Veterinary Integrative Sciences 2022; 20(1): 185-197. DOI; 10.12982/VIS.2022.015

Vet Integr Sci

Veterinary Integrative Sciences

ISSN; 2629-9968 (online)

Website; www.vet.cmu.ac.th/cmvj

Research article

Efficiency of dry bone inspection compared with two-dimensional os coxal images for age estimation in a Thai population

Pittayarat Intasuwan[1], Patison Palee[2], Apichat Sinthubua[1] and Pasuk Mahakkanukrauh[1,3,4,*]

[1]Department of Anatomy, Faculty of Medicine, Chiang Mai University, Chiang Mai 50200, Thailand
[2]Department of Information Technology Affairs, College of Arts, Media and Technology, Chiang Mai University, Chiang Mai 50200, Thailand
[3]Forensic Osteology Research Center, Faculty of Medicine, Chiang Mai University, Chiang Mai 50200, Thailand
[4]Excellence Center in Osteology Research and Training Center (ORTC), Chiang Mai University, Chiang Mai 50200, Thailand

Abstract

The auricular surface and pubic symphysis are commonly used in age estimation. This study aimed to compare the results of age estimation between dry bones and 2D images of the os coxae and to develop a tool specifically for Thai individuals. The total samples were 250 left os coxal dry bones divided into 200 samples (100 males, 100 females) for the training set and 50 samples for the test set. The age range was 26 – 94 years. We used the Suchey-Brooks method and Berg method for observing the pubic symphysis and the Buckberry-Chamberlain method for observing the auricular surface. Afterward we compared the dry bones and photo parts. Our results showed sex did not play a significant role in estimating the age-at-death. In both parts, the auricular surface yielded the highest accuracy (80 – 84%) with SEE = 13.99 – 14.24 years. The pubic symphysis showed an accuracy of 74 – 76% and SEE = 14.37 – 14.44 years. The results of the dry bone and photo parts did not differ significantly. In both dry bone and photo parts, the intra-observer agreement performed moderate to almost perfect agreement. On the other hand, the inter-observer agreement was slight to fair. In conclusion, our study can be potentially applied for distant consultation for age estimation using 2D pelvic images with a forensic anthropologist for estimating biological profiles.

Keywords: 2D images, Age estimation, Forensic anthropology, Os coxa dry bones, Thai population

---

Corresponding author: Pasuk Mahakkanukrauh, Research Cluster in Osteology Research and Training Center (ORTC), Chiang Mai University, 110 Intawaroros, Sriphum, Chiang Mai 50200, Thailand. Tel: +66 8188 59172, +66-53-939-474 E-mail: pasuk034@gmail.com

---

Funding; This study was supported by the Faculty of Medicine, Chiang Mai University [Grant Agreement No. 012-2564]. The first author received a TA/RA scholarship from the Graduate School, Chiang Mai University.

Article history; *received manuscript: 20 December 2021,*
revised manuscript: 6 January 2022,
accepted manuscript: 21 January 2022,
published online: 24 January 2022
Academic editor; *Korakot Nganvongpanit*

INTRODUCTION

Determining the age of human skeletal remains is an important part of biological profile estimation (consisting of sex, age, stature, and ancestry) in the forensic anthropological field for identifying deceased or missing persons in criminal cases or mass disasters. The age estimation can narrow down the list of the missing persons (Lam et al., 2016; Cappella et al., 2017). Age estimation is more accurate in children and adolescents than adults because of multiple confounding factors, such as genetics and environments, that cause age predictions less reliable when individuals reach maturity. Therefore, more accurate and precise methods for age estimation are necessary for all ages (Miranker, 2016).

The most widely used techniques for age estimation in adults are based on morphological features of pelvic bones due to the good preservation in the recovery process, including pubic symphysis, auricular surface, and acetabulum (Miranker, 2016; Mulhern and Jones, 2015; Mays, 2014; Milner and Boldsen, 2012). Many researchers utilized different parts of the os coxa and other bones, whereas Cappella et al., 2017 and Miranker et al., 2016 evaluated various pelvic parts for age estimation with the best parameters being the acetabulum and auricular surface. On the other hand, Milner and Boldsen, 2012 reported that the pubic symphysis performed the best for estimating the age-at-death, followed by the sacroiliac joint and cranial suture, in contemporary American populations. Moreover, Rivera-Sandoval et al., 2018 and Hagelthorn et al., 2019 stated that the auricular surface was the most accurate trait.

In general, the most commonly used features for age estimation are the auricular surface and pubic symphysis (Mulhern and Jones, 2015). Initially, the noticeable age-related changes in the auricular surface were described by Lovejoy et al. observing eight aspects of the auricular surface, which included auricular surface, demifaces, apex, retroauricular area, porosity, graininess, billowing, and density. The results showed that the accuracy was comparable to the pubic symphyseal method of Suchey-Brooks although the Lovejoy et al. method posed several problems in age estimation due to complicated descriptions of the auricular surface aspects (Lovejoy et al., 1985). Until Buckberry and Chamberlain et al., 2002 revised a method for estimating adult age based on the auricular surface originated by Lovejoy et al. in 1985. They decreased categories from eight to five for simplification including transverse organization, surface texture, microporosity, macroporosity, and apical changes. The scores from this method showed a slightly higher correlation with age than that of the pubic symphyseal method of Suchey-Brooks. In further studies, some researchers tested the revised auricular surface aging method from Buckberry and Chamberlain with a positive correlation with age-at-death (Mulhern and Jones, 2015; Hens and Belcastro, 2012; Moraitis et al., 2014).

For the pubic symphysis, the first study that reported age-related changes in this region was authored by the anatomist Todd (1920), and then Brooks and Suchey, 1990 modified the Todd method using six phases for age estimation. However, they were concerned about a wide age range between phase III and phase VI. Subsequently, Berg, 2008 estimated the age of older adult female European populations using the Suchey-Brooks method in phases I-IV as well as their new phases in phases V-VII. The amount of porosity was used to determine the new phases. The results showed that the average of ages were the early 50s, mid-50s to mid-60s, and mid-70s for phases V, VI, and VII, respectively. Similarly, Hartnett, 2010 used the Suchey-Brooks method in phases I-IV and their new phases in phases V-VII. The bone qualities in their new phases were observed although this method was deemed more subjective. Phase VII showed that the age range was over 70 years similar to Berg, 2008. Furthermore, Dudzik and Langley, 2015 and Shirley and Ramirez Montes, 2015 used the component-based system method for estimating age with more precision for individuals under 40 years of age. In this study, we applied the Buckberry-Chamberlain method in the auricular surface and Suchey-Brooks method and Berg methods in the pubic symphysis for estimating age in the Thai population based on the morphological method.

Nowadays, 2D or 3D images such as conventional photography, computed tomography (CT) scans, magnetic resonance imaging (MRI) scans, X-rays, etc. are increasingly utilized in forensic anthropology (Pattamapaspong et al., 2019). In this study, we were interested in the application of 2D images of the os coxa because the 2D images were easier to retrieve and analyze. This study aimed to compare the results of age predictions between dry bones and 2D images of the os coxae and to develop the age estimation tool for the Thai population, which could also be used for remote consultations with the specialties in this field.

MATERIALS AND METHODS

The study protocol was approved by the Research Ethics Committee, Faculty of Medicine, Chiang Mai University, Thailand (Research ID: ANA-2563-07285).

Data Collection

The os coxae were provided by the Forensic Osteology Research Center (FORC), Faculty of Medicine, Chiang Mai University. The total samples were 250 os coxal dry bones divided into 200 samples (100 males, 100 females) for the training set and 50 samples for the test set. The age range was 26-94 years, and the stature ranged from 135 to 190 cm. The age at death of samples was collected as widely distributed as possible (Table 1). The selected os coxae for our study were all left-sided, complete, and Thai individuals. The samples with trauma, pathology, and non-Thai origin were excluded from this study.

Table 1 Sex and age distribution of total samples studied.

Age (years)	Male (n = 100)	Female (n = 100)	Total (n=200)
20-29	2	2	4
30-39	5	7	12
40-49	20	10	30
50-59	14	21	35
60-69	17	27	44
70-79	25	21	46
80-89	15	8	23
90-99	2	4	6

Technical Photography

2D images of the os coxae were used for observing features at the auricular surface and pubic symphysis areas. Normally, the os coxa dry bone can lie in three positions including top view, lateral view, and medial view. We chose the top view position for this study for observation of both areas. For each image one area (auricular surface or pubic symphysis) was chosen each time. Due to the auricular surface and pubic symphysis being on different planes, the camera could not focus on two areas at the same time. Therefore, each sample yielded two images with one focused on the auricular surface and the other on the pubic symphysis. All images of the bones were taken with a digital camera with technical specs: Sony α57 Lens; Sony dt 18-55mm F3.5-5.6 SAM, at focus on 55 mm, autofocus mode iso 200. The images were saved in ARW file format for high-quality images. Photographs were taken using the top view, and the distance between the lens and bones was standardized in every photograph. Each left os coxa was placed on a black silk velvet background. Each bone was positioned with the auricular surface of the ilium facing upwards with the pubic symphysis pointing to the top. The camera lens was parallel to the os coxa. The anatomical landmarks of the os coxa marked on the camera screen grid belonged to the auricular area. This position was in the same plane for all images. All images showed a whole os coxae (Figure 1).

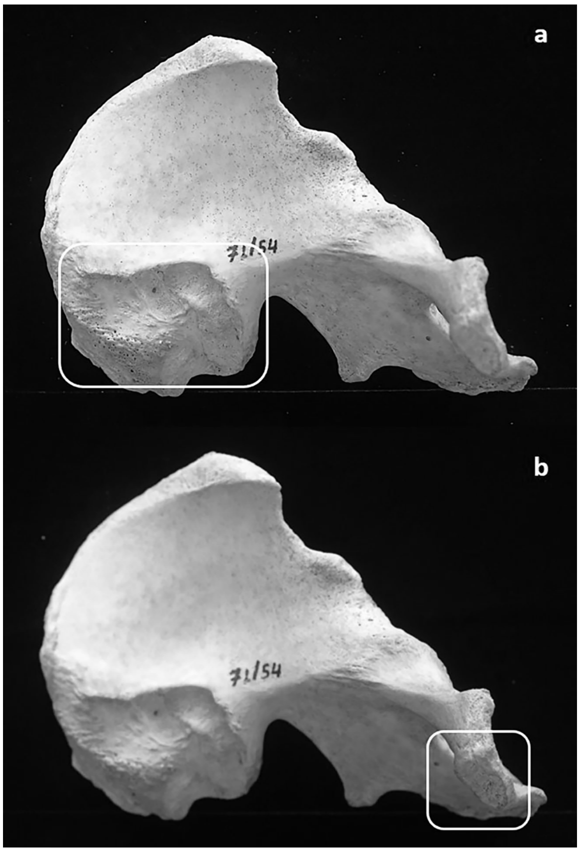

Figure 1 Two-dimensional images of the os coxae display the top view position each focusing on two areas: (a) the auricular surface and (b) the pubic symphysis.

Scoring System of the Features of the Pubic Symphysis and Auricular Surface

Both dry bones and 2D images were observed and scored using the same features. The pubic symphysis phases in this study were derived from the Suchey-Brooks method for phases I – IV (Brooks and Suchey, 1990) and Berg method for phases V – VII (Berg, 2008) (Table 2).

The auricular surface features in this study were derived from the Buckberry-Chamberlain method consisting of transverse organization, surface texture, microporosity (hole size < 1 mm), macroporosity (hole size > 1 mm), and apical changes. We scored five features according to the Buckberry-Chamberlain criteria (Buckberry and Chamberlain, 2002) and summarized scores in each case. The scores ranged from 5 (minimum) to 19 (maximum).

Table 2 Definition of characteristic features of the pubic symphysis in this study derived from the Suchey Brooks method in phases I - IV and Berg method in phases V - VII.

Phase	Definition
Phase I	The symphyseal surface has ridges and furrows which can call billowing surfaces. The ridges and furrows extend to the pubic tubercle. The horizontal ridges are evident and initiate the ventral beveling. Some ossific nodules may appear on the upper extremity but the upper and lower extremity are continuous.
Phase II	The pubic symphyseal face appears a ridge development. The surface has an initial delimitation of the lower and /or upper extremities with or without nodule ossifications. The ventral rampart may occur in the beginning phases which is an extension of the bony activity at either or both extremities.
Phase III	The symphyseal face has a rampart or complete lower and ventral extremity. The continuous fusing of ossific nodules forms at the upper extremity and along the ventral border. The symphyseal face is smooth or shows continuous to distinct ridges. The dorsal plateau is complete but absences a lipping of symphyseal dorsal margin which is not bony ligamentous outgrowths.
Phase IV	The symphyseal face has fine grains although the old remnants of ridge and furrow may be remaining. The oval outline is usually complete in this phase but the upper ventral rim can appear as a hiatus. The pubic tubercle separates from the symphyseal face. The symphyseal face may have an obvious rim. At the ventral part, an inferior portion of pubic bone may occur the bony ligamentous outgrowths adjacent to the symphyseal face. If any lipping occurs it will be slight and located on the dorsal border.
Phase V	In this stage, the rim is completely but the symphyseal face may occur a slight depression or erode. The pubic tubercle is separated from the face. The quality of bone at the articular surface of the pubic symphysis is still good and so compact. In some cases, a few of porosity may occur but it occurs less than 15% of the symphyseal face. Only extremely mild signs of osteoporosis or osteopenia appear and the ventral aspect of the symphysis is normally not porous. Decision-makings of this phase are 1) the articular surface still has the majority of compact bone with less than 15% porosity anywhere on the surface, and 2) osteoporosis or osteopenia is absent or extremely mild. This score is a phase V. If either of these two traits is observed greater than specified, then the score is greater than a phase V.
Phase VI	The symphyseal face is normally depressed and the rim begins to erode at the superior ventral aspect. The quality of bone on the articular surface is collapse which is no longer retaining the smooth and compact surface. The symphyseal face is eroded and has porosities or small channel-like structures which combine with smaller porosities into oblong pores or channels. Osteoporosis is mild to a moderate level in this phase. Lipping of the articular surfaces can occur. Decision-makings of this phase are 1) The porous is less than 50% on the symphyseal surface and 2) the lipping is mild to moderate level So the score is a phase VI. If the symphyseal face appears to be borderline which is porous about 40–60% of a face but still a fair amount of compact bone, then osteoporosis or osteopenia should be used for the deciding feature. If this trait is moderate to severe so the score is phase VII.
Phase VII	The symphyseal face is the most porous and eroded more than 50% on the surface. Osteoporosis or osteopenia occurs and is usually moderate to severe. Since the rim is highly eroded and is losing definition, the symphyseal face appears to be flat. The ventral surface of the pubic symphysis is normally scarred or has a striated bone with ligamentous outgrowths. It occurs near the obturator foramen. Lipping of the articular surfaces is moderate but may be mild or severe.

Statistical Analysis

Descriptive statistics such as minimum, maximum, mean, standard deviation, and the number of samples were used in this study. In both dry bone and image parts, the linear regression statistics were used to estimate the correlation between the features and the age-at-death of samples. Afterward, the equations for age estimation were formulated by using the multiple regression statistics improved by the stepwise method. Moreover, the coefficient of determination (r2) and standard error of the estimate (SEE) was calculated (Igarashi et al., 2005). The age estimation function was created using SPSS and was tested on 50 blind cases using the best-performing formulas of two areas of the os coxae. The intra- and inter-observer reliabilities were tested on 30 randomly training cases using Cohen's kappa coefficient (Mukaka, 2012) in each method. IBM SPSS statistics version 22 was utilized to examine all data.

RESULTS

The total samples were 200 left os coxal dry bones (100 males and 100 females). The age range was from 26 to 94 years, and the mean age at death was 62.4 years. We found that sex did not affect the age in both dry bone and image parts.

For the dry bone part, when we observed at the auricular surface, transverse organization and surface texture were significantly correlated with age and SEE ± 13.997 years (Table 3). The best-performing equation for estimating age was model 2 with an accuracy of 84% in blind cases (Table 4). For the pubic symphyseal observation, the linear regression statistics showed phases and age-at-death were correlated and SEE ± 14.373 years (Table 3). The equation was derived for age estimation as Y(age) = 39.725 + 4.236*phase (Table 4). When this equation was tested on 50 blind cases, the accuracy was 74%. When we combined the variables of the auricular surface and pubic symphysis, we found the transverse organization, surface texture, and phases of pubis were correlated significantly with age-at-death, and R was higher than that of a single area. The equation was derived for age estimation as model 3 (Table 4). However, although a higher correlation was found and SEE ± 13.360 years (Table 3), the test accuracy was lower than those of the auricular surface and pubic symphysis only (72%). The intra observer agreement was substantial to almost perfect agreement (Kappa = 0.731 and 0.867 of the auricular surface and pubic symphysis, respectively). On the other hand, the inter observer agreement was slight to fair agreement (Kappa = 0.251 and 0.384 of the auricular surface and pubic symphysis, respectively).

Table 3 Correlation of variables with age-at-death of individual os coxa and best formulas derived from multiple regression statistics improved by stepwise method in dry bone and image parts.

Method	variables	Model	Sig.	R	R square	Std. Error of the Estimate (SEE)
Dry bone	Components of the auricular surface	1 (Constant) surface texture	0.000 0.000	0.401	0.161	14.213
		2 (Constant) surface texture transverse organization	0.000 0.000 0.006	0.439	0.192	13.977
	Phases of the pubic symphysis	(Constant) phase	0.000 0.000	0.376	0.142	14.373
	Auricular surface + Pubic symphysis	1 (Constant) surface texture	0.000 0.000	0.401	0.161	14.213
		2 (Constant) surface texture phase	0.000 0.000 0.000	0.495	0.245	13.517
		3 (Constant) surface texture phase transverse organization	0.000 0.000 0.000 0.018	0.516	0.266	13.360
Photo	Components of the auricular surface	1 (Constant) microporosity	0.000 0.000	0.339	0.115	14.598
		2 (Constant) surface texture microporosity	0.000 0.001 0.001	0.401	0.161	14.248
	Phases of the pubic symphysis	(Constant) phase	0.000 0.000	0.365	0.133	14.442
	Auricular surface + Pubic symphysis	1 (Constant) phase	0.000 0.000	0.365	0.133	14.442
		2 (Constant) phase surface texture	0.000 0.000 0.000	0.470	0.221	13.731
		3 (Constant) surface texture macroporosity phase	0.000 0.000 0.000 0.035	0.488	0.238	13.609

For the photo part, when we observed at the auricular surface, surface texture and microporosity were significantly correlated with age and SEE ± 14.248 years (Table 3). The best-performing equation for estimating age was model 2 with an accuracy of 80% in blind cases (Table 4). For the pubic symphyseal observation, the linear regression statistics showed that the phases and age-at-death were correlated and SEE ± 14.442 years (Table 3). The equation was derived for age estimation as Y(age) = 38.613 + 4.418*phase (Table 4). When this equation was tested on 50 blind cases, the accuracy was 76%. Similar to the previous section, we combined the variables of auricular and pubic areas, we found that the surface texture, macroporosity, and phases of pubis were correlated significantly with age-at-death and R was higher than that of single area. The equation was derived for age estimation as model 3 (Table 4). However, despite a higher correlation (SEE ± 13.609 years (Table 3), the test accuracy was still lower than those of the auricular surface and pubic symphysis only (78%), yielding similar results as the dry bone part. The intra-observer agreement was moderate to substantial agreement (Kappa = 0.508 and 0.767 of the auricular surface and pubic symphysis, respectively). On the other hand, the inter-observer agreement was slight to a fair agreement (Kappa = 0.131 and 0.27 of the auricular surface and pubic symphysis, respectively).

Table 4 Equations of age estimation derived from multiple regression statistics improved by stepwise method with significant variables in dry bone and image parts.

Methods	Variables	Model	Equations
Dry bone	Components of the auricular surface	1 (Constant) surface texture	Y(age) = 48.364 + 5.481* score of surface texture
		2 (Constant) surface texture transverse organization	Y(age) = 41.447 + 4.494*score of surface texture + 2.793*score of transverse organization
	Phases of the pubic symphysis	(Constant) phase	Y(age) = 39.725 + 4.236*phase
	Auricular surface + Pubic symphysis	1 (Constant) surface texture	Y(age) = 48.368 + 5.481* score of surface texture
		2 (Constant) surface texture phase	Y(age) = 32.845 + 4.515* score of surface texture + 3.355*phase
		3 (Constant) surface texture phase transverse organization	Y(age) = 28.038 + 3.757* score of surface texture + 3.161*phase + 2.304*score of transverse organization
Photo	Components of the auricular surface	1 (Constant) microporosity	Y(age) = 48.409 + 7.390* score of microporosity
		2 (Constant) surface texture microporosity	Y(age) = 42.861 + 3.905*score of surface texture + 5.285*score of microporosity
	Phases of the pubic symphysis	(Constant) phase	Y(age) = 38.613 + 4.418*phase
	Auricular surface + Pubic symphysis	1 (Constant) phase	Y(age) = 38.613 + 4.418*phase
		2 (Constant) phase surface texture	Y(age) = 28.758 + 4.012*phase + 4.927* score of surface texture
		3 (Constant) surface texture macroporosityphase	Y(age) = 25.485 + 4.377*score of surface texture + 3.132* score of macroporosity + 3.751*phase

DISCUSSION

In this study, we estimated the age by observing the auricular surface and pubic symphysis based on their morphology. According to the literature review, we chose the Buckberry-Chamberlain method for the auricular surface area and the Suchey-Brooks method and Berg method for the pubic symphysis area to apply in Thai population. We compared two methods (dry bone and 2D images of the os coxae) in terms of accuracy, SEE, and correlation between age and variables. In our experiment, we combined sexes as they did play a significant role in age estimation.

In theory, the transitional analysis method for age estimation was studied in pelvic and cranial structure, and Milner and Boldsen, 2012 studied the age estimation using transitional analysis in modern American skeletons. Their study showed the age intervals were the narrowest in young adults, but the late 40s into 70s became more uncertain. The pubic symphysis performed the best in estimating the age. They concluded that transitional analysis methods did not perform as well as experiment-based assessments. Therefore, the first systemic method of age estimating using pubic symphysis was initially studied by Todd (1920), and Brooks and Suchey, 1990 later modified his method to six phases. Their study performed exceptionally for estimating the age in young adults. Similarly, Berg, 2008 and Harnett, 2010 applied the Suchey-Brooks method in phases I-IV and they formed their new phases in V-VII. Their results showed a relatively high correlation with the age-at-death (r = 0.681 - 0.872). The Suchey-Brooks method was primarily popular for pubic age estimation in many studies. For example, Sakaue, 2006 performed the method on the Japanese skeletons and achieved highly reliable age predictions among young adults. Moreover, Wärmländer and Sholts, 2011 used the Suchey-Brooks method in two populations (Europe and Asia). Furthermore, Joubert et al., 2019 studied white South African populations with moderate positive correlations. In our study, we had a limited number of young samples (20-40 years). Our results yielded a low correlation with r = 0.365- 0.376, but the accuracy was moderate in blind cases with 74% - 76% for both dry bones and 2D images.

For the age estimating method using the auricular surface, Lovejoy et al., 1985 built a new method for estimating adult skeletal age. They observed at the auricular surface with eight components, their result showed the accuracy was equal to pubic symphyseal changes. Moreover, Osborne et al., 2004 used the Lovejoy method, and the range of age was narrower. Buckberry and Chamberlain, 2002 reduced components from eight to five for higher correlation with age. Their results yielded a slightly higher correlation than that of the pubic symphyseal changes. The auricular surface was comparably popular for age predictions. Michopoulou et al., 2017 compared the correlation with age between Schmitt and Buckberry-Chamberlain methods. The results showed the original Buckberry-Chamberlain method was more correlated with age, and the Schmitt method did not provide any correlation. Moreover, Rivera-Sandoval et al., 2018 compared four methods for bone age assessment consisting of Suchey-Brooks pubic symphysis, Lovejoy iliac auricular surface, Buckberry and Chamberlain iliac auricular surface and Rouge-Millart iliac auricular surface and acetabulum. Every method showed increased bias and low correlation with age except the Buckberry-Chamberlain method, which performed the best in older Columbian populations. Therefore, the

Buckberry-Chamberlain method was the gold standard for age estimation using the auricular surface. For example, Mulhern and Jones, 2005, Hens and Belcastro, 2012, and Moraitis et al., 2014 revised the method of age estimation using the auricular surface with a positive correlation with age-at-death. In Moraitis et al., 2014 study, the correlation of each feature and age ranged from 0.170 to 0.483. The stepwise multiple regression showed two features that were the best predictive variables: the surface texture and microporosity. Similarly, in our study, we found the surface texture and transverse organization were the best predictive variables in the dry bone part. In the photo part, the surface texture and microporosity were the best predictive variables similar to Moraitis's study. The implication from these results indicates the auricular surface yielded a high accuracy for estimating age.

Additionally, in our study, we combined two areas for estimating age for increasing the higher correlation with age. The results showed that the correlation of two areas combined was higher than that of one area of the os coxae. The surface texture, phase, and transverse organization were the best features for predicting the age in the dry bones, and surface texture, phases, and macroporosity were the best features in the photo part. Likewise, Pattamapaspong et al., 2019 combined two areas using the Suchey-Brooks and Buckberry-Chamberlain methods in the Thai population. They found that the phases of the pubic symphyseal method and surface texture of the auricular method were the highest correlated features with age. Moreover, Martins et al., 2012 estimated the age at death from the pubic symphysis and the auricular surface. Their statistics resulted in decreasing the bias of the estimates. In our experiment, the auricular surface was more accurate in the blind cases than that of pubic symphysis only and combined variables in both dry bone and photo parts. When we compared the age correlation between the auricular surface and pubic symphysis, we found the auricular surface was higher correlated with age than that of the pubic symphysis. Additionally, Hens et al., 2008 estimated the age in Italian skeletal collection using the pubic symphysis and the auricular area with Lovejoy and Suchey-Brooks methods, respectively. Their results showed that in both methods, bias and inaccuracy were increased in the samples aged over 40 years. The auricular surface method performed slightly better than the pubic symphysis method. Moreover, Millan et al., 2013 used two methods similar to the current study in the Spanish samples, and their results showed that the accuracies of estimation were 97.3% and 85.7%, for the Buckberry-Chamberlain method and Suchey-Brooks method, respectively. Although their study was more accurate than that of our study (accuracy = 80-84% of the auricular surface and 74-76% of pubic symphysis), the auricular surface performed the best for estimating the age in both studies. Also, the SEEs of Millan et al., 2013 were 11.24 years and 14.38 years for the auricular surface and pubic symphysis, respectively. In our study, SEEs were 13.99-14.24 years and 14.37-14.44 years, for the auricular surface and pubic symphysis, respectively, in both parts. Millan's study had a slightly narrower age range in the auricular surface than that of our study. In conclusion, the auricular surface performed better in age estimation than the method that relies on the pubic symphyseal changes.

2-Dimensional or 3-Dimensional Images are increasingly dominating in the medical field and forensic field, which include the uses of magnetic resonance imaging (MRI) scans, computed tomography (CT) scans, X-ray, photography, etc. (Suzuki, 2017; Ker et al, 2018). Many studies used 2D or 3D images in their experiment. For instance, Pattamapaspong et al., 2019 and Villa et al., 2015 used 3D computed tomography images for age-at-death estimation with moderate to strong correlations with age. Moreover, Bartolini et al., 2018 and Li et al., 2019 used 2D pelvic X-ray images for age estimation with high reliability for both reproducibility and repeatability. Therefore, we are interested in the applications of the 2D image that can easily be taken with the digital camera or mobile phones.

Nowadays, mobile phones are used worldwide and can take high-quality photographs like a digital camera. The strength of this study was using 2D images to compare with the traditional dry bone method, and our result showed the accuracy in blind cases, SEE, and R-values for both parts did not differ significantly. Therefore, the 2D os coxal images in this study can be efficiently applied to estimate the age among Thai individuals. For the future direction of this study, when a person encounters the human skeletal remains or pelvis at the crime scene, they can take photos of the os coxa in the top view position and send the images to an expert for estimating biological profiles remotely.

ACKNOWLEDGEMENTS

The authors are gratefully thankful for the support from Forensic Osteology Research Center, Faculty of Medicine, Chiang Mai University for the samples used in this study. We would also like to thank the Excellence in Osteology Research and Training Center (ORTC) with partially supported by Chiang Mai University. A special thanks to Patara Rattanachet for the linguistic review.

AUTHOR CONTRIBUTIONS

Pittayarat Intasuwan: Data curation, Writing - original draft preparation.
Patison Palee: Methodology, Software.
Apichat Sinthubua: Conceptualization, Methodology.
Pasuk Mahakkanukrauh: Conceptualization, Supervision, Writing - review and editing.

CONFLICT OF INTEREST

The authors declare no competing interests.

REFERENCES

Bartolini, V., Pinchi, V., Gualco, B., Vanin, S., Chiaracane, G., D'Elia, G., Norelli, G. A., Focardi, M., 2018. The iliac crest in forensic age estimation: evaluation of three methods in pelvis X-rays. Int. J. Legal Med. 132(1), 279–288.

Berg, G. E., 2008. Pubic bone age estimation in adult women. J. Forensic Sci. 53(3), 569–577.

Brooks, S., Suchey, J.M., 1990. Skeletal age determination based on the os pubis: A comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods. Human Evolution. 5, 227-238.

Buckberry, J. L., Chamberlain, A. T., 2002. Age estimation from the auricular surface of the ilium: a revised method. Am. J. Phys. Anthropol. 119(3), 231–239.

Cappella, A., Cummaudo, M., Arrigoni, E., Collini, F., Cattaneo, C., 2017. 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. 62(1), 12–17.

Dudzik, B., Langley, N. R., 2015. Estimating age from the pubic symphysis: A new component-based system. Forensic Sci. Int. 257, 98–105.

Hagelthorn, C. L., Alblas, A., Greyling, L., 2019. The accuracy of the transition analysis of aging on a heterogenic South African population. Forensic Sci. Int. 297, 370.e1–370.e5.

Hartnett, K. M., 2010. Analysis of age-at-death estimation using data from a new, modern autopsy sample--part I: pubic bone. J. Forensic Sci. 55(5), 1145–1151.

Hens, S. M., Belcastro, M. G., 2012. Auricular surface aging: a blind test of the revised method on historic Italians from Sardinia. Forensic Sci. Int. 214(1-3), 209.e1–209.e2095.

Hens, S. M., Rastelli, E., Belcastro, G., 2008. Age estimation from the human os coxa: a test on a documented Italian collection. J. Forensic Sci. 53(5), 1040–1043.

Igarashi, Y., Uesu, K., Wakebe, T., Kanazawa, E., 2005. New method for estimation of adult skeletal age at death from the morphology of the auricular surface of the ilium. Am. J. Phys. Anthropol. 128(2), 324–339.

Mukaka, MM., 2012. Statistics corner: A guide to appropriate use of correlation coefficient in medical research. Malawi Med J. 24(3):69-71.

Joubert, L. C., Briers, N., Meyer, A., 2019. Evaluation of the Suchey-Brooks age estimation method in a white South African population. Forensic Sci. Int. 301, e14–e19.

Ker, J., Wang, L., Rao, J., Lim, T., 2018. Deep learning applications in medical image analysis. IEEE Access. 6, 9375-9389.

Lam, J. F., Johansen, A. C., Rogers, T. L., 2016. An Evaluation of the Calce method for age estimation. J. Forensic Sci. 61(5), 1319–1321.

Li, Y., Huang, Z., Dong, X., Liang, W., Xue, H., Zhang, L., Zhang, Y., Deng, Z., 2019. Forensic age estimation for pelvic X-ray images using deep learning. European radiology, 29(5), 2322–2329.

Lovejoy, C. O., Meindl, R. S., Pryzbeck, T. R., Mensforth, R. P., 1985. Chronological metamorphosis of the auricular surface of the ilium: a new method for the determination of adult skeletal age at death. Am. J. Phys. Anthropol. 68(1), 15–28.

Martins, R., Oliveira, P. E., Schmitt, A., 2012. Estimation of age at death from the pubic symphysis and the auricular surface of the ilium using a smoothing procedure. Forensic Sci. Int. 219(1-3), 287.e1–287.e2877.

Mays, S., 2014. A test of a recently devised method of estimating skeletal age at death using features of the adult acetabulum. J. Forensic Sci. 59(1), 184–187.

Michopoulou, E., Negre, P., Nikita, E., Kranioti, E. F., 2017. The auricular surface as age indicator in a modern Greek sample: A test of two qualitative methods. Forensic Sci. Int. 280, 246.e1–246.e7.

Millán, M.S., Rissech, C., Turbón, D., 2013. A test of Suchey–Brooks (pubic symphysis) and Buckberry–Chamberlain (auricular surface) methods on an identified Spanish sample: paleodemographic implications. J. Archaeol. Sci. 40, 1743-1751.

Milner, G. R., Boldsen, J. L., 2012. Transition analysis: a validation study with known-age modern American skeletons. Am. J. Phys. Anthropol. 148(1), 98–110.

Miranker, M., 2016. A comparison of different age estimation methods of the adult pelvis. J. Forensic Sci. 61(5), 1173–1179.

Moraitis, K., Zorba, E., Eliopoulos, C., Fox, S. C., 2014. A test of the revised auricular surface aging method on a modern European population. J. Forensic Sci. 59(1), 188–194.

Mulhern, D. M., Jones, E. B., 2005. Test of revised method of age estimation from the auricular surface of the ilium. Am. J. Phys. Anthropol. 126(1), 61–65.

Osborne, D. L., Simmons, T. L., Nawrocki, S. P., 2004. Reconsidering the auricular surface as an indicator of age at death. J. Forensic Sci. 49(5), 905–911.

Pattamapaspong, N., Kanthawang, T., Singsuwan, P., Sansiri, W., Prasitwattanaseree, S., Mahakkanukrauh, P., 2019. Efficacy of three-dimensional cinematic rendering computed tomography images in visualizing features related to age estimation in pelvic bones. Forensic Sci. Int. 294, 48–56.

Rivera-Sandoval, J., Monsalve, T., Cattaneo, C., 2018. A test of four innominate bone age assessment methods in a modern skeletal collection from Medellin, Colombia. Forensic Sci. Int. 282, 232.e1–232.e8.

Sakaue, K., 2006. Application of the Suchey-Brooks system of pubic age estimation to recent Japanese skeletal material. Anthropol. Sci. 114(1), 59-64.

Shirley, N. R., Ramirez Montes, P. A., 2015. Age estimation in forensic anthropology: quantification of observer error in phase versus component-based methods. J. Forensic Sci. 60(1), 107–111.

Suzuki, K., 2017. Overview of deep learning in medical imaging. Radiol. Phys. Technol. 10(3), 257–273.

Todd, T.W., 1920. Age changes in the pubic bone. I The male White pubis. Am. J. Phys. Anthropol. 3: 285–334.

Villa, C., Buckberry, J., Cattaneo, C., Frohlich, B., Lynnerup, N., 2015. Quantitative analysis of the morphological changes of the pubic symphyseal face and the auricular surface and implications for age at death estimation. J. Forensic Sci. 60(3), 556–565.

Wärmländer, S. K., Sholts, S. B., 2011. Sampling and statistical considerations for the Suchey-Brooks method for pubic bone age estimation: implications for regional comparisons. Sci. Justice. 51(3), 131–134.

How to cite this article;

Pittayarat Intasuwan Patison Palee Apichat Sinthubua and Pasuk Mahakkanukrauh. Efficiency of dry bone inspection compared with two-dimensional os coxal images for age estimation in a Thai population. Veterinary Integrative Sciences. 2022; 20(1): 185- 197.
