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Review

Age Estimation through Analysis of Suture Synostosis in Forensic Practice: A Mini Review

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ABSTRACT: Age estimation is essential in forensic sciences. The examination of neurocranium suture closure, along with other methods, is used to estimate age in skeletal remains. The aim of this review was to identify in the literature methods used through neurocranial sutures for estimating age and analyze the recommendations by its researchers. One electronic research database, Pubmed, was investigated using the following restricted keywords: "age estimation", "suture" and "forensic". A search was conducted in March 2024 resulting in 12 articles being included in the final review. The articles were published between 2010 and 2024. Many studies recommend combining suture age estimation with other methods to improve accuracy in both dry skulls and CT scans, as cranial suture results alone are often insufficient. There is still no consensus on the endocranial versus ectocranial evaluation of sutures, with researchers calling for further studies. Population characteristics also affect results, highlighting the need for broader research. Despite its limitations, cranial suture closure remains valuable, with new technologies offering potential improvements.

Keywords: Age estimation; Suture; Synostosis; Forensic

1. Introduction

Sutures are joints present between the skull bones, which are composed of fibrous tissue. It allows cranial development due to its sites of bone growth along the margins of the skull bones [1].

Medico-legal examinations frequently involve the analysis of bodies in various stages of decomposition, including dismembered, mutilated, putrefied, or skeletal remains. The skull is often well preserved in forensic contexts and is sometimes the only recovered part of the skeleton [2–4].

Age estimation holds significant importance in forensic osteology [5]. Observation of neurocranium suture closure, in conjunction with other methods involving the pubic symphysis, sternum, auricular surface of the ilium, and dental wear, is used for age estimation in skeletal remains [6]. The initial studies reportedly began with Broca (1824–1880), who used ossification of the neurocranial sutures as a characteristic of age [5], and the main studies began in the 1920s. The skulls were evaluated, and a pattern of suture closure related to the age of the individuals was noticed, and this was proposed as a way to estimate age [7–10]. Despite being studied for many years, there is still some doubt about its reliability and there are populations in which age estimation methods using cranial sutures were uncommon [11].

In recent years, technological advancements have provided forensic anthropologists with new tools to improve age estimation. The computed tomography (CT) scans, frequently performed on cadavers during autopsies to help determine the cause of death, have become valuable in this context. Utilizing CT scans to estimate age at death is particularly useful when law enforcement requires quick information, as age is a critical factor in preliminary screening methods. Numerous studies have explored CT scans as a fast, non-invasive method for estimating age at death from cranial

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sutures. While the definition and clarity of cranial sutures can vary depending on the slice increment and scan type, the efficiency and convenience of CT scans make them a promising tool for age estimation research [12].

Different techniques were developed in the most varied populations [13–15]. The objective of the study is to focus on the forensic context. Still, there are differences regarding archaeological and forensic cases that may vary in relation to the age estimation method. As the archaeological context takes place in locations that have not been modified for a long time in relation to forensics, the remains can be found with greater wear and tear [14]. Another factor contributing to this difference in material conservation is that corpses in forensic practice often contain more organic material than archaeological remains, and are subjected to current forensic techniques to prevent putrefaction.

There is no definitive method of age estimation from skull sutures and, due to anatomical differences between populations, some methods are specifically more reliable than others [16]. Furthermore, the vast majority of studies focus on adults. As a consequence, there is a scarcity of research about suture ossification in subadults.

The skull is frequently well preserved and sometimes can be the only reference for age estimation. This highlights the importance of developing and knowing methods for age estimation using cranial sutures [16–18]. Cranial sutures progressively obliterate in a predictable pattern as an individual ages, and the degree of this obliteration can assist medicolegal professionals in estimating an individual's age [19]. The aim of this narrative review was to identify methods used in the literature for estimating age through neurocranial sutures, primarily in adults, and to analyze the recommendations made by researchers.

2. Materials and Methods

A narrative review was described based on a manuscript collected from the electronic research database Pubmed and investigated using the following restricted keywords: "age estimation", "suture" and "forensic". The search was conducted in March 2024. After the search, the abstracts of the remaining articles were reviewed to ensure that they addressed the review context. The final review included findings from 12 articles, 11 original articles and 1 case report. The articles were published between 2010 and 2024.

The findings were extracted from the articles according to the context of the literature review approach: methods for estimating age through sutures and application in forensic practice.

3. Literature Review

3.1. Methods for Age Estimation through Sutures

Harth et al. [5] analyzed a total of 221 calvaria, the same sample as their previous study, with known sex and age obtained from autopsies conducted at the Department of Legal Medicine at the University Hospital of Gießen and Marburg in 2007/2008. The skullcaps were collected continuously during autopsies. The skullcaps were then scanned using the flat-panel CT eXplore Locus Ultra system (GE Healthcare, London, ON, Canada) and subsequently returned to the corpse unaltered. Cranial sutures were divided into 16 segments, as described by Oppenheim. Following the macroscopic assessment of suture obliteration, based on Broca's classification, each ossification of the parts was scored into one of seven stages. Since no significant difference was found between men and women regarding the relationship between age and ossification, both sexes were analyzed together.

Chiba et al. [16] used postmortem computed tomography (PMCT) from 125 subjects with known age and sex (64 men with a median age of 55 years and quartile deviation of 15.38 years and 61 women with a median age of 67 years and quartile deviation of 23.5 years) to evaluate the sagittal suture closure. The authors concluded that the evaluation of the sagittal suture closure from PMCT was positively correlated with age at death, which indicates that PMCT can be a useful tool to measure the suture closure and perform age estimation.

Boyd et al. [12] assessed the utility of CT scans for evaluating the degree of ectocranial suture closure. Five cranial points (left and right midcoronal positions, left and right midlambdoidal positions, and the lambda) were analyzed in 231 CT scans of an autopsy sample of individuals with ages between 19–89 years utilizing a three-point scoring system: open, partial, closed and closed. The results demonstrated an adequate correlation between the degree of suture closure and increasing age in each group. Individuals with lower total scores were predicted to be younger, while those with higher scores were expected to be older. The total scores were then compared with each subject's actual age, and a subsequent data analysis was conducted to evaluate the accuracy of the system.

Konigsberg [20] studied data on ectocranial suture closure from 1152 individuals from McKern & Stewart's (1957) Korean War dead study and Robert J. Terry Anatomical Collection [21] that was analyzed using a multivariate cumulative probit model, fitted through a Markov Chain Monte Carlo (MCMC) method. The study focused on five

suture sites: the mid-lambdoid suture, the sagittal/lambdoid suture at lambda, the anterior part of the sagittal suture, the coronal/sagittal suture at bregma, and the sphenofrontal suture.

Chandra et al. [22] evaluated the lambdoid suture through reverse panoramic radiograph (RPRg) to verify if there is a correlation between lambdoid suture closure and age. Eighty-five subjects participated in the study and were divided into 4 groups. The subjects were submitted to a modified technique of RPRg to make it possible to analyze the lambdoid suture. The authors reported that statistical analysis revealed a strong correlation between lambdoid suture closure and an individual's age.Because of the age at which suture closure begins (before age 25) and complete suture closure occurs (approximately age 65), it can be difficult to estimate the age of individuals from the lambdoid suture before age 25 and after age 65. The authors concluded that the technique used in this study is effective for estimating age, especially in mortals.

Ishikawa et al. [11] performed bone impedance of the sagittal suture of 100 skulls of individuals with known age (male: $n = 66$, female: $n = 34$, 6–89 years old) to compare the results with the conventional method for age estimation. The sample was divided into 4 groups. The bone impedance value was obtained between 2 points across the sagittal suture. In addition to the impedance, the conventional visual method of age estimation was performed. The results obtained showed that as age increased, the bone impedance value of the sagittal suture also increased. However, after the age of 64.5, the impedance value decreased, both in women and men. The authors suggest that the bone impedance method is more accurate for estimating the age of a skeleton than the conventional method of observing suture closure. The authors conclude by stating that because the bone impedance method does not require expensive equipment or special techniques, it may be a useful tool in forensic anthropology for estimating the age of an unidentified skull.

Fan et al. [18] evaluated computed tomography scans (CT) of 230 Chinese Han males with known age (23.33–76.93 years), aiming to verify whether images of cranial sutures can help in estimating age. The authors observed the sagittal, coronal and lambdoid sutures. The authors suggested that the degree of suture closure corresponds to the age of the individuals evaluated and that, associated with other methods, the assessment of suture closure helps to estimate the age of individuals with unknown age.

Lottering et al. [23] in their study aimed to quantify and statistically model the age-related decline in the fibrous connective tissue of the anterior fontanelle in modern Australian infants aged < 30 months (males: $n = 126$, females: $n = 109$), utilizing three-dimensional, semi-automated computer-assisted design protocols. The sample comprised de-identified retrospective cranial and cervical spine DICOM datasets from 235 multi-ancestral individuals. These datasets were obtained through multi-slice computed tomography (MSCT) scans. With the statistical studies of the research, it was possible to observe a relationship between the estimated age and the coronal diameter of the anterior fontanelle. Thus, this information can contribute to a possible correlation in forensic findings in subadults according to the diameter found at the location of the anterior fontanelle. For this, studies focused on the scientific findings on age estimation and the relationship between infant skulls found in forensic contexts are necessary.

Barszcz et al. [24] utilized 255 calvariae from Polish males, which were examined using postmortem imaging (PMCT) and medicolegal postmortem examinations. The ages of the evaluated decedents ranged from 10.3 to 92.6 years (mean age: 49.13 ± 18.19 years; median age: 51.8 years). The study evaluations were performed in two stages, one with preliminary volume rendering technique (VRT) images used to represent endocranial and exocranial views, and the sagittal suture obliteration was classified with 6 grades; and the other with multiplanar reconstruction (MPR) images, mapping the path of each sagittal suture in consecutive coronal cross-sections. The sutures were examined for signs of incomplete closure and the presence of any "notches" or indentations visible in coronal cross-sections of the calvaria at the suture level.

Akbar et al. [19] applied a three-stage scoring system to cranial suture obliteration in 3D CT images to construct regression models for accurate age estimation in an Indian population. The research included 263 patients (183 males and 80 females) aged 18 years and above admitted to the Department of Diagnostic and Interventional Radiology, AIIMS (All India Institute of Medical Sciences) Jodhpur, an Indian tertiary healthcare center. The males were aged between 18 and 83 years (mean + SD: 41.22 + 17.37 years), and the females were aged between 18 and 84 years (mean + SD: 47.46 + 16.16 years). The three cranial sutures (sagittal, coronal, and lambdoid) were analyzed using the Radiant Dicom software.

Chawla et al. [4] studied a total of 100 cases with more than 20 years of age brought for postmortem examination from February 2019 to February 2020. A thorough forensic autopsy was conducted, including a detailed examination and dissection of the cranium. After dissection, the coronal, sagittal, and lambdoid sutures were examined ectocranially. After opening the skull with an oscillating saw, the interior surface of the skull cap was inspected, focusing on the coronal and sagittal sutures. The lambdoid suture was studied in its original position within the skull, on the inner

surface. The extent of suture closure was assessed both externally and internally, following the method described by Acsádi and Nemeskéri [13].

3.2. Application in Forensic Practice

Kanchan et al. [25] reported a case of asymmetric closure of the squamous suture found during a medicolegal examination of an Indian skeletonized human body. The ectocranial sutures were evaluated for age estimation. During the evaluation of the sutures, it was possible to note that the left squamous suture was still open, suggesting a middle age. Still, the right squamous suture was totally closed, suggesting an older age. The authors reported that all other cranial sutures evaluated—the sagittal, coronal, and lambdoid sutures—appeared symmetrical. The evaluation of the sagittal, coronal and lambdoid sutures indicated an early adulthood individual. The authors stated that, by the time the article was published, more than five years had passed since the skeleton was examined, and the individual had still not been identified. In conclusion, the authors stated that asymmetrical closure of the squamous suture may be a factor of inaccuracy in age estimation, especially in cases where only half of the skull is available for evaluation. In this specific case, the other sutures were symmetrical and should therefore be considered for age estimation, excluding the one that was asymmetrical.

4. Conclusions

According to the present literature review, many studies recommend the concurrent use of suture age estimation along with other methods, both when applied to dry skulls and CT scans. This recommendation is due to enhance accuracy when estimating age, since the results with cranial sutures are still not satisfactory.

In the scientific community, there is still no consensus on the endocranial versus ectocranial evaluation of sutures or the applicability of the techniques, with researchers recommending further studies on this matter.

The sample population is also a crucial factor, as individual characteristics of the samples analyzed in scientific studies can affect the results of each proposed analysis when replicated in other populations. Moreover, most studies primarily focus on adults, lacking research on suture ossification in subadults. Therefore, there is a recommendation for most researchers to carry out further studies.

Author Contributions

Conceptualization: A.R.F., A.C.R.; Writing—Original Draft Preparation: F.S.d.J., A.C.R., B.C.F.-P., L.N.O.W.; Writing—Review & Editing: A.R.F., A.C.R., B.C.F.-P., L.N.O.W., F.B.P.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Alesbury HS, Ubelaker DH, Bernstein R. Utility of the frontonasal suture for estimating age at death in human skeletal remains. *J. Forensic Sci.* **2013**, *58*, 104–108.
2. Masset C. Age Estimation on the basis of cranial sutures. In *Age Markers in the Human Skeleton*; Iscan MY, Ed.; Charles C Thomas: Springfield, IL, USA, 1989; pp. 71–103.
3. Boldsen JL, Milner GR, Konigsberg LW, Wood JW. Transition analysis: A new method for estimating age from skeletons. In *Cambridge Studies in Biological and Evolutionary Anthropology*; Cambridge University Press: Cambridge, UK, 2002; pp. 73–106.

4. Chawla H, Shankar S, Tyagi A, Panchal J. Cranial Vault Suture Obliteration in Relation to Age: An Autopsy-Based Observational Study. *Cureus* **2023**, *15*, e39759.
5. Harth S, Obert M, Ramsthaler F, Reuss C, Traupe H, Verhoff MA. Ossification degrees of cranial sutures determined with flat-panel computed tomography: narrowing the age estimate with extrema. *J. Forensic Sci.* **2010**, *55*, 690–694.
6. Garvin HM, Passalacqua NV. Current practices by forensic anthropologists in adult skeletal age estimation. *J. Forensic Sci.* **2012**, *57*, 427–433.
7. Todd TW, Lyon D. Endocranial suture closure, its progress and age relationship: part I. Adult males of the white stock. *Am. J. Physical Anthropol.* **1924**, *7*, 325–384.
8. Todd TW, Lyon D. Cranial suture closure. Its progress and age relationship. Part II.—ectocranial closure in adult males of white stock. *Am. J. Phys. Anthropol.* **1925**, *8*, 23–45.
9. Todd TW, Lyon D. Cranial suture closure. Its progress and age relationship. Part III.—endocranial closure in adult males of Negro stock. *Am. J. Phys. Anthropol.* **1925**, *8*, 47–71.
10. Todd TW, Lyon D. Suture closure—Its progress and age relationship. Part IV.—ectocranial closure in adult males of Negro stock. *Am. J. Phys. Anthropol.* **1925**, *8*, 149–168.
11. Ishikawa N, Suganami H, Nishida A, Miyamori D, Kakiuchi Y, Yamada N, et al. Utilization of bone impedance for age estimation in postmortem cases. *J. Forensic Leg. Med.* **2015**, *36*, 102–107.
12. Boyd KL, Villa C, Lynnerup N. The use of CT scans in estimating age at death by examining the extent of ectocranial suture closure. *J. Forensic Sci.* **2015**, *60*, 363–369.
13. Acsádi G, Nemeskéri J. *History of Human Life Span and Mortality*; Akadémiai Kiadó: Budapest, Hungary, 1970.
14. Meindl RS, Lovejoy CO. Ectocranial suture closure: a revised method for the determination of skeletal age at death based on the lateral anterior sutures. *Am. J. Phys. Anthropol.* **1985**, *68*, 57–66.
15. Mann RW, Jantz RL, Bass WM, Willey PS. Maxillary suture obliteration: a visual method for estimating skeletal age. *J. Forensic Sci.* **1991**, *36*, 781–791.
16. Chiba F, Makino Y, Motomura A, Inokuchi G, Torimitsu S, Ishii N, et al. Age estimation by multidetector CT images of the sagittal suture. *Int. J. Legal Med.* **2013**, *127*, 1005–1011.
17. Parchake SB, Tumram NK, Kasote AP, Meshram MM. Estimation of age from macroscopic sagittal suture closure in an Indian population. *Sch. J. Appl. Med. Sci.* **2015**, *3*, 249–256.
18. Fan F, Tu M, Li R, Dai X, Zhang K, Chen H, et al. Age estimation by multidetector computed tomography of cranial sutures in Chinese male adults. *Am. J. Phys. Anthropol.* **2020**, *171*, 550–558.
19. Akbar NJM, Shekhawat RS, Kanchan T, Yadav T, Meshram VP, Shedge R, et al. Computed Tomographic Evaluation of Cranial Suture Obliteration for Age Estimation in an Indian Population. *Cureus* **2023**, *15*, e36160.
20. Konigsberg LW. Multivariate cumulative probit for age estimation using ordinal categorical data. *Ann. Hum. Biol.* **2015**, *42*, 368–378.
21. Hunt DR, Albanese J. History and demographic composition of the Robert J. Terry Anatomical Collection. *Am. J. Phys. Anthropol.* **2005**, *127*, 406–417.
22. Chandra S, Dwivedy S, Sah K, Sinha S. Application of modified reverse panoramic radiograph on lambdoid suture for age estimation. *Quant. Imaging Med. Surg.* **2015**, *5*, 519–523.
23. Lottering N, Alston CL, Barry MD, MacGregor DM, Gregory LS. Temporal mapping of the closure of the anterior fontanelle and contiguous sutures using computed tomography, in silico models of modern infants. *J. Anat.* **2020**, *237*, 379–390.
24. Barszcz M, Woźniak K. Complete sagittal suture closure evaluation based on post mortem computed tomography. *Leg. Med.* **2021**, *52*, 101907.
25. Kanchan T, Krishan K, Kumar GP. Squamous suture--a rare case of asymmetrical closure with review of literature. *Forensic Sci. Int.* **2013**, *231*, 410.e1–e3.