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REVIEW ARTICLE

Sex estimation in the South-East Asian population: A systematic review

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Abstract

Introduction: Sex estimation is crucial in forensic anthropology. In situations such as mass disasters, and forensic anthropology cases, sex estimation is a very important initial step in the disaster victim identification process. Literature has acknowledged that sex estimation is population-specific. However, sex estimation standards in South-East Asian populations are limited, leading to the usage of most Thais discriminant function equations on sex estimation by other South-East Asian countries including Malaysia. This systematic review was conducted to summarise the findings of sex estimation studies in South-East Asian countries. *Materials and Methods:* A systematic literature search was performed through the SCOPUS database and Web of Science (WOS) database for relevant studies between 2014 and 2022. All published articles that are related to sex estimation from different types of bone, methods, landmarks, and sample sources (i.e., photographs, dry bones, and CT images) were included in this review. The main inclusion criteria were studies on (i) sex estimation; (ii) in South-East Asian populations; (iii) between the years 2014 and 2022; and (iv) in English. *Results:* The literature search identified 30 potentially relevant studies, of which 15 publications met all the inclusion criteria. From those research, 13 studies were related to the Thai population and two to the Malaysian population. Only one study was based on morphological traits, while the rest were based on a morphometric approach. *Conclusion:* All studies found that sex estimation is population-specific. Therefore, further research is recommended to explore more on population-specific sex estimation using different parts of bone.

Keywords: Forensic anthropology, Sex estimation, South-East Asian, Systematic review

INTRODUCTION

Forensic anthropology is concerned with the analysis and identification of decomposed or skeletal remains, which includes the construction of a biological profile and the evaluation of bone pathologies and trauma.[1] The process of identification and investigation of fresh remains is relatively straightforward, as internal organs and body structures are available for examination. Difficulties arise when the body received is in a state of decomposition either fully or partially, fully skeletal, or in the form of bone fragments. Therefore, the science of forensic anthropology is very important.

For forensic anthropologists, biological profiling is a routine task for every case which includes estimating sex, age, ancestry, and stature. Determination of biological profiles through bones can help in the process of narrowing the scope of investigation. Today, these contexts are augmented by the analysis of mass graves in global human rights investigations, for example the Wang Kelian mass grave in Malaysia[2], and decedents in mass disasters such as massive floods.[3]

Often pelvic bones and skulls are used in the process of sex estimation due to their morphological traits that are highly sexually dimorphic. High sexual dimorphism between female and male pelvis and skulls is due to the differences in their biological and physiological function in both sexes. Assessment of sex using the skull and pelvis does not require any metric methods, they can be assessed morphologically.

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The female pelvis shows a wider shape compared to the male because of its functional requirement for childbirth. That is why both bones are usually used in sex estimation. In situations where these bones are not available, other bones should be fully utilised, such as the sternum, humerus, femur, and cervical.

According to Franklin *et. al*[4], if the statistical model for skeletal sex and age estimation were applied to individuals foreign to the reference sample, there would almost always be an associated reduction in classification accuracy. Therefore, this study highlighted the importance of and necessity for a population-specific standard.

Population-specific standards are important due to human variation. It is acknowledged that skeletal characteristics differ among various populations.[5] Geographic, socioeconomics, health, climate changes, lifestyle, and immigration were among the factors that contributed to human evolution and variation.[4] This is supported by findings from research done by Myint tun, S., *et. al*[6] where they found that the length of mesosternum in their current study was longer compared to the length of mesosternum of sample from the previous study done by Mahakkanukrauh in 2001. The previous study used a skeletal sample from Northern Thailand a decade ago, while the current study used a skeletal sample collected from the Forensic Osteology Research Centre at Chiang Mai University Thailand. The authors concluded that the difference in the mesosternum length between the two research samples was possibly due to the population experiencing secular changes, different lifestyles, and nutritional patterns. Moreover, the samples used in their current study were different. Therefore, it is shown that there is a population difference, even in the same country. The importance of population-specific standards was emphasised by researchers.[5-21]

This systematic review aims to summarise findings on sex estimation specifically in South-East Asian countries to (i) gather new knowledge of forensic anthropology practice in South-East Asians, and (ii) investigate the current forensic anthropological practice and techniques used for sex estimation in South-East Asian countries.

MATERIALS AND METHODS

Data sources and searches

Literature search was conducted in February 2022 using the SCOPUS and Web of Science database. The search was limited to publications between year 2014 and 2021 to see the current trends in forensic anthropology. All published articles related to sex estimation from different types of bone, methods, and types of measurements/landmarks (i.e., using photographs, dry bones, and CT scan images) were included in this review. The main inclusion criteria for the literature search are sex estimation articles published in English, published between the years 2014 and 2021, and on South-East Asian populations. The search method involved a combination of the following keywords: "sex estimation", "South-East Asian", and "sex estimation Malaysia" followed by names of other South-East Asian countries (Indonesia, Brunei, Thailand, Myanmar, Singapore, Philippines, Laos, Cambodia, and Vietnam). This is to avoid missing any relevant articles. Articles that meet the inclusion criteria, but cannot be retrieved, and with limited access were excluded from the review.

Study Selection

All published articles that met the inclusion criteria were included in this study regardless of the type of bones being used. Based on the title and abstract information, the included studies were filtered. Therefore, only fifteen articles met the inclusion criteria, and are being reviewed in this study.

Managing References

All searched articles were exported into EndNote 20 reference management software. Duplicated articles were identified individually. From the list of references listed in the software, no duplicated articles were found, and all articles retrieved were within the inclusion criteria. The selection of articles for this study was performed by the first author with the approvals of other authors.

Data Extraction

Data extracted from the articles were presented in the form of a systematic review, which included an abstract, introduction, materials and methods, results, discussion, and conclusion. This review was prepared according to PRISMA guidelines.

Ethics

This review was approved by the National Medical Research Register (NMRR): NMRR ID-22-01147-IOS. Ethics approval and consent to participate are not applicable in this study.

RESULTS

Selection and Characteristics of Studies

There was a total of 777 articles retrieved from SCOPUS and Web of Science (WoS) databases. Out of 777 articles, 767 remained after removing all duplicates. After revising the title and abstract of the articles, 736 were removed due to irrelevance to the study. Only 31 articles were fully reviewed. Three articles were removed due to limited access to the full text, and another 13 articles were excluded due to not fulfilling the inclusion criteria. Finally, 15 articles were found to be eligible to be included in the present study.

Figure 1 shows the flow diagram of study selection, while Table 1 shows the list of summaries of sex estimation in South-East Asian populations articles published between 2014 and 2021. The list was arranged according to country, namely, Malaysia (2) and Thailand (13).

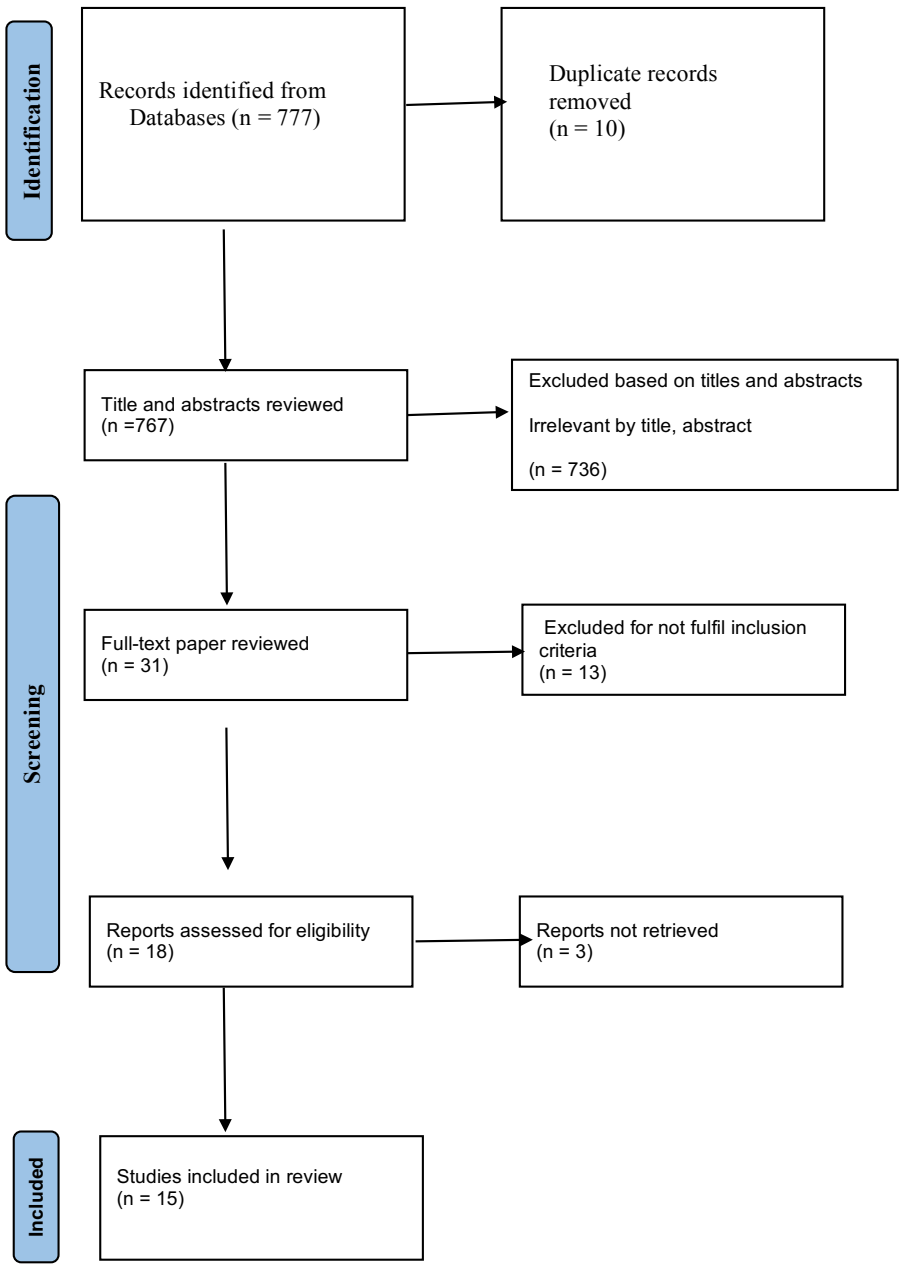

FIG. 1: Flow diagram of study selection.

TABLE 1: Sex estimation in Southeast Asian Population

No.	Author	Study	Population	Methods	Bones	Sample size	Age range
1	Suwanlikhid *et al*. (2020)	Sex and stature estimation from adult Lumbar Vertebrae in a Thai population based on image analysis	Thailand	Dry bones (morpho-metric)	Lumbar column (Photographed of bones)	150 75 males 75 females	22 to 89 years
2	Sintubua *et al*. (2017)	A new method for sex estimation from maxillary suture length in a Thai population	Thailand	Dry bones (skull) (morpho-metric)	Maxilla (maxillary suture) was photographed using a Canon EOS camera (Tokyo, Japan)	190 96 males 94 females	15 to 93 years
3	Duangto & Mahakkan ukrauh (2020)	Sex estimation from upper limb bones in a Thai population	Thailand	Skeleton (morpho-metric)	Humerus, ulna, radius	228 114 males 114 females	36 to 91 years
4	Mahakkan ukrauh *et al*. (2014)	Sex estimation from the talus in the Thai population	Thailand	Skeleton (morpho-metric)	Talus	252 126 males 126 females	22 to 91 years
5	Techatawe ewan *et al*. (2021)	Metric sexual dimorphism of the skull in Thailand	Thailand	Dry bones (morpho-metric)	Skulls	322 162 females 160 males	24 to 94 years
6	Jongmuen wai *et al*. (2021)	Sex estimation using radius in a Thai population	Thailand	Dry bones (morpho-metric)	Radius	200 100 males 100 females	Male 19 to 90 years Females 29 to 91 years
7	Peckmann *et al*. (2017)	Sex estimation from the scapula in a contemporary Thai population: Applications for forensic anthropology	Thailand	Dry bones (skeletal) (morpho-metric)	Scapulae	191 95 males 96 females	19 to 96 years
8	Myint tun *et al*. (2015)	Sex determination from different sternal measurements: A study in Thai population.	Thailand	Dry bones (morpho-metric)	Sternum	281 192 males 89 females	28 to 96 years

9	Naksuwan *et al*. (2021)	Sacral morphometrics for sex estimation of dead cases in Central Thailand	Thailand	Skeleton (morpho-metric)	Sacral	78 46 males 32 females	-
10	Mahakkan ukrauh *et al*. (2017)	Osteometric sex estimation from the os coxa in a Thai population	Thailand	Skeleton (morpho-metric)	Coxal bone	200 100 males 100 females	22 to 94 years
11	Tallman & Blanton (2020)	Distal humerus morphological variation and sex estimation in modern Thai individuals.	Thailand	Skeleton (morpho-logy)	Humerus	616 198 females 418 males	18 to 96 years
12	Barnes *et al*. (2019)	Sex estimation from the carpal bones in a Thai population	Thailand	Skeletons (morpho-metric)	Carpal bones	100 50 males 50 females .	Males 37 – 59 years Females 26 – 63 years
13	Scott *et al*. (2017)	Sex estimation from measurements of the calcaneus: Applications for personal identification in Thailand.	Thailand	Skeleton (morpho-metric)	Calcaneus (left)	232 116 males 116 females	22 to 96 years.
14	Mohd Ali *et al*. (2020)	Sex estimation using the subpubic angle from reconstructed three-dimensional computed tomography pelvic model in a contemporary Malaysia population.	Malaysia	Multidetector computed tomography (MDCT)	Pelvis (morpho-metric)	100 50 males 50 females	Males 20 – 78 years Females 20 – 79 years
15	Fauad *et al*. (2021)	Sexual dimorphism from third cervical vertebra (C3) on lateral cervical radiograph: A 2-dimensional geometric morphometric approach.	Malaysia	X-ray (Two-dimension (2D) geometric morphometric)	Cervical (C3) (morpho-metric)	432. 262 males 170 females	20 to 60 years

DISCUSSION

As a result of the literature search for articles in Southeast Asia, only 15 articles were retrieved related to sex estimation. Of those 15 articles, two were based on a Malaysian population and 13 were on the Thai population. Findings on other Southeast Asian countries are not available in the literature. Compared to Thailand, digital images were widely used in Malaysian anthropology research due to the limited source of dry bones. Therefore, the most convenient and resourceful method was to use the virtual anthropological examination.

Thai researchers utilised a large number of samples to be used for anthropology research as they have access to several skeletal remains collections. In this review, research done by Thai researchers assessed skeletal remains from Khon Kaen University and the Forensic Osteology Research Centre in the Faculty of Medicine, Chiang Mai University. In Thailand, body donation contributes to the large number of skeletal collections. Body bequests are accepted from the age of 18 years and donations are also accepted at the time of death from the next of kin on a case-by-case basis.[22] The current Thai skeletal collection consists of skeletons macerated from bodies bequeathed between 1979 and 2014. This gives a maximum period of 35 years during which the collection has accumulated. The main centres that housed the skeletal collections were Khon Kaen University and Forensic Osteology Research Centre, Chiang Mai University.

Much research is being conducted using various parts of the skeletal system. From 13 articles retrieved, it can be summarised that the lumbar, maxilla, humerus, radius, ulna, talus, cranium, mandible, scapulae, sternum, sacral, os coxa, carpal, and calcaneus bones had been used by the Thais researcher for sex estimation study. All research concluded that sex estimation is population-specific, and suggested a population-specific sex estimation method being developed for other populations. In research done by Scott *et al*.[17], they illustrate the necessity of population-specific discriminant functions for the Thai population by entering the Thai metric data into the discriminant functions derived from other studies including Greek, white South African, black South African, and southern Italian population. With a sample size of 232 subjects, consisting of 116 males and 116 females, they found that the average accuracy rates of the cross-validated Thai discriminant functions ranged from 50.0% to 84.3%, which is lower than the overall accuracy rates of the original population functions.

Out of 13 research papers on the Thai population, only one used a morphological method for assessment, while others were using morphometric assessment. Computed tomography (CT), three-dimensional (3D) imaging, and geometric morphometric (GM) methods are currently widely used by anthropologists, allowing them to study morphological structures virtually through multivariate methods.[23] A geometric morphometric method is an approach that utilises a qualitative description of biological forms according to geometric definitions of their shape.[10]

All research was conducted using dry bones/full skeletal since Thailand has numerous sources of dry bones and skeletal. This is evident by the sample size in each study. Out of 13 studies, only one study with a sample size of 78[15], and other studies had sample sizes of more than 100, with a maximum of 600 samples.[6-9,12-18,20,21] Out of 12 research using dry bones/skeletal, only one study took measurements on photographs of the bones.[18] It is acknowledged that image analysis generates quantitative analysis by sex and stature estimate with a method comparable to other methods and provides consistent results.[7]

Malaysian and Thais had conducted sex estimation studies using the pelvis (Table 2). Mohd Ali *et al*.[5] used multidetector computed tomography (MDCT) scans of 50 male and 50 female Malaysian adults. In which segmentation of the MDCT scans was performed using 3D Slicer, and four landmarks of subpubic angle were measured using Stratovan Checkpoint: L1 and L4 – most inferior points on ischiopubic ramus, L2 and L3 – most anteroinferior points on symphysis pubis. They found that the subpubic angle in females was significantly larger than in males ($p<0.001$) where males were $68.6^{\circ}\pm7.6^{\circ}$ and in females $87.4^{\circ}\pm 6.5^{\circ}$. The overall accuracy of sex estimation using the subpubic angle was 94% ($p<0.001$). Therefore, they concluded that sex estimation using subpubic angle is highly accurate, with a high degree of expected sensitivity and specificity in the Malaysian population.

While for the Thai population, Mahakkanukrauh *et al*.[14] had done a sex estimation study using coxal bones. A 200 pair of coxal bones were used, and six parameters were measured: maximum width of the ilium (MW),

Table 2: Sex estimation from pelvic bones

Author (yr)	Bones	Parameters	Accuracy	Outcomes
Mohd Ali *et al*. (2019)	Pubic	L1 and L4 – most inferior points on ischiopubic ramus, L2 and L3 – most anteroinferior points on the symphysis pubis	94%	Results show the subpubic angle in females was significantly larger than in males ($p<0.001$). Therefore, sex estimation using the subpubic angle is highly accurate, with a high degree of expected sensitivity and specificity in the Malaysian population.
Mahakkan ukrauh *et al*. (2016)	Coxal	Maximum width of the ilium (MW) Pubis length (PL) Ischium length (IL) Total height of the os coxa (TH) Acetabulum diameter (AcetD) Pubic tubercle-acetabulum length (PTAD). Another 8 indices were measured: Ischio-pubic index (IP) Pubis length-total height index (PL-TH) Acetabular diameter-maximum width index (AcetD-MW) Maximum width-total height index (MW-TH) Acetabulum diameter-pubic tubercle-acetabular index (AcetD-PTAD) Pubic tubercle-acetabular-ischium length index (PTAD-IL) Ischium length-total height index (IL-TH) Pubic tubercle-acetabular-maximum width index (PTAD-MW).	72% - 95.5%	Independent t-test revealed statistically significant differences between males and females for all but one of the measurements. The equation with the highest correct allocation accuracy was based on 4 measurements (pubis length, ischium length, total height, and acetabulum diameter). The single variable equation with the highest correct allocation accuracy of 94.4% and a tested accuracy of 97.5% was for the ischiopubic index, which is calculated from ischium length and pubis length. Four coxal bone measurements, used together, obtained from complete os coxa can deliver almost 97% sex allocation accuracy. Also, only 2 measurements used for computing the indices are required to obtain sexing accuracies over 90%.

pubis length (PL), ischium length (IL), total height of the os coxa (TH), acetabulum diameter (AcetD), and pubic tubercle-acetabulum length (PTAD). Another 8 indices were measured: ischio-pubic index (IP), pubis length-total height index (PL-TH), acetabular diameter-maximum width index (AcetD-MW), maximum width-total height index (MW-TH), acetabulum diameter-pubic tubercle-acetabular index (AcetD-PTAD), pubic tubercle-acetabular-ischium length index (PTAD-IL), ischium length-total height index (IL-TH), and pubic tubercle-acetabular-

maximum width index (PTAD-MW). They found a significant difference in measurements between males and females for all but one, that is ischium length (IL). The accuracy range was 72%-95.5%, and therefore, they concluded that the equation derived from their study would be a standard formula for Thai individuals since there is no other study available. They also stated that the equation derived from their study will be an invaluable tool for sex identification in forensic circumstances, especially when an incomplete pelvis is all that remains.

In a study done by Mohd Fauad *et al*.[10], two-dimensional (2D) X-ray images of cervical C3 of 432 samples comprising 262 males and 170 females were examined for sex estimation. This study involves measurements from 11 landmarks: L1 – the most anterior and superior point of the C3 vertebra body, L2 - the most posterior and superior point of the C3 vertebra body, L3 - the most posterior and inferior point of the C3 vertebra body, L4 - the most anterior and inferior point of C3 vertebra body, L5 – the most anterior point of C3 superior zygapophyseal joint, L6 - the most posterior point of C3 superior zygapophyseal joint, L7 – the most posterior point of C3 inferior zygapophyseal joint, L8 - the most anterior point of C3 inferior zygapophyseal joint, L9 – the most anterior and superior point of C3 spinous process, L10 – the most anterior and inferior point of C3 spinous process, and L11 – the tip of the spinous process. They found out that, males have larger cervical vertebra landmark distances as compared to females. The results of their research demonstrated a robust sexual dimorphism in the C3 vertebra morphology among the Malaysian adult population.

Myint Tun *et al*.[6] used 281 adult Thais dry sterna of known sex (192 males, 89 females) to research sex estimation using sternum. There were 10 parameters being measured and analysed. All parameters included in the study were significantly sexually dimorphic except the sternal width index (p=0.176). Discriminant function analyses were used to determine which parameter can be used for sex determination and to create formulae that may be useful in cases where a well-preserved sternum with both manubrium and mesosternum could not be found. Cross-validation methods were used to evaluate the performance of the discriminant function model obtained for sex determination in unknown cases. From the data analysis, they found out that, the best parameter was the combined length of manubrium and mesosternum with a cross-validation sex accuracy rate of 85.8% (82.4% male and 95.7% female). Followed by the sternal area with a classification accuracy rate of 82.9% (79.2% male and 91.2% female), and the length of mesosternum with a classification accuracy rate of 81.1% (78.8% male and 88% female). Stepwise discriminant function analysis which includes 5 linear measurements from both manubrium and mesosternum yielded the highest classification accuracy rate of 86.4%. Therefore, they concluded that the sternum is a reliable element for sex determination. They also stated that their findings were in line with most of the previous studies conducted on dry sternums of their images.

In this systematic review, four studies were done by Thai researchers using upper limb bones as the sample for sex estimations (Table 3). The upper limb, the forelimbs of an upright-postured tetrapod vertebrate, extends from the scapulae and clavicles down to the knuckle joints which include the shoulder, elbow, and wrist. The upper limb bones are the clavicle, scapula, humerus, radius, ulna, carpal bones, metacarpal bones, and phalanges. A sex estimation study using scapula in a contemporary Thai population was done by Peckmann *et al*.[16] and resulted in a formulation of population-specific discriminant functions for the Thai population with an overall sex classification accuracy rate of 83% to 88%. Their study aims to evaluate the accuracy of sex estimation discriminant functions, created using contemporary Mexican and Greek populations when applied to a contemporary Thai sample. The study was done using dry bones of 191 individuals (95 males and 96 females). The length of the glenoid cavity (LGC) of the scapula and the breadth of the glenoid cavity (BGC) of the scapula were measured and recorded. There is no statistically significant difference between the left and right scapula, therefore only the left scapula is being measured. The intra- and inter-observer error rates show no statistically significant difference between left and right LGC and BGC measurements ($p>0.05$). Descriptive statistical analysis was done and resulted in LGC and BGC being larger in male scapulae than in females, both with p-values <0.05, indicating that both LGC and BGC were sexually dimorphic in the contemporary Thai sample. Comparison with other populations was done, which resulted in the scapulae of the Thai population being smaller than the Mexican, White American, and Greek populations but larger than the Guatemalan sample. As a result, from their study,

Table 3: Sex estimation from upper limb bones

Author (yr)	Bones	Parameters	Accuracy	Outcomes
Tallman & Blanton (2019)	Distal humerus	MEA, OFS, TE, TC	37.7% - 100%	Ordered logit analyses indicate that all four traits are sexually dimorphic with significance values for sex below 0.001. All 4 distal humerus traits are minimal to moderately positively correlated. Medial epicondyle angle and trochlear extension are most correlated. Medial epicondyle angle and olecranon fossa shape are the least correlated. Overall, the results demonstrate that distal humerus morphology can predict the sex in modern Thai individuals; however, the traits are somewhat less sexually dimorphic than in non-Asian groups, as demonstrated by the relatively large sex biases. In particular, distal humerus morphology can predict the sex of modern Thai individuals using population-specific univariate statistics (37.7 – 90.1%, composite scores (77.0 – 90.1%), binary logistic regression equations (63.3 – 92.2%), and binary probit regression (74.1 – 100%)
Jongmuenwai *et al*. (2020)	Radius	MDH, MNH, UNL, RDEW, CN, UNW, HTL, CT	90.5% - 91.5%	The most dimorphic single parameter was maximum head diameter (MDH) with accuracies of 92.0% for the right side and 90.5% for the left side At the distal part of the radius, the distal end width of the radius (RDEW) was the best sex indicator, in which the sex classification accuracies were 91.5% and 89.0%, for the right and left sides, respectively. The circumference of the radial neck, head tuberosity length, MDH, and RDEW were selected for the stepwise procedure as these parameters produced the correct classification results for both sides. The fragments of radius indicated a high ability to estimate sex in the Northern Thai population.

Author (yr)	Bones	Parameters	Accuracy	Outcomes
Duangto & Mahakkan ukrauh (2020)	Humerus, ulna, radius	MaxH, EH, MaxmH, MinmH, MaxU, APU, MLU, PhyU, MinU, MaxR, APR, MLR	89.5% - 98.2%	Results show that the male bone lengths were longer than the female. All measurement shows significant differences between males and females ($p<0.05$), indicating high sexual dimorphism in Thai samples. For univariate discriminant function analysis, the result showed that the epicondylar breadth of the humerus, the physiological length of the ulna, and the anteroposterior diameter at the midshaft of the radius were the best indicators for sex estimation in the humerus, ulna, and radius, respectively. As a conclusion, the discriminant function equations derived from upper limb bone measurements provided highly accurate sex estimation in Thai samples. Therefore, these equations using humerus, radius, and ulna measurements can be applied for sex estimation with good accuracy in Thais.
Peckman *et al*. (2017)	Scapula	LGC, BGC	83% - 88%	LGC and BGC are larger in the male scapulae than the female scapulae, with p-values are <0.05 for both, indicating that both the LGC and BGC measurements were sexually dimorphic in the contemporary Thai sample. Population-specific discriminant functions were created for the Thai population with an overall sex classification accuracy rate of 83% to 88%.

they created a population-specific discriminant function for the Thai population with an overall sex classification accuracy rate of 83% to 88%.

The other three studies on sex estimation using upper limb bones of the Thai population were done using distal humerus[20], radius[12], and humerus, ulna, and radius[9] (Table 3). Sex estimation of the humerus was done by Tallman & Blanton[20], and Jongmuenwai *et al*.[12], using a different approach and different parts of the humerus. Tallman & Blanton[20] involved a morphological method focusing on the distal parts of the humerus, where they used medial epicondyle angle (MEA), olecranon fossa shape (OFS), trochlear extension (TE), and trochlear constriction (TC) as the parameter. The morphological traits of the parameters were observed and scored based on Vance *et al*. based on their "female-like"/"women" or "male-like"/"male" diagrams and descriptions. On the other hand, research done by Duangto & Mahakkanukrauh[9], involved a morphometric method focusing on the entire humerus, measuring 4 parameters of the humerus, the maximum length of the humerus (MaxH), epicondylar breadth of the humerus (EH), maximum diameter at the midshaft of the humerus (MaxmH), and minimum diameter at the midshaft of the humerus (MinmH). Both studies concluded that humerus can be used in the sex estimation of Thai populations. Tallman & Blanton[20], specifically concluded that distal

humerus morphology can be used to estimate the sex of Thai individuals when a more sexually dimorphic region is absent. Sex estimation using radius in a Thai population study was done by Jongmuenwai *et al*.[12], and Duangto & Mahakkanukrauh[9], using a morphometric method but with different parameters. Jongmuenwai *et al*.[12], measure the radius maximum diameter of the head, the minimum diameter of the head, the circumference of the neck, the head-tuberosity length, the circumference of the tuberosity, ulnar notch length, ulnar notch width, and distal end width of the radius, while parameters measured by Duangto & Mahakkanukrauh[9], were anteroposterior diameter at the midshaft of the radius and mediolateral diameter at the midshaft of the radius for both left and right radius. Both studies result in the development of sex estimation function from the parameters being measured. Jonmuenwai *et al*.[12] concluded that their study provides sex estimation functions for various measurements that can be applied to the radius of Northern Thai individuals with an accuracy of over 85%. Duangto & Mahakkanukrauh[9], with an accuracy rate of 89.5%-98.2%, concluded that their results confirm that the discriminant function equations using measurements of upper limb bines are useful for estimating sex. Therefore, the metric method of sex estimation using the upper limb bones can be used to identify sex with great accuracy in the Thai population.

The lower limb is a part of the human body and consists of the thigh, leg, and foot. The thigh consists of the femur, while the leg consists of 2 long bones are tibia and fibula, and the sesamoid bone, the patella which serves as the knee cap. Lastly, the foot consists of tarsal, metatarsal, and phalanges. In this systematic review, of 15 papers being reviewed, 3 of them were studies done using the lower limb bones (Table 4). All 3 studies examined the foot bones, calcaneus[17], carpal[8], and talus.[13] From these 3 studies, sex estimation using talus used the highest number of samples 252 skeletons, followed by sex estimation using calcaneus 232 individuals, and sex estimation using carpal used the least sample 100 skeletons. In both sex estimation using calcaneus and talus, all the parameters used in the study result in a significant range of accuracy percentage.

Scott *et al*.[17], investigated 9 parameters in their study of the calcaneus: maximum length (MAXL), maximum height (MAXH), cuboidal facet height (CFH), body height (BH), minimum breadth (MINB), load arm length (LAL), middle breadth (MIDB), dorsal articular facet breadth (DAFB), and dorsal articular facet length (DAFL). They found out that all nine parameters were useful in sex estimation using calcaneus with overall cross-validation accuracies ranging from 73.4% to 94.3%. They compare their findings to other populations, and they found out that, the comparison result demonstrates the need for a population-specific discriminant function for sex estimation using calcaneus. On the other hand, all 10 parameters from the talus used by Mahanukkrauh *et al*.[13] maximum talar length (MaxLg), maximum talar breadth (MaxBr), maximum talar height (MaxHt), maximum trochlear length (MaxTrLg), maximum trochlear breadth (MaxTrBr), maximum length of the inferior articular surface (MaxIASLg), maximum breadth of the inferior articular surface (MaxIASBr), minimum inferior interarticular distance (MinIID), maximum lateral malleolar surface height (MaxLMSHt), and minimum interarticular distance across the neck (MinIDNk), were acceptable to be used for sex estimation in a forensic context. However, from their findings, they suggested other researchers consider trochlear length and breadth to be included in their analysis. This suggestion was made based on their combined logistic regression results, which ranged from 79.1%-89.8%. The results show that trochlear length and breadth were the most accurate measurements for sex estimation using talus in the Thai population.

Compared to Scott *et al*.[17], and Mahanukkrauh *et al*.[13], Barnes *et al*.[8] had performed a study of sex estimation using carpal bones of the Thai population, using 100 skeletons, with the most parameters being measured among the three studies, 15 parameters, trapezium maximum length (Trapezium ML), scaphoid maximum length (Scaphoid ML), lunate maximum length (Lunate ML), capitate maximum height (Capitate MH), lunate maximum width (Lunate MW), trapezoid maximum height (Trapezoid MH), hamate maximum height (Hamate MH), capitate distal base maximum length (Capitate DBML), hamate hamulus maximum width (Hamate HMW), trapezoid dorsal surface length (Trapezoid DSL), scaphoid Radial Facet Maximum Length (Scaphoid RFML), Trapezoid Trapezium Facet Maximum Length (Trapezoid TFML), Trapezium MC 1 Facet Maximum Length (Trapezium MC1FML), Hamate MC 5 Facet Height (Hamate MC5FH), and Triquetrum

TABLE 4: Sex estimation from lower limb bones

Author (yr)	Bones	Parameters	Accuracy	Outcomes
Scott *et al*. (2017)	Calcaneus	MAXL, MAXH CFH BH MINB LAL MIDB DAFB DAFL	73.4% - 94.3%	All variables are larger in male calcanei than in female calcanei. All p-values are less than 0.005 ($p<0.005$), which indicates the presence of significant sexual dimorphism in all calcanei variables. MIDB variable showed the highest overall original accuracy rate (84.6%), which indicates that this variable is a good predictor of sex in the contemporary Thai population. Multivariate analyses showed accuracy rates from 81.5% to 87.7% in males and 84.05 to 87.7% in females. Univariate analyses showed accuracy rates from 71.6% to 84.05% in males and 67.9% to 85.2% in females. This study demonstrates that the calcaneus is useful for sex estimation in the contemporary Thai population.
Barnes *et al*. (2019)	Carpal	Trapezium ML Scaphoid ML Lunate ML Capitate MH Lunate MW Trapezoid MH Hamate MH Capitate DBML Hamate HMW Trapezoid DSL Scaphoid RFML Trapezoid TFML Trapezium MC1FML Hamate MC5FH Triquetrum HFMW	69.9% - 92%	6 of the 7 carpals produced logistic regression equations with correct allocation accuracies of 84.0% or higher. The only exception was the triquetrum, which did not reach the 80% threshold. This result suggests a fair degree of sexual dimorphism in the wrists of Thai individuals. The trapezium, trapezoid, and capitate all had at least one measurement that produced a correct allocation accuracy of 87.8% or higher. These 3 bones appear to show the greatest sexual dimorphism among this Thai sample. The only bone that did not have at least one measurement that correctly allocated individuals above the 805 threshold was the triquetrum. The trapezium appears to be the most useful bone for sex estimation in this Thai sample. Overall, the results of this study suggest that it is possible to obtain 90% correct allocation accuracy or better for the sexing of modern Thai individuals using either the right trapezium or the right scaphoid.

Author (yr)	Bones	Parameters	Accuracy	Outcomes
Mahanuk-krauh *et al*. (2014)	Talus	MaxLg MaxBr MaxHt) MaxTrLg MaxTrBr MaxIASLg MaxIASBr MinIID MaxLMSHt MinIDNk	79% - 89.8%	Averaging the results from both sides, the individual measurements with the highest correct allocation accuracies based on logistic regression analysis were trochlear length (88.2%), trochlear breadth (87.3%), talar length (85.5%), and inferior articular surface length (84.5%). When pairs of measurements were considered using logistic regression, 4 equations produced predicted allocation accuracies greater than 90% - 3 from the right talus, and 1 from the left. The highest accuracy on both sides resulted from a combination of the two most sexually dimorphic individual measurements of trochlear length and trochlear breadth. Together, they produced predicted allocation accuracies of 91.3% on the right side and 91.4% on the left side. This study found that trochlear length and breadth to be the most accurate measurements for distinguishing the sexes. Talus was found to be a useful bone for the identification of sex among modern Thai individuals from the Chiang Mai area.

Hamate Facet Maximum Width (Triquetrum HFMW). From the 15 parameters being measured, they ended up with 14 parameters included in the study, triquetrum was excluded due to not reaching the 80% threshold. Therefore, Barnes *et al*.[8], suggested that it is possible to obtain 90% correct allocation accuracy or better for sexing of modern Thai individuals using either the right trapezium or right scaphoid.

The skull is one of the most sexually dimorphic bones morphologically and is widely used in sex estimation of unknown skulls found in most forensic cases. For this systematic review, 2 studies were conductedusing the skull for sex estimation (Table 5). Techataweewan *et al*.[21] researched the metric sexual dimorphism of 322 skulls used as the sample of their study. The morphometric method used, involve measurement of 30 parameters; maximum cranial length (g-op, GOL), parietal chord (b-l, PAC), maximum cranial breadth (eu-eu, XCB), occipital chord (l-o, OCC), bizygomatic breadth (zy-zy, ZYB), foramen magnum length (ba-o, FOL), basion-bregma height (ba-b, BBH), foramen magnum breadth (FOB), basion-nasion length (ba-n, BNL), mastoid height (Right) (MDHR), biauricular breadth (au-au, AUB), mastoid height (Left) (MDHL), minimum frontal breadth (ft-ft, WFB), maximum frontal breadth (MFB), upper facial breadth (fmt-fmt,UFBR), basion-nasospinale length (ba-ns, BNS), nasal height (n-ns, NLH), biasterionic breadth (ast-ast, ASB), nasal breadth (al-al, NLB), minimum breadth nasal bones (WNB), orbital breadth (d-ec, OBB), bicondylar breadth (cdl-cdl, BCB), orbital height (OBH), bigonial breadth (go-go, BGB), biorbital breadth (ec-ec, EKB), mandibular ramus height (GCB), interorbital breadth (d-d, DKB), minimum ramus breadth (MRB), frontal chord (n-b, FRC), and mandibular angle (MANG).

TABLE 5: Sex estimation from cranial bones

Author	Bones	Parameters	Accuracy	Outcome
Techatawee-wan *et al*. (2021)	Skull	Maximum Cranial Length (g-op, GOL), Parietal Chord (b-l, PAC), Maximum Cranial Breadth (eu-eu, XCB), Occipital Chord (l-o, OCC), Bizygomatic Breadth (zy-zy, ZYB), Foramen Magnum Length (ba-o, FOL), Basion-Bregma Height (ba-b, BBH), Foramen Magnum Breadth (FOB), Basion-Nasion Length (ba-n, BNL), Mastoid Height (Right MDHR), Biauricular Breadth (au-au, AUB), Mastoid Height (Left) (MDHL), Minimum Frontal Breadth (ft-ft, WFB), Maximum Frontal Breadth (MFB), Upper Facial Breadth (fmt-fmt, UFBR), Basion Nasospinale Length (ba-ns, BNS), Nasal Height (n-ns, NLH), Biasterionic Breadth (ast-ast, ASB), Nasal Breadth (al-al, NLB), Minimum Breadth Nasal Bones (WNB), Orbital Breadth (d-ec, OBB), Bicondylar Breadth (cdl-cdl, BCB), Orbital Height (OBH), Bigonial Breadth (go-go, BGB), Biorbital Breadth (ec-ec, EKB), Mandibular Ramus Height (GCB), Interorbital Breadth (d-d, DKB), Minimum Ramus Breadth (MRB), Frontal Chord (n-b, FRC), Mandibular Angle (MANG)	82.5% - 92.1%	Males are statistically significantly larger than females in nearly all cranial and mandibular dimensions.
Sinthubua *et al*. (2017)	Maxillary suture	Anterior maxillary suture length Transverse maxillary suture length Post-maxillary suture lengh	76.8421%	Independent t-test revealed a statistically significant difference ($p<0.01$) between males and females in all maxillary suture measurements. The finding is useful for both sex and age estimation.

Twenty-five from the cranium and five from the mandible. A discriminant function was derived from the results of the study. From all the parameters being measured, they found out that all variables were sexually dimorphic, and for most measurements, male dimensions are significantly larger than female.

Compared to Techataweewan *et al*.[21], Sinthubua *et al*.[18] conducted a research on sex estimation using a photograph of the maxillary suture. The maxillary suture is difficult to examine, due to its fine characteristics and position in the small area of the maxilla, macroscopic assessment may be an inappropriate method to examine such. Therefore, photographing and computerising were found to be more suitable methods that can provide more accurate information from the sutures. The author found that there are no studies on these sutures in the Thai population. Thus, their study aimed to investigate maxillary sutures by a new method in the Thai population from 190 Thai bone samples. Three maxillary suture lengths: anterior, transverse, and post maxillary suture were photographed and measured. The results of their study derived the equation from the prediction model which required 3 maxillary suture lengths giving 76.8421% accuracy from the leave-one-out cross-validation in estimating sex percentage accuracies. Sinthubua *et al*.[18], found a significant difference between male and female suture length, therefore they suggested that maxillary suture length can be applied for sex estimation.

The vertebral column, also known as the spinal column, is the central axis of the skeleton in all vertebrates. The vertebral column consists of cervical vertebrae (C1 – C7), thoracic vertebrae (T1 – T12), lumbar vertebrae (L1 – L5), sacrum (S1 – S5), and coccyx. In this systematic review, 3 studies on sex estimation were done using cervical, lumbar, and sacral vertebrae (Table 6). Mohd Fauad *et al*.[10] had done a sex estimation study using C3 in the Malaysian population. The study involves 432 radiographs of a living subject. Measurement involving 11 landmarks, L1 – the most anterior and superior point of C3 vertebra body, L2 - the most posterior and superior point of C3 vertebra body, L3 - the most posterior and inferior point of C3 vertebra body, L4 - the most anterior and inferior point of C3 vertebra body, L5 – the most anterior point of C3 superior zygapophyseal joint, L6 - the most posterior point of C3 superior zygapophyseal joint, L7 – the most posterior point of C3 inferior zygapophyseal joint, L8 - the most anterior point of C3 inferior zygapophyseal joint, L9 – the most anterior and superior point of C3 spinous process, L10 – the most anterior and inferior point of C3 spinous process, and L11 – the tip of the spinous process was taken from the radiograph images. Results show a robust sexual dimorphism in the C3 vertebra morphology among the Malaysian adult population with accuracy ranging from 70.0 to 70.6%. Males show larger cervical vertebra landmark distances and greater cervical size as compared to females.

Suwanlikhid *et al*.[7] had done a sex estimation study using lumbar. Photographed images of the lumbar were taken from 150 dry bones of Thais. Three quantitative variables were measured: Area (the area of the total surface (AA), cortical (AC), and trabecular surface (AT)), major axis (the longest axis passes through the total surface (MAA), cortical (MAC) and trabecular surface (MAT)). Minor axis (the shortest axis passes through perpendicular to the major axis at the center from one side of the total surface (MIA), cortical (MIC), and trabecular surface (MIT) to the other). The accuracy of the results ranged from 57.4 to 81.85%. Most of the variables were found to be greater in males than females. Most of the Area quantitative variables were more accurate than other quantitative variables and most of the females are more accurate than males. The univariate discriminant function coefficients derived from this study found that the MAT was the best predictive variable. Therefore, they concluded that vertebrates can be used accurately as part of the sexual process.

Lastly, Naksuwan *et al*.[15] did a sex estimation study using the sacral of the Thai population. Their study involved 78 skeletons, and 13 parameters were measured. The parameters are 13 sacral parameters consisting of 7 sacral morphometrics: anterior sacral length (ASL), anterior sacral curvature (ASC), superior breadth of the sacrum (SBS), breadth of sacral alar (BAL), anterior breadth of the sacrum (ABS), transverse diameter of S1 vertebra corpus (TDS), anterior-posterior diameter of S1 vertebra corpus (APS), and 6 sacral indexes: sacral index (SAI), curvature index (CUI), corporobasal index (COI), S1 vertebra corpus index (SCI), alar index (ALI), and sacral base index (SBI). All parameters show a significant difference between males and females, where the most accurate sacral parameter for sex estimation was APS, with 82.1% accuracy. The accuracy was improved to 97.4% when a combination of 3 sacral variables (ASL, ALI, and ABS) was computed together

Table 6: Sex estimation from cervical bones

Author (yr)	Bones	Parameters	Accuracy	Outcomes
Mohd Fauad *et al*. (2021)	Cervical	L1 – the most anterior and superior point of the C3 vertebra body L2 - the most posterior and superior point of the C3 vertebra body L3 - the most posterior and inferior point of the C3 vertebra body L4 - the most anterior and inferior point of the C3 vertebra body L5 – the most anterior point of the C3 superior zygapophyseal joint L6 - the most posterior point of the C3 superior zygapophyseal joint L7 – the most posterior point of the C3 inferior zygapophyseal joint L8 - the most anterior point of the C3 inferior zygapophyseal joint L9 – the most anterior and superior point of the C3 spinous process L10 – the most anterior and inferior point of the C3 spinous process L11 – the tip of the spinous process	70% - 74.8%	Males have larger cervical vertebra landmark distances as compared to females. Results demonstrated a robust sexual dimorphism in the C3 vertebra morphology among the Malaysian adult population. Males generally showed a greater cervical size as compared to females.

Naksuwan *et al*. (2020)	Sacral	13 sacral parameters consist of 7 sacral morphometrics and 6 sacral indexes. 7 sacral morphometrics: Anterior sacral length (ASL) Anterior sacral curvature (ASC) Superior breadth of sacrum (SBS) Breadth of sacral alar (BAL) Anterior breadth of sacrum (ABS) Transverse diameter of S1 vertebra corpus (TDS) Anterior=posterior diameter of S1 vertebra corpus (APS) measurements were taken using a calibrated vernier caliper. 6 sacral indexes: Sacral index (SAI) Curvature index (CUI) Corporobasal index (COI) S1 vertebra corpus index (SCI) Alar index (ALI) Sacral base index (SBI	82.1% - 97.4%	Discriminant analysis exhibited that the anterior-posterior diameter of the S1 vertebra corpus (APS) is the most accurate sacral parameter for sex determination in this study with an 82.1% correct discrimination rate. The accuracy could be improved up to 97.4% when an additional 3 sacral variables including the length of sacrum measured from the medial anterior-superior sacral promontory to the medial anterior-inferior S5 vertebra (ASL), ala index (ALI), and the maximum anterior breadth of sacrum measured across sacral alar (ABS) were computed together with APS. D = 0.346(APS) + 0.088(ASL) - 0.040(ALI) - 0.104(ABS) - 7.134. These encourage the use of sacral morphometrics for sex assessment of human sacrum remains in Central Thailand.

Suwanlikhid Lumbar *et al*. (2020)	3 quantitative variables: 1. Area – the area of total surface (AA), cortical (AC), and trabecular surface (AT) 2. Major axis – the longest axis passes through the total surface (MAA), cortical (MAC), and trabecular surface (MAT). 3. Minor axis – the shortest axis passes through perpendicular to the major axis at the center from one side of the total surface (MIA), cortical (MIC), and trabecular surface (MIT) to the other.	Most of the quantitative variables were greater in males than in females. Most of the area in each of the lumbar vertebrae is more accurate than other quantitative variables. Most of the female is more accurate than the male. Upper-end plate MAT of the L1 vertebra had the most predictive precision (81.8%) There were no significant differences ($p<0.001$) between sex in the AC on the lower end plates of the vertebrae L1 to L3 and the AC on the upper and lower end plates of the vertebrae L4 to L5. The univariate of the discriminant function coefficients found that the MAT was the best predictive variable. Vertebrae can be used accurately as part of the sexual process. It can be applied in incomplete bone to estimate the sex and stature of the individual lumbar vertebral body.

with APS. A single sacral parameter could not achieve high reliability, multiple sacral variables were required to be computed together to increase the accuracy. The authors concluded that their findings support the potential use of sacral morphometrics as an additive approach for sex estimation. They suggested future research, to set another population-specific standard for sacral morphometrics in Thai, larger samples are required, and the nationality must be correctly verified.

LIMITATIONS

This research only includes studies done between 2014 and 2021. Secondly, searching the article from the online database was done from SCOPUS and Web of Science (WOS), there might be related articles from other databases that were missed out. Lastly, literature searching was done in February 2022, hence articles published after that period were not captured.

CONCLUSION

It can be concluded that subpubic, cervical (C3), lumbar, maxilla, humerus, radius, ulna, talus, cranium, mandible, scapulae, sternum, sacral, os coxa, carpal, and calcaneus bones were sexually dimorphic, providing good accuracies for sex estimation. Sex estimation using these bones was population-specific. In Southeast Asia, Thailand is the most active country in conducting population-specific research on sex estimation, followed by Malaysia, while research done by other countries is not available. More research should be conducted in this area of interest to develop population-specific formulae. In the current situation where there is an increase in the occurrence of natural disasters in Malaysia, there is a need to develop population-specific formulae for sex estimation using other parts of bones.

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