



Original Research Article

Assessment of Lambdoid Suture Closure for Age Estimation: A Morphological Autopsy Study.

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Abstract: Background: Age estimation is an important component of forensic identification, particularly in cases involving decomposed, mutilated, burned, or unidentified bodies. Cranial suture closure has been used as a morphological indicator of age, although its reliability varies among populations. This study evaluated the pattern of lambdoid suture closure and its utility for age estimation in an Indian population. **Methods:** This autopsy-based observational study included 100 medicolegal cases aged ≥ 20 years undergoing post-mortem examination at a tertiary care teaching hospital between December 2010 and September 2012. Cases with known age and suitable cranial integrity were included. The lambdoid suture was assessed at three segments—pars lambdica (L1), pars intermedia (L2), and pars asterica (L3)—on both ectocranial and endocranial surfaces. Suture closure was graded using the Acsadi-Nemeskeri scoring system. Age-wise and sex-wise distributions were assessed, and the relationship between ectocranial and endocranial closure was evaluated using Spearman's rank correlation coefficient. **Results:** Of the 100 cases, 68% were male and 32% were female. Endocranial fusion commenced earlier than ectocranial fusion. In males, endocranial fusion began at approximately 32 years and complete fusion occurred at approximately 66 years, whereas in females, corresponding ages were approximately 33 and 75 years. Ectocranial fusion began later, at approximately 53 years in males and 48 years in females. No significant correlation was observed between ectocranial and endocranial suture closure across the evaluated age groups. No consistent bilateral differences were identified. **Conclusion:** Lambdoid suture closure demonstrates an age-related pattern and may provide supportive information for forensic age estimation. However, its morphological variability and lack of significant correlation between ectocranial and endocranial closure limit its use as a standalone method.

Keywords: Age estimation; Acsadi- Nemeskeri Method, Endocranium; Ectocranium; Lambdoid suture; Suture closure.

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INTRODUCTION

Identification is an important component of forensic medicine, with age estimation having considerable medicolegal significance, particularly in decomposed,

burned, mutilated, or partially preserved bodies. In such cases, skeletal remains, especially the skull, can provide valuable information because bone is relatively resistant to decomposition and other destructive processes.¹ Age

estimation in adults is challenging because most developmental indicators are completed by adulthood. Consequently, morphological changes in the adult skeleton, including cranial suture closure, have been used as supplementary indicators of age. Cranial sutures progressively undergo morphological changes and obliteration with advancing age, although the timing and extent of closure vary among individuals and populations.²⁻³

The lambdoid suture is a major cranial vault suture formed by the articulation of the occipital and parietal bones. It can be divided into three segments—pars lambdica (L1), pars intermedia (L2), and pars asterica (L3)—allowing segment-wise assessment of suture closure.⁴⁻⁶

The Acsadi–Nemeskeri method provides a standardized morphological scale for grading cranial suture closure from open to completely obliterated.²⁻³ Assessment of both endocranial and ectocranial surfaces is useful because closure may differ in timing and extent between the two surfaces. Previous studies have demonstrated variability in lambdoid suture closure and its relationship with age. However, cranial suture closure has limitations for chronological age estimation due to individual, sex-, population-, and segment-related variations.⁷⁻⁹ The subjective nature of morphological scoring may further affect assessment, highlighting the need for population-specific studies.

Indian studies have also reported variation in cranial suture closure. Makhani et al.⁸ demonstrated differences between endocranial and ectocranial closure during autopsy, while Ullas Shetty reported a segmental pattern of lambdoid suture fusion.⁹ These findings support the need for population-specific evaluation. The

present study evaluated the temporal pattern of lambdoid suture closure in adult autopsy cases, including endocranial and ectocranial surfaces and all three lambdoid segments, using the Acsadi–Nemeskeri scoring system. Sex-wise differences and the relationship between endocranial and ectocranial closure were also assessed.

MATERIALS AND METHODS

Study Design and Study Population: This autopsy-based observational study was conducted on 100 deceased individuals who underwent medicolegal post-mortem examination at a tertiary-care teaching hospital in India between December 2010 and September 2012. Individuals aged ≥ 20 years with a documented chronological age were included. Age was established from available documentary evidence, including passports, birth certificates, official identity documents, and school records. Cases with a deformed, fractured, or diseased cranium; severely burned bodies; unidentified or unknown bodies; and cases in which the exact age could not be established were excluded.

Examination of Cranial Sutures: All autopsies were performed using standard post-mortem techniques. Following a mastoid-to-mastoid incision and reflection of the scalp, the calvarium was exposed and the three major cranial vault sutures—sagittal, coronal, and lambdoid—were examined. In fresh bodies, the calvarium was cleared of soft tissue from both surfaces using hydrogen peroxide, whereas in decomposed bodies, the soft tissue was removed manually. The lambdoid suture was examined separately on its endocranial and ectocranial surfaces. For segment-wise assessment, it was divided into three segments: pars lambdica (L1), pars intermedia (L2), and pars asterica (L3).^{2,3-5}

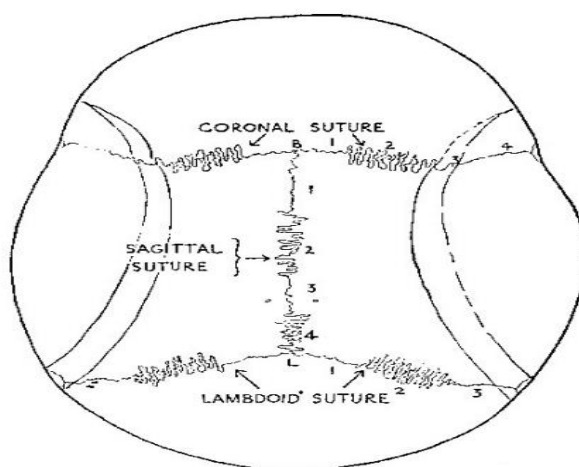


Figure 1: Skull sutures and their patterns in segments.

- 1= Pars lambdica (L1)
- 2= Pars intermedia(L2)
- 3= Pars asterica(L3)

Table 1: Acsadi - Nemeskeri Scale (2) Lambdoid suture and its segments: (2,4,5,6)

Score	Description
0	Open: There is still little space left between the edges of adjoining bones.
1	Incipient closure: Clearly visible as a continuous, often zigzagging line. Less than ½ of the suture length is obliterated.
2	Closure in process: The line is thinner, with fewer zigzags, and is interrupted by complete closure. Approximately ½ of the suture length is obliterated.
3	Advanced closure: Only pits indicate where the suture is located. More than ½ of the suture length is obliterated.
4	Closed: Even the location of the suture cannot be recognized.

Assessment of Lambdoid Suture Closure: The degree of lambdoid suture closure was assessed morphologically using the Acsadi–Nemeskeri scoring system. The same scoring system was applied to both ectocranial and endocranial surfaces. The stages of closure were graded from 0 to 4:

closure was assessed using Spearman’s rank correlation coefficient (ρ). The analysis was performed separately for the specified age groups and by sex. A p-value <0.05 was considered statistically significant. Data were entered and tabulated using Microsoft Excel and analysed using the Statistical Package for the Social Sciences (SPSS), version 17.

Statistical Analysis: The observations were tabulated and analysed according to age and sex. The relationship between ectocranial and endocranial lambdoid suture

RESULTS

There were 100 cases in total, with 68% of them being male and 32% being female.

Table 2: Score wise distribution of male cases for lambdoid suture over endocranium

Suture	Score	Side	Total Cases	Mean Age	SD	Min	Max
L1	0	Left	1	24.00	–	24	24
	0	Right	2	23.00	1.41	22	24
	1	Left	7	33.29	8.85	22	50
	1	Right	6	35.17	8.01	28	50
	2	Left	11	45.00	12.66	21	67
	2	Right	11	45.00	12.66	21	67
	3	Left	31	52.81	13.44	25	75
	3	Right	32	52.72	13.21	25	75
	4	Left	18	64.67	11.54	45	80
	4	Right	17	65.53	11.28	45	80
	0	Left	2	28.50	6.36	24	33
	0	Right	3	26.33	5.86	22	33
L2	1	Left	5	29.40	4.88	22	35
	1	Right	5	35.00	8.77	28	50
	2	Left	14	48.64	9.34	34	65
	2	Right	13	49.85	10.98	34	67
	3	Left	33	51.85	14.57	21	78
	3	Right	34	51.44	14.22	21	78
	4	Left	14	68.36	7.80	50	80
	4	Right	13	69.38	6.45	60	80
	0	Left	0	–	–	–	–
	0	Right	2	34.00	1.41	33	35
	1	Left	7	34.60	9.63	24	50
	1	Right	4	27.50	5.51	22	34
L3	2	Left	13	42.31	11.81	21	65
	2	Right	14	43.21	11.84	21	65
	3	Left	28	52.07	12.70	25	78
	3	Right	27	52.15	13.09	25	78
	4	Left	20	65.85	10.72	35	80
	4	Right	21	64.86	11.06	35	80

It is evident from table-2 that endocranially, the mean age at the beginning of fusion (score 1) was 33.29 years in L1, 29.40 years in L2, and 34.60 years in L3 on the left side, and 35.17 years in L1, 35.00 years in L2, and 27.50 years in L3 on the right side. The mean age at complete obliteration (score 4) was 64.67 years in L1, 68.36 years in L2, and 65.85 years in L3 on the left side, and 65.53 years in L1, 69.38 years in L2, and 64.86 years in L3 on the right side. Standard deviation for mean age of fusion of sutures from starting to obliteration was varying about from 5 to14. Range of age for score 1 was 22 to 50 years in L1,22 to 35 years in L2,24 to 50 years in L3 on left side and 28 to 50 years in L1,28 to 50 years in L2,22 to 34 years in L3 on right side.

Table 3: Score wise distribution of female cases for lambdoid suture over endocranium

Suture	Score	Left Total Cases	Left Mean Age	Left SD	Left Min Age	Left Max Age	Right Total Cases	Right Mean Age	Right SD	Right Min Age	Right Max Age
L1	0	4	26.25	4.65	20	31	4	26.25	4.65	21	31
	1	7	35.71	9.66	25	55	6	32.50	5.00	25	40
	2	9	37.78	6.92	27	45	6	37.00	10.39	27	55
	3	9	53.00	7.79	40	60	13	50.00	7.99	40	60
	4	3	75.00	5.00	70	80	3	75.00	5.00	70	80
L2	0	5	27.60	5.03	20	33	5	27.60	5.03	20	33
	1	3	36.67	16.07	25	55	2	27.50	3.54	25	30
	2	11	42.36	9.74	27	60	11	43.27	10.45	27	60
	3	10	45.80	11.44	30	60	11	45.73	10.85	30	60
	4	3	75.00	5.00	70	80	3	75.00	5.00	70	80
L3	0	3	26.33	6.51	20	33	3	26.33	6.51	20	33
	1	4	31.50	5.92	27	40	4	31.50	5.92	27	40
	2	7	36.29	10.18	25	55	9	36.00	7.28	25	45
	3	15	47.53	9.77	30	60	13	49.46	9.89	30	60
	4	3	75.00	5.00	70	80	3	75.00	5.00	70	80

It is evident from table-3 that endocranially, the mean age at the beginning of fusion (score 1) was 35.71 years in L1, 36.67 years in L2, and 31.50 years in L3 on the left side, and 32.50 years in L1, 27.50 years in L2, and 31.50 years in L3 on the right side. Complete obliteration (score 4) was observed at a mean age of 75 years in all three segments on both the left and right side. Standard deviation for mean age of fusion of sutures from starting to obliteration was varying about from 5 to10. Range of age for score 1 was 25 to 55 years in L1, 25 to 55 years in L2, 27 to 40 years in L3 on left side and 25 to 40 years in L1, 25 to 30 years in L2, 27 to 40 years in L3 on right side.

Table 4: Score wise distribution of male cases for lambdoid suture over ectocranium.

Suture	Score	Left Total Cases	Left Mean Age	Left SD	Left Min Age	Left Max Age	Right Total Cases	Right Mean Age	Right SD	Right Min Age	Right Max Age
L1	0	19	39.53	15.13	21	78	18	39.22	15.51	21	78
	1	26	53.77	10.64	32	75	23	51.87	8.11	32	65
	2	18	59.56	11.31	25	70	20	59.35	12.86	25	75
	3	4	76.75	3.95	72	80	6	73.67	5.89	65	80
	4	1	25.00	–	25	25	1	25.00	–	25	25
L2	0	17	36.41	8.37	22	50	20	40.05	14.11	22	78
	1	23	55.17	15.53	21	78	18	52.17	13.76	21	70
	2	19	57.00	9.61	35	80	20	58.30	10.53	35	80
	3	8	62.75	15.96	25	75	8	67.75	4.83	60	75
	4	1	80.00	–	80	80	2	52.50	38.89	25	80
L3	0	22	40.36	14.66	21	78	19	36.11	9.68	21	55
	1	17	51.94	12.15	25	70	21	54.52	13.16	25	78
	2	15	58.73	9.52	43	75	12	57.58	9.55	45	75
	3	12	62.17	13.70	25	80	14	62.57	12.64	25	80
	4	2	77.50	3.54	75	80	2	77.50	3.54	75	80

It is evident from table-4 that ectocranially, the mean age for beginning of fusion of suture (score-1) was 53.77 years in segment L1, 55.17 years in segment L2, 51.94 years in segment L3 on left lambdoid suture and 51.87 years in segment L1, 52.17 years in segment L2, 54.52 years in segment L3 on right lambdoid suture. Complete ectocranial obliteration was uncommon among male cases, with only a small number of observations recorded across the three segments. The

corresponding mean ages should be interpreted cautiously because of the small sample sizes. Standard deviation for mean age of fusion of sutures from starting to obliteration was varying about from 4 to15. Range of age for score 1 was 32 to 75 years in L1, 21 to 78 years in L2, 25 to 70 years in L3 on left side and 32 to 65 years in L1, 21 to 70 years in L2, 25 to 78 years in L3 on right side.

Table 5: Score wise distribution of female cases for lambdoid suture over ectocranium

Suture	Score	Left					Right				
		Total Cases	Mean Age	SD	Min Age	Max Age	Total Cases	Mean Age	SD	Min Age	Max Age
L1	0	19	39.53	15.13	21	78	18	39.22	15.51	21	78
	1	26	53.77	10.64	32	75	23	51.87	8.11	32	65
	2	18	59.56	11.31	25	70	20	59.35	12.86	25	75
	3	4	76.75	3.95	72	80	6	73.67	5.89	65	80
	4	1	25.00	–	25	25	1	25.00	–	25	25
L2	0	17	36.41	8.37	22	50	20	40.05	14.11	22	78
	1	23	55.17	15.53	21	78	18	52.17	13.76	21	70
	2	19	57.00	9.61	35	80	20	58.30	10.53	35	80
	3	8	62.75	15.96	25	75	8	67.75	4.83	60	75
	4	1	80.00	–	80	80	2	52.50	38.89	25	80
L3	0	22	40.36	14.66	21	78	19	36.11	9.68	21	55
	1	17	51.94	12.15	25	70	21	54.52	13.16	25	78
	2	15	58.73	9.52	43	75	12	57.58	9.55	45	75
	3	12	62.17	13.70	25	80	14	62.57	12.64	25	80
	4	2	77.50	3.54	75	80	2	77.50	3.54	75	80

It is evident from table-5 that ectocranially, the mean age for beginning of fusion of suture (score-1) was 50 years in segment L1, 50.55 years in segment L2, 43.36 years in segment L3 on left lambdoid suture and 49.33 years in segment L1, 50.23 years in segment L2, 45.92 years in segment L3 on right lambdoid suture. No female case showed complete ectocranial obliteration (score 4) in any segment on either side. Standard deviation for mean age of fusion of sutures from starting to obliteration was varying about from 5 to18. Range of age for score 1 was 30 to 75 years in L1, 30 to 75 years in L2, 30 to 75 years in L3 on left side and 30 to 75 years in L1, 30 to 75 years in L2, 30 to 75 years in L3 on right side.

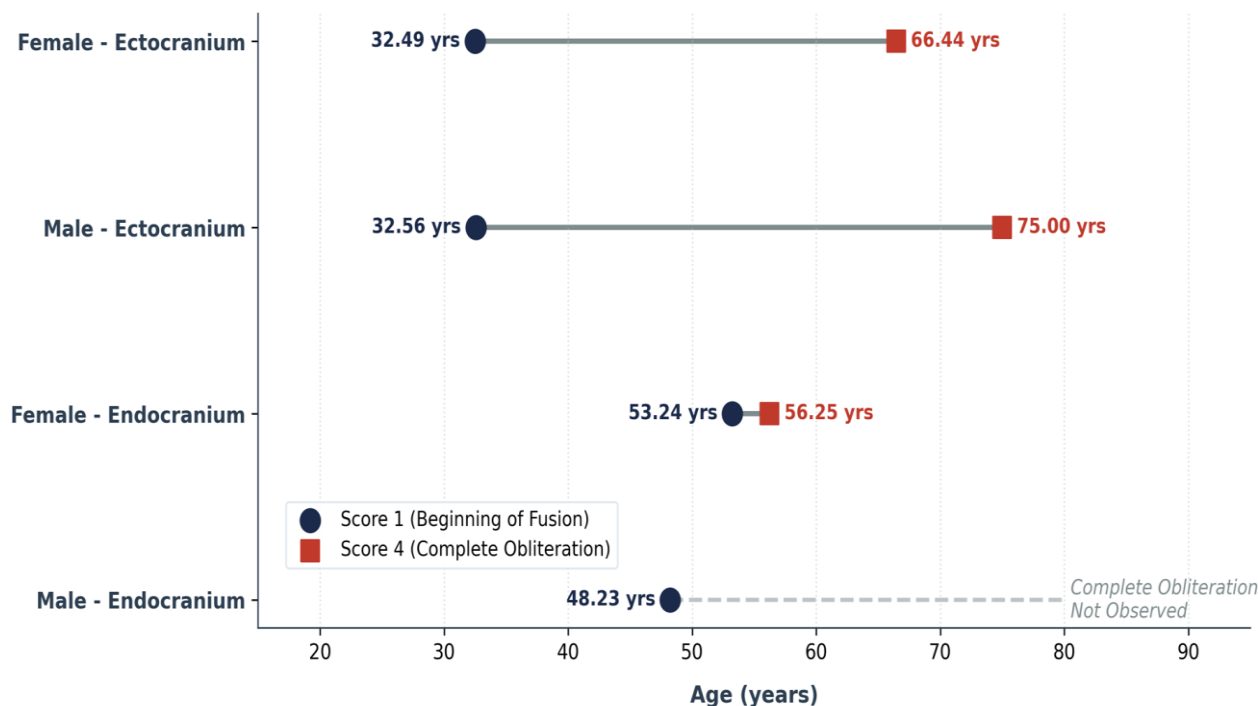


Figure 2: Age at initiation and complete obliteration of lambdoid suture closure by sex and cranial surface

Table 6: Age-group wise correlation of ratio of score of ecto/endo lambdoid suture fusion based on spearman's rank correlation coefficient (rho) in male and female

Age Group	Parameter (C/P)	Male ECTLL/ENDLL	Male ECTRL/ENDRL	Female ECTLL/ENDLL	Female ECTRL/ENDRL
20–29	C	0.123	0.123	-0.354	-0.354
	P	0.816	0.816	0.559	0.559
30–39	C	0.379	0.362	0.552	0.552
	P	0.280	0.304	0.119	0.119
40–49	C	-0.281	0.053	0.400	0.429
	P	0.464	0.892	0.252	0.215
50–59	C	0.278	0.469	0.258	-0.258
	P	0.264	0.053	0.742	0.742
60–69	C	0.102	0.110	XXX	XXX
	P	0.741	0.720	XXX	XXX
70–79	C	0.066	0.025	-1.000	-1.000
	P	0.856	0.942	0.010	0.010
80–>80	C	XXX	XXX	XXX	XXX
	P	XXX	XXX	XXX	XXX

C – Correlation Coefficient, P – ‘p value’

In both, male and female, status of fusion of ectocranial sutures were compared with endocranial suture in lambdoid sutures and on the basis of Spearman's correlation coefficient (rho), data were analysed. Correlation was considered significant at the level p value <0.05. No statistically significant correlation was observed among males in any age group. Among females, most age groups showed no significant correlation; however, a significant inverse correlation was observed in the 70–79-year age group for both the left and right sides ($\rho = -1.000$, $p = 0.010$). This finding should be interpreted cautiously because of the small number of observations in this age group.

Table 7: Age groups wise distribution of mean value of score for fusion of lambdoid sutures in each segment.

Age Group	Endocranial Lambdoid Suture – Left L1	L2	L3	Right L1	L2	L3	Ectocranial Lambdoid Suture – Left L1	L2	L3	Right L1	L2	L3
20–29	1.18	1.27	1.45	1.09	1.18	1.55	0.55	0.45	0.36	0.55	0.55	0.36
30–39	1.65	1.71	1.82	1.65	1.71	1.71	0.24	0.29	0.29	0.29	0.24	0.29
40–49	2.53	2.47	2.58	2.74	2.53	2.47	0.63	0.58	0.89	0.74	0.68	0.84
50–59	2.77	2.68	2.82	2.77	2.68	2.95	1.14	1.50	1.41	1.23	1.45	1.45
60–69	3.19	3.13	3.38	3.19	3.06	3.38	1.44	1.75	2.13	1.56	1.75	2.13
70–79	3.75	3.67	3.83	3.75	3.67	3.83	1.58	1.83	2.08	1.83	1.92	2.25
80–>80	4.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	3.67	3.00	3.00	3.67
TOTAL	2.72	2.70	2.84	2.74	2.69	2.84	1.22	1.34	1.55	1.31	1.37	1.57

The overall mean lambdoid suture score was 2.75 on the left side and 2.76 on the right side on the endocranial surface. On the ectocranial surface, the overall mean score was 1.37 on the left side and 1.42 on the right side. Overall, the mean lambdoid suture score was 2.75 on the endocranial surface and 1.39 on the ectocranial surface.

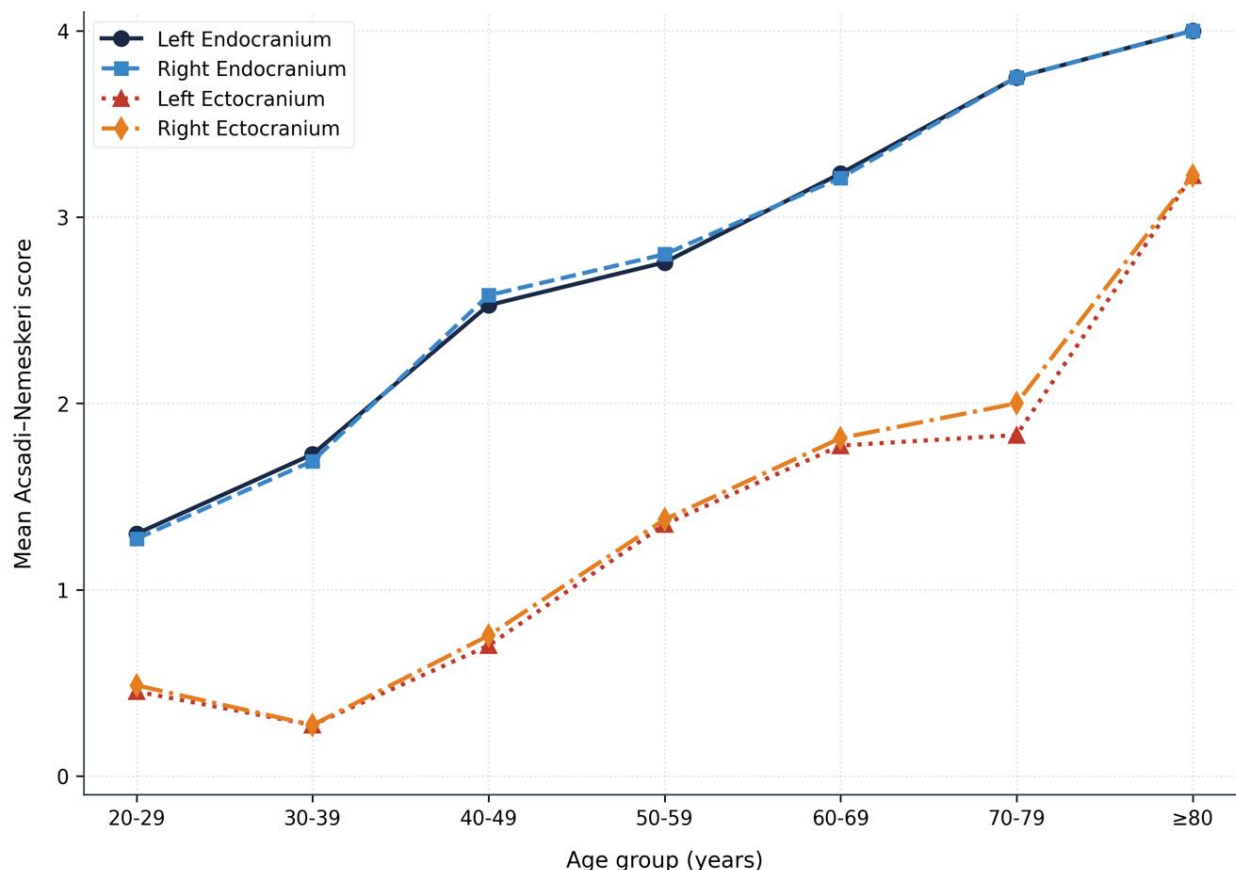


Figure 3: Age-related progression of lambdoid suture closure scores on endocranial and ectocranial surface

DISCUSSION

Table 8: Comparison of age for beginning of fusion of lambdoid sutures.

Lambdoid Suture	Region	Cobbs Study – Male White	Cobbs Study – Male Negro	Makhani et al. – Male	Makhani et al. – Female	Present Study – Male	Present Study – Female
L1	Endocranium	26	23	—	—	22	25
L2	Endocranium	—	—	28.46 ± 5.35	29.72 ± 6.96	—	—
L3	Endocranium	26	27	—	—	22	27
L1	Ectocranium	26	23	41.56 ± 7.57	39.58 ± 9.32	21	30
L2	Ectocranium	—	—	—	—	—	—
L3	Ectocranium	26	23	—	—	21	30

According to Cobbs' study⁷, the lambdoid suture over the endocranium began to fuse at the earliest age of 26 years in white males, whereas the lambdoid sutures in black males began to fuse at the earliest age of 23 years for the L1, L2 segments, and 27 years for the L3 segment. While in Makhani et al.⁸ the endocranial Lambdoid suture began to close at age ≥ 30 - < 40 years (mean $\pm$ SD = 33.59 $\pm$ 2.59) in males and ≥ 30 - < 40 years (mean $\pm$ SD = 34.10 $\pm$ 2.70) in females. The earliest age for fusion to start in the lambdoid suture in the current study's male subjects over the endocranium was 22 years.

In a Cobbs study⁷ over the ectocranium in white males, the earliest age for fusion in the lambdoid suture was 26 years, but in black males, the earliest age for fusion in the L1, L2, and L3 segments of the lambdoid suture was 23 years. While in Makhani et al.⁸ the ectocranial Lambdoid suture began to close at age ≥ 30 - < 60 years (mean $\pm$ SD = 41.56 $\pm$ 7.57) in males and ≥ 30 - < 60 years (mean $\pm$ SD = 39.58 $\pm$ 9.32) in females and in the current study, in males the earliest age for fusion to start over the ectocranium was 21 years old.

Table 9: Comparison of mean value in each segment of lambdoid suture

Region	Segment	Ullas et al. Study 9 – Left	Ullas et al. Study 9 – Right	Present Study – Left	Present Study – Right
Endocranium	L1	2.04	2.03	2.72	2.74
	L2	2.05	2.04	2.70	2.69
	L3	2.16	2.16	2.84	2.84
Ectocranium	L1	1.00	1.02	1.22	1.31
	L2	1.06	1.06	1.34	1.37
	L3	1.25	1.27	1.55	1.57

In the study by Ullas et al.,⁹ no bilateral difference in the fusion of the lambdoid suture was identified over both the endocranium and the ectocranium; the same observation was also made in the current study. In a research by Ullas et al.,⁹ over both the endocranium and the ectocranium in the lambdoid suture, the L3 segment fused first, then the L2 and L1 segments, and the same finding was made in the current study. In the study of Makhani et al.,⁸ in the ectocranial Lambdoid suture, complete obliteration was found at age ≥ 50 - < 80 years (mean $\pm$ SD = 62.1 ± 10.03) in males and ≥ 50 - < 80 years (mean $\pm$ SD = 64 ± 10.84) in females and in the endocranial Lambdoid suture, complete obliteration was found at age ≥ 40 - < 70 years (mean $\pm$ SD = 47.96 ± 7.31) in males and ≥ 40 - < 70 years (mean $\pm$ SD = 49.66 ± 8.70) in females. This was somewhat consistent with the current study, which found that complete fusion occurred in the endocranial Lambdoid suture at 66.44 (± 1.96) years in men and 75 years in women, and in the ectocranial Lambdoid suture at 56.25 (± 26.21) years in men and not in women.

CONCLUSION

Lambdoid suture closure showed a progressive age-related pattern, with endocranial closure occurring earlier and being more advanced than ectocranial closure. No consistent bilateral differences were observed. The comparison between ectocranial and endocranial closure showed no consistent significant correlation across age groups, limiting the reliability of ectocranial closure as an independent indicator of adult age. The Acsadi–Nemeskeri method provides a practical morphological approach for assessing lambdoid suture closure; however, individual variation, unequal age-group distribution, and the subjective nature of suture identification and scoring limit its accuracy. Therefore, lambdoid suture closure should be considered an adjunct rather than an independent method for adult age estimation. Larger population-specific studies with standardized assessment protocols are recommended.

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