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Sex Determination by Using Discriminant Function Analyses from the Northeastern-Thai Occipital Bones

Determinación del Sexo Mediante Análisis de Funciones Discriminantes de los Huesos Occipitales del Nordeste de Tailandia

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SUMMARY: Since the facial bone remains are mostly damaged or fractured in the crime scenes, the occipital bone (OB) is a possible skull bone to be used for sex determination in forensic sciences. The high accuracy of the use of the OB for sex estimation has been reported in many populations. This recent study attempted to modify and apply the 12 parameters on OB for such determination in the Northeastern Thai skulls. Discriminant function analyses and descriptive statistics were performed. The results showed that all parameters including the hormion-basion length, bi-lower part of temporo-occipital suture breadth, bi-asterios breadth, opisthion-lambda length, foramen magnum breadth, foramen magnum length, right-lower part of temporo-occipital suture to opisthion length, left-lower part of temporo-occipital suture to opisthion length, right-asterion to basion length, left-asterion to basion length, right-asterion to lambda length, and left-asterion to lambda length of males were significantly higher than those of females (P<0.01). Interestingly, the discriminant equation analyzed from univariable showed that the temporo-occipital suture breadth (TOB) has the highest accuracy rate (75.4 %) among 12 parameters. For multivariable analysis via stepwise method, the hormion-basion length (HBL), temporo-occipital suture breadth (TOB), and left asterion to basion length (Lt. ABL) provided the highest rate of accuracy (78.8 %). In conclusion, this study suggested that TOB, HBL, and Lt. ABL are potential parameters to be used for sex determination on dry occipital bone remains of the Northeastern Thai population.

KEY WORDS: Sex determination; Occipital bone; Discriminant function analysis; Northeastern Thai population.

INTRODUCTION

Sex determination using human bones is of a particular interest to the forensic sciences. This is especially useful in cases where skeletons or bone fragments are found at the crime scenes, disaster, or natural disasters. Therefore, determination of sex is one of the important methods in the evaluation of the biological profile of unknown human skeletal remains. In the case of a complete skeleton, it is not difficult to identify individual sex as compared to in the case of a fragmented or incomplete one. Previous studies have reported that many dry bones could be used for sex estimation including the vertebral column (Ostrofsky & Churchill, 2015; Ekizoglu *et al*., 2021), radius (Suwanlikhid & Mahakkanukrauh, 2015), pelvis (Steyn *et al*., 2012), scapula (Frutos, 2002), femur (Purkait, 2005), and skull (Sobhani *et al*., 2021; Toneva *et al*., 2022).

The skull is commonly found as skeletal remains in crime scenes. It is also used for sex determination by using cranial index (Sangvichien *et al*., 2007; Mahakkanukrauh *et al*., 2015; Botwe *et al*., 2021). Such cranial analysis is involved with several parts of the skull, including facial bones (Franklin *et al*., 2013; Toneva *et al*., 2022), frontal bone (Garcovich *et al*., 2022), mastoid process (Kanchan *et al*., 2013; Sobhani *et al*., 2021) and the occipital bone (Sharma *et al*., 2020). However, the facial bones have limitations in resistance to fracture and other mechanical forces from accidences or facial concealing murder. Therefore, the base of the skull, particularly occipital part, has been proposed to apply as another possible sex estimation, because it is more resistant to physical damage (Kanchan *et al*., 2013; Kamath *et al*., 2015). Previously, the

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sex dimorphism from dry occipital bone has been demonstrated in many populations including the Native Americans (Hoover & Thomas, 2022), French (Macaluso, 2011), Indians (Sharen & Mohanraj, 2020; Meera & Bindhu, 2022), Portuguese (Veroni *et al*., 2010), and Western Europeans (Boucherie *et al*., 2022). This study attempted to analyze the sex determination by using discriminant function analyses in Northeastern Thai skulls.

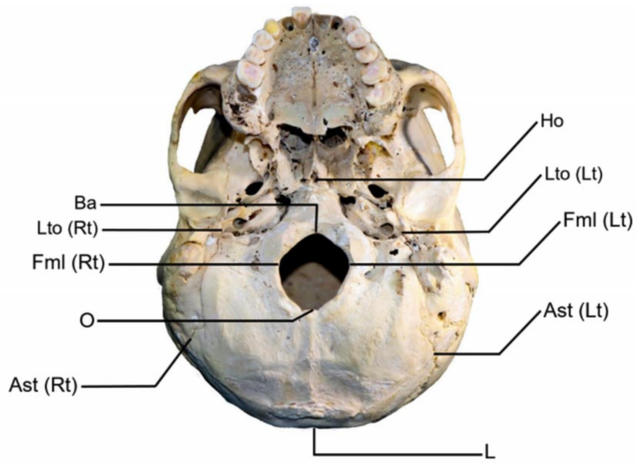

Fig. 1. Skull landmarks (midline and bilateral) at the inferior view of skull base used for measurement. Ho, hormion; Ba, basion; O, opisthion; L, lambda; Ast, asterion; Lto, lower part of temporo-occipital suture; Fml, foramen magnum lateral; Rt, right side; Lt, left side.

MATERIAL AND METHOD

Skull collection and human ethics. The identified 240 dry skulls (120 males and 120 females) were obtained from the Unit of Human Bone Warehouse for Research (UHBWR), Department of Anatomy, Faculty of Medicine, Khon Kaen University. The age average of male was 67.21 years (42 – 89 years) and that of female was 64.82 years (32 – 94 years). The skulls with any deformity and fractures were excluded from this study. This study has already been approved for the human research approval from the Center for Ethics in Human Research, Khon Kaen University (code number: HE651222).

Measurements on occipital bone. The skull landmarks used in this study had 7 points as previously described (Fig. 1 and Table I). Total 12 parameters of length distances that were measured among skull landmarks were explained in the Table II. The measurements were performed in two different times by using a sliding digital caliper vernier to the nearest 0.1 mm to avoid inter-observer error. If there was a difference of more than 0.1 mm, the third measurement was performed.

Statistical analysis. The measured data of all parameters were subjected into statistical analysis program (SPSS V. 21.0) to analyze the descriptive statistical data and to perform the discriminant function analysis by using univariable or multivariable. The stepwise method was applied for

Table I. Definitions of the 7 skull landmarks used in the this study.

Skull landmarks	Definitions
Midline landmarks	
Hormion (Ho)[a]	A midline point on the posterior margin of the vomer
Basion (Ba)[a]	A midline point on the anterior margin of the foramen magnum
Opisthion (O)[b]	A midline point at the posterior margin of the foramen magnum
Lambda (L)[a]	The apex of the occipital bone at its junction with the parietals at the midline
Bilateral landmarks	
Asterion (Ast)[a]	The point where the temporal, parietal, and occipital bones joined
Lower part of temporo-occipital suture (Lto)	The lower part of temporo-occipital suture
Foramen magnum lateral (Fml)[c]	A point of the greatest lateral curvature of the foramen magnum

Note: the landmarks used in this study based on previous reports: [a]White & Folkens (2000); [b]Wood & Lynch (1996) and [c]Franklin *et al*. (2013).

Table II. Explanations of the different lengths used to measure on the base of skull.

Measurement parameters	Definitions
Hormion-basion length (HBL)	The distance between hormion to basion (Ho-Ba)
Bi-lower part of temporo-occipital suture breadth (TOB)	The distance between left to right lower part of temporo-occipital suture (Lto [Lt. to Rt.])
Bi-asterios breadth (ASB)	The distance between left and right asterion (Ast [Lt. to Rt.])
Opisthion-lambda length (OLL)	The distance between opisthion to lambda (O-L)
Foramen magnum Width (FMW)	The distance between the lateral margins of the foramen magnum at the point of greatest lateral curvature (FML [Lt. – Rt.])
Foramen magnum length (FML)	The distance between basion to opisthion (Ba-O)
The lower part of temporo-occipital suture to opisthion length (TOL)	The distance between the lower part of temporo-occipital suture to opisthion (Lto-O)
Asterion to basion length (ABL)	The distance between asterion to basion (Ast-Ba)
Asterion to lambda length (ALL)	The distance between asterion to lambda (Ast-L)

multivariable to gain the highest accuracy rate (%) from the discriminant equation. All data were expressed as means ± SD. The P value that was lesser than 0.05 was considered as significantly statistical difference.

RESULTS

The descriptive statistics of all parameter profiles were shown in the Table III. Significantly, the results showed that the values of 12 occipital parameters measured in males were greater than those of female ($P < 0.05$).

The discriminant function analysis with accuracy rate results was demonstrated in the Table IV. For univariable evaluation, it was found that the highest accuracy rate to be used in sex estimation was of the temporo-occipital suture breadth (TOB) parameter (Table IV). Such rate was approximately 75.4 % as compared to that of 12 parameters.

Table III. Descriptive statistics of 12 occipital measurement parameters observed on occipital dry bones of Thai skulls in each sex and all samples.

Parameters	Total (n, 240) Mean ± SD	Male (n, 120 Mean ± SD	Female (n, 120) Mean ± SD	*P*-value (2-tailed)
HBL	30.17 ± 2.96	30.91 ± 2.93	29.43 ± 2.82	0.00*
TOB	79.77 ± 4.36	82.05 ± 3.61	77.49 ± 3.81	0.00*
ASB	107.47 ± 4.99	108.96 ± 4.98	105.97 ± 4.54	0.00*
OLL	96.01 ± 5.83	97.40 ± 6.24	94.62 ± 5.04	0.00*
FMB	29.56 ± 1.95	30.02 ± 1.97	29.10 ± 1.81	0.00*
FML	33.93 ± 2.38	34.65 ± 2.50	33.22 ± 2.04	0.00*
Rt. TOL	50.31 ± 3.03	51.65 ± 2.60	48.96 ± 2.83	0.00*
Lt. TOL	49.81 ± 2.78	51.11 ± 2.62	48.51 ± 2.29	0.00*
Rt. ABL	75.92 ± 3.83	77.63 ± 3.54	74.22 ± 3.33	0.00*
Lt. ABL	75.00 ± 3.54	76.81 ± 3.22	73.19 ± 2.87	0.00*
Rt. ALL	82.71 ± 6.14	84.06 ± 6.65	81.36 ± 5.28	0.00*
Lt. ALL	81.84 ± 5.44	82.85 ± 5.81	80.84 ± 4.86	0.00*

*P < 0.01, compared between sexes

Table IV. Accuracies and discriminant equation obtained from discriminant function analysis.

Measurement	Sex	Discriminant equation	Sectioning point	Accuracy rate (%)
HBL	M	HBLm = 3.738 (HBL) - 58.470	30.10	61.3
	F	HBLf = 3.558 (HBL) - 53.052		
TOB	M	TOBm = 5.944 (TOB) - 244.543	79.74	75.4
	F	TOBf = 5.613 (TOB) - 218.149		
ASB	M	ASBm = 4.796 (ASB) - 261.972	107.25	65.8
	F	ASBf = 4.664 (ASB) - 247.814		
OLL	M	OLLm = 3.027(OLL) - 148.106	95.52	60.4
	F	OLLf = 2.940 (OLL) - 139.795		
FMW	M	FMWm = 8.357(FMW) - 126.108	29.48	58.3
	F	FMWf = 8.101(FMW) - 118.560		
FML	M	FMLm = 6.671(FML) - 116.274	33.90	60.8
	F	FMLf = 6.395 (FML) - 106.914		
Rt. TOL	M	Rt. TOLm = 6.994 (Rt. TOL) - 181.325	50.29	69.2
	F	Rt. TOLf = 6.629 (Rt. TOL) - 162.969		
Lt. TOL	M	Lt. TOLm = 8.444 (Lt. TOL) - 216.500	49.88	69.2
	F	Lt. TOLf = 8.015 (Lt. TOL) - 195.099		
Rt. ABL	M	Rt. ABLm = 6.572 (Rt. ABL) - 255.786	76.09	70.0
	F	Rt. ABLf = 6.284 (Rt. ABL) - 233.870		
Lt. ABL	M	Lt. ABLm = 8.263 (Lt. ABL) - 318.057	75.10	72.5
	F	Lt. ABLf = 7.874 (Lt. ABL) - 288.840		
Rt. ALL	M	Rt. ALLm = 2.331 (Rt. ALL) - 98.653	82.56	56.7
	F	Rt. ALLf = 2.256 (Rt. ALL) - 92.461		
Lt. ALL	M	Lt. ALLm = 2.889 (Lt. ALL) - 120.388	82.14	60.0
	F	Lt. ALLf = 2.819 (Lt. ALL) - 114.638		
Stepwise method	M	3.172 (HBL) + 2.974 (TOB) + 6.305 (Lt. ABL) - 413.895	NA	78.8
	F	3.028 (HBL) + 2.764 (TOB) + 6.052 (Lt. ABL) - 373.813		

Rt, right; Lt, left; M (m), male; F (f), female; NA, not assessed

In addition, the parameters of asterion to basion length (ABL) in both sides also provided the good accuracy rates of 70 % (Rt. ABL) and 72.5 % (Lt. ABL), respectively (Table IV). The lowest accuracy rate was observed in the right asterion to lambda length (Rt. ALL) parameter (56.7 %). A stepwise discriminant analysis for multivariable was performed and it revealed only 3 parameters in the discriminant equation to gain the excellent accuracy rate (Table IV). It was determined that the equation formulated from the hormion-basion length (HBL), temporo-occipital suture breadth (TOB), and left asterion to basion length (Lt. ABL) would give approximately 78.8 % of accuracy rate in both male and female skulls as shown in the Table IV.

DISCUSSION

There are many landmarks on cranial and facial bones that have been documented to have potential for sexual determination. Because facial and superior part of cranial bones are known to be easily fractured, the base of the skull, particularly the occipital which is rarely damaged, is suggested in sex estimation in many populations as summarized in the Table V. In Thai race, sex identifications from dry skull by using craniometrical analysis involved with both facial and cranial bone parameters have been reported in the Central and Northern regions of Thailand (Sangvichien *et al*., 2007; Mahakkanukrauh *et al*., 2015). This study has attempted to use the occipital bones to be alternative parameters in sex determination for the first time. Similar to a previous study, the accuracy rate by using univariable (TOB) in Thais was closed to that of Western European (74 %) analyzed from the centroid size of occipital bone (Boucherie *et al*., 2022). In addition, it was reported that the highest accuracy rate by using such single variable of the bicondylar breadth parameter in French was approximately 67.6 % (Macaluso, 2011). However, it is well known that the use of only univariable of occipital parameters for sex estimation provides low potency when compared to discriminant function analysis subjected with multiple variables. Indeed, higher accuracy rate performed by multivariable were reported in Native American (71 %), French (67.7 %), Indian (63.3 %), South Indian (70.3 %), Portuguese (75.8 %) and also Thai (78.8 %) populations (Veroni *et al*., 2010; Macaluso, 2011; Sharen & Mohanraj, 2020; Meera & Bindhu, 2022; Hoover & Thomas, 2022). In contrast to other populations that mostly used foramen magnum and occipital condyle as parameters, our study used 12 mixed parameters on occipital bone for the first time. Interestingly, we found that only 3 parameters (HBL, TOB, and Lt. ABL) analyzed by stepwise method provided the highest accuracy rates up to 78.8 %, which was higher than other population (Table V). This study has indicated the new possible parameters on occipital bone to be applied in forensic anthropology.

CONCLUSION

This study has provided the alternative parameters on occipital bone to be applied in sex determination in the cases of facial bone damages on the crime scenes. Particularly, TOB can be used for univariable parameter. To gain the highest accuracy rate, the multivariable analysis of HBL, TOB, and Lt. ABL with stepwise method was suggested to be used for sex estimation in Northeastern Thai skulls.

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Table V. Summary of previous and present studies demonstrating the sex determination from the dry occipital bone in many populations

Authors	Population	No. of samples	Measurement	Accuracy rate (%)
Hoover & Thomas, 2022	Native American	328M, 335F	DECP, LID, BCB, FMW, FML	66.0 - 71.0
Macaluso, 2011	France	36M, 32F	FMW, FML, FMC, MLC, MWC, BCB, MnD, MxID, EHC	53.0 - 67.7
Meera & Bindhu, 2022	Indian	45M, 41F	MLC, MWC, AICD, PICD	63.3[b]
Sharen & Mohanraj, 2020	South Indian	50[a]	MLC, MWC, BCB, FML, FMW	66.4 - 70.3
Boucherie *et al.*, 2022	Western European	25M, 25F	PCs, CS	38.0 - 74.0
Veroni *et al*., 2010	Portuguese	19M, 17F	BCB, FMW, FML, MCL, MCW,	75.8[b]
Present study, 2024	Thai	120M, 120F	HBL, TOB, ASB, OLL, FMW, FWL, TOL, ABL, ALL	56.7 - 78.8

[a]Not determined number of sex; [b]reported only the highest accuracy rate; DECP, depth of external occipital protuberance; LID, lambda and inion distance; BCB, bicondylar breadth; FMW, foramen magnum breadth; FML, foramen magnum length; FMC, circumference of the foramen magnum; MLC, maximum length of the occipital condyle; MWC, maximum width of the occipital condyle;MnD, minimum distance between occipital condyles; MxID, maximum interior distance between occipital condyles; EHC, external hypoglossal canal distance; AICD, anterior intercondylar distance; PICD, posterior intercondylar distance; PCs, principal component; CS, centroid size; HBL, hormion-basion length; TOB, bi-lower part of temporo-occipital suture breadth; ASB, bi-asterios breadth; OLL, opisthion-lambda length; TOL, the lower part of temporo-occipital suture to opisthion length; ABL, asterion to basion length;ALL, asterion to lambda length.

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RESUMEN: Dado que los restos de huesos faciales en la escena del crimen en su mayoría resultan dañados o fracturados, el hueso occipital (HO) es un posible hueso del cráneo que se puede utilizar para la determinación del sexo en las ciencias forenses. En muchas poblaciones se ha informado de la alta precisión del uso del HO para la estimación del sexo. Este estudio reciente intentó modificar y aplicar los 12 parámetros en HO para dicha determinación en los cráneos del nordeste de Tailandia. Se realizaron análisis de funciones discriminantes y estadística descriptiva. Los resultados mostraron que todos los parámetros, incluido la longitud hormion-basion, la parte bi-inferior de la sutura temporo-occipital, la anchura bi-asterion, la longitud del opisthion-lambda, la anchura del foramen magnum, la longitud del foramen magnum, la parte inferior derecha temporo-occipital, longitud de la sutura al opistion, la parte inferior izquierda de la sutura témporo-occipital a la longitud del opistion, la longitud del asterion derecho al basion, la longitud del asterion izquierdo al basion, la longitud del asterion derecho al lambda y la longitud del asterion izquierdo a lambda, de los hombres fueron significativamente mayores que los de las mujeres (P<0,01). Curiosamente, la ecuación discriminante univariable analizada mostró que la amplitud de la sutura temporooccipital (STO) tiene la tasa de precisión más alta (75,4 %) entre 12 parámetros. Para el análisis multivariable mediante el método paso a paso, la longitud del hormion-basion (LHB), la amplitud de la sutura témporo-occipital (TOB) y la longitud del asterion izquierdo al basion (Lt. ABL) proporcionaron la mayor tasa de precisión (78,8 %). En conclusión, este estudio sugirió que TOB, LHB y Lt. ABL son parámetros potenciales que se pueden utilizar para determinar el sexo en restos de hueso occipital seco de la población del noreste de Tailandia.

PALABRAS CLAVE: Determinación del sexo; Hueso occipital; Análisis de funciones discriminantes; Población del noreste de Tailandia.

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