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Original article

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Sex determination in Northern Thai from crania by using computer-aided design software and conventional caliper methods

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Abstract

Background: Identification of sex from skeletal remains is an essential step in forensic anthropology. The skull is the second choice, after the pelvis, to estimate sex by osteometric methods.

Objective: To evaluate the process of identification of sex in Northern Thai from crania by using computer-aided design (AutoCAD) software and conventional caliper methods.

Methods: Dry skulls of 86 men and 74 women were examined. AutoCAD software and digital calipers were used to measure dimensions. Eleven of the 15 parameters were created for this study.

Results: Men are significantly larger than women in all parameters, except in the nasospinale–prosthion measurement. There were no significant differences in the intraobserver error test and between the AutoCAD and digital caliper measurements. The logistic regression analysis yielded a sex classification accuracy rate of 92.9% in men, 93.4% in women, and 93.1% of overall accuracy for AutoCAD software. When using digital calipers, there was an accuracy rate of 89.3% in men, 94.7% in women, and 91.9% for overall accuracy.

Conclusions: AutoCAD software is a reliable method to predict the sex and provide high accuracy in sex determination from crania.

Keywords: computer-aided design, skull, Northern Thai, sex determination by skeleton

Sex determination from an unknown human skeleton to identify an individual is an important aspect of forensic anthropology. Although DNA analysis is the most reliable method to identify an individual, it requires special tools and time. One simple method to identify sex is by using the skeletal remains. The identification of sex from skeletal remains is 100% reliable [1] if the entire skeleton is present; however, skeletal remains are often incomplete or fragmented. To identify sex, several studies used various bones, such as the mandible [2–4], scapula [5], pelvis [6–9], and skull [4, 10–15]. The pelvis is the most accurate bone for sex determination and can predict sex with an accuracy of >95% [1]. However, a complete pelvis is not always easily available. It is often necessary to use other bones for sex determination.

There are two major methods to determine sex from skeletal remains. The visual method is based on observation of morphological characteristics of sex, is easy to assess, and does not require measuring tools, but it is highly subjective and depends on the skill of the anthropologist [16, 17]. The osteometric measurement is a method of measuring the skeleton,

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requiring a specific tool for measurement, but is reliable, decreases the problem of the investigator's subjective evaluation [17], and can be reevaluated easily in the assessment of sex. While the conventional technique of using calipers to measure bones has been used for years, the use of computer-aided design software for engineering and architecture, such as AutoCAD, has been reported to be successful in measuring the sacral base [17], acetabular rim [18], and frontal bone [19] for sex determination in the field of forensic anthropology.

Because it has been recognized that sexual characteristics are specific to each population due to genetics, environment, and culture, specific standards in one population cannot be applied to another group [1, 10]. Therefore, the purpose of this study was to determine sex from crania of Northern Thai using craniometry by digital photograph processing with AutoCAD and digital calipers.

Materials and methods

Sample

The sample consisted of 160 dry skulls (84 men and 76 women) from the collection housed at the Department of Anatomy, Faculty of Medicine, Chiang Mai University, Thailand. The mean age at death of donors of this sample was 66.02 ± 12.61 years with no significant difference between the sexes ($P = 0.132$). Specimens with a pathological skull or loss of the anterior point on the upper alveolar aspect were excluded from the present study. The study was exempted from formal human research ethics review by the Research Ethics Committee of Faculty of Medicine, Chiang Mai University (May 29, 2009).

Photography measurement

Each skull was set on a sand bag with a black background and the same plane of reference for photography. A Canon EOS 1000D digital camera (10.0 megapixel) was used in this study. The digital camera was set on a stand with a fixed distance (300 mm) to take the photograph of the anterior and lateral views of the left side of the skull (**Figure 1**). The photographs of the anterior and lateral views were referenced by the median sagittal and horizontal planes of Frankfurt, respectively. Two 10 mm scale references were placed on the skull, one on the glabella region and the second above the external auditory meatus. The digital photograph was analyzed on a computer screen using AutoCAD (version 2010, Autodesk).

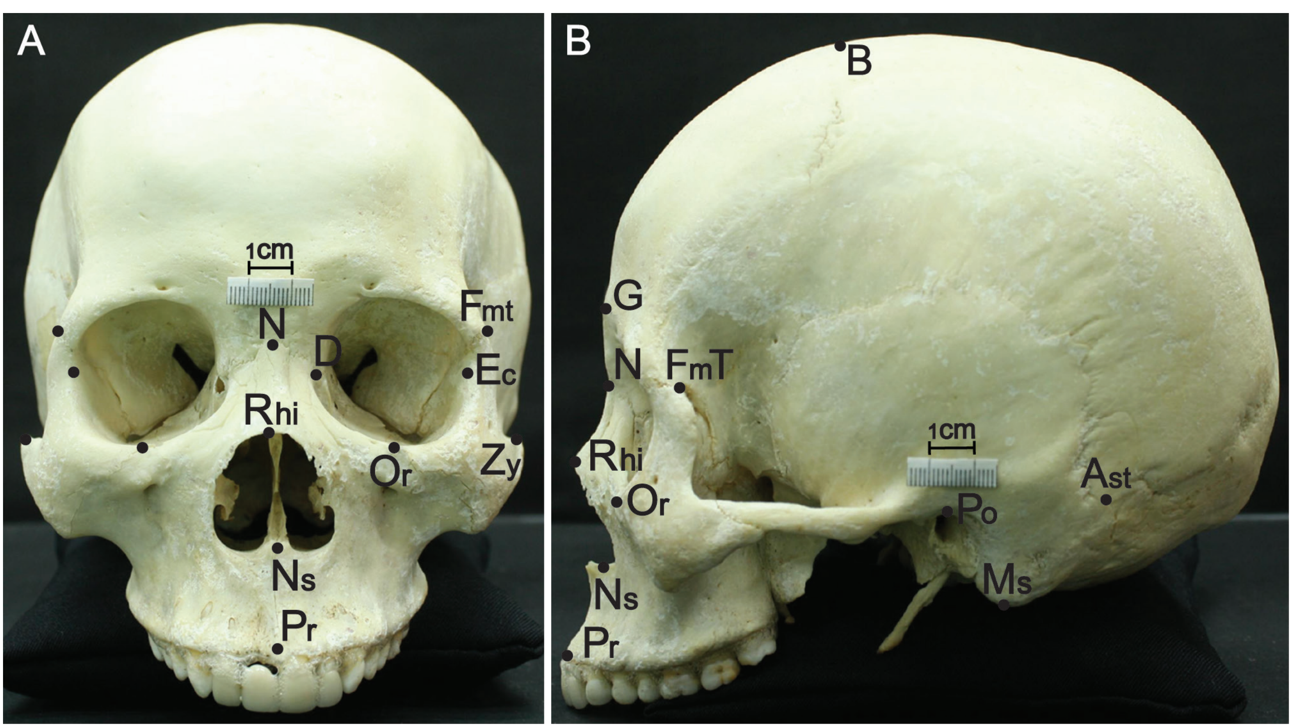

Figure 1. Anterior and lateral views of skull showing landmarks used in the present study.
D: dacryon, Ec: ectoconchion, Fmt: frontomalare temporale, N: nasion, Ns: nasospinale, Pr: prosthion, Or: orbitale, Rhi: rhinion, Zy: zygion, Ast: asterion, B: bregma, G: glabella, Po: porion, Ms: mastoidale.

Parameters and measurements

The landmarks of Krogman and Iscan [1] and Buikstra and Ubelaker [20] were followed (**Figure 1)**. All parameters in this study are shown in **Table 1** and **Figure 2**. Fifteen parameters, namely, orbital height (OrH), orbital breadth (D-Ec), nasal bone length (NL), external nasal opening height (ENOH), alveolar process of maxilla height (APMH), bizygomatic breadth (Zy–Zy), orbital area (OrA), orbital perimeter (OrP), external nasal opening area (ENOA), external nasal opening perimeter (ENOP), mastoid triangle area (MTA), zygomatic arch area (ZaA), zygomatic arch perimeter (ZaP), glabella-bregma area (GBA), and glabella-bregma perimeter (GBP), were measured. Digital calipers were also used to investigate six parameters as follows; OrH, D-Ec, NL, ENOH, APMH, and Zy–Zy.

Test of difference method

To evaluate the values of the measurements obtained from the AutoCAD technique, the length of OrH, D-Ec, NL, ENOH, APMH, and Zy–Zy were measured to compare with the values obtained from the digital calipers. An independent *t* test was performed to observe the measurement error.

Reliability measurement

To assess the intraobserver error, 30 crania were measured a second time after 1 month by the same observer, and a paired *t* test was performed.

Statistical analysis

The data were analyzed using SPSS Statistics for Windows software package (version 17.0, SPSS). Descriptive statistics, including the mean and standard deviation, were calculated. An independent *t* test was performed to check the significant differences between men and women for each parameter. Differences were considered significant at $P < 0.05$. Following this, logistic regression analysis was performed to predict the sex.

Results

The mean and standard deviation for measurement of the cranium were calculated for both men and women, and the *P* values for the 15 parameters were obtained. Then, the results obtained from AutoCAD (**Table 2**) were compared with those

Table 1. Definitions of measurements

Abbreviation	Definition	Measurement
OrH†	Orbital height	Distance between orbitale to supraorbital margin
D-Ec†	Orbital breadth	Distance between dacryon to ectoconchion
NL§	Nasal bone length	Distance between nasion and rhinion
ENOH§	External nasal opening height	Distance between rhinion and nasospinale
APMH§	Alveolar process of maxilla height	Distance between nasospinale and prosthion
Zy–Zy†	Bizygomatic breadth	Distance between the right and left parts, or the widest part of the zygoma
OrA§	Orbital area	Area of orbital margin
OrP§	Orbital perimeter	Perimeter of orbital margin
ENOA§	External nasal opening area	Area of external nasal opening
ENOP§	External nasal opening perimeter	Perimeter of external nasal opening
MTA‡	Mastoid triangle area	Area of triangle drawn from three points (porion, mastoidale, and asterion)
ZaA§	Zygomatic arch area	Area of space between the line drawn from the frontomalare temporale to the zygomatic arch above the porion
ZaP§	Zygomatic arch perimeter	Perimeter of space between the line drawn from the frontomalare temporale to the zygomatic arch above the porion
GBA§	Glabella-bregma area	Area of space between the straight line drawn through bregma in the horizontal plane and perpendicular to the straight line drawn through the glabella in the vertical plane
GBP§	Glabella-bregma perimeter	Perimeter of space between the straight line drawn through the bregma in the horizontal plane and perpendicular to the straight line drawn through the glabella in the vertical plane

†Parameters described by Krogman and Iscan [1] and Buikstra and Ubelaker [20]; ‡parameters described by Paiva and Segre [21]; §parameters created for the present study.

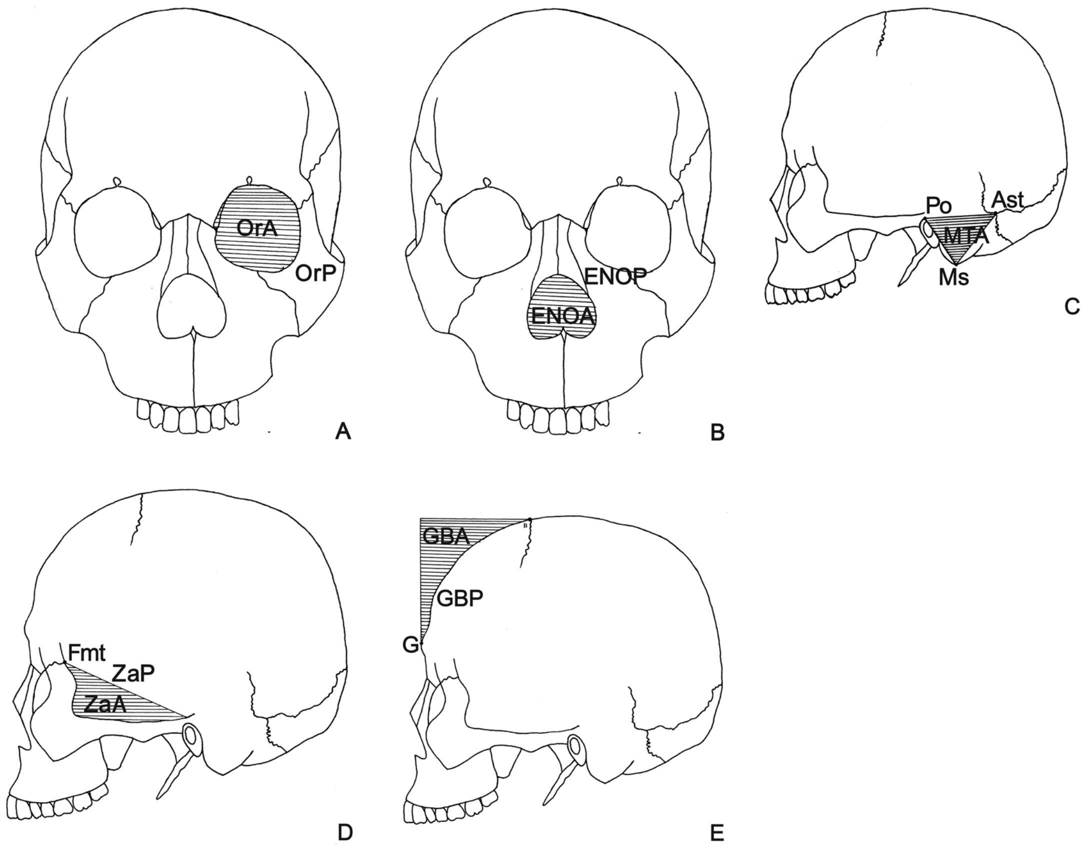

Figure 2. Nine drawings were photographed and analyzed by using AutoCAD software.
(**A**) OrA and OrP measurements; (**B**) ENOA and ENOP measurements; (**C**) MTA measurement; (**D**) ZaA and ZaP measurements; and (**E**) GBA and GBP measurements.

obtained using digital calipers (**Table 3**). All parameters were larger for men than for women, except APMH. Significant differences were found for ENOP, OrP, and ZaP. Significant differences at $P < 0.01$ were found for ENOA and ZaA. A highly significant difference ($P < 0.001$) was found in OrH, D-Ec, NL, ENOH, Zy–Zy, OrA, ENOA, MTA, GBA, and GBP. Parameters with significant differences ($P < 0.05$) were analyzed by logistic regression analysis.

There was no significant difference ($P < 0.05$) between the AutoCAD and digital caliper measurements (**Table 4**). By using paired *t* test for intraobserver error, we found that there was no significant difference ($P < 0.05$) between the values obtained at the 2 different times (**Table 5**), indicating that the error in this method was unlikely due to bias.

Logistic regression analysis created a linear regression equation for calculating the logistic regression score (*y*). The sex of the specimen can be determined from the linear regression equation as follows:

By using AutoCAD

$$y = -25.308 + (0.813\ \text{ENOH}) + (0.396\ \text{NL}) + (0.056\ \text{GBP}) + (0.008\ \text{OrA}) + (-0.198\ \text{OrP}) \quad (1)$$

By using digital calipers

$$y = -30.588 + (0.890\ \text{ENOH}) + (0.362\ \text{NL}) \quad (2)$$

The probability (*P*) of diagnosis of sex is $1/(1 + e^{-y})$, where $e = 2.718$. Specimens with a score >0.5 at the sectioning point are classified as male, while specimens with a score <0.5 are classified as female.

The result of the logistic regression analysis is presented in **Table 6**. Fourteen parameters from AutoCAD have provided sex classification accuracy rates of 92.9% for men, 93.4% for women, and 93.1% overall. Additionally, 5 parameters from the caliper method have provided sex classification accuracy rates of 89.3% for men, 94.7% for women, and 91.9% overall.

Discussion

Identification of sex from human skeletal remains is essential in forensic investigation. The present study attempts to predict sex from 15 parameters of the cranium using craniometry, and 11 newly developed parameters, i.e., NL,

Table 2. Descriptive statistics of the cranium's parameters using the AutoCAD method ($P < 0.05$)

Parameter	Sex	n	Mean	SD	P
OrH†	Male	84	34.40	1.78	<0.001
	Female	76	32.10	1.35	
D-Ec†	Male	84	38.64	2.51	<0.001
	Female	76	35.42	1.55	
NL†	Male	84	24.38	2.84	<0.001
	Female	76	21.34	1.49	
ENOH†	Male	84	28.40	2.75	<0.001
	Female	76	22.72	1.96	
APMH†	Male	84	16.81	3.29	0.08
	Female	76	17.62	2.33	
Zy–Zy†	Male	84	126.23	6.52	<0.001
	Female	76	121.90	5.33	
OrA‡	Male	84	1032.80	93.06	<0.001
	Female	76	924.11	81.58	
OrP†	Male	84	117.30	6.01	0.04
	Female	76	115.43	5.14	
ENOA‡	Male	84	583.57	79.73	0.001
	Female	76	548.95	41.61	
ENOP†	Male	84	90.42	6.70	0.03
	Female	76	88.34	5.31	
MTA‡	Male	84	686.33	91.769	<0.001
	Female	76	591.07	76.43	
ZaA‡	Male	84	724.95	108.41	0.002
	Female	76	679.75	62.39	
ZaP†	Male	84	149.07	10.79	0.014
	Female	76	145.07	9.48	
GBA‡	Male	84	1010.86	138.17	<0.001
	Female	76	816.78	119.04	
GBP†	Male	84	213.19	17.22	<0.001
	Female	76	183.87	17.92	

†Measured in millimeters (mm); ‡Measured in square millimeters (mm^2).

ENOH, APMH, OrA, OrP, ENOA, ENOP, ZaA, ZaP, GBA, and GBP.

From the results shown in **Tables 2 and 3**, it was found that male crania were larger than those of female crania for all parameters, except APMH. Generally, male crania tend to be higher, larger, and more robust than female crania, but the size depends on various factors. One essential factor is the hormonal system. In men, testosterone promotes on increase in the size and mass of skeletal muscles and bones [22, 23]. Because the skeletal muscles are attached to the bones, they pass their force by contraction through their attachments; thus, these effects may cause the sexual dimorphism in bones, so that the values and sizes are greater in men than they are in women.

For the parameter APMH, no significant differences were found between men and women, and this may be because of the lack of muscle attachment to bones in the nasospinale–prosthion region. This result was similar for the chin height and symphysis menti, which is a part that rarely varies when compared to the other parts of the jaw [3]. APMH is also one part of the maxillary intermaxillary suture, which is associated

Table 3. Descriptive statistics of the cranium's parameters using the digital caliper method

Parameter	Sex	n	Mean	SD	P
OrH†	Male	84	34.40	1.79	<0.001
	Female	76	32.14	1.40	
D-Ec†	Male	84	38.80	2.57	<0.001
	Female	76	35.42	1.58	
NL	Male	84	24.36	2.86	<0.001
	Female	76	21.35	1.51	
ENOH†	Male	84	28.41	2.76	<0.001
	Female	76	22.74	1.96	
APMH†	Male	84	16.81	3.29	<0.07
	Female	76	16.81	3.29	
Zy–Zy†	Male	84	126.29	6.42	<0.001
	Female	76	121.77	5.24	

†Parameter described by Krogman and Iscan [1] and Buikstra and Ubelaker [20]; as defined in **Table 1**.

Table 4. Comparison between AutoCAD and digital caliper measurements using an independent *t* test

Parameters	Methods	N	Mean	SD	P
OrH†	AutoCAD	160	33.30	1.96	0.91
	Calipers	160	33.33	1.97	
D-Ec†	AutoCAD	160	37.11	2.65	0.78
	Calipers	160	37.19	2.74	
NL	AutoCAD	160	22.93	2.75	0.99
	Calipers	160	22.93	2.76	
ENOH†	AutoCAD	160	25.71	3.72	0.97
	Calipers	160	25.72	3.72	
APMH†	AutoCAD	160	17.19	2.90	0.97
	Calipers	160	17.21	2.88	
Zy–Zy†	AutoCAD	160	124.18	6.35	0.96
	Calipers	160	124.14	6.29	

†Parameter described by Krogman and Iscan [1] and Buikstra and Ubelaker [20]; as defined in **Table 1**.

Table 5. Evaluating intraobserver error using a paired *t* test to compare the data between the first and second measurements

Parameter	n	First measurement		Second measurement		Intraobserver error
		Mean	SD	Mean	SD	*P*
OrH	30	33.82	1.92	33.84	1.96	0.84
D-Ec	30	38.05	2.22	38.00	2.18	0.17
NL	30	24.00	3.13	24.13	3.19	0.22
ENOH	30	27.18	3.86	27.19	3.86	0.11
APMH	30	23.90	6.45	24.91	8.82	0.32
Zy–Zy	30	124.62	6.15	121.30	19.96	0.33
OrA	30	1034.18	101.13	1030.74	101.50	0.40
OrP	30	115.78	6.05	116.06	6.01	0.17
ENOA	30	563.44	80.40	563.91	80.78	0.29
ENOP	30	88.52	7.11	88.46	7.10	0.32
ENOP	30	666.14	96.17	666.16	96.17	0.22
ZaA	30	694.32	109.64	694.30	109.62	0.34
ZaP	30	143.41	9.72	143.32	9.57	0.37
GBA	30	955.06	167.50	955.08	167.52	0.54
GBP	30	207.17	20.39	207.20	20.33	0.33

Table 6. Sex classification accuracy of craniometry determined using logistic regression analysis

Methods	Sex	Male		Female		Overall	
		n (84)	%	n (76)	%	N (160)	%
AutoCAD	Male	78	92.9	6	7.1	149	93.1
	Female	5	6.6	71	93.4		
Calipers	Male	75	89.3	9	10.7	147	91.9
	Female	4	5.3	72	94.7		

with the development of the musculoskeletal system. Most parameters, such as bizygomatic breadth, have significant differences between the sexes and can be used to determine sex with high accuracy and a high degree of sexual dimorphism [4, 12]. This significance may be due to the attachments of the masseter, zygomaticus major, and zygomaticus minor muscles at the points of the landmark.

When comparing the values derived from the present study with those from previous studies, we found that D-Ec and Zy–Zy indicated sexual dimorphism is similar to that found in previous studies [11, 14], while OrH ($P < 0.001$) produced results contrary to those found in the study by Sangvichien et al. [14] among people from central Thailand ($P = 0.26$) and the study by Dayal et al. [11] of black South Africans ($P = 0.98$). However, the mean values among Thais for the D-Ec, and Zy–Zy were smaller than those of black South Africans [11] because these are influenced by population ancestry. Thais are eastern Asian, being generally smaller than black South Africans, who have African ancestry. Each population has different lifestyles and cultures, which may affect the morphological characteristics. The results showed that the data for the northern region of Thailand are different from the results of Sangvichien et al. [14]. It may be due to the different methodologies used, geographies, and genetic factors, especially since the study of Sangvichien et al. was based on Thai skulls from individuals from the central region of Thailand [14].

A study made use of the parameters of the mastoid process to predict sex, which were modified from the paper by Paiva and Segre [21] by using the AutoCAD method based on scale references to calculate the mastoid triangle area. This suggests that the mastoid process is a good process for sex identification. The present study found a high accuracy (77.5%) of sex prediction for the MTA, while Paiva and Segre [21] – by the Xerographic copy method – reported overlapping values of 60.0% for the right side, 51.67% for the left side, and 36.67% for the total area. Kemkes and Globel [24] presented an accuracy rate of 58.8% for MTA in a German sample, 66.0% in a Portuguese sample, and 65.0% in the combined sample by the digital caliper method.

In 2011, AutoCAD was applied to determine the sex of Thai skeletal remains by using the frontal bone [19]. It was appropriate to investigate these parameters although those for the zygomatic angle were inappropriate [25]. Nevertheless, the present study found that AutoCAD software could be applied to craniometry with high prediction accuracy in the work of forensic anthropology using the sacral base and acetabular rim [17, 18].

Logistic regression analysis of the AutoCAD method displayed an overall sex classification accuracy rate of 93.1%. The digital caliper method showed 91.9% sex classification accuracy rate. The percentage accuracy in this study leans toward higher rates, compared to other studies on Thai populations, which found 90.6% accuracy [15] and studies on other populations such as white South Africans, which found an accuracy of 85.7% from the crania [4]; 80.8% accuracy among black South Africans [11], and 88.2% accuracy among Cretans [12], in predicting the sex correctly. However, the percentage accuracy of sex prediction by statistical analysis is dependent on sexual dimorphism. The number of parameters and samples are also important. The study by Iscan and Steyn [10] used 13 crania and 4 mandible parameters to predict sex, and the sample sizes of men and women were equal, showing a high accuracy rate of 97.8% using the crania. In the present study, 15 parameters of 84 men, and 76 women were used.

This study used an AutoCAD method with digital photographs. This method was convenient and durable for reassessment and took less time to reset the point of landmark to measure the area and perimeter dimensions of the crania. Moreover, this method could examine each position, which may be away from the skeletal line, and expand it using an automatic method for 3D digital skull construction [26]. Caliper measurement may be difficult to reevaluate, and to sustain landmark points in the case of bone loss or fracture may also be difficult.

The accuracy of the AutoCAD measurements was also assessed. The study showed no significant difference between the AutoCAD measurement, which was measured from the digital photograph, and the digital caliper measurement, which was taken directly on the crania. In addition, the test for intraobserver error from AutoCAD reassessment showed that there was no significant difference between measurements made at the first and second time points, suggesting that the AutoCAD method is sufficiently accurate to be used for sex determination. Moreover, in the application of the AutoCAD method, one should be aware of the plane of reference setting for photography.

Conclusions

The determination of sex from Northern Thai crania using AutoCAD and conventional caliper methods examined in the present study shows high accuracy for both methods and is suggested for use to predict sex from skeletal remains.

Author contributions. TT and PS substantially contributed to the concept and design of the study and analyzed and interpreted the data collected substantially by TT, who drafted the manuscript. PS critically revised the manuscript. Both authors approved the final version submitted for publication and take responsibility for the statements made in the published article.

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Conflict of interest statement. The authors have each completed and submitted an International Committee of Medical Journal Editors' Uniform Disclosure Form for Potential Conflicts of Interest. None of the authors disclose any conflict of interest.

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