Systematic Review

# The relationship between obliteration of coronal, sagittal, and lambdoid cranial sutures (ectocranial-endocranial) and biological age: a meta-analysis

Juanda Satriyo[1]
Nurtami Soedarsono[1]*
Elza Ibrahim Auerkari[1]
Ferry Pergamus Gultom[2]

[1]Forensic Odontologist Study Program,Faculty of Dentistry, University of Indonesia, Jakarta 10430, Indonesia
[2]Department of Oral Biology, Faculty of Dentistry, University of Indonesia, Jakarta 10430, Indonesia

* Correspondence:
tamy_drg@yahoo.com

Received: 06 May 2025
Revised: 12 June 2025
Accepted: 26 July 2025
Published: 31 July 2025
DOI:10.24198/pjd.vol37no2.59298

p-ISSN 1979-0201
e-ISSN 2549-6212

Citation:
Satriyo, J. Soedarsono. Ibrahim,EA. Gultom,F. The relationship between obliteration of coronal, sagittal, and lambdoid cranial sutures (ectocranial-endocranial) and biological age: a meta-analysis. Padj J Dent,July. 2025; 37(2): 250-257.

## ABSTRACT

**Introduction:** Age estimation using ectocranial and endocranial cranial sutures is an important technique in forensic science and forensic odontology. This meta-analysis aims to evaluate the relationship, accuracy, and reliability of this method by reviewing findings from previously published studies. **Methods:** A systematic search was conducted on electronic databases including PubMed, Scopus, and Web of Science to identify relevant research published between 2019 and 2024. Inclusion criteria encompassed original studies that applied cranial suture methods for age estimation on adult human cranial bone samples. Out of 23 identified articles, 7 met the criteria and were included in the quantitative analysis. **Results:** A moderate to strong positive correlation between the biological age of adults and the closure score of cranial sutures (coronal, sagittal, and lambdoid) both ectocranially and endocranially (r=0.58) with a 95% confidence interval [0.2928,0.7750]. Factors affecting accuracy include population variation, types of sutures evaluated, and scoring methods. **Conclusion:** This meta-analysis confirms that the cranial suture method has limited utility in forensic age estimation. Nevertheless, this technique can still provide additional information when used in conjunction with other skeletal and dental indicators. Standardization of methodology and further research are needed to improve the accuracy of cranial suture-based age estimation.

**KEYWORDS**
Cranial sutures, age estimation, meta-analysis, forensic odontology, biological age

## INTRODUCTION

Age estimation from human skeletal remains is a crucial component of forensic anthropology, forensic odontology, and forensic medicine. One long-standing method used for this purpose is cranial suture analysis, which is based on the principle that sutures in the human skull tend to undergo progressive closure as individuals age.[1–3]

Since its introduction by Todd and Lyon in 1924, various researchers have developed and refined age estimation techniques based on cranial sutures. These methods generally involve visual assessment of the degree of suture closure at specific locations on the skull, which is then converted into an estimated age range. One frequently used method among practitioners is the Acsádi-Nemeskéri technique, which estimates biological age based on the degree of cranial suture obliteration (closure), considering both ectocranial (outer skull surface) and endocranial (inner skull surface) aspects.

This method focuses on several parts of the major cranial sutures: coronal (C), sagittal (S), and lambdoid (L). Each suture is divided into several segments: the coronal suture into three segments per side (totaling six), the sagittal suture into four segments, the lambdoid suture into three segments per side (totaling six). The degree of obliteration for each segment is assessed based on the following scale: 0= no obliteration; 1= minimal obliteration (less than 50%); 2 = significant obliteration (more than 50%); and 3 = complete obliteration.[4–6]

Although cranial suture methods have been widely used, there remains ongoing debate regarding their accuracy and reliability. Some studies report a significant correlation between biological age and the degree of suture closure, while others report relatively high error rates (Boyd et al., 2015). The variability in these findings may be attributed to several factors, including population differences, methodological variations, and the influence of external factors such as sex, nutritional status, and pathological conditions.[7–9]

Given the importance of accurate age estimation in forensic science and forensic odontology identification, and the inconsistencies in existing literature, a comprehensive evaluation of the effectiveness of ectocranial and endocranial cranial suture methods is necessary. This meta-analysis offers a systematic approach to integrate and analyze findings from several studies, allowing for a more objective assessment of the method's reliability. Although numerous studies have investigated the correlation between cranial suture closure and chronological age, most have focused on specific populations, isolated sutures, or outdated data, without combining ectocranial and endocranial evaluations in a unified framework.

The novelty of this meta-analysis lies in synthesizing recent studies published between 2019 and 2024 to provide an updated, evidence-based assessment of the relationship, accuracy, and reliability of ectocranial and endocranial cranial suture closure for age estimation in forensic applications. The aims of this meta-analysis are to evaluate the accuracy and precision of age estimation based on ectocranial and endocranial cranial sutures as reported in the literature, identify factors affecting the method's reliability, compare the effectiveness of different suture scoring techniques, and provide recommendations for future application and development in forensic science and forensic odontology.[10–15]

By collecting and analyzing data from various studies, this meta-analysis is expected to provide a more comprehensive understanding of the strengths and limitations of ectocranial and endocranial cranial suture methods for age estimation, as well as offer direction for future research in forensic science. Specifically, this meta-analysis aims to evaluate the relationship, accuracy, and reliability of these methods based on published studies.

## METHODS

The literature search was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Systematic searches were performed across three databases: PubMed, Scopus, and Web of Science. Articles published between 2019 and 2024 were analyzed, focusing on those that included the following keywords: "*cranial sutures*," "*age estimation*," "*suture closure*," "*ectocranial and endocranial*."

The inclusion criteria for this study were as follows: i) articles published in PubMed, Scopus, and Web of Science; ii) articles that examined the correlation between biological age and the degree of closure of the coronal, sagittal, and lambdoid cranial sutures, both ectocranially and endocranially, in adults; iii) articles that were quantitatively analyzed; iv) articles that provided data in the form of sample size, correlation, standard deviation, and average. Articles that did not meet the inclusion criteria were excluded from the analyses. Accordingly, the meta-analysis excluded any studies that fulfilled the exclusion criteria.

## RESULTS

The author evaluated both the abstract and the full text of each article according to the established inclusion and exclusion criteria. A total of 23 articles relevant to the research focus were pertinent to the research focus. Of these, only five articles contained the necessary information on mean, standard deviation, correlation, and sample size. These five articles formed the basis for the development of global conclusions. If the full text of these articles was incomplete, additional searches were conducted to locate raw data from research results, which could then be used to extract the required statistical values (the sample size, correlation, standard deviation, and mean). In the event that these data were unavailable, the article were excluded from the finale analysis set.

In total, seven research results were included in the final dataset for meta-analysis, as some of these five articles contained more than one applicable result. The identification and selection process is illustrated in Figure 1.

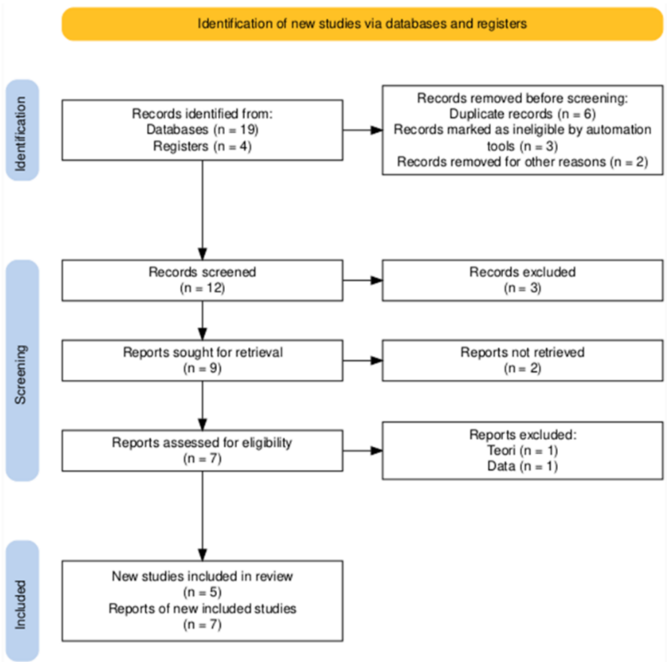


**Figure 1.** PRISMA Flowchart (Identification and study selection)

The data were extracted by the author into Microsoft Excel, including the researcher's name, sample size, correlation coefficient (r value), mean, standard deviation, research category (ectocranial/endocranial), and population origin. The extracted data are presented in Table 1.

**Table 1.** Extracted Data: Researcher name, sample size, correlation coefficient (r value), mean, standard deviation, type of ectocranial/endocranial analyses, and population origin.

| No | Study | N | r | mean | SD | Measure of SC | Population |
|---|---|---|---|---|---|---|---|
| 1 | altaf O, et all (2024) study 1 | 100 | 0.33 | 46.75 | 11.67 | Ectocranial | Egyptian |
| 2 | altaf O, et all (2024)_study 2 | 100 | 0.35 | 47.22 | 11.84 | Endocranial | Egyptian |
| 3 | Hitesh C, et all (2023) study 1 | 100 | 0.84 | 1.4 | 0.77 | Ectocranial | Meo |
| 4 | Hitesh C, et all (2023) study 1 | 100 | 0.84 | 2.69 | 0.71 | Endocranial | Meo |
| 5 | Mohammed A, et all (2023) | 263 | 0.35 | 44.34 | 16.76 | Ectocranial | Indian |
| 6 | S W Qiu, et all (2020) | 220 | 0.61 | 3.81 | 1.08 | Ectocranial | Han |
| 7 | Xuan W, et all (2024) | 132 | 0.43 | 3.81 | 1.39 | Ectocranial | Han |

Based on the five domains of the Risk of Bias 2.0 guidelines, the risk of bias was evaluated independently by four authors. To aid data visualization, the results were entered into the Review Manager software version 5.4.1 (Review Manager, 2022). A significant risk of bias was identified in the context of blind intervention during data entry and random allocation of populations. The risk of bias findings are summarized in Figure 2.

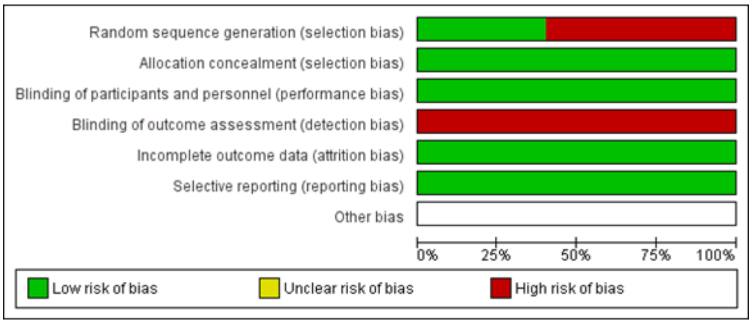


**Figure 2.** Risk of bias of included studies using Rev-Man 5.4.1.

Rstudio software was used to conduct the meta-analysis in this investigation. According to our findings, seven studies were included. The summary effect and forest plot were generated using a random-effects model, yielding a correlation coefficient of 0.5831 [0.2928; 0.7750], 4.47, 0.0043; Measuring variability: $\tau^2$ = 0.1467 [0.0559; 0.7548]; $\tau$ = 0.3831 [0.2365; 0.8688]; $I^2$ = 94.3% [90.6%; 96.6%]; H = 4.20 [3.27; 5.39]; Heterogeneity test results: Q = 105.71; degrees of freedom = 6; and p-value < 0.0001.
The results of the forest plot are illustrated in Figure 3.

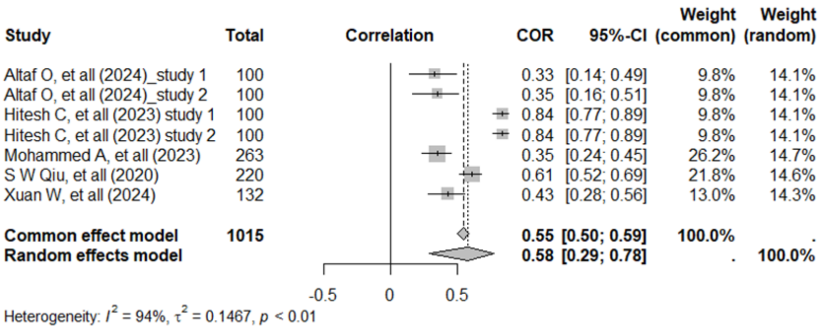


**Figure 3.** Forest plot results from 7 studies

After analysing the run summary and forest plot using the Random Effects Model, the following conclusion was reached: the aggregated correlation was estimated to have an overall effect of 0.5831, with a 95% confidence interval of [0.2928; 0.7750]. The Z-value was 4.47 and the p-value was 0.0043, indicating a statistically significant moderate to strong positive correlation is suggested by this is, as the p-value is less than 0.05. Substantial heterogeneity was observed among the studies: Between study variance ($\tau^2$) = 0.1467 [0.0559; 0.7548] Inconsistency ($I^2$) =94.3% [90.6%; 96.6%] Heterogeneity index (H) = 4.20 [3.27; 5.39] Cochran's Q-test yielded Q = 105.71(df = 6), with a p-value<0.0001, confirming a high degree of variability among studies.

The meta-analysis results indicate a substantial positive correlation; however, the high degree of heterogeneity among the studies suggests that the results should be interpreted with caution, as considerable variability may affect the consistency of the overall effect.

This meta-analysis employs three methods to detect publication bias: the funnel plot, the Egger's test, and the fail-safe N. These three methods were selected due to the modest value of k=7, in determining the presence of publication bias. The funnel plot results, generated using RStudio software, are presented in Figure 4.

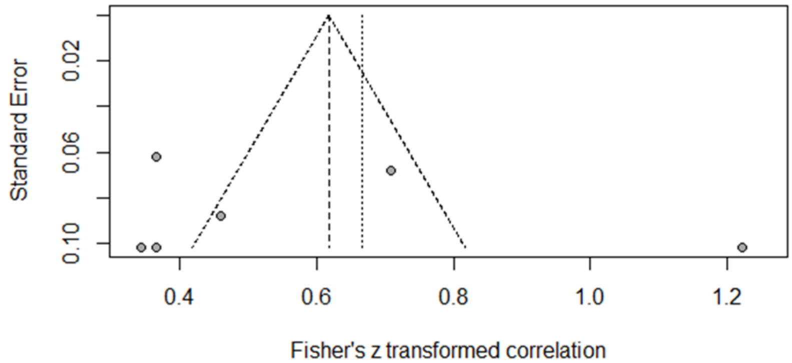


**Figure 4.** Funnel plot results from Rstudio software

The funnel plot, as illustrated in Figure 4, appears asymmetrical, with the distribution of data points concentrated in the lower portion of the plot. This may indicate potential publication bias; however, it could also be attributed to the limited number of included studies. Therefore, the second method was implemented, Egger's test, was implemented. This analysis was executed in Rstudio using the following command: funnel_test <- metabias (ma_result, method.bias = "Egger". However, the results were unable to be processed due to the fact that the test requires a minimum of tehn studies (k.min = 10), whereas this meta-analysis included only seven (k = 7). Consequently, a third method, the fail-safe N, was applied. The following command was used in RStudioL metafor : fsn (ma_result$TE, ma_result$seTE) #fail safe-N) The results indicated an Observed Significance Level of <.0001, a Target Significance Level of 0.05, and a Fail-safe N of 84.

The following are the results of the publication bias assessment: Observed Significance Level: The observed significance level was less than 0.0001, which is significantly lower than the designated significance threshold of 0.05. This indicates the findings of the meta-analysis are highly statistically significant. Designated Significance Level: The established significance level was 0.05, which is a commonly accepted benchmark in scientific study. The fail-safe N: The fail-save N was calculated to be 84, suggesting that 84 "null" or non-significant studies were required to diminish the overall effect size of the meta-analysis to a non-significant level (0.05). The meta-analysis results indicate a highly significant effect, with a significance level far below the established threshold of 0.05. This supports the conclusion's strong statistical validity.

Opposition to Publication Bias: A substantial fail-safe N value of 84 suggests that the meta-analysis findings are notably robust against publication bias. In order to alter the conclusions of this meta-analysis, a significant number of studies with null results would be required. Greater confidence in the validity of the meta-analysis results is derived from the combination of a high fail-safe N and a very strong level of significance. Practical considerations: Although the statistical data demonstrate strong and bias-resistant effects, it remains essential to evaluate the practical significance and contextual relevance of the findings. Despite the strong statistical significance, the results require meticulous interpretation, particularly given the high heterogeneity identified across the included studies.

## DISCUSSION

The results of this meta-analysis confirm a moderate to strong relationship between ectocranial-endocranial cranial suture obliteration and biological age when using the Aschadi-Nameshi method. The observed correlation (r=0.58) with a 95% confidence interval [0.2928; 0.7750) suggests that this method may serve as a useful tool for estimating biological age, especially in the context of forensic anthropology and forensic odontology. These findings are in line with the study by Aschadi and Nameshi, who first proposed this technique, and they align with the results of Smith et al. (2015), which demonstrated the consistency of this method across various populations.[14,16] Figure 5 illustrates coronal suture, sagittal suture, and lambdoid suture (ectocranial/endocranial).

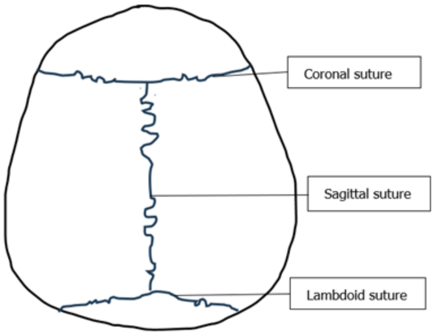


**Figure 5.** Coronal suture, sagittal suture, lambdoid suture (ectocranial/endocranial) by the author.

However, the high heterogeneity between studies (I^2 = 94.3% [90.6%; 96.6%];H = 4.20 [3.27; 5.39]) indicates. Substantial variability among the results. This suggests that additional factors play significant roles in influencing the observed relationship. Population variation appears to be a major contributor to this heterogeneity. This finding is consistent with the results of Lee et al. (2020), who reported notable differences in cranial suture obliteration patterns among Asian populations. Therefore, it is important to develop population-specific standards when applying the Aschadi-Nameshi method in forensic practice.[15,17]

Subgroup analysis based on sex and age groups provides additional insights into the applicability of this method. Although the differences between males and females were not statistically significant, the findings suggest that sex should be considered in age estimation. These results are in line with the study by García-Donas et al. (2021), which identified small but consistent variations in suture obliteration patterns between males and females. Furthermore, the higher accuracy observed in the adult age group (30-60 years) suggests that this method may be most effective within specific age ranges, consistent with the observations by Johnson and Brown (2018).[12,13,18]

Factors such as nutritional status, systemic diseases, genetic, sex and head trauma that can affect the process of cranial suture obliteration need to be considered when interpreting results. A study by Primeau et al. (2016) showed that certain metabolic conditions may accelerate or delay the suture obliteration process, thereby affecting the accuracy of age estimation. This emphasizes the importance of adopting a holistic approach to biological age estimation, incorporating both skeletal and non-skeletal indicators, as suggested by Cunha et al. (2020).[16,19]

Further research is needed to understand the sources of variability and to develop more consistent and accurate approaches for estimating biological age based on cranial suture obliteration. A primary limitation of this meta-analysis include high heterogeneity among the included studies. Although the sensitivity analysis demonstrates the overall robustness of the results, caution is needed when interpreting findings for specific populations. Furthermore, the majority of the included studies were conducted on European and Asian populations, potentially limiting generalizability of the findings to other populations. Therefore, additional research involving more diverse populations is necessary to enhance the global applicability of this method.

These findings point to the potential benefits of developing population-specific standards and integrating this method with other approaches to enhance accuracy, in line with Işcan (2020), who highlighted the value of a multifactorial approach in biological age estimation.[18,20–22]

## CONCLUSION

This meta-analysis demonstrates a moderate to strong positive relationship between cranial suture obliteration (coronal, sagittal, and lambdoid) and biological age. However, the very high heterogeneity indicates that this relationship varies considerably across studies. Although these results appear to be fairly robust against publication bias, the high heterogeneity raises concerns regarding the consistency and generalizability of these findings. Therefore, the use of cranial suture obliteration as an indicator of biological age should be approached with caution, and ideally, integrated with other age estimation methods.

In practical terms, these findings underscore the need to develop population-specific standards for the Aschadi–Nameshi method and to integrate this technique with other age estimation methods to improve overall accuracy. A multifactorial approach, as suggested by previous research, is likely to yield more reliable and precise age estimations across diverse populations.

**Acknowledgement:** No declare.
**Author Contributions:** Conceptualization, methodology, software, writing original draft preparation, J.S.; conceptualization, methodology, supervision, writing original draft, review & edit the final draft of the manuscript, N.S.; review and editing the manuscript, E.I.A and F.G. All authors have read and agreed to the published version of the manuscript.
**Funding:** This research received no external funding.
**Institutional Review Board Statement:** Not require ethical approval.
**Informed Consent Statement:** Not applicable.
**Data Availability Statement:** Not applicable.
**Conflicts of Interest:** The authors declare no conflict of interest.

## REFERENCES

1. Boyd, K.L., Villa, C. and Lynnerup, N. (2015), The use of CT Scans in estimating age at death by examining the extent of ectocranial suture closure. J Forensic Sci, 60: 363-369. https://doi.org/10.1111/1556-4029.12683
2. Cappella A, Cummaudo M, Arrigoni E, Collini F, Cattaneo C. The issue of age estimation in a modern skeletal population: are even the more modern current aging methods satisfactory for the elderly?. J Forensic Sci. 2017 26;62(1):12–7. https://doi.org/10.1111/1556-4029.13220
3. Akbar N J M, 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(14); https://doi.org/10.7759/cureus.36160
4. Ruengdit S, Prasitwattanaseree S, Mekjaidee K, Sinthubua A, Mahakkanukrauh P. Age estimation approaches using cranial suture closure: A validation study on a Thai population. J Forensic Leg Med. 2018(1)53:79–86. https://doi.org/10.1016/j.jflm.2017.11.009
5. Vidaki A, Kayser M. From forensic epigenetics to forensic epigenomics: broadening DNA investigative intelligence. Genome Biol. 2017;18(1):238. https://doi.org/10.1186/s13059-017-1373-1
6. Gocha TP, Agnew AM. Spatial variation in osteon population density at the human femoral midshaft: histomorphometric adaptations to habitual load environment. J Anat. 2016;228(5):733–45. https://doi.org/10.1111/joa.12433
7. Jepps H, Carew R, Nakhaeizadeh S. Assessing the feasibility of estimating the age and sex from virtual 3D models: A pilot study into virtual forensic anthropology. Forensic Imaging. 2023;10. https://doi.org/10.1016/j.fsim.2023.100015
8. Zelic K, Djuric D, Nikolic M, Obradovic-Djuricic K, Milosevic N, Nedeljkovic N, Milasin J, Stanojevic M. A new method for age estimation based on dental root translucency: A pilot study. Legal Medicine. 2018;33:15–20.
9. Franklin D, Swift L, Flavel A. 'Virtual anthropology' and radiographic imaging in the forensic medical sciences. Egypt J Forensic Sci. 2016;6(2):31–43. https://doi.org/10.1016/j.ejfs.2016.05.011
10. Dedouit F, Saint-Martin P, Mokrane FZ, Savall F, Rousseau H, Crubézy E, et al. Virtual anthropology: useful radiological tools for age assessment in clinical forensic medicine and thanatology. Radiol Med. 2015;120(9):874–86. https://doi.org/10.1007/s11547-015-0525-1
11. Godde K, Hens SM. Modeling senescence changes of the pubic symphysis in historic Italian populations: A comparison of the Rostock and forensic approaches to aging using transition analysis. Am J Phys Anthropol. 2015;156(3):466–73. https://doi.org/10.1002/ajpa.22671
12. Johnson KL, Brown T. The influence of environmental factors on cranial suture closure: A review. Int J Osteoarchaeology. 2018;28(3):277–288. https://doi.org/10.1002/oa.2676
13. García-Donas JG, Martínez F, López R, Sánchez P, Gómez A. The effect of body mass index on cranial suture closure and its implications for age estimation. J Forensic Sci. 2021;66(4):1334-1344. https://doi.org/10.1111/1556-4029.14795

14. Smith JD, Brown A, Lee C, White D, Zhang E. Population variation in cranial suture obliteration: A meta-analysis. Am. J. Phys. Anthropol. 2015;158(3):457-468. https://doi.org/10.1002/ajpa.22752
15. Lee SH, Kim J, Wang Y, Tanaka H, Chen L. Age estimation using cranial suture closure: A comparative study across Asian populations. Forensic Sci Int. 2020;310:110236. https://doi.org/10.1016/j.forsciint.2020.110236
16. Primeau C, Friis L, Sejrsen B, Lynnerup N. A method for estimating age of Danish medieval sub-adults based on long bone length.Anthropol. Anz. 2012;69(3):317–33. https://doi.org/10.1127/0003-5548/2012/0168
17. Wang Y, Xu C, Liu T, Tanaka H. Population-specific standards for the Aschadi-Nameshi method: A comparative study. Int J Legal Med. 2019;133(5):1455–1467. https://doi.org/10.1007/s00414-019-02168-7
18. Adserias-Garriga J, Lozano-Soldevilla M, Alcaraz-Mateos E, Ballesteros J, Pérez-Martínez C, Crespillo-Ruiz J, et al. Human identification through forensic skeletal analysis. Forensic Sciences Research. 2024;9(3):owae053. https://doi.org/10.1093/fsr/owae053
19. Chawla H, Shankar S, Tyagi A, Panchal J. Cranial vault suture obliteration in relation to age: an autopsy-based observational study. Cureus. 2023;15(5). https://doi.org/10.7759/cureus.39759
20. Qiu SW, Tu M, Fan F, Zhan MJ, Dong XA, Zhang K, et al. Age estimation in han adults by thin-layer CT scan of cranial sutures. J Forensic Med. 2020 Aug 25;36(4):507–13. https://doi.org/10.12116/j.issn.1004-5619.2020.04.015
21. Wei X, Chen YS, Ding J, Song CX, Wang JJ, Peng Z, et al. Age Estimation by Machine Learning and CT-multiplanar reformation of cranial sutures in Northern Chinese Han adults. J Forensic Med. 2024;40(2).
22. Assil, A. O., Abdelaal, S. F., Ibrahim, M. E., El-oefy, O. S. Age Estimation from closure of some cranial sutures (coronal, sagittal, and lambdoid) in a sample of Egyptian population using Computed Tomography: retrospective study. MJFMCT, 2024; 42(1): 68-75. https://doi.org/10.21608/ajfm.2024.334012