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Age estimation by an analysis of spheno-occipital synchondrosis using cone-beam computed tomography

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ABSTRACT

The spheno-occipital synchondrosis has a relatively late ossification in comparison with other cranial base synchondroses, which makes it a point of interest for forensic age determination studies. The purpose of the present study was to evaluate the reliability of spheno-occipital synchondrosis development in age determination in a Turkish population and to evaluate the reproducibility and reliability of cone beam computed tomography (CBCT) in an evaluation of the fusion stages of spheno-occipital synchondrosis. CBCT mid-sagittal images of 238 (90 males and 148 females) patients between the ages of 7 and 25, with a mean age of 15.45 ± 0.26 and 16.43 ± 0.37, respectively, were examined by three Oral and Maxillofacial Radiologists who evaluated the degree of synchondrosis fusion using a four-stage system. A reevaluation of 50 cases was conducted for intraobserver assessment. Multiple statistical analyses were used to assess the correlation between age and the fusion stage, to compare gender and age according to stages, and to evaluate the inter- and intraobserver agreement. The mean ages for complete fusion (Stage 3) were 18 and 20 for females and males, respectively. The interobserver agreement ranged between substantial and perfect, while the intraobserver agreement was substantial for all three observers. Based on these results, CBCT, when available, might be the method of choice for age estimation using the spheno-occipital synchondrosis fusion stages. Evaluating spheno-occipital synchondrosis has a value for age estimation around the age of 18 years, which affects the legal decisions in Turkey.

1. Introduction

Centers of ossification appear early in embryonic life in the chondrocranium, and as ossification proceeds, the cartilage band, called the synchondrosis, persists between the centers of ossification and will eventually be replaced by bone [1]. The spheno-occipital synchondrosis is a linear cleft that passes from the intracranial clivus to the pharyngeal surface of the basicranium and is a critical growth site due to its influence on the elongation of the basicranial axis, which creates room for dento-alveolar development [2,3]. It has a relatively late ossification in comparison to other cranial base synchondroses that fuse prenatally or during early childhood [4,5]. Therefore, the degree of fusion of the spheno-occipital synchondrosis has been a point of interest for forensic age estimation studies.

The degree of fusion of the synchondrosis is a vital contributor to subadult age estimates for forensic purposes [6]. There are several circumstances and conditions that require the knowledge of subjects' true age when such information is not readily available. Knowing the chronological age of subjects will result in different decisions in forensic and medical practice. Specifically, the establishment of the likelihood of a subject being an adult (18 years of age or older) is critical. Criminal prosecution, immigration proceedings, and other legal factors are strongly dependent on a subject's minority status. According to Prasad et al., the two main reasons for age estimation are primarily due to the progress of sociopolitical development. The first reason is a rising number of unidentified human remains; the second is an increase in cases requiring age determination in living individuals with no legal proof of their date of birth [7]. These developments have greatly underlined the importance of age determination both in human remains and living individuals. From a legal point of view, age estimations between 15 and 18 years affect legal decisions in Turkey. This age range corresponds the beginning of adulthood in European countries, which ranges from 14 to 21 years [8–10].

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It has been reported that a great deal of disparity exists in terms of fusion degrees in different populations due to developmental factors [6,8]. Furthermore, the results of these studies also vary due to the use of different investigation methodologies. These methods include dry bone gross morphology, wet bone morphology at autopsy, bone histology, and the use of conventional radiographic images and computed tomography (CT) scans [6]. The variable results of these studies were related to the analysis methods, postmortem analysis (macroscopic and histologic methods) and live individual analysis (conventional radiography and CT) [8]. Live individual analysis recently became an interesting area of forensic research, with increasing relevance for criminal, civil and asylum proceedings. It has been reported that the demand for estimating the age of living persons is growing due to the global increase in immigration in recent years. Additionally, age estimates of living individuals generally have to be more accurate than of deceased persons [11].

For determining the closure of the spheno-occipital synchondrosis, the use of conventional radiography is reported to be inexpensive and attainable, although it has disadvantages, including superimposition and low resolution [8]. With a three dimensional assessment and a high resolution of the region of interest, the use of medical CT scans was reported to be more accurate and to offer an appropriate, reliable and arguably more representative source of contemporary population-specific data [5,8,12,13]. On the other hand, cost, attainability, and radiation exposure are the reported disadvantages of CT scan investigations [8].

Cone beam computed tomography (CBCT) is an emerging imaging modality that is capable of eliminating superimposition by adding a third dimension over two-dimensional conventional radiography [14] with a considerable dose reduction in comparison to medical CT [15,16]. The advantage of CBCT over medical CT has been investigated by various studies in recent years [17,18]. To our knowledge, the use of CBCT has not yet been investigated for the evaluation of spheno-occipital synchondrosis. Therefore, the present study aimed to assess the spheno-occipital synchondrosis for age estimations in a Turkish subpopulation and to investigate the reproducibility and reliability of CBCT evaluations for this purpose.

2. Materials and methods

2.1. Case selection

The Ethics Committee of Kocaeli University (KOU KAEK 2014/309) approved this retrospective study. The study population consisted of 90 males and 148 females between the ages of 7 and 25. An upper age limit of 25 was used for comparisons with previous CT based studies [5,8,12]. The participants were referred to the University of Kocaeli, Faculty of Dentistry, Kocaeli, Turkey, between May 2013 and December 2014 and required CBCT scans as part of their diagnostic package. CBCT scans displaying modifications of the cranium or developmental disorders, abnormal morphology resulting from trauma and pathologic conditions that potentially affected the area of interest were excluded [5,8,12].

2.2. CBCT evaluation

CBCT images were acquired using a Planmeca CBCT machine (Planmeca, Promax 3D max, Helsinki, Finland). Images were reconstructed with Romexis®, the proprietary software of Planmeca. Depending on the voxel size of the volumetric data, sub-millimeter slice thicknesses were preferred (0.2–0.4 mm) for the investigation of each plane. Axial and coronal views are used to situate the cranium in a standardized position to allow for the assessment of the fusion status in the mid-sagittal plane [5]. As the view of choice, the mid-sagittal images of each spheno-occipital synchondrosis were exported and saved in jpeg format [12]. The CBCT images were adjusted and exported to Microsoft Office PowerPoint to create a separate file set for observer evaluation. The file set did not contain any demographic data, and the images were displayed in a random order.

2.3. Scoring and data analysis

A four-stage system was used to evaluate the degree of fusion of the spheno-occipital synchondrosis, which was previously proposed by Franklin and Flavel [5] (Table 1 and Fig. 1). Before the case, a calibration session was held to interpret the staging system used for the study.

Three maxillofacial radiologists independently evaluated a total of 238 images and were unaware of one another's results. Separated by a 2-week interval, 50 randomly selected images from the file set were re-evaluated for intraobserver agreement. After the evaluating sessions, another session was held for the final scoring of all cases with the consensus of all three observers. During this session, as suggested by Okamoto et al., axial images were also used for the assessment of the synchondrosis in cases of disagreements to reach a consensus [19].

2.4. Statistical analysis

Statistical analysis was performed with the Statistical Package for the Social Sciences package (Version 18, SPSS Inc., Chicago, IL). Spearman correlation analysis was used to assess the correlation between age and the fusion stage. The difference between stages and gender, considering age, and the comparison between gender and age according to stages were determined by the Mann–Whitney test and Student's T test. Linear regression analysis was used to calculate the average ages at transitions between fusion stages. Regression analysis was carried out using age as a dependent variable and the stage of spheno-occipital fusion as an independent variable. Linear regression parameters for the prediction of average ages between fusion stages for both genders were calculated.

Intra- and interobserver agreement were also assessed using Kappa test values (κ), with a value >0.81, 0.80–0.61, 0.60–0.41, 0.40–0.21 and <0.20 denoting perfect, substantial, moderate, fair, and slight agreement, respectively. Inter-observer disagreement for each stage was also determined using the Friedman test. For all analyses, $P < 0.05$ was considered to be statistically significant.

Table 1
Definition of the staging system used for scoring spheno-occipital synchondrosis fusion degree [5].

Stage	Status	Description
0	Unfused	Completely open with no evidence of fusion between the basilar portion of the occipital and the sphenoid – no bone present in the gap
1	Fusing endocranially	No more than half the length of the synchondrosis is fused proceeding endo – to ectocranially
2	Fusing ectocranially	Greater than half the length of the synchondrosis is fused – the ectocranial (inferior) border remains unfused
3	Complete fusion	Completely fused with the appearance of normal bone throughout – a fusion scar may be present