A New Method for Age Estimation from Ectocranial Suture Closure in a Thai Population

Natnicha Kampan, M.Sc., Apichat Sinthubua, M.Sc., Pasuk Mahakkanukrauh, M.D.
Department of Anatomy, Faculty of Medicine, Chiang Mai University, Chiang Mai 50200, Thailand.

ABSTRACT

Age estimation is one of the major components of forensic identification. Cranial sutures have long been used as indicators for age estimation, because they vary in their timing of closure with age. The purpose was to estimate age in 100 Thai skulls with age ranging between 15-96 years from the Department of Anatomy, Faculty of Medicine, Chiang Mai University by using a new method for assessing ectocranial suture closure. Cranial sutures were the coronal, sagittal and lambdoid sutures on the ectocranial surface. In order to investigate the closure, obliteration of each suture was recorded using two techniques: photographing and tracing. The degree of suture obliteration was measured by counting the pixels of the remaining sutures using ImageJ software. The length of each suture was recorded in centimeters and the number of pixels per centimeter in each suture was analyzed using Pearson's correlations at the 0.05 significance level. The results showed a significant negative correlation between age and the number of pixels per centimeter only in the coronal suture, and only when measured from tracing. A predictive model established using stepwise linear regression in this study was age = 76.872 – (19.609 x the number of pixels per centimeter in the coronal suture from tracing) + (3.710 x the number of pixels per centimeter in the lambdoid suture from tracing), with a standard error of ±13.9 years. Since this is the first attempt at age estimation using this method in Thailand, these results may assist in estimating age in forensic anthropological contexts.

Keywords: Age estimation, ectocranial suture, Thai population

Siriraj Med J 2014;66:61-65
E-journal: http://www.sirirajmedj.com

INTRODUCTION

Human skeleton remains provide important sources of information about sex, age, race or stature, which are the major components of forensic identifications. While sex determination in adults generally does not present any difficulty,[1] age estimation from adults is difficult and is subject to considerable error in human populations.[2] Various methods have been suggested to estimate the age of individuals using different parts of the human skeleton for anthropological and forensic medical purposes. In previous studies, areas of the skeleton commonly used for aging adults were the pubic symphysis,[3-6] auricular surface of the pelvis[7,8] sternal end of the ribs[9] and cranial suture closure.[10-13]

Cranial sutures were among the first areas of the skeleton to be used for age estimation, based on the hypothesis that suture closure is part of an age-related physiological process.[2] During development, cranial sutures remain patent, allowing the cranial vault to expand for the growing brain. After cessation of growth, cranial bones fuse progressively as individuals age and the intervening sutures are obliterated over time.[14] Although estimation of age based on macroscopic examination of cranial suture closure has led to various studies with conflicting results, cranial suture closure is still frequently used to estimate the age of adults because the cranium is often well-preserved in a forensic context.

Age estimation from cranial suture closure has been studied among people from Thailand by Tiengpitak,[15] Kij-ngarm[16] and Jangjetriew et al.[17] Unfortunately, these studies used the standard macroscopic approach, which has largely been reported in many studies to be an unreliable and highly variable method.[18] Consequently, the current study tests two new techniques for cranial suture aging of Thai individuals using photography and tracing with Adobe® Photoshop® CS4 software and the ImageJ

Correspondence to: Pasuk Mahakkanukrauh
E-mail:pasuk034@gmail.com
Received 2 January 2014
Revised 7 May 2014
Accepted 19 May 2014

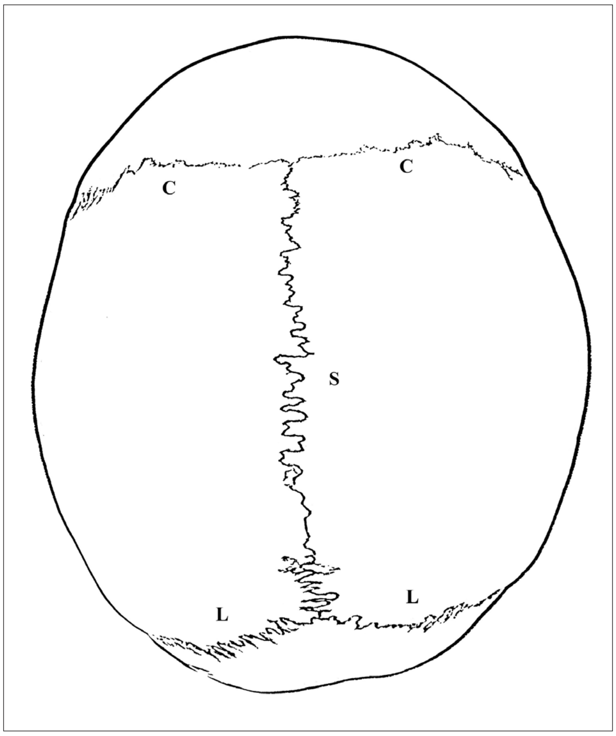

Fig 1. The coronal (C), sagittal (S) and lambdoid (L) sutures on the ectocranial surface were used in this study.

software to count the number of pixels in the remaining sutures as an alternative method for age estimation from cranial suture closure.

MATERIALS AND METHODS

The skulls of 100 Thai individuals of known sex, and with ages at death ranging from 15-96 years, were obtained from the Forensic Osteology Research Center (FORC), Faculty of Medicine, Chiang Mai University. Skulls exhibiting fractures or pathologies of the coronal, sagittal and lambdoid sutures on the ectocranial surface were excluded from this study. The coronal, sagittal and lambdoid sutures (Fig 1) were photographed using a Canon EOS Rebel XSi camera with a Canon EF 50 mm f/1.8 II lens and were also traced onto a clear plastic sheet by hand using a permanent marker (Fig 2). The coronal and lambdoid sutures were divided into left and right sides for photographing and tracing. In addition, the direct linear length of each suture was measured in centimeters using a measuring tape. Photos of each suture were retouched to highlight the visible parts of each suture using the Adobe® Photoshop® CS4 software (Fig 3) so that the ImageJ software could more easily measure the number of pixels (Pixel is the basic unit of programmable color to display the images on the digital media. Each pixel can only be one color at a time, Fig 4), while a scanner was used to scan the pictures of the sutures from tracing. Next, the suture images from both the photography and tracing were analyzed using ImageJ software to measure the number of pixels visible in the remaining sutures (Fig 5).

Fig 2. The tracing method was used to investigate the closure of sutures in this study.

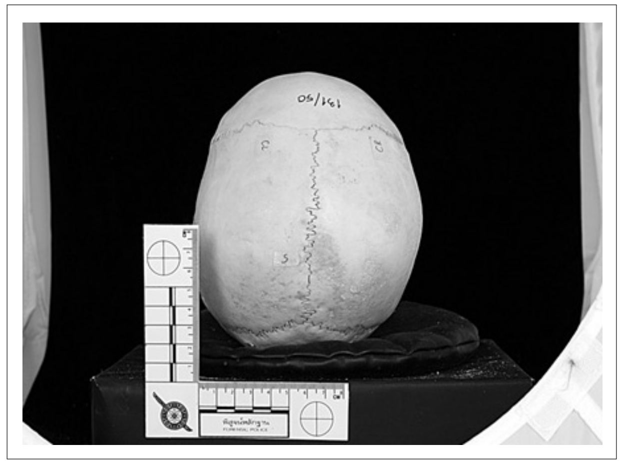

Fig 3. The Adobe® Photoshop® CS4 software was used to retouch the photos of each suture from photography.

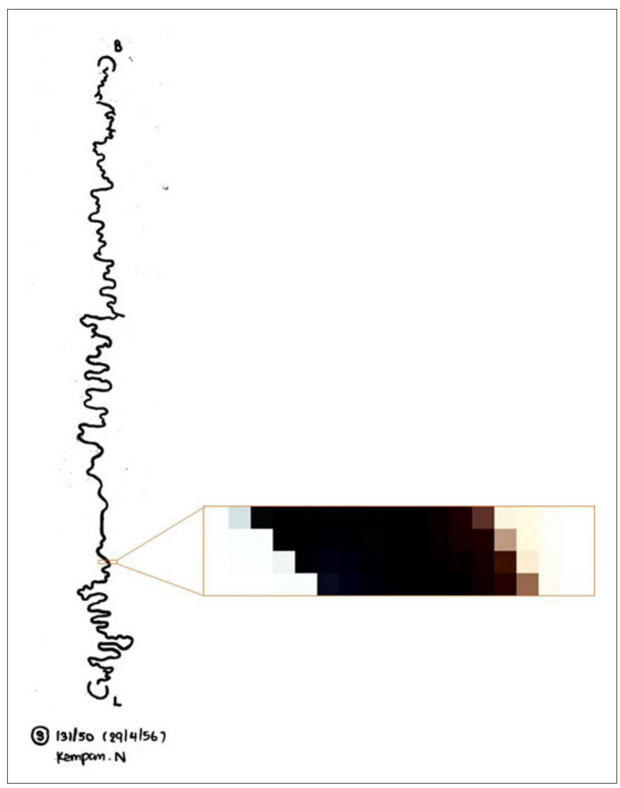

Fig 4. The example of enlarged pixels from the suture image.

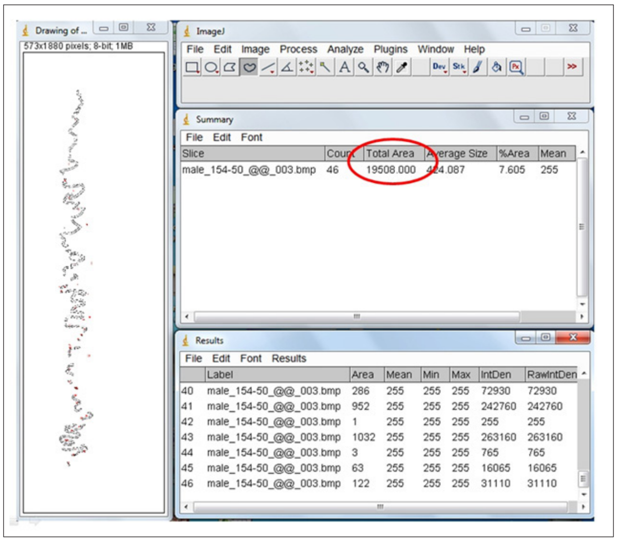

Fig 5. The example of ImageJ software output; the number of pixels was shown in the circle.

Statistical analysis was performed using SPSS for Windows version 17, and Pearson's correlations were calculated to evaluate the relationship between age and the number of pixels per centimeter in each suture from both photography and tracing. Finally, stepwise linear regression was used to establish a predictive model for age estimation consisting of only the variables which provide the most accurate predicted age. Statistical significance was assessed at an alpha level of 0.05 in all analyses.

RESULTS

The mean age of the 100 Thai skulls was 66.7 years. Descriptive analysis of the number of pixels per centimeter in each suture from both photography and tracing have been shown in Table 1. The relationships between age and the number of pixels per centimeter in each suture from photography and tracing by means of Pearson's correlations have been shown in Table 2. Table 2 indicates a negative correlation between age and the number of pixels per centimeter in each suture from both photography and tracing, as would be expected if sutures obliterate with age. However, only in the coronal suture, was found a significant negative correlation between the number of pixels per centimeter and age, and this correlation was only found by the tracing approach (p=0.001).

Stepwise linear regression was used to establish a predictive model for age estimation with only the pixel counts for the cranial sutures that were most closely related

TABLE 1. Mean and standard deviation (SD) of the number of pixels per centimeter (cm) in each suture by photography and tracing.

Suture	Photography		Tracing	
	Mean	S.D.	Mean	S.D.
Coronal	0.35150	0.241665	0.84633	0.357812
Sagittal	0.58133	0.494126	1.05613	0.662392
Lambdoid	0.81845	0.614348	1.74214	0.964774

TABLE 2. The relationship between age and the number of pixels per centimeter (cm) in each suture from photography and tracing.

	Photography		Tracing	
	Correlation Coefficient	p-value	Correlation Coefficient	p-value
Coronal/cm	-0.191	0.057	-0.339	0.001
Sagittal/cm	-0.039	0.702	-0.116	0.249
Lambdoid/cm	-0.038	0.704	-0.014	0.889

TABLE 3. The results of stepwise linear regression analysis were used to establish a predictive model for age estimation from ectocranial suture closure.

	Coefficient regression	Standard error	p-value
Constant	76.872	3.701	0.000
Coronal/cm from tracing	-19.609	4.655	0.000
Lambdoid/cm from Tracing	3.710	1.726	0.034

TABLE 4. Validity of predictive model for age estimation in this study.

Age of sample	Subject	Mean of % error of prediction
< 50	10	75.39
50 - 74	58	11.56
≥ 75	32	17.79

to age (Table 3). Based on this analysis, the equation that best estimates age was one that includes the number of pixels per centimeter in the coronal and lambdoid sutures from tracing. The most accurate predictive model established from stepwise linear regression in this study was age = 76.872 – (19.609 x the number of pixels per centimeter in coronal suture from tracing) + (3.710 x the number of pixels per centimeter in lambdoid suture from tracing), with a standard error of the estimate of 13.9 years. The validity of the predictive model for age estimation has been shown in Table 4.

DISCUSSION

Cranial sutures can be seen on both the ectocranial and endocranial surfaces. They fuse progressively at various times, and each has a different time of closure. Cranial suture closure has been used as an age estimation indicator since the 19th century,[19] but its reliability is still inconsistent. Many studies have reported that cranial suture closure could be valuable for age estimation,[2,11-13,17,20] while some have argued that it is too unreliable.[5,21-23]

Various methods have been applied to age estimation using cranial suture closure with macroscopic examination of the most common, but the results have not been reliable.[18] Such a study was conducted by Dorandeu et al[20] who assessed the value of microscopic analysis of the fronto-sphenoidal sutures (FSSs) for age estimation using the vascular skull sutures and the degree of apoptosis of conjunctive cells as parameters, which could establish the predictive model with a standard error of 1.6 years.

Another study by Harth et al[18] used a Flat-Panel-CT modality and a cross-sectional view of the sagittal, coronal, and lambdoid sutures to create a regression model for estimating age at death in which the standard error was 31.1 years. Likewise, the current study was conducted to attempt to improve age estimation among Thai individuals using new methods of cranial suture analysis and a predictive model.

In the Thai population, macroscopic examination has been used to estimate age from several parts of the human skeleton such as the auricular surface of the ilium,[24] the symphyseal surface of the pubic symphysis[25] and cranial sutures.[15-17] These results were unsatisfactory enough to accurately estimate age. Traditionally macroscopic examination is the method using only the human eyes to observe the obliteration of cranial suture without any recording, whereas this study used the photographic and computer technologies to record the observation of cranial suture closure. Therefore, the aim of this study was to attempt to reduce the unreliability of macroscopic examination by applying pixel counting to assess the cranial sutures.

In the samples in this study, 90 percent of 100 Thai skulls had ages at death from 50 years or above in both male and female, while skulls with ages at death less than 30 years were only females. However, we required the samples with various ages at death included, and the previous studies found no significant difference of suture closure between sex,[12,13,17,26] so we studied the skulls of both male and female together. Table 1 shows that the lambdoid suture has the greater mean number of pixels compared with the coronal and sagittal sutures from both photography and tracing. These results are compatible with studies by Todd and Lyon,[10] Sabini and Elkowitz,[26] and Murlimanju et al[14] who reported that the lambdoid suture was the most patent suture of the cranial vault. This makes sense, as the occipital bone has more muscle attachments along its surface than the frontal and parietal bones, so the patency of the lambdoid suture can be attributed to the presence of external forces from muscles acting on it.

As for the relationships between age and the number of pixels per centimeter in each suture from both photography and tracing (Table 2), we found a negative correlation, which indicated a tendency for a decreasing number of pixels per centimeter in each suture as age increases, as expected. Although, only the coronal suture from tracing exhibited a pixel count per centimeter that correlated significantly with age (p=0.001), we also found that the coronal suture pixel count from photography showed the higher correlation with age than the other sutures. The relationship between coronal suture closure and age in this study is similar to Perizonius' study[12] which stated that the coronal suture had a significant correlation with age on both the ectocranial and endocranial surfaces.

For the validity of this predictive model for age estimation in Table 4, the samples with ages at death from 50 years or above had the percent errors of prediction less than the samples with ages at death of less than 50 years. This result might be due to the ages of samples of which 90 percent had age at death of 50 years or above, so age estimation using the predictive model which was established with samples in this study, were similar to the real ages of the samples with ages at death from 50 years or above more than the samples with ages at death less than 50 years. To reduce this limitation, future studies should increase the amount of samples with ages at death less than 50 years, and should divide the samples into groups by ages to establish the predictive models which are suited to the samples in each group of ages.

CONCLUSION

Our model with the lowest standard error of the estimate is age = 76.872 – (19.609 x the number of pixels per centimeter in the coronal suture from tracing) + (3.710 x the number of pixels per centimeter in the lambdoid suture from tracing) with the standard error of 13.9 years. Even though this standard error seems high, it is actually lower than the standard errors from the studies of Dorandeu et al[2] and Harth et al[18] which were 23.0 and 31.1 years, respectively. Moreover, application of the predictive model from this study to the unknown skull is considered useful to approximately estimate age. This study presents a new method that can provide an alternative for age estimation using cranial suture closure. However, age estimation in a forensic context should include other remaining bones, such as the hip bone or clavicle, in conjunction with cranial suture closure for the greatest accuracy.

ACKNOWLEDGMENTS

We would like to thank Asst. Prof. Dr. Sukon Prasitwattanaseree for valuable guidance and advice about statistical analysis. In addition, we greatly appreciate Mr. Chaktawat Polcharoensook for his kind help by photography and use of the Adobe® Photoshop® CS4 and ImageJ software. In particular, Natnicha Kampan is sincerely grateful to her parents and all the graduate students for their support.

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