



Naif Arab University for Security Sciences
Arab Journal of Forensic Sciences & Forensic Medicine
المجلة العربية لعلوم الأدلة الجنائية والطب الشرعي
<https://journals.nauss.edu.sa/index.php/AJFSFM>



Macroscopic Cranial Suture Closure in An Adult Population: Is It Reliable for Estimating Age?

غلق الدرز القحفي العياني عند البالغين: هل هو موثوق لتقدير العمر؟



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Received 18 Sep. 2020; Accepted 13 Apr. 2021; Available Online 01 Jun. 2021

Abstract

Age estimation is a key factor for the estimation of true sketch of an individual. Generally speaking, assessment of the age of a person either alive or dead is very important in medicolegal and forensic scenarios.

The purpose of the present study was to examine the chronology and mold of union of cranial sutures, specifically sagittal, coronal, and lambdoid, and to find out the association between cranial suture closures with the age of the dead. An attempt was also made to see the applicability of the Acsadi and Nemeskeri method in an Indian population. A total of 193 adult calvarias (133 males and 60 females) were studied from autopsy cases. The degree of closure was studied in the three main sutures of the calvarium namely sagittal, coronal and lambdoid.

The ectocranial sutures closed after the closure of endocranial sutures in all three studied sutures in various age groups. The sagittal suture showed earlier closure than coronal and lambdoid sutures on the scoring scale. When the Acsadi and Nemeskeri method was analysed using our data, it showed that scale of 0 to 4 worked fairly well with increasing age, with a score near 0 in younger populations and a score of 4 in older populations.

Keywords: Forensic Science, Forensic Anthropology, Age Estimation, Cranial Suture Closure, Ectocranial, Endocranial.

المستخلص

تقدير العمر هو عامل رئيسي لتقدير الحالة الحقيقية للفرد، وبشكل عام فإن تقييم عمر الشخص، سواء كان حياً أو ميتاً مهم جداً في الحالات الجنائية. وهدفت هذه الدراسة إلى فحص التسلسل الزمني والقوالب الموحدة للدرز القحفي وتحديدًا السهمي والإكليلي واللامبي، ومعرفة العلاقة بين غلق الدرز القحفي وعمر الموتى. وأيضاً جرت محاولة معرفة قابلية تطبيق طريقة Acsadi و Nemeskeri عند السكان الهنود. وتمت دراسة ما مجموعه 193 سقوف جمجمة لبالغين (133 من الذكور و60 من الإناث) من حالات التشريح. ودرست درجة الغلق في أنواع الغلق الثلاثة الرئيسية لسقوف الجمجمة أي السهمي والإكليلي واللامبي.

وتم ملاحظة أنه تم غلق الدرز خارج القحف بعد غلق الدرز داخل القحف لجميع الدرز الثلاثة المدروسة في مختلف الفئات العمرية. وأظهر الدرز السهمي غلقاً بشكل أبكر مقارنة بالدرز الإكليلي والدرز اللامبي وفق درجات التقييم. وبيّن تحليل البيانات باستخدام طريقة Acsadi و Nemeskeri أن درجات التقييم من 0 إلى 4 تتناسب بشكل جيد مع تقدم العمر، مع درجة قريبة من 0 لدى السكان الأصغر

الكلمات المفتاحية: علوم الأدلة الجنائية، الأنثروبولوجيا الجنائية، تقدير العمر، غلق الدرز القحفي، خارج القحف، باطن القحف.

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doi: 10.26735/IJFM2816



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Thus, we can conclude that closure of sutures occurs with advancing age in sagittal, coronal and lambdoid sutures. The sagittal, coronal, and lambdoid sutures are usually open in younger populations below 28 years of age while they are almost always closed in the age group above 70 years. The obliteration score of suture closure increased with increasing age ectocranially and endocranially. Thus, Acsadi and Nemeskeri's method was found to be applicable to the Indian population for the estimation of age from cranial sutures.

1. Introduction

Estimating age is a vital aspect in various forensic investigations. In case of unknown, unclaimed dead bodies or in decomposed, dismembered, and mutilated remains, identification is important on forensic and humanitarian grounds. For identification, estimation of the biological profile of the individual is required. Estimating age is one of the key factors for establishing the biological profile of the dead.

The cranium is believed to be the best conserved segment of the human skeleton in archaeological and forensic recoveries of human remains. Hence, the technique of estimating age from cranial suture closure is of greater interest. Reliable estimation of stature, age, race, or sex of an individual from the skull can be done as the bone resists putrefaction or damage by animals [1-5].

In the past, many age estimation techniques have been employed in studies. However, the human skull remained one important part of the skeleton for estimation of age whether from suture closure, spheno-occipital synchondrosis and from different stages of the mandible. Recent literature shows new methods such as CT imaging for the estimation of age from cranial suture closure [1-5]. In the absence of skeletal collections, these indirect CT imaging methods are timely and provide valuable data and material for studying suture closure in contemporary populations. Spheno-occipital synchondrosis also provides information about the age

سناً ودرجة 4 في الفئات الأكبر سناً.

وعليه يمكن الاستنتاج بأن غلق الدرز يحدث مع تقدم العمر في كل من الدرز السهمي والإكليلي واللامبي. وعادةً ما تكون الدرز السهمية والتاجية واللامبية مفتوحة عند الأشخاص الأصغر سناً الذين تقل أعمارهم عن 28 عامًا، بينما تكون مغلقة دائمًا تقريبًا في الفئة العمرية فوق 70 عامًا. وتزيد درجة الغلق مع زيادة العمر سواء داخل القحف أو خارجه. ووجد أن طريقة Acsadi و Nemeskeri قابلة للتطبيق على السكان الهنود لتحديد العمر من خلال غلق الدرز القحفية.

of the persons when the cranium is used for forensic examinations [6-8], however, due to its erratic closure pattern, it may not be reliable for age estimation [9].

Age estimation from observing suture closure can provide reliable estimates for the age of persons beyond 20 to 25 years. In other words, the age of persons less than 25 years can be estimated with relative precision, based on epiphysis-diaphysis closure of the long bones the eruption and sequence of eruption of teeth from infancy to approximately 17 to 25 years, and the union of the medial clavicular epiphysis between 25 and 28 years [10,11]. With increasing age, the task of estimating age gets more complex because we can only apply a few methods. While age estimation with suture closure is more complex, it can only provide ages in decades. However, in the absence of any other material and methods available for forensic investigation, suture closure may provide clues to investigating agencies for identification purposes [10].

Krogman et al., [11] noted certain series of morphological changes in the norma verticalis around the sagittal suture, referred to as Pacchionian depressions, which became more pronounced with age. Therefore, this may also give a broad indication of the person's age.

The current study is an effort to examine cranial suture closure in various age groups, which would assist in devising a reference value relating to our



living population. In addition, the objective was to study the chronology and model of the union of cranial sutures specifically sagittal, coronal, and lambdoid sutures. Also, we were interested in identifying the association between cranial suture closure and individual's ages, and to develop a useful method for estimating age based on cranial suture closures by utilizing the acquired information.

2. Materials and Methods

2.1 Samples

The present study comprises a total of 193 adult calvarias (133 males and 60 females) from autopsy cases received in our medical college and hospital. The study was conducted during a period from 2010 to 2013. The preparation of samples was done according to a previously conducted study [10] where sagittal suture was used for age estimation. The same samples were evaluated for sagittal, coronal, and lambdoid sutures by following the methodology used by Sahni et al. [12]. The subjects above 20 years of age were incorporated in the study. Cases

of unknown origin, unclaimed bodies with no known data regarding age, and those having distorted, diseased, or fractured skulls were excluded.

2.2 Methodology

The extent of closure of the sutures was observed both ectocranially and endocranially in the sagittal, coronal and lambdoid sutures according to Acsadi and Nemeskeri's scale [13]. The sutures were equally divided into four segments for the sagittal suture (from bregma to lambda) as S1, S2, S3, and S4 and three segments for the coronal suture (inside-out) on the right side as RC1, RC2, and RC3 and on the left side as LC1, LC2, and LC3. Similarly, the lambdoid suture was divided into three segments on the right side as RL1, RL2, and RL3 and on left side as LL1, LL2, and LL3.

Thus, a total of sixteen segments were studied for suture closure by point score scaling as mentioned below (Figure-1).

2.3. Scaling for suture closure: Acsadi-Nemeskeri

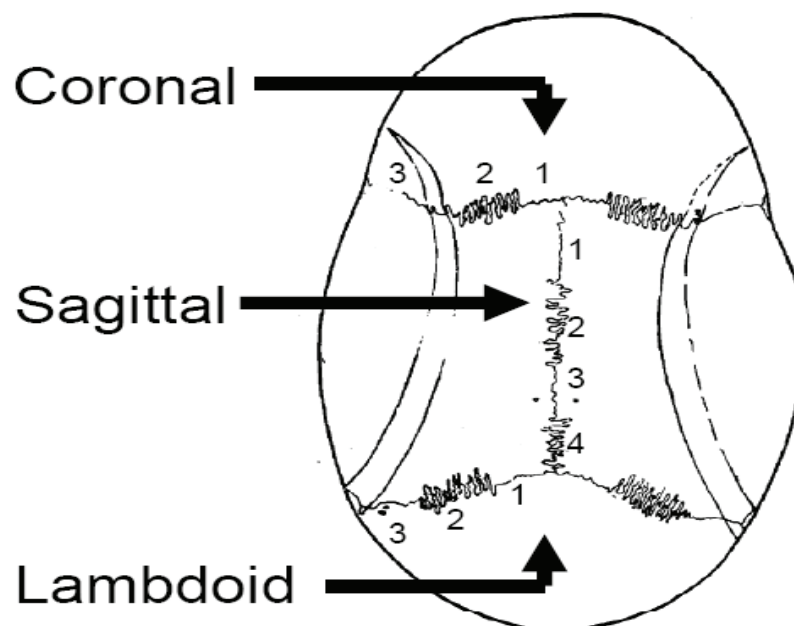


Figure 1- Diagram showing studied segments of coronal, sagittal and lambdoid suture.



Table 1- Distribution of cases according to age and gender.

Age (Years)	Male	Female	Total
21-30	(23.3%) 31	(25%) 15	(23.8%) 46
31-40	(15.8%) 21	(28.3%) 17	(19.7%) 38
41-50	(14.3%) 19	(16.7%) 10	(15.1%) 29
51-60	(15.8%) 21	(3.3%) 02	(11.9%) 23
>60	(30.8%) 41	(26.7%) 16	(29.5%) 57
Total	(100%) 133	(100%) 60	(100%) 193

complex technique (Figure-2 and 3)

0 = Open. There is still tiny space left between ends of adjoining bones.

1 = Incipient closure. Evidently noticeable as an unbroken often zigzagging line.

2 = Closure in process. Line up thinner, less zig-zags, interrupted by complete closure.

3 = Advanced closure. Only pits point to where the suture is situated.

4 = Closed. Even location cannot be identified.

Also, application of the Acsadi and Nemeskeri scoring system for determining age in human skulls of Indian population was studied. The sum of the total score of the sixteen segments was divided by 16 to get the average score for suture closure as per the Acsadi and Nemeskeri scoring system.

2.4. Statistical Analysis

Sagittal, Coronal, and lambdoid scores were articulated by mean and standard deviation. Data

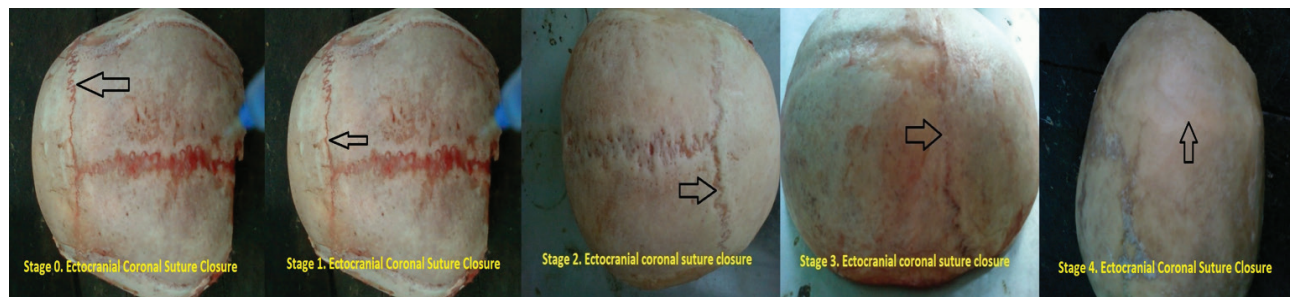
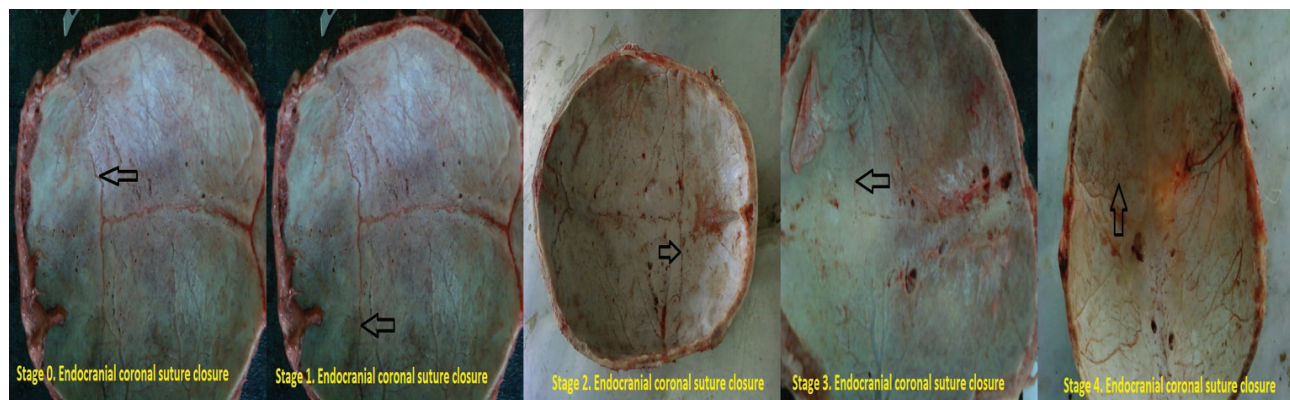
**Figure 2-** Scale for suture closure: Acsadi- Nemeskeri complex method (Ectocranial Suture closure).**Figure 3-** Scale for suture closure: Acsadi-Nemeskeri complex method (Endocranial Suture closure).

Table 2- Comparison of mean ectocranial closure stages in three sutures.

Age Group (Years)	Sagittal	Coronal	Lambdoid
	Mean ± SD	Mean ± SD	Mean ± SD
21-30	0.02 (0.15)	0.02 (0.5)	0.00 (0.0)
31-40	1.48 (0.69)	1.11 (0.58)	0.23 (0.35)
41-50	2.00 (0.54)	1.90 (0.63)	1.175 (0.72)
51-60	2.46 (1.48)	2.20 (1.43)	1.85 (0.67)
>60	3.21 (0.6)	3.08 (0.7)	2.80 (0.86)

Table 3- Comparison of mean endocranial closure score in three sutures.

Age group (years)	Sagittal	Coronal	Lambdoid
	Mean ± SD	Mean ± SD	Mean ± SD
21-30	0.16 (0.39)	0.13 (0.4)	0.00 (0.0)
31-40	2.33 (0.56)	2.10 (0.56)	0.71 (0.75)
41-50	2.81 (0.49)	2.89 (0.17)	2.01 (0.83)
51-60	3.23 (0.46)	3.03 (0.49)	2.76 (0.52)
>60	3.42 (0.55)	3.76 (0.44)	3.49 (0.54)

were analyzed by means of statistical software in Microsoft excel version 2007.

3. Results

A total of 193 cases of both genders were studied. Males were predominant to females with a male to female ratio of 2.21:1. Age groups in the study ranged from 20 - 94 years. Most cases were >60 years (29.5%) followed by 21-30 years (23.8%), 31-40 years (19.7%), while the least cases were 51-60 years (11.9%) (Table-1).

The sagittal suture showed a mean obliteration from 0.02 in 21-30 year olds to 3.21 in those >60 years. Coronal sutures showed mean obliteration from 0.02 in 21-30 year olds to 3.08 at >60 years, and lambdoid sutures showed mean obliteration from 0.0 in 21-30 year olds to 2.80 at >60 years. Overall, the ectocranial sagittal suture fused first followed by coronal and the lambdoid sutures (Ta-

ble-2).

Sagittal and Coronal sutures starts to obliterate from 21 to 30 years, while lambdoid sutures start to obliterate after 31 to 40 years. Sagittal and Coronal sutures show near complete obliteration at 51 to 60 years (mean > 3). Almost Complete obliteration was seen >60 for sagittal, coronal, and (mean \geq 3.5). The endocranial obliteration mean score of the sagittal suture was from 0.16 at 21-30 years to 3.42 >60 years. The coronal sutures obliteration mean was from 0.13 at 21-30 years to 3.76 >60 years, and the lambdoid suture obliteration mean score was from 0.71 at 30-39 years to 3.49 >60 years. Overall endocranial sagittal and coronal sutures fuse first followed by lambdoid sutures (Table-3).

On evaluation using the Acsadi and Nemeskeri's Method, age was ascertained by computing the mean value that is, total score based on all sutural parts divided by 16. The mean values show that



Table 4 - Determination of age by sutural closure in ectocranial suture (As per Acsadi and Nemeskeri Method).

Mean Closure Stage	n	Age Mean \pm SD (Years)	Range of Age (Years)	
<0.4	41	23.63 \pm 2.13	21 – 28	Young adult
0.4 – 1.5	26	31.03 \pm 3.43	25 – 40	Young adult
1.5 – 2.5	30	40.56 \pm 6.5	32 – 60	Young adult – middle adult
2.5 – 2.9	26	48.84 \pm 8.23	38 – 70	Middle adult – old adult
3.0 – 3.9	43	59.02 \pm 8.37	40 – 72	Middle adult – old adult
4.0	27	75.29 \pm 7.22	60 – 94	Old adult

there is wide age range for each stage. A score up to 1.5 indicates the age to be that of a young adult (<40 years) while scoring of >1.5 but <3.9 indicates the age to be that of a middle aged adult (>40 and <60 years). A score of 4.0 indicates that the person is an older adult (> 60 years). However, it is important to note that the mean age (in years) increased with increasing mean scoring of the closure of sutures. The mean score for ectocranial suture closure was <0.4 and 0.4-1.5 found belonging to young adults with a mean age of 23.6 years (\pm 2.13) and 31.03 years(\pm 3.43) with an age range of 21-28 years and 25-40 years respectively. However, the mean ectocranial suture closure score of 1.5-2.5 belonged to the young adult-middle-aged adult group with a mean age of 40.56 (\pm 6.5) years with an age range of 32-60 years. Similarly, the mean score for ectocranial suture was 2.5-2.9 and 3.0-3.9 belonged to middle-aged adult and older adult age groups with a mean age of 48.84 (\pm 8.23) years and 59.02 (\pm 8.37) and age range of 38-70 years and 40-72 years respectively. Finally, the mean ectocranial suture closure score of >4.0 belonged to the older adult group with mean age of 75.2 (\pm 7.22) years with age range of 60-94 years (Table-4).

Table-5 showed that there is wide age range for each stage. A score <0.4 indicates a young adult (<40 years) while scoring of >0.4 but <3.9 indicates

a middle aged adult (>40 and <60 years). A score of 4.0 indicates that the person is an older adult (> 60 years). A mean score for endocranial suture closure of <0.4 belonged to young adults the a mean age of 24.56 years (\pm 2.85) with an age range of 21-30 years. However, a mean ectocranial suture closure score of 0.4-1.5 and 1.5-2.5 belonged to the young-middle-aged adult group and the young adult – older adult group respectively with mean age of 36.87 years (\pm 5.87) with an age range of 25-53 years and 38-70 years, respectively. Similarly, the mean score for the ectocranial suture of 2.5-2.9 and 3.0-3.9 belonged to the middle aged adult - older adult age group with a mean age of 63.6 years (\pm 5.69) and 64.53 (\pm 6.84) and an age range of 54-72 years and 50-78 years, respectively. Finally, the mean ectocranial suture closure score of >4.0 belonged to the older adult group with mean age of 77.61 years (\pm 5.5) with age range of 70-94 years.

4. Discussion

External examination of the dead allows only a rough assessment of age. Age, however, is a key feature in identification and its evaluation is of substantial significance. The skeletal bones and teeth are major sources of information in the direction of the age estimation. Estimation of age becomes increasingly more complex as age progresses, main-



Table 5 - Determination of age by sutural closure in endocranial suture (As per Acsadi and Nemeskeri Method).

Mean Closure Stage	n	Age Mean \pm SD (Years)	Range of Age (Years)	
<0.4	51	24.56 \pm 2.85	21 – 30	Young adult
0.4 – 1.5	41	36.87 \pm 5.87	25 – 53	Young adult – middle adult
1.5 – 2.5	55	51.54 \pm 9.11	38 – 70	Young adult – old adult
2.5 – 2.9	10	63.6 \pm 5.69	54 – 72	Middle adult – old adult
3.0 – 3.9	15	64.53 \pm 6.84	50 – 78	Middle adult – old adult
4.0	21	77.61 \pm 5.50	70 – 94	Old adult

ly after the age of 20-25 years. Scientific evaluation of the age of a person from human remains is a complex predicament for medical jurist in civil and criminal matters.

Estimating the age of individuals has been a focus from conception to death. As the individual starts to age systematic changes occur in various part of human body. These changes, if scientifically, followed can give a valuable clue regarding the age of an individual with a fair degree of reliability. The study of human development as per aging is usually based on biological changes that occur due to the process of growth, development, and maturity. However, such changes are having physiological variations in different individuals. As with other bones, the human skull can give many reliable indicators that can be useful for determining age. Hence, such studies on different aspects of the skull have been researched for a while [1-10]. In the present study, macroscopic findings were studied for closure of sagittal, coronal, and lambdoid sutures to determine age.

In the present study, there was male predominance over female. Most of the cases belonged to the youngest and oldest age groups. Though, an even distribution of cases was attempted in all age groups in both sexes, unfortunately only 2 cases were noted in the female age group 51-60 years. In the present study the distribution of cases in a sim-

ilar pattern were seen as found in the studies done by Sahani et al. [12], Alves et al. [14], Gaur et al. [15], Jangietrew [16], and Perizonius [17]. Although a higher number of cases will give more constructive results, the present study has a fair number of cases to infer a conclusion.

In our study, we observed that in ectocranial suture closure, Sagittal suture showed mean obliteration score of 0.02 in persons 21-30 while it was 3.21 in the >60 age group. Coronal sutures showed a mean obliteration of 0.02 at 21-30 years to 3.08 at >60 years, and lambdoid suture showing a mean obliteration of 0.0 at 21-30 years to 2.80 at >60 years. Overall ectocranial sagittal sutures fuse first followed by coronal and lambdoid sutures. Sahana [18], Fredric [19] and Todd and Lyon [22-25] also observed similar findings in their studies. The ectocranial suture closure showed a more affirmative pattern of closure with increasing age. The scoring scale in sutures was much closer in sagittal and coronal sutures than in lambdoid sutures. The ectocranial lambdoid suture was found to be open in much older ages than the sagittal and coronal sutures.

Similarly, in endocranial suture closure, sagittal suture showed a mean obliteration score of 0.16 at 21-30 years while it was 3.42 in the >60 years age group. Coronal sutures showed mean obliteration of 0.13 at 21-30 years to 3.76 at >60 years, and



lambdoid sutures showed a mean obliteration of 0.0 at 21-30 years to 3.49 at >60 years. Overall endocranial sagittal suture fuse first followed by coronal and lambdoid sutures. It was interesting to observe that the suture closure scoring was more or less the same with sagittal and coronal sutures in the early age group. However, all three sutures showed similar suture closure scores at ages >60 years. So, for endocranial suture closure all three sutures if found on the higher side of the suture closure scale then, to a reasonable extent, we can opine regarding the older range of age.

Studies done by Sahana [18], Fredric [19], and Todd and Lyon [22-25] also observed similar results. On the other hand, the findings of present study do not conform to the findings of Gratiolet L.P [20], Ribbe F.C [21], and Parmar P [26], who found that obliteration of cranial sutures is seen first in lambdoid and then in the coronal suture. This may be due to the racial or ethnic variation that arises in different geographical regions. Also, the pattern of cranial suture fusion may change with time probably under influence of genetic factors and environmental factors such as dietary habits, daily water intake, and climatic condition.

Sahni D et al., [12] studied the time of closure of sagittal, coronal, and lambdoid sutures at autopsy in 538 male and 127 female adults belonging to the Chandigarh zone of northwest India. They divided the sagittal into four parts and coronal and lambdoid sutures into three parts. To study whether the suture was open or closed. They concluded that suture closure was earlier in males than females. Endocranial sutures closes much earlier than ectocranial sutures.

Fredric et al., [18] examined 255 European and 119 non-European crania of known age. However, only 91 European and 13 non-European crania of both sexes were opened so that the internal sur-

face could be examined. In endocranial sutures, authors found that the lambdoid closed after the sagittal and coronal sutures. They concluded that it was not possible to determine the age of a skull by the condition of suture union closure with any accuracy greater than +/- one decade. More ever, they stated that suture closure occurred later in females.

Perizonius WRK [17] studied closing and non-closing sutures in 256 crania of known age and sex from Amsterdam. He analysed both ecto- and endocranial suture obliteration in late nineteen century samples (N=256 males and females over 20 years age). From the study it was clear that mean closure increases \approx up to the fourth decade ectocranially and the fifth decade endocranially. After this decade, the mean increase is highly variable. No one suture was found to be a better indicator of age than any other and all are highly varied after about 50 years of age. Jangjetriew B [16] studied cranial suture closure and age estimation in the Thai population. A total of 166 adult Thai crania with known age, 30 females and 136 male, were studied. The age group ranged from 15 to 83 years. The degree of suture closure was recorded for endocranial and ectocranial sides by a composite scoring system. They noticed that suture closure starts from a mean age of 25 years. The authors found that endocranial sagittal sutures begin to close at the age 21 to 45 years in males and 26 to 47 years in females, with complete closure at 21 to 83 years in males and 26 to 74 years in females. The ectocranial sagittal sutures began at 17 to 45 years and 21 to 47 years in females, with complete closure at 17 to 83 years in males and 28 to 72 years in females. He found that endocranial coronal sutures begin to close at 19 to 45 years in males and 21 to 31 years in females, with complete closure at 20 to 83 in males and 26 to 74 years in females. The ectocranial coronal suture began to fuse at age 22 to 54 years in males and 25



to 59 years in females, complete closure was found at age 30 to 83 years in males and 28 to 72 years in females. They observed that ectocranial lambdoid suture began to close at age 17 to 62 years in males and 17 to 74 years in females, complete closure at age 17 to 83 years males and 28 to 72 years in females. The sum of endocranial suture scores (composite score) are statistically proven to be most related to age without statistical difference between the two ages. The association between age and the interval of composite scores was shown and suggested to be the predicating age.

Sahana [18] stated that with advancing age obliteration of sutures occurred mainly in vault. At first, endocranial suture closure occurs followed by ectocranial. The sagittal suture closure occurs at the age of 35, followed by coronal suture at the ages of 38 to 41 years while lambdoid suture closure occurs at the age of 47 to 50 years. Such types of obliterations of suture were subjected to a great deal of individual variation, particularly after the age of 25 when accurate estimation of age from the skull is indeed very difficult.

Fredric et al. [19] examined 255 European and 119 non-European crania of known age. However, only 91 European and 13 non-European crania of both sexes were opened so that the internal surface could be examined. In endocranial sutures, he found that the lambdoid closed after the sagittal and coronal sutures. He concluded that it was not possible to determine the age of a skull by the condition of suture union closure with any accuracy greater than +/- one decade. He stated that suture closure occurred later in females. Gratiolet et al. [20] proposed a sequence for suture closure and stated that union occurred earlier in Negroes. They made distinction in order of cranial closure between higher and lower races of mankind with Negroid races belonging to lower group. They observed that ectocra-

nial suture closure progressed sequentially, sagittal, lambdoid then coronal. Ribbé et al. [21] studied 50 skulls out of which 40 were of white and 10 were non-white. He found that the earliest occurrence of cranial suture union was at 21 years and the latest at 55 years. He concluded that closure commenced between the ages of 40 and 45, with standard deviation of 15 to 20 years. He stated that ectocranially, sagittal, and lambdoid sutures closed before the coronal suture

Dwight et al., [26] proposed that before the age of 30, all the cranial sutures were open while he also observed that suture closure began endocranially and occurred later in females than in males. Parsons and Box [30] studied closure of endocranial sutures and found that these sutures rarely close before 30 years. The coronal and sagittal sutures showed a fair amount of endocranial suture closure above 30 years. All endocranial sutures were usually obliterated over 50 years and always after 60 years.

Todd et al. and Lyon et al. [22-25] studied ectocranial and endocranial suture closure on 307 white and 120 black American males. They excluded 40 white skulls and 41 black skulls, terming them as 'anomalous', because of irregularities in closure. They followed Fredric in used of a rating scale of 0 to 4 for white male skulls deriving a closure formula for given skulls. They divided the sagittal, coronal sutures into 4 parts and lambdoid into 3 parts for calculating the closure formula. They found no onset-timing differences between endocranial and ectocranial sutures. They also observed that endocranial suture is a more reliable age indicator than ectocranial sutures because the later frequently showed lapsed unions. They also observed no race differences for suture closure. No difference in timing of suture closure was seen between right and left sides of the skull. They studied endocrani-



al suture closure. Its progress and age relationship part. A sample of male skulls (347) was selected for study consisting of adult white males. He found that sagittal suture closure started at 22 years and completed at 35 years, while coronal suture closure started at the age of 26 and completed at the age of 42, lambdoid suture closure started at the age of 26 and completed at the age of 47. They found that there were no onset differences between endocranial and ectocranial suture closure. They said that endocranial suture was a more reliable age indicator since they later frequently showed lapsed union. They found no race differences and no difference between right and left sides of the skull.

Mckern and Stewart [31] studied the skeletal age changes in young American males, analyzed from the standpoint of identification. Only ectocranial suture closure was studied. They observed extreme variability of vault suture closure. They observed that the vault suture closure tends to begin in the first and fourth parts of the sagittal suture, the first part of lambdoid and the first and fourth part of coronal suture; the final stage of closure tends to be seen in the first and second part of the sagittal, first or second part of the lambdoid, and the first of the coronal suture. Generally, the sagittal suture unites quite evenly, front to back, the coronal medially to laterally, and lambdoid medially to laterally, though not so markedly. They concluded that the progress of suture closure has only a very general relationship with age.

Tiengpitak [32] studied 110 known age Thai and Chinese crania, which revealed that closure of the endocranial sagittal suture began between the ages of 23-37 years and was completed between 31-71 years. He also stated that the endocranial surface began to fuse before the ectocranial and the former was more related to age. He did not find any differences between sexes. Kij-ngarm [29] concluded

that closure of the ectocranial sagittal suture began between 30-40 years and was completed between 50-60 years. The ectocranial coronal suture began to obliterate between 30-40 years and was completed at age 60 years while the ectocranial lambdoid suture began to close between 30-42 years and was completed between 50-60 years. There was no significant difference between sexes.

Singh et al. [33] studied total 100 cases (male & female) between the ages of 40 and 70 years. Ectocranial closures of skull suture by CT scan were studied by taking age intervals of five years and twenty cases for each age group. They observed that in ages between 45 to 50 years, both lambdoid and coronal sutures fuse. Gaur et al. [15] carried out a radiological study in 104 individuals to determine age in living by closure of cranial sutures. The 20 cases were studied in 20–25 years and 26-30 years age groups and found that there was no evidence of fusion in any of the sutures. Twenty-four cases were studied in the age group 31 – 35 years where sagittal sutures showed complete fusion in 14 cases (58.33%), partial fusion in 10 cases (41.67%) while in coronal sutures, 7 showed complete fusion (19.17%) and 17 showed partial fusion (70.83%), and finally in lambdoid sutures, there was no evidence of fusion in this age group. In the age group of 36 – 40 years 19 cases were studied and the sagittal sutures showed complete fusion in 12 cases (63.13%) and partial fusion in 7 cases (36.84%); coronoid sutures showed complete fusion in 11 cases (57.89%) and partial fusion in 8 cases (42.11%) and lambdoid sutures 11 cases showed partial fusion (57.89%). The last age group comprised 21 cases belonging to the 41 – 45 years and above age group. The sagittal suture showed complete fusion in 20 case (95.24%) partial fusion in one case (4.76%). The coronoid suture showed complete fusion in 16 cases (76.19%), 5 cases



(21.81%) showed partial fusion, and lambdoid sutures showed complete fusion in 9 cases (42.86%) and partial fusion in 11 cases (52.38%).

Verma et al. [34] studied age assessment from radiological cranial suture closure in the fourth to seventh decade in total 100 individuals comprising 67 male and 33 female. In males the lower half of coronal suture fused at the age of 42 to 44 years followed by to the upper half at the age of 52 years. In female subjects, the coronal suture fuses at the age of 42 to 44 years which is followed by upper half at the age of 56 years. Parmar et al., [26] studied radiological aspects of the skull for closure of suture ectocranially for determination of age in 220 cases with known age. The age group ranged from 15-70 years. In their study, they considered only completed union of the sagittal, coronal, lambdoid, parieto-mastoid, parieto-temporal (squamous), and baso-occiput with baso-sphenoid sutures instead of taking into account other scoring systems of suture closure and compared with standard data mentioned in different text books and previous studies. They observed suture closure for sagittal, lambdoid, and coronal sutures at ages of 50-60 years, 45-55 years, and 50-60 years, respectively. Suture closure occurred from their endo-cranial to ecto-cranial aspects. Closure of skull sutures occurred earlier in male than in females. The most successful estimate was done from sagittal suture, next the lambdoid suture and then the coronal suture.

The Acsadi Nemeskeri method when applied to the present study data, was found to be very informative and gave a good correlation with advancing age in both ectocranial and endocranial suture closures. It was also very important to note that the endocranial mean suture closure score was found much earlier in various age groups than the ectocranial mean suture closure. A fair amount of accuracy in determining the age range either as young adult,

middle-aged adult or older adult was found. In our present study, we found that a score up to 1.5 indicates the age to be that of a young adult (<40 years) while scoring of >1.5 but <3.9 indicates the age to be that of a middle aged adult (>40 and <60 years). A score of 4.0 indicates that the person is an older adult (> 60 years).

The findings in the present study compare with the study of Acsadi and Nemeskeri [13] who found that scores up-to 1.5 indicate the age to be that of a young adult (<40 years) while scoring of >1.5 but <3.9 indicates the age to be that of a middle aged adult (>30 years > 75 years). A score of 4.0 indicates that the person is an older adult (50 to 80 years).

Galera et al., [35] studied 963 skeletons (408 White and 555 Black) from the Terry Collection to examine macroscopic cranial methods for age estimation. By randomly selecting the individuals they used methods of Acsadi and Nemeskeri, Masset, Baker and Meindl and Lovejoy for every skull. They used the Masset endocranial formulae for individuals of 20 years or younger, then individuals between 21 and 25 years used Acsadi and Nemeskeri methods, individuals between 26 and 50 years used Meindl and Lovejoy and Lovejoy methods, individuals between 51 and 60 years used the Masset ectocranial formula, individuals between 61 to 65 years used Masset ectocranial formula, individuals from 66 years or older used Acsadi Nemeskeri table. They found that none of the techniques were highly accurate to determine the age at death and accuracy varied within different age categories. They concluded that use of all methods collectively may increase the accuracy.

When applied in conjugation with other parameters of age determination such as the mean scoring system of Acsadi and Nemeskeri, it was found to be of much help in the light of the data studied in present study. Also, it is very important to note that



such application of methods needs to be validated in various other population groups rather than trying to make newer methods which may cause more complexity and confusion for routine estimation of age from skull bone suture obliteration.

5. Conclusion

Suture obliteration starts earlier on endocranial surfaces than on the ectocranial. Though there is some difference in suture obliteration between males and females, statistically nonsignificant. Endocranial Sagittal and Coronal suture start to obliterate at 21 to 30 years, near complete obliteration occurs by the age of 51 to 60 years and total obliteration occurs by >60 years. Lambdoid sutures start to obliterate at 31 to 40 years of age, near complete obliteration occurs >60 years.

Similarly, ectocranial suture obliteration starts in the 21-30 age group in sagittal and coronal sutures; while in lambdoid sutures, obliteration starts at the age of 31 to 40 years. Complete obliteration occurred above 60 years. However, it was important to note that the scoring of obliteration of sutures was higher for endocranial sutures in comparison to ectocranial sutures. In addition, the Acsadi and Nemeskeri method was found to be applicable on the Indian population and can give a reliable estimate of age from skull sutures.

Abbreviations

RC1: Right Coronal upper one-third; RC2: Right Coronal middle one-third; RC3: Right Coronal lower one-third; LC1: Left Coronal upper one-third; LC2: Left Coronal middle one-third; LC3: Left Coronal lower one-third; RL1: Right Lambdoid upper one-third; RL2: Right Lambdoid upper one-third; RL3: Right Lambdoid lower one-third; LL1: Left Lambdoid upper one-third; LL2: Left Lambdoid middle one-third; LL3: Left Lambdoid lower one-third; SD:

Standard Deviation.

Conflict of Interests

The authors declare that they have no conflicting interests.

Funding

No funding was received from anyone regarding this research.

Acknowledgement

None.

Authors' Contribution

The first author collected, and compiled the data. The second, third, and fourth authors analyzed the data. The first and corresponding author performed the actual dissection, and analysis of the skulls for suture closure and writing of the manuscript. All the authors read and approved the final manuscript.

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