Cranial Suture Closure and Age Determination in the Thai Population

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ABSTRACT

Objective: To determine whether the time of cranial suture closure in the Thai population has changed compared to findings in the past or not. Is there any difference between sexes? Also to determine the difference between the time of ectocranium and endocranium closure and their reliability for age determination in the Thai population.

Methods: The time of closure of the sagittal, coronal and lambdoid sutures was studied in 166 crania (known age Thai adults, 30 females and 136 males) for which the medicolegal autopsies were performed at the Department of Forensic Medicine, Faculty of Medicine Siriraj Hospital, Mahidol University, during the year 2006, age range between 15 to 83 years old. The sagittal suture was divided into four segments and those of each side of the coronal and lambdoid sutures into three segments. The degree of suture closure was recorded for endocranial and ectocranial sides by our scoring system. The sum of all endocranial suture scores, which were also defined as "Composite scores", were divided into 7 stages (designated as S0-S6). The graph showing the association between chronological age and endocranial composite scores was plotted. The correlation coefficient, chi-square tests, and independent t test were used for statistical analysis, P-value <0.05 was statistically significant.

Results: It was found that the Thai new generation's ectocranial suture closure starts and completes earlier than those in the past while endocranial sagittal suture closure starts and completes at a similar time as found in the past. Endocranial sutures start closing before ectocranial and endocranial closure is more related to age than another and no difference between sexes could be found. Using the closure of each suture separately to determine the age at death, somehow, may not be appropriate while using the sum of suture scores reduces variations. The sum of endocranial suture scores (composite scores) are statistically proven to be most related to age without significant statistical difference between the two sexes. The association between age and the interval of composite scores was shown and suggested to be the age predicting tool.

Conclusion: The time of cranial suture closure is stated as one of indicators of age at death but its progression varies greatly According to our study, using composite scores helps in diminishing this variation. The information on suture closure is useful when other criteria are not available or when being used in conjunction with other attributes.

Keywords: Age estimation; anthropology; cranial sutures; Thai population

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Generally, the examination of human remains by the forensic anthropologist focuses on three tasks.[1]

1. Identifying the victim or at least providing a biological profile (age, sex, stature, ancestry, anomalies, pathology, individual features).
2. Reconstructing the post mortem period based on the condition of the remains and the recovery context.
3. Providing data regarding the death event, including evidence of trauma occurring during the perimortem period.

As age determination is one of the very important aspects in forensic identification, therefore, various methods are used to estimate age at death, such as in the sub-adult group; long bone lengths, appearance of primary and secondary ossification centers (usually by X-ray), epiphyseal union, tooth formation, and tooth eruption have long been studied and proved useful. In adults; pubic symphyses, auricular surface, sternal rib ends, cranial suture closure, dental changes and histological methods were also mentioned in various studies.[2] Some were widely used as standard procedures for data collection from human skeletal remains, and cranial suture closure is one of them[3] although it has a long and controversial history.[2]

The human skull is composed of 22 bones, most of which are divided from each other by sutures.[2] Cranial

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sutures, which are the fibrous joints, begin to obliterate in early adulthood and disappear in old age.[4] Some studies[5-10] concluded that the degree of obliteration of these sutures could be used to estimate the age at death of the bodies, whereas some considered it unreliable.[4,11-15]

In a Thai forensic medicine textbook[16], the time of cranial sutures closure was stated, as an age at death estimation tool, and that sagittal suture complete obliteration meant that the age of the skull was not less than 35 years, coronal suture complete obliteration meant that the age of the skull was at 40 years or more, and lambdoid suture complete obliteration meant that the age of the skull was at least 45 years. There were also two related studies among the Thai population which were performed in 1964 and 1974.[21,22]

As years have gone by, we wonder if the time of cranial sutures closure in the new generation is still the same as in the past, when affected by different kinds of food, life styles, and environments. This study has been designed to find out whether the time of cranial suture closure in the Thai population nowadays has changed or not. Is there any difference between sexes? Also to determine the difference between the time of ectocranium and endocranium closure and their reliability for age determination in the Thai population.

MATERIALS AND METHODS

For this study, the calvaria of 166 adult (15 years and above) Thai cadavers (30 females, 136 males) of known ages were examined while conducting medicolegal autopsies at the Department of Forensic Medicine, Faculty of Medicine Siriraj Hospital, Mahidol University, during 2006. Cadavers with fractured skulls, previously performed cranial surgery e.g. craniectomy, skulls with abnor-malities or diseases e.g. congenital anomaly or metastatic cancer were excluded. However, during the study period, the number of male cadavers was much greater than female, so their number could not be matched, moreover, most of our cases were more composed of the accidental cases with head injuries so we could not collect the crania as much as we planned. We recorded the number of the skull, age, sex, supine body length, weight, body mass index, and address of the deceased before dissection of the body, then, after finishing autopsies the cause of death was also noted. In each case, the calvarium was removed carefully by hand saw, closest to the base of skull so that transverse cut passed well below the lambda, including the lambdoid suture totally, and above the bregma, including the coronal suture totally. The removed calvarium was immersed into sodium hypochlorite as available chlorine 6% w/w for 20 minutes in order to clean soft tissues on both sides and then rinsed off with water and dried with an electric hair dryer.

The extent of obliteration of sutures was noted both on the outer and inner surface in the three main sutures: sagittal, coronal and lambdoid. The sutures were divided into various parts and scored. The sagittal suture was divided into four equal segments from bregma to lambda: S1, S2, S3, S4, respectively. Each half of the coronal suture, starting from the sagittal suture, was divided into three equal segments CR1, CR2, CR3 on the right side and CL1, CL2, CL3 on the left. Similarly, each half of the lambdoid suture was divided into three equal segments LR1, LR2, LR3 on the right side and LL1, LL2, LL3 on the left. Closure of each segment of a suture was scored both for the ecto- and endocranial surface separately.

The scores were designated and recorded as follows:
0 = no union ("open" suture not fused at any point)
1 = commencing union
2 = half obliterated suture
3 = more than half obliterated
4 = completely obliterated suture

In order to simplify data demonstration, we divided them into 3 groups composed of totally closed, partially closed, and all open. The partially closed data were the majority of cases, they were shown as the average percentage of closure progression in each sutures in order that we could easily compare their progression. Besides, the sum of each suture score (sagittal, coronal, lambdoid) were calculated and recorded, ectocranially as well as endocranially. The correlation coefficient, Chi-square tests, and independent t-test were used for statistical analysis, P-value<0.05 was considered statistically significant.

RESULTS

166 crania were studied, 30 females (18.1%), age range between 21-72 years (mean ± SD = 42.4 ± 17.9 years) and 136 males (81.9%), age range between 15-83 years (mean ± SD = 38.8 ± 14.4 years). There was no significant difference between the mean age in females and males. The age range between two sexes is shown in Table 1. The female's mean BMI was 22.7 ± 4.7, the male's was 22.6 ± 3.9. Neither statistically significant difference in age range or BMI was observed between females and males. The majority of our cases died from natural causes (51%). The other causes were wound (stabbed, gun shot, and traffic accident) (28%), asphyxia (hanging and drowning) (15%), electrocution (4%), and poisoning (caused by carbamate, organophosphate, toluene, paraquat), respectively.

We found that the endocranial sagittal suture began to close at age 21-45 years (mean ± SD = 37.3 ± 7.7) in males and 26-47 years (mean ± SD = 36.5 ± 14.8) in females, complete closure was found at age 21-83 years (mean ± SD = 47.2 ± 13.3) in males and 26-74 years (mean ± SD = 51 ± 17.5) in females. The endocranial coronal suture began to fuse at age 19-45 years (mean ± SD = 27.4 ± 10) in males and 21-31 years (mean ± SD = 26 ± 7.1) in females, complete obliteration was found at age 20-83 years (mean ± SD = 44.4 ± 13.6) in males and 24-74 (mean ± SD = 48.7 ± 17.2) in females. The endocranial lambdoid suture began to close at age 21- 45 years (mean ± SD = 35 ± 9.5) in males and 26-59 years (mean ± SD = 50 ± 12.5) in females, complete obliteration was found at age 21-83 years (mean ± SD = 47.1 ± 13) in malea and 26-74 years (mean ± SD = 51.5 ± 16.9) in femalea. The ectocranial sagittal suture began to close at age 17-45 years (mean ± SD = 30.25 ± 11.95) in males and 21-47 years (mean ± SD = 35.7 ± 9) in females, complete closure was found at age 17-83 years (mean ± SD = 39.3 ± 19.8) in males and 28-72 years (mean ± SD

TABLE 1. The number of skull in each age range between females and males.

	Age [yr]					
Sex	**≤19**	**20-34**	**35-49**	**50+**	**Total**	**P-value**
Female	1	14	2	13	30	
Male	8	46	56	26	136	
Total	9	60	58	39	166	0.35

= 52.25 ± 18.3) in females. The ectocranial coronal suture began to fuse at age 22-54 years (mean ± SD = 34.3 ± 17.2) in males and 25-59 years (mean ± SD = 36 ± 13.8) in females, complete obliteration was found at age 30-83 years (mean ± SD = 51.4 ± 19.7) in males and 28-72 years (mean ± SD = 52.8 ± 18.7) in females. The ectocranial lambdoid suture began to close at age 17-62 years (mean ± SD = 40.9 ± 17.74) in males and 17-74 years (mean ± SD = 37.1 ± 17) in females, complete obliteration was found at age 17-83 years (mean ± SD = 44.3 ± 19.1) in males and 28-72 years (mean ± SD = 54 ± 19.2) in females.

There were 6 cases (3 males, 3 females) in which all sutures had been completely obliterated, the ages at death were 30, 42, 83 (male), 28, 52, 72 (female) years old. There were 23 cases that no commencing union occurred at all, the age range was 15-56 years (mean ± SD = 25.54 ± 9.9 years).

The other 137 cases showed partially closed sutures, the average percentage of obliterations in each suture in different age groups are shown in Fig 1, 2.

As mentioned above, we could notice that if the sutures were completely obliterated, the age could vary from 28 to 72 years old in females and 30-83 years old in males. Due to a small number of cases we could not definitely conclude at which age the complete obliteration would be observed. We could also observe that the cranial sutures were all open at the age varying from 17-56 years old (mean ± SD = 29.4 ± 10.7) in females, 15-45 years old (mean ± SD = 23 ± 8.4) in males. We could roughly state that if all sutures are still open, the age at death is less than 15 years old. Mostly the fusion started after 17 years, but there were still some exceptions as one could see that some skull sutures were still totally open at an age more than 40 years. We could also notice that the endocranial suture closure progression seemed to begin earlier than the ectocranial and was related to age more than the ectocranial one which was obviously variable in every age group. From Fig 2, we could see that the endocranial coronal suture was found totally closed at age more than 55 years, (only one exceptional case in which sutures were totally open at age 56). However, using each suture closure for age at death prediction had much variation because our data showed that any suture could start closing at various ages and their closures were not in a sequential pattern.

According to the Thai forensic medicine textbook,[16] which briefly stated that complete obliteration of endocranial sagittal suture was found in the skull at age 35 years or more, coronal suture showed complete obliteration at age 40 years or more, and complete obliteration was seen in lambdoid suture at 45 years or more, we found that those statements were not 100% true. From our data, at age 35 years there were 81.97 % whose sagittal suture was completely closed while the other 18.3% are still partially closed or totally open. Similarly for coronal and lambdoid sutures which were completely closed only 62.62% at age 40 and 59.37% at age 45 years, respectively.

For the decades we have been using the time of each cranial suture closure as a predicting tool of age following the former studies and textbook in Thailand, but the present study shows much variation. The cranial sutures in the very old age cadavers (more than 60 year old), which according to previous theories should be completely disappeared, are still partially open in sagittal, coronal, and lambdoid sutures. In these cases if we use each cranial suture closure for age estimation, the prediction will be much less than the actual age (because there is no complete closure at all) whereas some of very young crania (less than 20 -year-old) showed complete sagittal suture obliteration while other sutures were still all open. In the latter case, if age estimation is based on complete sagittal suture closure only, the predicted age will be more than the actual one. So that using closure of each suture separately to determine age at death may not be appropriate while using the sum of suture scores may reduce variations. Hence, if we add their scores together and consider them as the degree of sum of suture scores this will be more helpful.

As the correlation coefficient (Table 2), obliteration progression of cranial sutures was considered as the sum of each suture score individually, the sum of all suture scores internally, the sum of all suture scores externally and the sum of all suture scores. Correlations to the progressed age showed the different relationship. The correlation between age and cranial suture closure by sum of ectocranial suture scores (S,C,L or S+C+L) indicated a little to fair degree of relationship, whereas sum of endocranial suture scores (S,C,L or S+C+L) and sum of ecto- and endocranial S+C+L suture scores showed a moderate to good relationship. We also found that the correlation of the sum of endocranial suture scores, which was calculated by adding endocranial sagittal suture scores, coronal suture scores and lambdoid suture scores altogether, was even better than others (r = 0.612), therefore, we considered the sum of endocranial suture scores to be the best value that should be used for predicting age at death. Neither male nor female group has statistically significance between the sum of endocranial suture scores and the sum of ectocranial suture scores, so we considered them to be the same (Table 3).

As the sum of all endocranial suture scores (S+C+L),

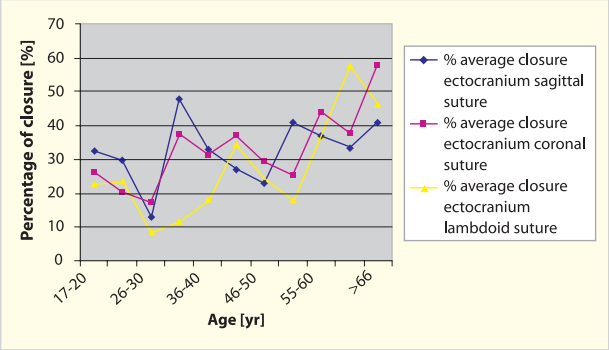

Fig 1. Average percentages of each skull suture ectocranially that were partially closed.

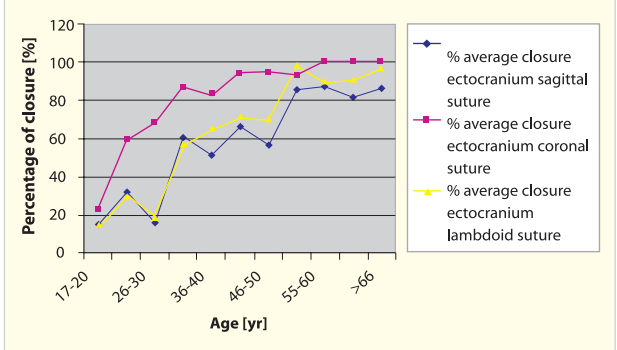

Fig 2. Average percentages of each skull suture endocranially that were partially closed.

which we defined as "composite scores"; started from 0 to 64, seemed to relate to age more than others, so we paid our attentions to this and divided the composite scores into 7 stages as follows:

S_0 = 0 (totally open)
S_1 = 1-15
S_2 = 16-31
S_3 = 32-45
S_4 = 46-51
S_5 = 52-63
S_6 = 64 (completely obliterated).

The calculated mean ± SD of age and composite scores were plotted as shown in Fig 3. We noticed that suture closure started from the mean age at 25 years, then, increasing scores were accompanied by progressing age. In cases of more than S_4, we could see that the mean age was mostly not less than 45 years.

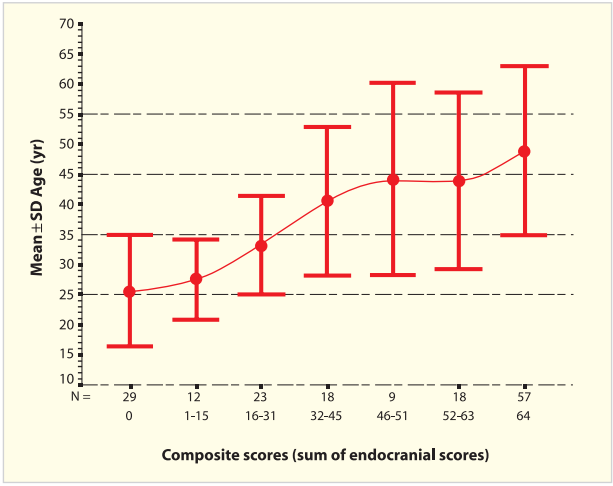

Fig 3. Distribution of age by interval of composite scores.

CONCLUSION

For person identification, age estimation is certainly one of the important biological profiles. Cranial suture closures have been used as an age determination tool since the 16th century[17], but their reliability is still questionable. Several studies have revealed that the cranial suture closure could be useful in determining age at death, on the other hand, some concluded that it was unreliable. Although cranial sutures generally close with increasing age, there is considerable variability in closure rates.[3]

Todd and Lyon[5-8] and Hrdlicka[9] have shown that skull sutures closed earlier on the endocranial surface than the ectocranial. They also found that the inner sutures were more reliable than the outer ones which had "lapsed union". Neither did they find any gender difference in closure of skull suture. Nor did they observe any difference in the time of suture closure on the two surfaces. The present observations reveal that endocranial surface fusion is earlier as well and there is no significant difference between sexes. We also found that endocranial closure is more related to age and more reliable, especially, the sum of endocranial suture scores (composite scores), is statistically proven to be most related to age.

Topinard[10] made some specific observations regarding estimation of age from the extent of obliteration of skull sutures. According to him if all the sutures were open, the age of the skull was 35 years or less, if the posterior part of sagittal suture started closing, the age would be about 40 years and if the coronal suture near the bregma started closing, the age should be 50 years or more. His observations were contra-indicated by Dwight[11] and Parsons and Box[18] who showed that suture closure commenced much earlier. Dwight[7] examined 100 skulls whose ages had been recorded. According to him the sutures started to close under 30 years, closing of the sutures almost invariably began on the endocranial surface earlier than the ectocranial one.

TABLE 2. The correlation coefficient between age and sum of suture scores.

	Correlation coefficient	
Sum of suture scores	**Age**	**P-value**
EC_S	0.213*	0.005
EC_C	0.370*	<0.001
EC_L	0.312*	<0.001
EN_S	0.526*	<0.001
EN_C	0.536*	<0.001
EN_L	0.579*	<0.001
EC_SUM	0.351*	<0.001
EN_SUM	**0.612***	<0.001
EC_EN SUM	0.561*	<0.001

EC_S = sum of ectocranial sagittal suture scores, EC_C = sum of ectocranial coronal suture scores, EC_L = sum of ectocranial lambdoid suture scores, EN_S = sum of endocranial sagittal suture scores, EN_C = sum of endocranial coronal suture scores, EN_L = sum of endocranial lambdoid suture scores, EC_SUM = sum of all ectocranial suture scores, EN_SUM = sum of all endocranial suture scores, EC_EN SUM = sum of all ectocranial sagittal suture scores and endocranial suture scores [correlations from 0-0.25 = little or no relationship ; those from 0.25-0.50 = fair degree of relationship ; those from 0.50-0.75 = moderate to good relationship ; and those greater than 0.75 = very good to excellent relationship (Calton: 1974)]

TABLE 3. Mean ± SD of the sum of suture scores in female and male.

Sum of suture scores	Sex	N	Mean	Std. Deviation	P-value
EC_S	Female	30	4.167	5.767	
	Male	136	4.603	5.631	0.703
EC_C	Female	30	8.567	9.171	
	Male	136	6.912	7.084	0.359
EC_L	Female	30	5.9	9.341	
	Male	136	5.758	8.548	0.935
EN_S	Female	30	8.867	7.509	
	Male	136	7.67	7.118	0.41
EN_C	Female	30	17.033	10.545	
	Male	136	18	9.478	0.621
EN_L	Female	30	12.533	11.861	
	Male	136	13.147	10.8	0.796
EC_SUM	Female	30	18.633	21.686	
	Male	136	17.272	18.449	0.724
EN_SUM	Female	30	38.433	27.161	
	Male	136	38.816	24.492	0.94

EC_S = sum of ectocranial sagittal suture scores, EC_C = sum of ectocranial coronal suture scores, EC_L = sum of ectocranial lambdoid suture scores, EN_S = sum of endocranial sagittal suture scores, EN_C = sum of endocranial coronal suture scores, EN_L = sum of endocranial lambdoid suture scores, EC_SUM = sum of all ectocranial suture scores, EN_SUM = sum of all endocranial suture scores, EC_EN SUM = sum of all ectocranial sagittal suture scores and endocranial suture scores.

He, however, dismissed the suggestion that sutures were worthless in indicating the age of a given skull.

Todd and Lyon[5-8] undertook extensive studies on the time of closure of the skull sutures. They examined male skulls of 307 whites and 120 negroes, and found that in the former, on the outer surface, the sagittal suture started to close at the age of 22 years and was completely closed at 35 years, the obliteration of the coronal suture commenced at 26 years and was completed by 42 years; the lambdoid suture showed commencement of closure at 26 years and was completely closed at 42 years. Almost similar results were obtained in case of negro skulls. They excluded from their study 40 white and 41 black skulls as in those specimens suture closure did not fit a definite trend of progress. Their principle of rejecting "irregular" specimens was criticized by Cobb[19] as this rejection was responsible for the subsequent workers not being able to endorse the observations of Todd and Lyon.[5-8] Perizonius[20] studied the time of suture closure in 174 male and 82 female skulls of non-Jewish inhabitants of Amsterdam whose ages were between 20-99 years. He examined the suture endocranially by introducing a small lamp through the foramen magnum. He did not find any difference in the time of closure of the sutures between two sexes or on the two surfaces. According to him the obliteration of sutures was related to age in the age group of 20-49 years but not thereafter. Validity of his observations is questionable as it is not possible to observe the lateral parts of the lambdoid suture endocranially by his procedure. Some workers including Stewart[12], Singer[13], Mckern and Stewart[14], Powers[15] have stated that suture closure was unreliable as a guide to the age of the skull.

Sahni et al[4] studied 665 known age northwest Indian adult skulls, in India (538 males and 127 females). The sutures were divided and scored following Perizonius.[20] The conclusions were that (1) obliteration of sutures com-menced earlier in males than in females, (2) suture obliteration started earlier on the endocranial than on the the ectocranial surface, (3) commencement and complete obliteration of a segment or the entire suture is so erratic that it is not useful for estimating the age of the skull.

In Thailand, there were two related studies that had been performed. In 1964, Tiengpitak[21], who studied 110 known age Thai and Chinese crania, revealed that closure of the endocranial sagittal suture began between the age of 23-37 years and was complete 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. Another study had been performed, using 173 Thai known age crania, in 1974 by Kij-ngarm.[22] He concluded that closure of the ectocranial sagittal suture began between 30-40 years and was complete between 50-60 years. The ectocranial coronal suture began to obliterate between 30-40 years and was complete at age 60 years while the ectocranial lambdoid suture began to close between 30-42 years and was complete between 50-60 years. There was no significant difference between sexes. The present study shows that all open cranial sutures indicate that its host's age is surely less than 15 years and should not be over 17 years (but one has to keep in mind that some sutures of 17 years old bodies start to close in a small number of cases) and that if the endocranial coronal suture is completely closed, the age should be more than 55 years (there is one exceptional case in which all sutures are still open at age 56 years). Compared with Kij-ngarm's and Tiengpitak's results, obviously, the Thai new generation's ectocranial suture closures start and complete earlier than previously while the endocranial sagittal suture closures start and complete closure almost similar to those in the past. Our study also showed the same results that the endocranial surface starts closing before the ectocranial and that the endocranial closure is more related to age than another and no difference between sexes could be found.

From our results, correlation between the sum of the endocranial suture scores (which are also called "composite scores") and age is the best and no significant statistical difference between the two sexes was found. Using composite scores helps in diminishing the variation of the time of suture closure in each suture in each segment. The association between age and the interval of composite scores was shown and is suggested to be the preferred age predicting tool.

Very similar procedure, but a different scoring method was previously used to associate composite ectocranial scores and chronological age for the cranial vault and the lateral-anterior regions, as defined by Meindl and Lovejoy.[17] According to them, composite scores were reached by summing scores for five "vault" sites and five "lateral-anterior" sites. The scores could range between 0-21 for the vault system and 0-15 for the lateral anterior system. The composite scores were associated with the "S" designations in their graph. Predictions for completely open sutures were not possible with their method. Individuals whose sutures were fully closed fell into the older adult category (50+ years). They also concluded that the lateral-anterior was proven to be a better predictor of chronological age than the vault sites.

Endocranial and palate sutures could also serve as a basis for estimating age.[3] By young adulthood, the incisive suture (IN) has already closed, with activity evident within the transverse palatine (TP) and posterior median palatine (PMP) segments. Closures of IN, TP, PMP, with the anterior median palatine remaining at least partially open were characteristic of middle adulthood. Complete fusion was typical of older adults (Mann et al.1987). The endocranial suture closures for the sagittal, coronal, and lambdoid sutures began during young adults (20-34 years). Advanced but incomplete closure stages were characteristic of middle adults (35-49 years), while fully fused sutures were typically found in older adults (50+ years) (Krogman and Iscan 1986). Comparing to them, our studied cranial sutures closed earlier.

No single skeletal indicator of age at death is likely to accurately reflect the many factors which accumulate with chronological age, each of which can contribute valuable information to the age estimation.[17] The above data demonstrate that cranial suture closure is such a criterion. Even if there is some variation, the information on suture closure is useful when other criteria are not available or when being used in conjunction with other attributes.[17] Our disadvantages are that the number of cases in this study is rather small due to the limitation of time and we have limited cases for selection to study. Further development, in the large sample group, of suture closure as an age indicator in Thai population is suggested by the present study in order to increase the accuracy and precision.

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