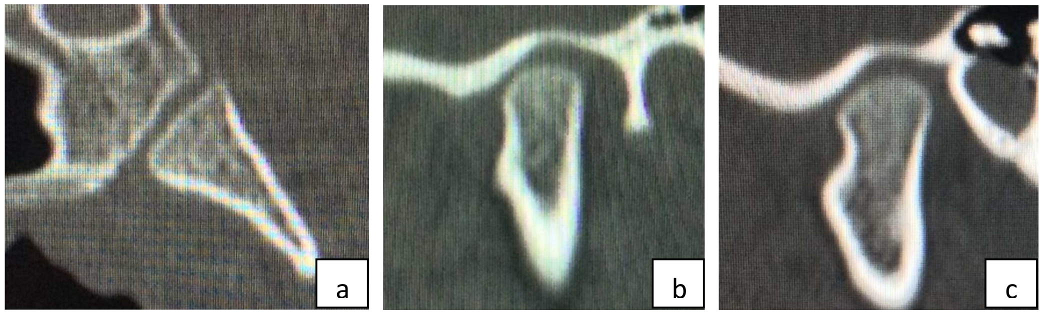


Figure 10: CT images of a 10-year-old boy revealing a) Stage 0 of Spheno-occipital synchondrosis; b) Type I Condylar cortication on right side; c) Type I Condylar cortication on left side

Figure 11: CT images of a 13-year-old girl showing a) Stage 1 of Spheno-occipital synchondrosis; b) Type I Condylar cortication on right side; c) Type I Condylar cortication on left side

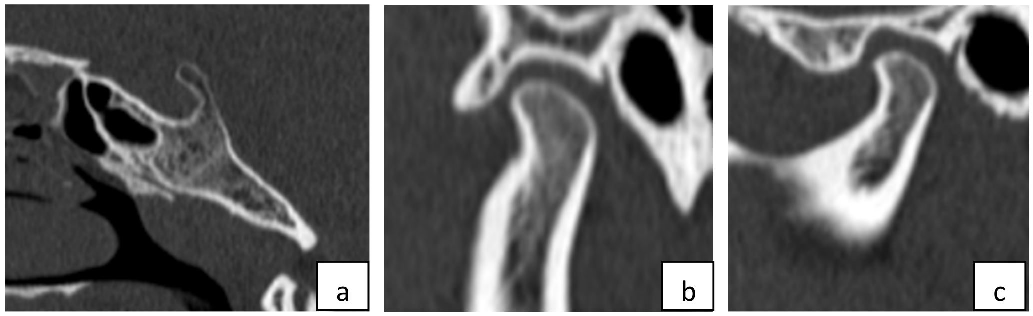


Figure 12: CT images of a 17-year-old male revealing a) Stage 2 of Spheno-occipital synchondrosis; b) Type II Condylar cortication on right side; c) Type II Condylar cortication on left side

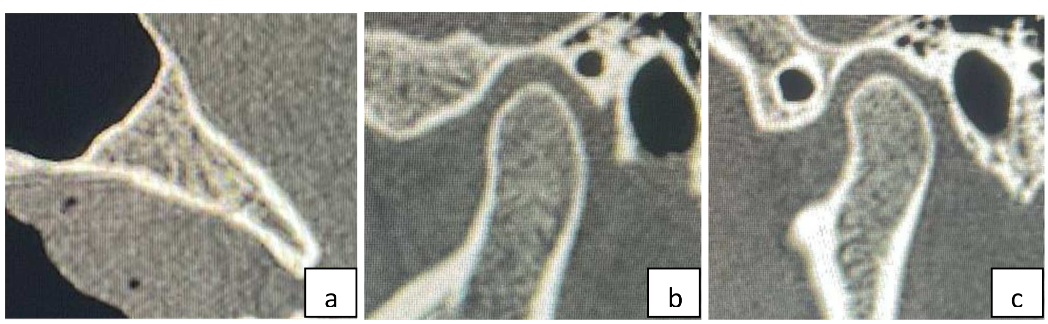


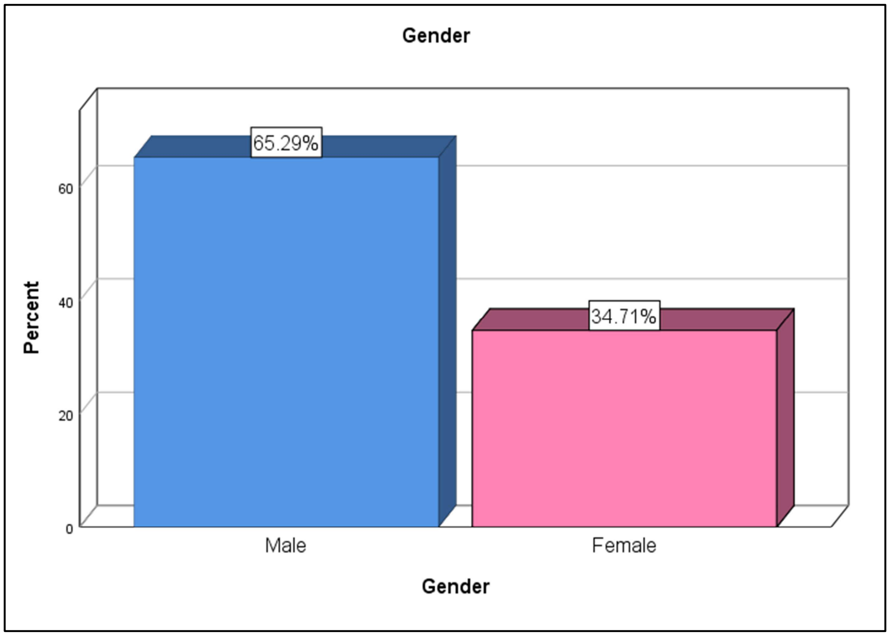
Figure 13: CT images of a 22-year-old female revealing a) Stage 3 of Spheno-occipital synchondrosis; b) Type III Condylar cortication on right side; c) Type III Condylar cortication on left side

RESULTS

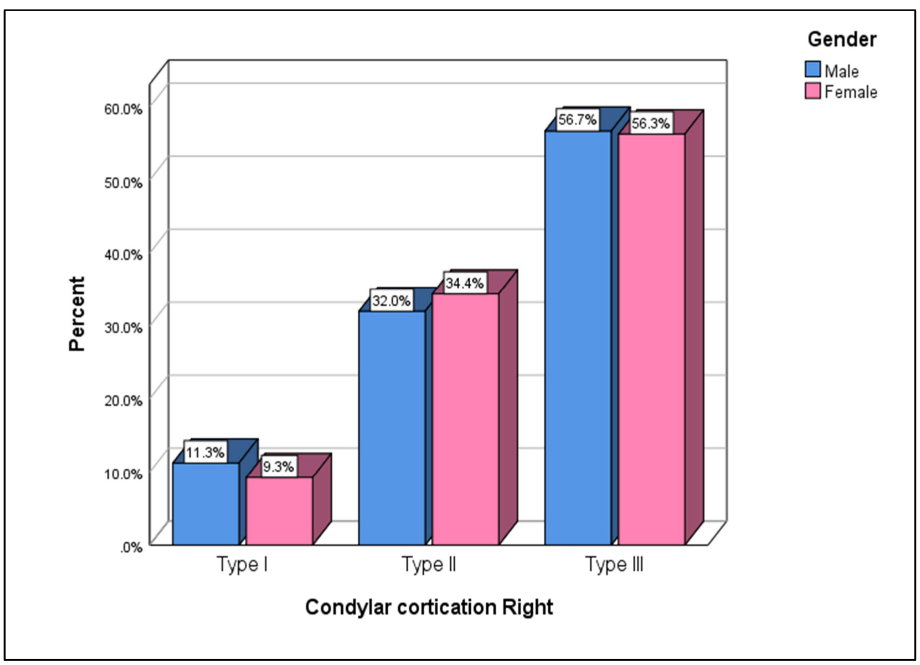
The study group consisted of 435 people belonging to the age of 10 to 25 years. Descriptive statistics for the distribution of patients according to stages of Spheno-occipital synchondrosis fusion degree and different types of condylar cortication on both sides along with gender are given in Table 3. Percentage-wise distribution of the population according to gender is described in Graph 1. Also, the percentage of the population with different types of condylar cortication on the right and left side, and SOS stages for males and females are depicted in Graphs 2, 3, and 4 respectively.

Table 3: Distribution of population according to gender, age group, Condylar cortication types on right and left side, and Spheno-occipital synchondrosis stages.

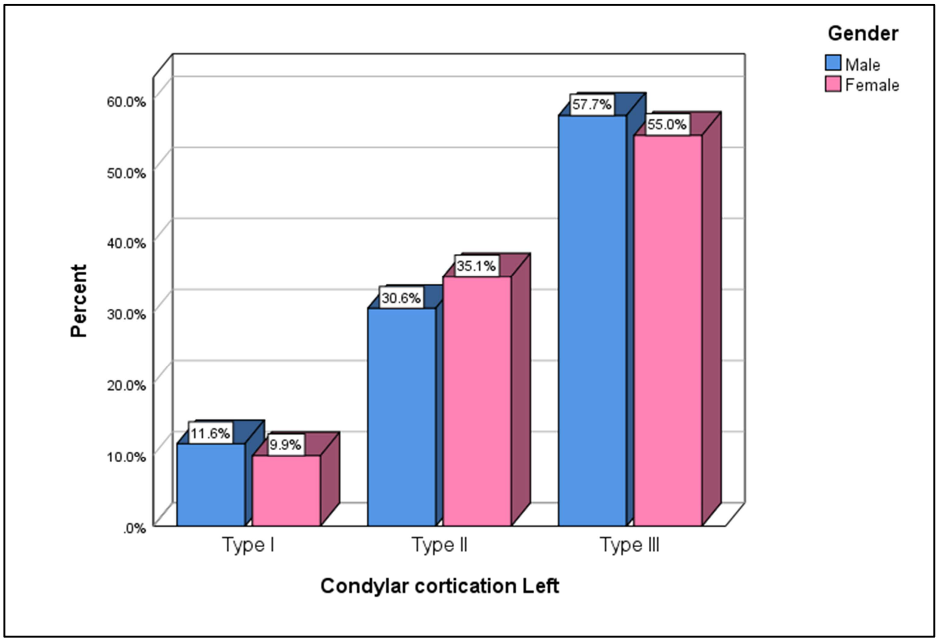
Category			n	%
Gender		**Male**	284	65.3
		Female	151	34.7
		Total	435	100
Age Group (years)		**10-14**	44	10.1
		15-20	113	26.0
		21-25	278	63.9
		Total	435	100
Condylar Cortication	**Right**	**Type I**	46	10.6
		Type II	143	32.9
		Type III	246	56.6
		Total	435	100
	Left	**Type I**	48	11.0
		Type II	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



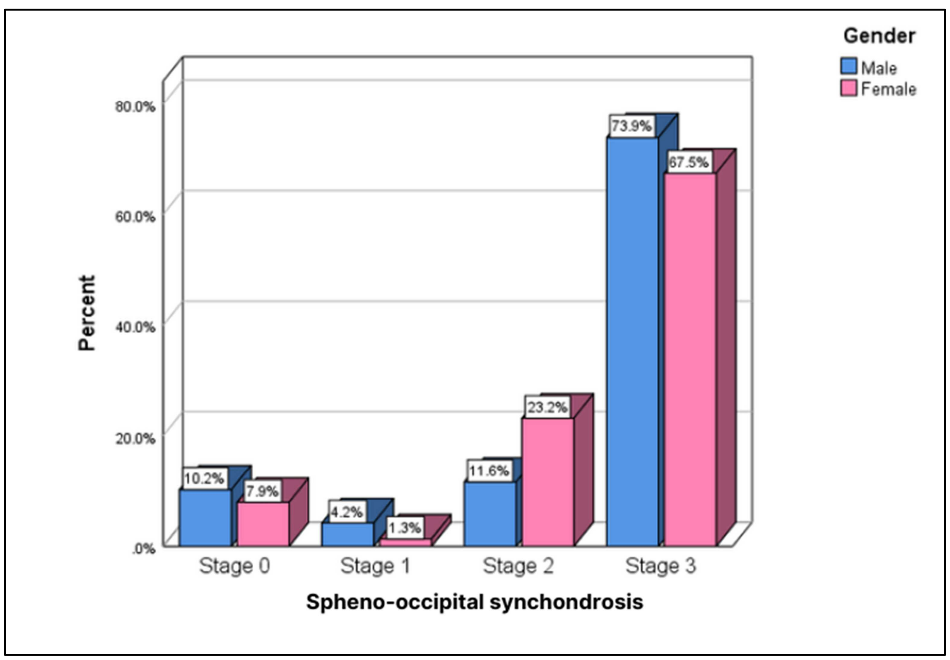
Graph 1: Distribution of population according to gender described in percentage.



Graph 2: Distribution of population according to gender for different types of condylar cortication on the right side described in percentage

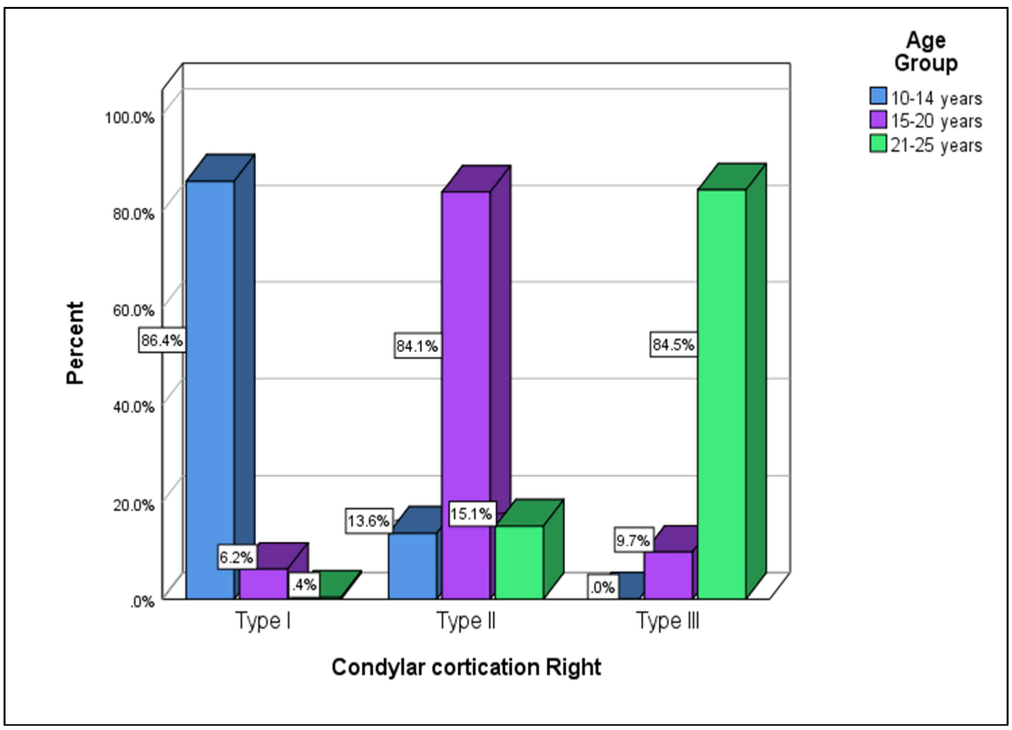


Graph 3: Distribution of population according to gender for different types of condylar cortication on left side described in percentage

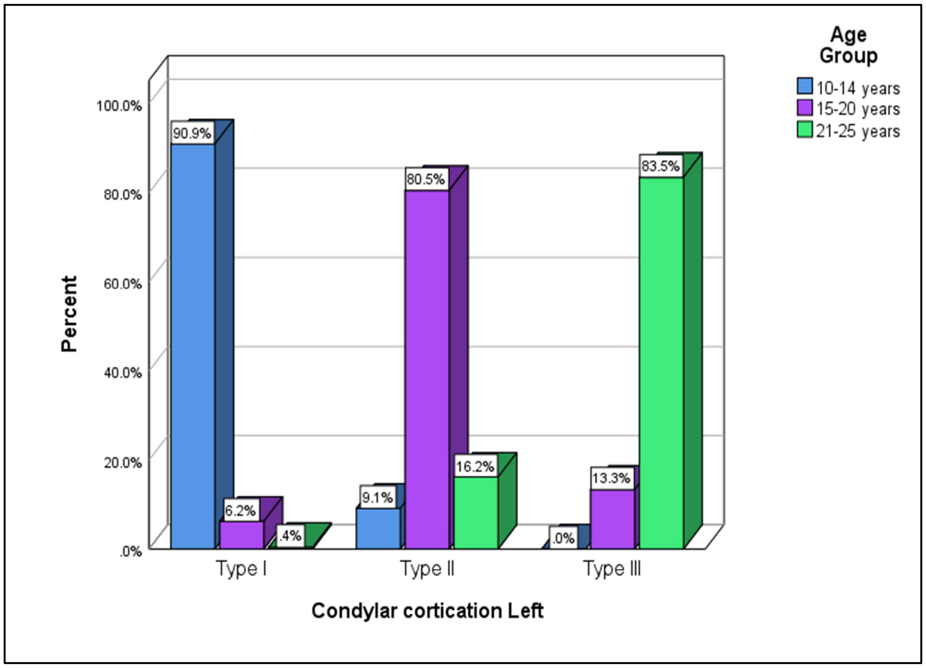


Graph 4: Distribution of population according to gender for different stages of Spheno-occipital synchondrosis described in percentage

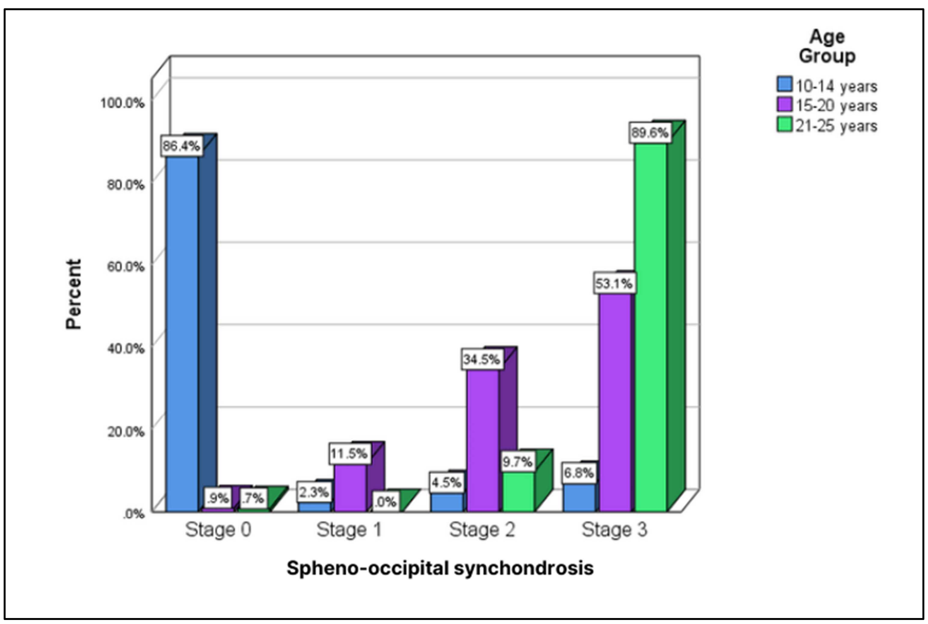
Descriptive statistics were carried out for the total sample according to the age group to compare it with different types of condylar cortication on both sides and Spheno-occipital synchondrosis. The Chi-square test revealed that all age groups had highly statistically significant differences for condylar cortication on both sides (right and left side; p = 0.000) and Spheno-occipital synchondrosis (p = 0.000). The distribution of the total sample in different age groups along with its respective condylar cortication type and synchondrosis stages is shown in Table 4. Graph 5 and 6 describes the distribution of the population according to the age group for condylar cortication for the right and left side respectively. Spheno-occipital synchondrosis distribution according to the age group is shown in Graph 7.



Graph 5: Distribution of population according to various age groups for different types of condylar cortication on the right side described in percentage



Graph 6: Distribution of population according to various age groups for different types of condylar cortication on the left side described in percentage



Graph 7: Distribution of population according to various age groups for different stages of Spheno-occipital synchondrosis described in percentage

Table 4: Distribution of total sample according to age group for condylar cortication (right and left) and Spheno-occipital synchondrosis described in terms of number of population and percentage Statistical test used: Chi-square test *p* value < 0.05 indicates statistically significant differences.

Age group	Condylar Cortication (Right)					Condylar Cortication (Left)					Spheno-occipital synchondrosis					
	Type I	**Type II**	**Type III**	**Total**	***p***	**Type I**	**Type II**	**Type III**	**Total**	***p***	**Stage 0**	**Stage 1**	**Stage 2**	**Stage 3**	**Total**	***p***
10-14 years	38 (86.4)	6 (13.6)	0 (0)	44 (100)	0.000*	40 (90.9)	4 (9.1)	0 (0)	44 (100)	0.000*	38 (86.4)	1 (2.3)	2 (4.5)	3 (6.8)	44 (100)	0.000*
15-20 years	7 (6.2)	95 (84.1)	11 (9.7)	113 (100)		7 (6.2)	91 (80.5)	15 (13.3)	113 (100)		1 (0.9)	13 911.5)	39 (34.5)	60 (53.1)	113 (100)	
21-25 years	1(0.4)	11 (15.1)	235(84.5)	278 (100)		1 (0.4)	45 (16.2)	232 (83.5)	278 (110)		2 (0.7)	0 (0)	27 (9.7)	249 (89.6)	278 (100)	
Total	46 (10.6)	143 (32.9)	246 (56.6)	435 (100)		48 (11)	140 (32.2)	247 (56.8)	435 (100)		41 (91.4)	14 (3.2)	68 (15.6)	312 (71.7)	435 (100)	

Cohen kappa statistics showed a reliable inter-observer (k=0.823) and intra-observer agreement (k=0.842) with statistically significant values ($p < 0.05$).

In this study, condylar cortication was assessed on both sides. Hence, different combinations of cortication types were noted when both sides were compared and results are described in terms of number and percentage as shown in Table 5.

Table 5: Combination of different types of condylar cortication noted on right and left sides described in terms of number of individuals and percentage

		Left Condyle			
		Type I	**Type II**	**Type III**	**Total**
Right Condyle	**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)

Gender-wise comparison with condylar cortication types on both sides and SOS fusion was carried out. Statistically significant differences were noted for SOS fusion stages ($p = 0.007$). whereas condylar cortication types on both sides revealed no statistically significant differences ($p = 0.761$ and $p = 0.607$ for the right and left sides respectively). Gender-wise distribution of samples belonging to different types of condylar cortication and synchondrosis stages is given in Table 6.

Table 6: Distribution of total sample according to age gender for condylar cortication (right and left) and Spheno-occipital synchondrosis for males and females Statistical test used: Chi-square test *p* < 0.05 indicates statistically significant difference n number of patients, SD Standard deviation

Gender	Condylar Cortication (Right)					Condylar Cortication (Left)					Spheno-occipital synchondrosis					
	Type I	Type II	Type III	Total	*p*	Type I	Type II	Type III	Total	*p*	Stage 0	Stage 1	Stage 2	Stage 3	Total	*p*
Males	32 (11.3)	91 (32.0)	161 (56.7)	284 (100)	0.761	33 (11.6)	87 (39.6)	164 (57.7)	284 (100)	0.607	29 (10.2)	12 (4.2)	33 (11.6)	210 (73.9)	284 (100)	0.007*
Females	14 (9.3)	52 (34.4)	85 (56.3)	151 (100)		15 (9.9)	53 (35.1)	83 (55)	151 (100)		12 (7.9)	2 (1.3)	35 (23.2)	102 (67.5)	151 (100)	
Total	46 (10.6)	143 (32.9)	246 (56.6)	435 (100)		48 (11)	140 (32.2)	247 (56.8)	435 (100)		41 (9.4)	14 (3.2)	68 (15.6)	312 (71.7)	435 (100)	

Among 435 patients, 285 were males with a mean age of 20.85 ± 3.93 years and 151 were females with a mean age of 20.17 ± 4.03 years. Mean age was calculated according to age groups and it was found that the mean age of people belonging to the age group 10-14 years was 11.59 ± 1.60 years, 15-20 years was 18.27 ± 1.79 years, and 21-25 years was 23.00 ± 1.46 years. The Mean age of different stages of condylar cortication for both sides and fusion stages of Spheno-occipital synchondrosis for both males and females are in the Table 7.

Table 7: Descriptive statistics with mean and standard deviation of chronological age for different types of condylar cortication and Spheno-occipital synchondrosis fusion for both genders n number of patients, SD Standard deviation

Category			Male			Female		
			n	Mean	SD	n	Mean	SD
Condylar Cortication	Right	Type I	32	12.84	3.18	14	10.93	1.07
		Type II	91	19.63	2.67	52	18.54	2.39
		Type III	161	23.14	1.53	85	22.69	1.72
		Total	284	20.85	3.93	151	20.17	4.02
	Left	Type I	33	12.76	3.09	15	11.47	2.33
		Type II	87	19.71	2.55	53	18.72	2.41
		Type III	164	23.09	1.57	83	22.67	1.86
		Total	284	20.85	3.93	151	20.17	4.02
Spheno-occipital synchondrosis		Stage 0	29	12.62	3.34	12	10.83	0.94
		Stage 1	12	16.67	1.44	2	14.50	6.36
		Stage 2	33	19.82	2.67	35	19.23	2.93
		Stage 3	210	22.39	2.28	102	21.71	2.64
		Total	284	20.85	3.93	151	20.17	4.02

Descriptive values of chronological age according to the types of condylar cortication on both sides for both genders were performed using a one-way ANOVA test. Results revealed that the average chronological age increased with an increase in types of condylar cortication. Chronological age was lowest for Type I on both sides, whereas the age was highest for Type III cortication with statistically significant differences ($p < 0.05$). Also, there were statistically significant differences between the cortication types ($p < 0.05$) as shown in Table 8.

Condylar cortication was also assessed side-wise. In both males and females, the chronological age was minimum for Type I cortication and it increased as the cortication gradually progressed to Type III cortication type on the right side with highly statistically significant differences ($p < 0.05$) among different groups of cortication types on the right side as given in Table 9. Similar results were noted when the left side was assessed for condylar cortication as there were highly statistically significant differences seen in the mean chronological age of various cortication types ($p < 0.05$), as given the Table 9. In the three cortication stages, the mean age of females was lower than that of males suggesting that ossification occurs a bit sooner in males than females.

Table 8: Descriptive statistics with mean values of chronological age of overall sample according to different types of condylar cortication for both sides Statistical test used: One-way ANOVA. Statistically significant values at $p < 0.05$ post-hoc Tukey analysis revealed statistically significant differences between cortication types denoted by superscript letters [a, ab, ac, b, bc, c] Number of patients is denoted by n SD stands for Standard deviation, Min stands for minimum, Max stands for maximum

Condylar Cortication	Right					F	*p*	Condylar Cortication	Left					F	*p*
	n	Mean	SD	Min	Max				n	Mean	SD	Min	Max		
Type I [a, ab, ac]	46	12.26	2.85	10	24	532.796	0.000*	**Type I [a, ab, ac]**	48	12.35	2.91	10	24	526.648	0.000*
Type II [b, bc]	143	19.23	2.62	12	25			**Type II [b, bc]**	140	19.34	2.54	14	25		
Type III [c]	246	22.98	1.61	16	25			**Type III [c]**	247	22.95	1.68	16	25		
Total	435	20.62	3.97	10	25			**Total**	435	20.62	3.97	10	25		

Table 9: Descriptive statistics with mean values of chronological age according to different types of condylar cortication for both the sides for males and females Statistical test used: One-way ANOVA. Statistically significant values at $p < 0.05$ post-hoc Tukey analysis revealed statistically significant differences between cortication types denoted by superscript letters $^{a, ab, ac, b, bc, c}$ Number of patients is denoted by n SD stands for Standard deviation, Min stands for minimum, Max stands for maximum

	Condylar Cortication	Males					F	*p*	Condylar Cortication	Females					F	*p*
		n	Mean	SD	Min	Max				n	Mean	SD	Min	Max		
Right Side	**Type I $^{a, ab, ac}$**	32	12.84	3.18	10	24	319.408	0.000*	**Type I $^{a, ab, ac}$**	14	10.93	1.07	10	13	250.580	0.000*
	Type II $^{b, bc}$	91	19.63	2.67	12	25			**Type II $^{b, bc}$**	52	18.54	2.39	14	24		
	Type III ^{c}	161	23.14	1.53	19	25			**Type III ^{c}**	85	22.69	1.72	16	25		
	Total	284	20.85	3.93	10	25			**Total**	151	20.17	4.03	10	25		
	Condylar Cortication	**Males**					**F**	***p***	**Condylar Cortication**	**Females**					**F**	***p***
		n	**Mean**	**SD**	**Min**	**Max**				**n**	**Mean**	**SD**	**Min**	**Max**		
Left Side	**Type I $^{a, ab, ac}$**	33	12.76	3.09	10	24	250.580	0.000*	**Type I $^{a, ab, ac}$**	15	11.47	2.37	10	19	198.110	0.000*
	Type II $^{b, bc}$	87	19.71	2.55	14	25			**Type II $^{b, bc}$**	53	18.72	2.41	14	24		
	Type III ^{c}	164	23.09	1.57	19	25			**Type III ^{c}**	83	22.67	1.86	16	25		
	Total	284	20.85	3.92	10	25			**Total**	151	20.17	4.03	10	25		

Fusion stages of Spheno-occipital synchondrosis were correlated with the chronological age of the overall sample. Stage 0 was noted in individuals belonging to the age range starting from 10 years (Mean age 12.10 ± 2.96 years) and as the stage progresses there was an increase in the chronological age. Stage 1 was seen 4 years after stage 0 with ages ranging from 19 years (Mean age 16.36 ± 2.34 years). Stage 2 and 3 were seen in individuals with a maximum age of 25 years with a mean age of 16.36 ± 2.34 years and 16.36 ± 2.34 years for stages 2 and 3 respectively. All the stages had statistically significant differences for chronological age (p = 0.000) as shown in Table 10.

Gender-wise comparison was carried out to assess the difference between the chronological age according to different stages of fusion. The mean age for stages 0 and 1 was found to be approximately 2 years greater in males compared to females. Stage 2 closure was seen in similar ages among males and females. Stage 3 was seen to close 1 year in advance in males than females. Table 10 shows the chronological age of different stages in males and females. All the stages of synchondrosis had statistically significant differences among males and females irrespective of the stages (p = 0.000).

Table 10: Descriptive statistics with mean values of chronological age according to different types of Spheno-occipital synchondrosis for overall sample, males and females Statistical test used: One-way ANOVA. Statistically significant values at *p* < 0.05 Number of patients are denoted by n SD stands for Standard deviation, Min stands for minimum, Max stands for maximum

Spheno-occipital synchondrosis		n	Mean	SD	Min	Max	F	*p*
Male	**Stage 0**	29	12.62	3.34	10	24	152.74	0.000*
	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	64.647	0.000*
	Stage 1	2	14.5	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	12.1	2.96	10	24	210.273	0.000*
	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		

Distribution of included population according to different condylar cortication types and Spheno-occipital synchondrosis fusion degree with chronological age was carried out for both sides as depicted in Table 11. Regarding the right side, there were no statistically significant differences between the synchondrosis stages and Type I and III cortication stages with p values being 0.068 and 0.162 respectively. Statistically significant differences were noted for the Type II cortication stage with SOS fusion (p = 0.000). Similarly, on the left side, statistically significant differences were noted for Type I and II condylar cortication stages with SOS fusion stages (p = 0.016 and 0.000 respectively). There were no statistically significant differences for Type III cortication with SOS fusion stages (p = 0.307).

Gender-wise comparison was performed using a one-way ANOVA statistical test for males and females for both sides. Statistically, a significant difference was noted only for Type II condylar cortication for both males and females on the right side (p = 0.000 and 0.029 respectively) as well as on the left side (p = 0.000 and 0.018 respectively) as shown in Table 12 and 13. Also, a statistically significant difference was noted for Type I cortication with SOS fusion stages on the left side for females (p = 0.002). Type III cortication stages did not reveal any statistically significant differences when compared with fusion stages for males and females on both sides as depicted in Tables 12 and 13.

Table 11: Descriptive statistics with mean values of chronological age according to different types of Spheno-occipital synchondrosis with condylar cortication for overall sample on right and left side Statistical test used: One-way ANOVA Statistically significant values at *p* < 0.05 Number of patients are denoted by n SD stands for Standard deviation, Min stands for minimum, Max stands for maximum

Condyle Corticaton	Spheno-occipital synchondrosis	Right					F	*p*	Condylar Cortication	Spheno-occipital synchondrosis	Left					F	*p*
		n	Mean	SD	Min	Max					n	Mean	SD	Min	Max		
Type I	**Stage 0**	37	11.73	2.58	10	24	2.558	0.068	**Type I**	**Stage 0**	39	11.79	2.54	10	24	4.514	0.016*
	Stage 1	5	14.40	2.61	10	17				**Stage 1**	5	14.40	2.61	10	17		
	Stage 2	1	16.00	-	16	16				**Stage 2**			-				
	Stage 3	3	14.00	4.58	10	19				**Stage 3**	4	15.25	4.50	10	19		
Type II	**Stage 0**	3	13.33	1.16	12	14	15.573	0.000*	**Type II**	**Stage 0**	1	14.00	-	14	14	10.103	0.000*
	Stage 1	9	17.44	1.33	16	19				**Stage 1**	9	17.44	1.33	16	19		
	Stage 2	46	18.28	2.21	14	23				**Stage 2**	49	18.39	2.30	14	23		
	Stage 3	85	20.14	2.42	14	25				**Stage 3**	81	20.19	2.41	14	25		
Type III	**Stage 0**	1	22.00	-	22	22	1.834	0.162	**Type III**	**Stage 0**	1	22.00	-	22	22	1.187	0.307
	Stage 2	21	22.38	1.63	19	25				**Stage 2**	19	22.42	1.68	19	25		
	Stage 3	224	23.04	1.60	16	25				**Stage 3**	227	23.00	1.68	16	25		

Table 12: Mean values of chronological age according to different types of Spheno-occipital synchondrosis with condylar cortication for males and females on right side Statistical test used: One-way ANOVA Statistically significant values at $p < 0.05$ Number of patients are denoted by n. SD stands for Standard deviation, Min stands for minimum, Max stands for maximum

Condyle Corticaton	**Spheno-occipital synchondrosis**	**Males**					**F**	***p***	**Condylar Cortication**	**Spheno-occipital synchondrosis**	**Female**					**F**	***p***
		n	Mean	SD	Min	Max					n	Mean	SD	Min	Max		
Type I	**Stage 0**	25	12.16	3.00	10	24	1.996	0.137	**Type I**	**Stage 0**	12	10.83	0.94	10	13	2.994	0.092
	Stage 1	4	15.50	1.00	15	17				**Stage 1**	1	10.00	-	10	10		
	Stage 2	1	16.00	-	16	16				**Stage 2**			-				
	Stage 3	2	14.50	6.36	10	19				**Stage 3**	2	14.50	6.36	10	19		
Type II	**Stage 0**	3	13.33	1.16	12	14	15.175	0.000*	**Type II**	**Stage 0**			-			3.811	0.029*
	Stage 1	8	17.25	1.28	16	19				**Stage 1**	1	19.00		19	19		
	Stage 2	23	19.00	2.34	14	23				**Stage 2**	23	17.57	1.85	14	21		
	Stage 3	57	20.54	2.27	15	25				**Stage 3**	28	19.32	2.55	14	24		
Type III	**Stage 0**	1	22.00		22	1	1.626	0.200	**Type III**	**Stage 0**			-			0.361	0.549
	Stage 2	9	22.33	1.66	19	9				**Stage 2**	12	22.42	1.68	19	25		
	Stage 3	151	23.19	1.52	20	151				**Stage 3**	73	22.74	1.73	16	25		

Table 13: Mean values of chronological age according to different types of spheno-occipital synchondrosis with condylar cortication for males and females on left side Statistical test used: One-way ANOVA Statistically significant values at $p < 0.05$ Number of patients are denoted by n. SD stands for Standard deviation, Min stands for minimum, Max stands for maximum

Condyle Corticaton	**Spheno-occipital synchondrosis**	**Males**					**F**	***p***	**Condylar Cortication**	**Spheno-occipital synchondrosis**	**Female**					**F**	***p***
		n	Mean	SD	Min	Max					n	Mean	SD	Min	Max		
Type I	**Stage 0**	27	12.22	2.90	10	24	2.511	0.098	**Type I**	**Stage 0**	12	10.83	0.94	10	13	10.424	0.002*
	Stage 1	4	15.50	1.00	15	17				**Stage 1**	1	10.00	-	10	10		
	Stage 2	1	16.00	-	16	16				**Stage 2**			-				
	Stage 3	2	14.50	6.36	10	19				**Stage 3**	2	16.00	4.24	13	19		
Type II	**Stage 0**	1	14.00	-	14	14	8.045	0.000*	**Type II**	**Stage 0**			-			4.358	0.018*
	Stage 1	8	17.25	1.28	16	19				**Stage 1**	1	19.00	-	19	19		
	Stage 2	25	19.04	2.46	14	23				**Stage 2**	24	17.71	1.94	14	21		
	Stage 3	53	20.51	2.31	15	25				**Stage 3**	28	19.57	2.52	14	24		
Type III	**Stage 0**	1	22.00	-	22	22	1.455	0.237	**Type III**	**Stage 0**			-			0.061	0.806
	Stage 2	8	22.25	1.75	19	25				**Stage 2**	11	22.55	1.70	19	25		
	Stage 3	155	23.14	1.56	20	25				**Stage 3**	72	22.69	1.89	16	25		

Pearson correlation ratio coefficient between spheno-occipital synchondrosis fusion stage, condylar cortication, and gender was carried out for both genders. Correlation coefficient values for individual parameters are shown in Table 14 for males and females separately. A very strong correlation was noted for males and females for the following parameters with statistically significant differences (p = 0.000).

1) Condylar cortication stages between the right side and left side
2) Condylar cortication stages between the right side and chronological age
3) Condylar cortication stages between the left side and chronological age.

Similarly, a Strong correlation was noted for males and females for the following parameters with statistically significant differences (p = 0.000).

1) Condylar cortication stages between the right side and spheno-occipital synchondrosis
2) Condylar cortication stages between the left side and spheno-occipital synchondrosis
3) Between Spheno-occipital synchondrosis stages and chronological age.

Table 14: Correlation of chronological age with Spheno-occipital synchondrosis and condylar cortication for males and females on both sides Statistical test used: Pearson Correlation Statistically significant values at p < 0.05. r_p is Pearson correlation coefficient

	Condylar Cortication Right (r_p)		Condylar Cortication Left (r_p)		Spheno-occipital Synchondrosis (r_p)		Chronological age (r_p)	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Condylar cortication Right (r_p)	1	1	.934*	.963*	.723*	.709*	.815*	.861*
Condylar cortication Left (r_p)			1	1	.754*	.694*	.821*	.836*
Spheno-occipital synchondrosis (r_p)					1	1	.785*	.746*
Chronological age (r_p)							1	1

DISCUSSION

Age estimation in living individuals is of extreme importance in living or dead individuals for various purposes like identification, obtaining civil rights and benefits from society, and medico-legal purposes [91]. Hence, forensic age estimation (FAE) has become an integral part of the forensic medicine field that focuses on utilizing an accurate way of establishing or estimating the chronological age of the person [92]. With a recent surge in the need for identification and estimation of age in living individuals for legal purposes, the forensic anthropologic field has extended into studying the same [93]. Forensic odontology is a subgroup of forensic medicine that deals with the human identification process by helping out in estimating age as well as determining the sex of the unknown individual [94].

Estimation of chronological age can be carried out with help of available data like height and weight of the individual, their pubertal status and dentition as well as dental findings [94]. Assessment of skeletal factors and dental factors like suture closure, maturity index assessment, tooth factors like teeth development, the ratio of the tooth pulp, coronal index, etc. can help in estimating the chronological age [68]. Evaluation of the above-mentioned factors can be carried out using three methods; Direct morphological assessment, radiographical assessment, and histological assessment. When compared among these three methods, the latter appears to be a bit more complicated than the former two methods [94]. Although various methods exist, there is no single method that can accurately tell us about the chronological age exactly of a human being [92].

Considerable variation in the closure of spheno-occipital synchondrosis among males, females, and different populations has provoked interest in the research field to further assess the fusion degree as an accurate age estimation method [10]. As mentioned earlier, the radiographic method is reliable and easy to perform compared to other methods which apply the same for the assessment of SOS. Conventional radiographs like plain radiographs and sagittal laminar radiographs are no longer used due to the superimposition of anatomical structures and reduced resolution. Hence, advanced imaging modalities like multi-slice computed tomography (MSCT), multi-detector computed tomography (MDCT), cone beam computed tomography (CBCT), and magnetic resonance imaging (MRI) are being employed to assess the structure and morphology of bones and teeth for the purpose of forensic identification due to its superior advantages compared to other methods [68].

The mandible is one such bone where the morphology corresponds to growth spurts in adolescents as it develops with an increase in age [95]. The condyle is one integral component of the mandible that has variations according to gender with respect to its growth or development and shape or morphological appearance [96]. Cortication or the process of formation of the layer of homogenous bone begins to appear approximately around 12-14 years and completes by 22 years of age [32]. These developmental changes can be detected in radiographs and assessment of these changes can be used to correlate with the age of the individual.

Assessment of SOS fusion was carried out with the help of CT and four stage system devised by **Franklin and Flavel *et al*** [72] Initial evaluation of four stage system in a sample of 312 Australian individuals revealed that the suture was open (Stage 0) in males at a mean age of 10.28 years with females having open suture

(Stage 0) at mean age of 8.62 years. There was complete fusion (Stage 3) of SOS 1 year earlier in females (18.62 years) than in males (19.83 years).

Similarly, **Hisham *et al*** [83] assessed the fusion of SOS using a four-stage system in CT scans of 500 Malaysian individuals. Stage 0 was noted 1 year later in males (10.26 years) compared to females (9.33 years). Stage 3 of SOS was also noted in a similar fashion with males (20.84 years) having earlier closure than females (19.78 years).

CBCT assessment of SOS fusion utilizing the four-stage system was carried out in different populations with four studies carried out in the Turkish population [33, 84-86] and one study in the American population. Complete fusion of SOS was noted at a similar age for males (18.92 years) and females (18.02 years) in a study by **Kocasarac *et al*** [86] whereas fusion was 1 year earlier in females compared to males in a study conducted by **Bayrak *et al*** [33] and **Alzhami *et al*** [85] Contrary to these results, **Kocasarac *et al*** [84] reported that the complete fusion was seen 2 years earlier in males (18.5 years) than females (20.56 years).

In our study, Stage 0 of SOS fusion was noted approximately 2 years earlier in females (10.83 years) compared to males (12.62 years) which is similar to the results obtained by **Flavel *et al*** [72] and **Hisham *et al*** [83] Except for stage 2 fusion where the mean age of males and females are similar (19.82 years and 19.23 years respectively), remaining stages favored early stage attainment in females. Complete fusion or Stage 3 of SOS was seen at the age of 22.39 years in males compared to 21.71 years in females. Our findings were similar to the results obtained in a study conducted by **Flavel *et al*** [72], **Bayrak *et al*** [33], **Alzhami *et al*** [85], and **Hisham *et al*** [83] where the fusion stages of females preceded males.

Lei *et al* [26] was first the person to classify the formation of cortical bone around the condyle based on the presence of a bony layer in the periphery of the condyle with CBCT as an imaging modality. He concluded that 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 and 20 years in females and males respectively.

A novel method of condylar cortication was devised by **Bayrak *et al*** [32] where three stages were named based on the density difference of cortical bone surrounding the condyle and areas adjacent to the condyle. Type I cortication was seen at a mean age of 14.14 years and 13.01 years for males and females respectively suggesting that no evidence of cortical bone formation was seen below this age category. Cortication of the condyle was complete by the age of 19 years for males and 18 years for females where the density of the condyle appeared to have a higher or similar density as that of surrounding areas.

Condylar cortication was assessed on both sides in our study. Irrespective of the sides, Type I cortication was seen at the mean age of 12-13 years and 10-11 years for males and females respectively. Completion of condylar cortication was noted in the mean age of 23 years for males and 22 years for females. These results were in concordance with a study conducted by **Lei *et al*** [26] and **Bayrak *et al*** [33].

Bayrak *et al* [33] was the first to assess the relationship between spheno-occipital synchondrosis fusion stages and different types of cortication of condyle using CBCT. They found that there was a positive correlation for the above-said parameters with statistically significant differences for both males (r_s = 0.553) and females (r_s = 0.645). Similarly, in our study, a positive correlation was seen for both genders with respect to right and left sided condylar cortication with spheno-occipital synchondrosis, as well as between the chronological age and measured parameters. This proves that along with SOS fusion, condylar cortication can be used as a reliable method to estimate age.

LIMITATIONS:

Variations in populations or different ethnicity can have an impact on the forensic identification of an individual. This can be affected by various factors like geographical location, gender, age, race, etc. Conclusions drawn from a particular population cannot be utilized for general applicability irrespective of race or ethnic origin.

The distribution of the study sample according to gender and age group was a minor setback in this study. Males and females were not equally distributed and the age group of individuals included for assessment should be made to cover a broader age group population.

Clinical assessment of the individuals included in this study was not carried out as the radiographs were obtained retrospectively. Subchondral bone formation is affected by various factors that can be iatrogenic, disturbances in development, and parafunctional habits which can produce altered remodeling of condyles leading to minor degenerative changes. Also, in females, hormonal activity in girls attaining puberty increases the metabolism of bone thereby exerting excessive loading forces. Hence these factors must be considered for the assessment of condyle in both genders, especially females.

Spheno-occipital synchondrosis is influenced in living or dead individuals due to health and nutritional status, growth and developmental status of bones, and to an extent ethnicity. This can potentially cause variability in the closure of the suture with respect to age and hence, this method can be used as an adjunct to other accurate and determinate age estimation methods.

FUTURE PROSPECTS OF THE STUDY

1) An equal number of individuals in both groups is needed to compare the accurate differences in ages for closure of Spheno-occipital synchondrosis as well as condylar cortication.
2) Improved sample size with more data from studies that utilized computed tomography for assessment of both the parameters in the Indian population is needed to create a population-specific dataset for future forensic purposes.
3) For age estimation in living individuals, clinical examination to rule out any evidence of potential condylar morphological alterations due to parafunctional habits or occlusal discrepancies can be performed to improve the accuracy of utilizing the method of condylar assessment.
4) Consideration of maximum and minimum age limits is also essential to describe a particular age range to which the individual might belong.

SUMMARY AND CONCLUSION

Forensic age estimation is an important aspect of forensic anthropology where there is the necessity of estimating the age of living as well as deceased individuals in cases like natural calamities and man-made disasters. Spheno-occipital synchondrosis is a growth center between the sphenoid and occipital bones and assessing the pattern and closure of this suture has been proven to provide an upper and lower age limit in the estimation age of an adolescent. Mandibular condyle develops in close association with that of the mandible and hence the completion of mineralization of cortical bone can be utilized to estimate the chronological age.

435 computed tomographic images of males and females belonging to 10 to 25 years that fulfilled the inclusion and exclusion criteria were assessed for spheno-occipital synchondrosis and condylar cortication. Spheno-occipital synchondrosis was assessed based on the four-stage system devised by **Franklin and Flavel *et al*** [72] where Stage 0 denotes completely open suture until Stage IV denoting complete fusion. Cortication of the condyle was assessed using three stage system given by **Bayrak *et al*** [32] where Type I indicates no evidence of cortication up to Type III which indicates completion of cortication

Stage 0 of SOS fusion was found in the mean age of 12.62 ± 3.34 years in males and 10.83 ± 0.94 years in females; Stage 1 was observed in the mean age of 16.67 ± 1.44 years in males and 14.50 ± 6.36 years in females; Stage 2 was noted in the mean age of 19.82 ± 2.68 years in males and 19.23 ± 2.93 years in females; Stage 3 was found in the mean age of 22.39 ± 2.28 years in males and 21.71 ± 2.64 years in females.

Previous studies assessed condylar cortication only on a side, either right or left because it was stated that there were no significant differences between the types of cortication on both sides. However, in our study, we found that Type I in 93.75% of cases, Type II in 92.85% of cases, and Type III in 95.95% of cases on both sides thereby implicating the significance of assessing condylar cortication on both sides.

Irrespective of the sides, Type I cortication was seen at the mean age of 12-13 years and 10-11 years for males and females respectively. Type II Cortication was observed at the mean age of 19 years in males and 18 years in females. Completion of condylar cortication was noted in the mean age of 23 years for males and 22 years for females.

A positive correlation was seen for both genders with respect to right and left-sided condylar cortication with spheno-occipital synchondrosis, as well as between the chronological age and measured parameters. This proves that along with SOS fusion, condylar cortication can be used as a reliable method to estimate age.

Estimation of age in forensic sciences is the primary need in the identification of individuals or for legal or criminal hearings. Since there is no single method that can accurately estimate the age of the individuals, multiple parameters utilizing skeletal and dental component is essential to improve the credibility of age estimation methods. Thus, this study concludes that spheno-occipital synchondrosis and condylar cortication can be reliably used to estimate age as there was a positive correlation between chronological age and the assessed parameters. The difference in results obtained is due to diversity in population and hence more studies on a specific subset of the population should be carried out to compare with other populations.

KEY POINTS

1) Spheno-occipital synchondrosis assessment using a four-stage system and computed tomography is consistent with chronological age.
2) Except for Stage 2, Spheno-occipital synchondrosis fusion occurred earlier in females by a mean age of 2 years when compared to males.
3) Condylar cortication was completed sooner in females than males by a mean period of 1 year.
4) A positive correlation is noted between chronological age and the measured parameters thereby making it a valuable adjunct method in forensic age estimation.

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ANNEXURE – I

ETHICAL CLEARANCE CERTIFICATE

Research and Ethics Committee
KLE V K INSTITUTE OF DENTAL SCIENCES
KLE University
Accredited 'A' Grade by NAAC   Placed in Category 'A' by MHRD (GoI)
Nehru Nagar, Belagavi - 590 010, Karnataka State
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Sl. No. : 1450

CERTIFICATE

This is to Certify that the synopsis titled Corelation of spheno-Occipital synchondrosis and Condylar cortication with chronological age using computed tomography - A cross sectional study *Submitted by Dr.* REG NO. IG0220003 *P. G. Student / Staff, Guided by* _ *from Department of* Oral Medicine & Radiology *has been critically evaluated by committee members and granted ethical clearance to conduct the above mentioned study*

Date : 5/5/21

Member Secretary
Research and Ethical Committee
KLEVK Institute of Dental Sciences
Belagavi

Chairman
Research and Ethical Committee
KLEVK Institute of Dental Sciences
Belagavi

Chairman
Research and Ethical Committee
KLE VK Institute of Dental Sciences

ANNEXURE – II

MASTER CHART – Spheno-occipital synchondrosis stages and Condylar cortication types in Males

Patient No	Age	Spheno-occipital Synchondrosis Stage	Condylar Cortication		Patient No	Age	Spheno-occipital Synchondrosis Stage	Condylar Cortication	
			Right	Left				Right	Left
1	22	Stage 3	Type III	Type III	**17**	21	Stage 3	Type III	Type III
2	25	Stage 3	Type III	Type III	**18**	24	Stage 3	Type III	Type III
3	18	Stage 1	Type II	Type II	**19**	22	Stage 3	Type III	Type III
4	25	Stage 3	Type III	Type III	**20**	18	Stage 2	Type II	Type II
5	25	Stage 3	Type III	Type III	**21**	25	Stage 3	Type III	Type III
6	25	Stage 3	Type II	Type III	**22**	18	Stage 3	Type II	Type II
7	14	Stage 0	Type 1	Type 1	**23**	22	Stage 2	Type III	Type III
8	14	Stage 0	Type 1	Type 1	**24**	22	Stage 3	Type III	Type III
9	13	Stage 0	Type 1	Type 1	**25**	24	Stage 3	Type III	Type III
10	20	Stage 3	Type II	Type III	**26**	16	Stage 1	Type II	Type II
11	23	Stage 2	Type II	Type II	**27**	20	Stage 3	Type III	Type II
12	21	Stage 3	Type III	Type III	**28**	18	Stage 3	Type II	Type II
13	23	Stage 3	Type III	Type III	**29**	23	Stage 3	Type III	Type III
14	25	Stage 3	Type III	Type III	**30**	23	Stage 3	Type III	Type III
15	12	Stage 0	Type 1	Type 1	**31**	17	Stage 1	Type II	Type II
16	22	Stage 3	Type III	Type III	**32**	16	Stage 2	Type II	Type II

Patient No	Age	Spheno-occipital Synchondrosis Stage	Condylar Cortication		Patient No	Age	Spheno-occipital Synchondrosis Stage	Condylar Cortication	
			Right	Left				Right	Left
33	23	Stage 3	Type III	Type III	**49**	25	Stage 3	Type III	Type III
34	20	Stage 3	Type II	Type III	**50**	22	Stage 3	Type III	Type II
35	19	Stage 2	Type II	Type II	**51**	23	Stage 3	Stage 2	Type II
36	19	Stage 1	Type II	Type II	**52**	19	Stage 3	Type 1	Type 1
37	10	Stage 0	Type 1	Type 1	**53**	21	Stage 3	Type II	Type II
38	23	Stage 3	Type III	Type III	**54**	25	Stage 3	Type III	Type III
39	17	Stage 2	Type II	Type II	**55**	25	Stage 3	Type III	Type III
40	23	Stage 3	Type III	Type III	**56**	13	Stage 0	Type 1	Type 1
41	23	Stage 2	Type II	Type II	**57**	22	Stage 2	Type III	Type III
42	22	Stage 3	Type II	Type II	**58**	25	Stage 3	Type III	Type III
43	22	Stage 3	Type III	Type III	**59**	25	Stage 3	Type III	Type III
44	25	Stage 3	Type III	Type III	**60**	23	Stage 3	Type II	Type II
45	25	Stage 3	Type II	Type II	**61**	24	Stage 0	Type 1	Type 1
46	22	Stage 3	Type III	Type III	**62**	21	Stage 3	Type III	Type III
47	25	Stage 3	Type III	Type III	**63**	12	Stage 0	Type 1	Type 1
48	12	Stage 0	Type 1	Type 1	**64**	23	Stage 3	Type II	Type II

Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication		Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication	
			Right	Left				Right	Left
65	25	Stage 3	Type III	Type III	**81**	25	Stage 3	Type III	Type III
66	25	Stage 3	Type III	Type III	**82**	19	Stage 3	Type II	Type II
67	22	Stage 3	Type II	Type II	**83**	18	Stage 2	Type II	Type II
68	10	Stage 0	Type 1	Type 1	**84**	24	Stage 3	Type III	Type III
69	25	Stage 3	Type III	Type III	**85**	21	Stage 3	Type III	Type III
70	25	Stage 3	Type III	Type III	**86**	22	Stage 3	Type III	Type III
71	25	Stage 3	Type III	Type III	**87**	23	Stage 3	Type III	Type III
72	24	Stage 3	Type III	Type III	**88**	23	Stage 3	Type III	Type III
73	21	Stage 3	Type III	Type III	**89**	21	Stage 3	Type II	Type III
74	22	Stage 3	Type III	Type III	**90**	10	Stage 0	Type 1	Type 1
75	25	Stage 3	Type III	Type III	**91**	22	Stage 3	Type III	Type III
76	18	Stage 3	Type II	Type II	**92**	25	Stage 3	Type II	Type II
77	16	Stage 1	Type II	Type II	**93**	25	Stage 3	Type III	Type II
78	22	Stage 3	Type III	Type III	**94**	23	Stage 3	Type III	Type III
79	10	Stage 0	Type 1	Type 1	**95**	20	Stage 3	Type III	Type III
80	23	Stage 3	Type III	Type III	**96**	10	Stage 0	Type 1	Type 1

Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication		Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication	
			Right	Left				Right	Left
97	24	Stage 3	Type III	Type III	**113**	25	Stage 3	Type III	Type III
98	22	Stage 3	Type III	Type III	**114**	24	Stage 3	Type III	Type III
99	24	Stage 3	Type III	Type III	**115**	25	Stage 3	Type III	Type III
100	22	Stage 3	Type III	Type III	**116**	19	Stage 2	Type II	Type II
101	18	Stage 2	Type II	Type II	**117**	22	Stage 3	Type III	Type III
102	17	Stage 1	Type II	Type II	**118**	21	Stage 3	Type III	Type III
103	19	Stage 2	Type II	Type II	**119**	17	Stage 1	Type 1	Type 1
104	21	Stage 3	Type III	Type III	**120**	10	Stage 0	Type 1	Type 1
105	22	Stage 3	Type III	Type III	**121**	25	Stage 3	Type III	Type III
106	19	Stage 3	Type II	Type II	**122**	18	Stage 3	Type II	Type II
107	25	Stage 3	Type III	Type III	**123**	22	Stage 3	Type III	Type III
108	23	Stage 2	Type III	Type III	**124**	19	Stage 3	Type II	Type II
109	22	Stage 3	Type III	Type III	**125**	22	Stage 3	Type III	Type III
110	25	Stage 3	Type III	Type III	**126**	20	Stage 3	Type II	Type III
111	23	Stage 3	Type III	Type III	**127**	14	Stage 0	Type 1	Type 1
112	24	Stage 3	Type III	Type III	**128**	22	Stage 3	Type III	Type III

Patient No	**Age / Sex**	**Spheno-occipital Synchondrosis Stage**	**Condylar Cortication**		**Patient No**	**Age / Sex**	**Spheno-occipital Synchondrosis Stage**	**Condylar Cortication**	
			Right	**Left**				**Right**	**Left**
129	19	Stage 3	Type II	Type II	**145**	25	Stage 2	Type III	Type III
130	22	Stage 3	Type III	Type III	**146**	22	Stage 3	Type III	Type III
131	22	Stage 3	Type III	Type III	**147**	25	Stage 3	Type III	Type III
132	16	Stage 2	Type II	Type II	**148**	10	Stage 0	Type 1	Type 1
133	17	Stage 3	Type II	Type II	**149**	24	Stage 3	Type III	Type III
134	22	Stage 3	Type III	Type III	**150**	21	Stage 3	Type III	Type III
135	25	Stage 3	Type III	Type III	**151**	25	Stage 3	Type III	Type III
136	21	Stage 3	Type III	Type III	**152**	22	Stage 3	Type III	Type III
137	20	Stage 3	Type III	Type III	**153**	25	Stage 3	Type III	Type III
138	24	Stage 3	Type III	Type III	**154**	12	Stage 0	Type II	Type 1
139	23	Stage 3	Type III	Type III	**155**	25	Stage 3	Type III	Type III
140	20	Stage 3	Type II	Type II	**156**	20	Stage 3	Type III	Type III
141	25	Stage 3	Type III	Type III	**157**	21	Stage 3	Type III	Type III
142	25	Stage 3	Type III	Type III	**158**	18	Stage 2	Type II	Type II
143	23	Stage 3	Type III	Type III	**159**	24	Stage 3	Type III	Type III
144	23	Stage 3	Type III	Type III	**160**	25	Stage 3	Type III	Type III

Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication		Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication	
			Right	Left				Right	Left
161	23	Stage 3	Type III	Type III	**177**	22	Stage 3	Type III	Type III
162	10	Stage 0	Type 1	Type 1	**178**	22	Stage 3	Type III	Type III
163	22	Stage 3	Type III	Type III	**179**	23	Stage 2	Type III	Type II
164	22	Stage 3	Type III	Type III	**180**	24	Stage 3	Type III	Type III
165	25	Stage 3	Type III	Type III	**181**	20	Stage 3	Type II	Type II
166	21	Stage 3	Type III	Type III	**182**	21	Stage 2	Type III	Type III
167	14	Stage 0	Type 1	Type 1	**183**	22	Stage 3	Type III	Type III
168	25	Stage 3	Type III	Type III	**184**	22	Stage 3	Type II	Type II
169	21	Stage 3	Type III	Type III	**185**	19	Stage 2	Type II	Type II
170	19	Stage 3	Type II	Type II	**186**	25	Stage 3	Type III	Type III
171	25	Stage 3	Type III	Type III	**187**	21	Stage 3	Type II	Type II
172	25	Stage 3	Type III	Type III	**188**	22	Stage 3	Type III	Type III
173	25	Stage 3	Type III	Type III	**189**	23	Stage 2	Type III	Type III
174	25	Stage 3	Type III	Type III	**190**	18	Stage 2	Type II	Type II
175	24	Stage 3	Type II	Type III	**191**	21	Stage 3	Type III	Type III
176	23	Stage 3	Type III	Type III	**192**	22	Stage 3	Type III	Type III

Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication		Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication	
			Right	Left				Right	Left
193	25	Stage 3	Type III	Type III	**209**	10	Stage 0	Type 1	Type 1
194	10	Stage 0	Type 1	Type 1	**210**	22	Stage 3	Type II	Type II
195	23	Stage 3	Type III	Type III	**211**	21	Stage 3	Type III	Type III
196	15	Stage 3	Type II	Type II	**212**	19	Stage 2	Type III	Type III
197	16	Stage 1	Type II	Type II	**213**	22	Stage 3	Type III	Type III
198	23	Stage 3	Type III	Type III	**214**	22	Stage 3	Type III	Type III
199	19	Stage 2	Type II	Type II	**215**	24	Stage 3	Type III	Type III
200	19	Stage 3	Type II	Type II	**216**	25	Stage 3	Type III	Type III
201	23	Stage 3	Type II	Type II	**217**	12	Stage 0	Type 1	Type 1
202	25	Stage 3	Type III	Type III	**218**	19	Stage 2	Type II	Type II
203	23	Stage 3	Type III	Type III	**219**	23	Stage 3	Type II	Type II
204	19	Stage 3	Type II	Type II	**220**	14	Stage 0	Type II	Type 1
205	22	Stage 0	Type III	Type III	**221**	25	Stage 3	Type III	Type III
206	10	Stage 3	Type 1	Type 1	**222**	17	Stage 3	Type II	Type II
207	22	Stage 3	Type II	Type II	**223**	25	Stage 3	Type III	Type III
208	21	Stage 3	Type III	Type III	**224**	23	Stage 3	Type III	Type III

Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication		Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication	
			Right	Left				Right	Left
225	21	Stage 3	Type II	Type III	**241**	20	Stage 3	Type II	Type II
226	16	Stage 2	Type 1	Type II	**242**	14	Stage 2	Type II	Type II
227	21	Stage 3	Type II	Type II	**243**	23	Stage 3	Type III	Type III
228	21	Stage 3	Type III	Type II	**244**	22	Stage 2	Type II	Type II
229	21	Stage 2	Type II	Type II	**245**	22	Stage 2	Type II	Type II
230	15	Stage 1	Type 1	Type 1	**246**	23	Stage 3	Type II	Type III
231	17	Stage 2	Type II	Type II	**247**	23	Stage 2	Type III	Type III
232	20	Stage 2	Type II	Type II	**248**	18	Stage 3	Type II	Type II
233	25	Stage 3	Type III	Type III	**249**	23	Stage 3	Type II	Type II
234	24	Stage 3	Type III	Type III	**250**	25	Stage 3	Type II	Type II
235	23	Stage 3	Type III	Type III	**251**	17	Stage 3	Type II	Type II
236	18	Stage 3	Type II	Type II	**252**	24	Stage 3	Type II	Type II
237	12	Stage 0	Type 1	Type 1	**253**	15	Stage 1	Type 1	Type 1
238	21	Stage 3	Type II	Type III	**254**	22	Stage 3	Type II	Type II
239	25	Stage 3	Type III	Type III	**255**	19	Stage 3	Type II	Type II
240	19	Stage 3	Type II	Type II	**256**	22	Stage 3	Type III	Type III

Patient No	**Age / Sex**	**Spheno-occipital Synchondrosis Stage**	**Condylar Cortication**		**Patient No**	**Age / Sex**	**Spheno-occipital Synchondrosis Stage**	**Condylar Cortication**	
			Right	**Left**				**Right**	**Left**
257	21	Stage 3	Type III	Type III	**273**	13	Stage 0	Type 1	Type 1
258	19	Stage 3	Type II	Type II	**274**	21	Stage 3	Type II	Type II
259	21	Stage 3	Type III	Type III	**275**	22	Stage 2	Type II	Type II
260	20	Stage 3	Type II	Type II	**276**	19	Stage 1	Type II	Type II
261	23	Stage 3	Type III	Type III	**277**	20	Stage 3	Type II	Type II
262	24	Stage 3	Type III	Type III	**278**	23	Stage 3	Type III	Type III
263	15	Stage 1	Type 1	Type 1	**279**	20	Stage 3	Type II	Type II
264	15	Stage 0	Type 1	Type 1	**280**	20	Stage 3	Type II	Type II
265	22	Stage 3	Type III	Type III	**281**	23	Stage 3	Type III	Type III
266	10	Stage 0	Type 1	Type 1	**282**	23	Stage 3	Type III	Type III
267	21	Stage 3	Type II	Type II	**283**	23	Stage 3	Type III	Type III
268	25	Stage 3	Type III	Type III	**284**	23	Stage 3	Type III	Type III
269	14	Stage 0	Type II	Type II					
270	24	Stage 3	Type III	Type III					
271	21	Stage 3	Type II	Type II					
272	23	Stage 3	Type III	Type III					

ANNEXURE – III

MASTER CHART – Spheno-occipital synchondrosis stages and Condylar cortication types in Females

Patient No	Age	Spheno-occipital Synchondrosis Stage	Condylar Cortication		Patient No	Age	Spheno-occipital Synchondrosis Stage	Condylar Cortication	
			Right	Left				Right	Left
1	25	Stage 3	Type III	Type III	**17**	24	Stage 3	Type III	Type III
2	22	Stage 3	Type II	Type II	**18**	22	Stage 3	Type III	Type III
3	17	Stage 2	Type II	Type II	**19**	25	Stage 2	Type III	Type III
4	22	Stage 2	Type III	Type III	**20**	20	Stage 2	Type II	Type II
5	24	Stage 3	Type III	Type III	**21**	18	Stage 2	Type II	Type II
6	25	Stage 3	Type III	Type III	**22**	10	Stage 0	Type 1	Type 1
7	25	Stage 3	Type III	Type III	**23**	23	Stage 2	Type III	Type III
8	25	Stage 3	Type III	Type III	**24**	19	Stage 2	Type II	Type II
9	22	Stage 3	Type II	Type II	**25**	21	Stage 3	Type III	Type III
10	10	Stage 0	Type 1	Type 1	**26**	25	Stage 3	Type III	Type III
11	17	Stage 2	Type II	Type II	**27**	22	Stage 2	Type III	Type III
12	19	Stage 2	Type II	Type II	**28**	20	Stage 2	Type II	Type II
13	11	Stage 0	Type 1	Type 1	**29**	17	Stage 2	Type II	Type II
14	14	Stage 3	Type II	Type II	**30**	23	Stage 3	Type II	Type II
15	22	Stage 3	Type III	Type III	**31**	22	Stage 3	Type II	Type II
16	10	Stage 0	Type 1	Type 1	**32**	23	Stage 3	Type III	Type III

Patient No	Age	Spheno-occipital Synchondrosis Stage	Condylar Cortication		Patient No	Age	Spheno-occipital Synchondrosis Stage	Condylar Cortication	
			Right	Left				Right	Left
33	25	Stage 3	Type III	Type III	**49**	22	Stage 3	Type III	Type III
34	21	Stage 3	Type III	Type III	**50**	23	Stage 3	Type III	Type III
35	25	Stage 3	Type III	Type III	**51**	21	Stage 2	Type III	Type III
36	19	Stage 3	Type II	Type II	**52**	25	Stage 3	Type III	Type III
37	23	Stage 3	Type III	Type III	**53**	21	Stage 2	Type II	Type II
38	24	Stage 3	Type II	Type II	**54**	24	Stage 3	Type III	Type III
39	23	Stage 3	Type III	Type III	**55**	23	Stage 2	Type III	Type III
40	22	Stage 3	Type III	Type III	**56**	16	Stage 2	Type II	Type II
41	22	Stage 3	Type III	Type III	**57**	16	Stage 3	Type III	Type III
42	19	Stage 1	Type II	Type II	**58**	21	Stage 2	Type III	Type II
43	21	Stage 3	Type III	Type III	**59**	22	Stage 2	Type III	Type III
44	21	Stage 3	Type III	Type III	**60**	22	Stage 3	Type III	Type III
45	22	Stage 3	Type III	Type III	**61**	21	Stage 3	Type III	Type III
46	23	Stage 2	Type III	Type III	**62**	21	Stage 3	Type III	Type III
47	25	Stage 3	Type III	Type III	**63**	19	Stage 2	Type II	Type II
48	19	Stage 3	Type II	Type II	**64**	20	Stage 3	Type II	Type II

Patient No	**Age / Sex**	**Spheno-occipital Synchondrosis Stage**	**Condylar Cortication**		**Patient No**	**Age / Sex**	**Spheno-occipital Synchondrosis Stage**	**Condylar Cortication**	
			Right	**Left**				**Right**	**Left**
65	22	Stage 3	Type III	Type III	**81**	15	Stage 3	Type II	Type II
66	10	Stage 0	Type 1	Type 1	**82**	20	Stage 3	Type III	Type III
67	21	Stage 3	Type III	Type III	**83**	24	Stage 3	Type III	Type III
68	25	Stage 2	Type III	Type III	**84**	23	Stage 2	Type III	Type III
69	24	Stage 3	Type III	Type III	**85**	11	Stage 0	Type 1	Type 1
70	25	Stage 3	Type III	Type III	**86**	22	Stage 3	Type III	Type III
71	17	Stage 3	Type II	Type II	**87**	17	Stage 2	Type II	Type II
72	22	Stage 3	Type III	Type III	**88**	21	Stage 3	Type III	Type III
73	24	Stage 3	Type III	Type III	**89**	21	Stage 3	Type III	Type III
74	25	Stage 3	Type III	Type III	**90**	23	Stage 3	Type III	Type III
75	19	Stage 3	Type II	Type II	**91**	16	Stage 3	Type II	Type III
76	19	Stage 3	Type II	Type 1	**92**	17	Stage 2	Type II	Type II
77	23	Stage 3	Type III	Type III	**93**	23	Stage 3	Type III	Type III
78	22	Stage 3	Type III	Type III	**94**	22	Stage 3	Type II	Type II
79	22	Stage 3	Type III	Type III	**95**	25	Stage 3	Type III	Type III
80	13	Stage 3	Type 1	Type 1	**96**	25	Stage 3	Type III	Type III

Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication		Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication	
			Right	Left				Right	Left
97	20	Stage 3	Type II	Type II	**113**	17	Stage 3	Type II	Type II
98	20	Stage 3	Type III	Type II	**114**	15	Stage 2	Type II	Type II
99	19	Stage 2	Type II	Type II	**115**	19	Stage 3	Type II	Type II
100	19	Stage 3	Type II	Type II	**116**	21	Stage 3	Type III	Type III
101	23	Stage 3	Type III	Type III	**117**	22	Stage 3	Type III	Type III
102	22	Stage 3	Type III	Type II	**118**	19	Stage 3	Type II	Type II
103	25	Stage 3	Type III	Type III	**119**	22	Stage 3	Type II	Type II
104	21	Stage 3	Type II	Type II	**120**	16	Stage 3	Type II	Type II
105	20	Stage 2	Type II	Type II	**121**	21	Stage 3	Type III	Type III
106	22	Stage 3	Type II	Type II	**122**	25	Stage 3	Type III	Type III
107	11	Stage 0	Type 1	Type 1	**123**	23	Stage 3	Type III	Type III
108	24	Stage 3	Type III	Type III	**124**	14	Stage 2	Type II	Type II
109	16	Stage 3	Type II	Type II	**125**	21	Stage 3	Type III	Type III
110	16	Stage 2	Type II	Type II	**126**	16	Stage 2	Type II	Type II
111	18	Stage 3	Type II	Type II	**127**	18	Stage 2	Type II	Type II
112	21	Stage 3	Type III	Type III	**128**	19	Stage 2	Type III	Type III

Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication		Patient No	Age / Sex	Spheno-occipital Synchondrosis Stage	Condylar Cortication	
			Right	Left				Right	Left
129	25	Stage 3	Type III	Type III	**145**	24	Stage 3	Type III	Type III
130	11	Stage 0	Type 1	Type 1	**146**	23	Stage 3	Type III	Type III
131	11	Stage 0	Type 1	Type 1	**147**	21	Stage 3	Type III	Type III
132	15	Stage 2	Type II	Type II	**148**	25	Stage 3	Type III	Type III
133	18	Stage 2	Type II	Type II	**149**	22	Stage 3	Type III	Type III
134	10	Stage 1	Type 1	Type 1	**150**	23	Stage 3	Type III	Type III
135	13	Stage 0	Type 1	Type 1	**151**	23	Stage 3	Type III	Type III
136	21	Stage 3	Type III	Type III					
137	22	Stage 3	Type III	Type III					
138	16	Stage 2	Type II	Type II					
139	12	Stage 0	Type 1	Type 1					
140	20	Stage 3	Type II	Type II					
141	22	Stage 3	Type III	Type III					
142	19	Stage 3	Type II	Type II					
143	10	Stage 0	Type 1	Type 1					
144	22	Stage 3	Type III	Type III					