Craniometric Study of Thai Skull Based on Three-Dimensional Computed Tomography (CT) Data

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The present study revealed an advanced method using data obtained from three-dimensional computed tomography (3D CT) to evaluate the craniometric data of the Thai population. Ninty-one Thai cadaveric dry skulls from the Faculty of Medicine, Khon Kaen University were investigated in the present study. It enabled the authors to assess the three-dimensional anatomical landmarks in digital format without physical measurements. The results have revealed that the craniometric data of Thai males were larger than Thai females with a statistical significant difference, especially, the maximum cranial length, basion-bregma height, nasion-basion length, nasion-bregma length and bizygomatic breadth parameters ($p << 0.001$). In addition, the craniometric data based on Thai skulls of the people in the northeast region was different from the people in the central region. Furthermore, the linear regression equations obtained from the pairwise parameter, it is useful to predict the craniometric parameters in forensic medicine.

Keywords: *Craniometric study, Three-dimensional computed tomography, Medical imaging, Thai skull, cephalometry, Three-dimensional images, X-ray computed tomography*

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Craniometry is the scientific measurement of the dimensions of the skull and face to determine its characteristics as related to sex, race, or body type. The underlying assumption of craniometry is that skull size and shape determine brain size(1-4). Normally, the practice consists of taking precise measurements using '*anatomical landmarks*' on the skull. These landmarks can be established using various methods such as physical direct measurement or using 2D images from x-ray and CT scan(5, 9). Although the various types of calipers and linear measuring devices can provide accurate and reproducible 3D surface measurements, the limitations include the time required for collecting data, as well as storing and reconstructing these data for 3D purposes(6).

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Currently, the development of computed tomographic and medical imaging techniques is widely accepted as a standard protocol for clinical diagnosis and surgical treatment planning. It enables 3D reconstruction and assesses craniofacial morphometric data both inner and outer anatomical landmark for the craniometric study(7,8,11). For the forensic studies of Thai skulls, they were mostly cranioscopy and craniometry which using either conventional (*e.g.*, use of spreading, sliding calipers, mandibulometer, and horizontal tracing needle)(12,14,15) or 3D coordination tacking device (*e.g.*, standard osteological diagraph)(13). However, no previous reports have reported such Thai craniometric study by means of three-dimensional computed tomography (3D CT) method. The 3D CT craniometric analysis is a relatively new method in forensic medicine especially in Thailand.

Therefore, the present study aimed to evaluate the craniometric data of Thai based on three dimensional computed tomographic data. Medical imaging technique were used to determine the craniometric data in digital format without physical measurement and destructive the specimens.

Material and Method

CT data acquisition

A total of 91 Thai cadaveric dry skulls obtained from the Department of Anatomy, Faculty of Medicine, Khon Kaen University, Khon Kaen, Thailand were used in the present study. The donors were 56 males (average 58.60 ± 15 years) and 35 females (average 57.06 ± 14 years) with age ranging from 26 to 80 years at the time of death. A set of four skulls was prepared in the acrylic box for each CT scan with the SIEMENS spiral CT scanner as shown in Fig. 1. The CT scan acquisition was performed with 1.5-mm slice thickness and reconstruction was done with 1.0-mm slice thickness. All CT data sets were recorded using DICOM 3.0 as a medical image file format into CD-ROM and subsequently imported to the medical imaging software (MIMICS, Materialise N.V., Belgium). The segmentation technique was used to identify the region of interest of the CT image based on Hounsfield unit. The selected regions were calculated into the three-dimensional model as shown in Fig. 2, which enable the authors to determine the three-dimensional craniometric data.

Fig. 1 Preparation of a set of four skulls for each CT-scanning

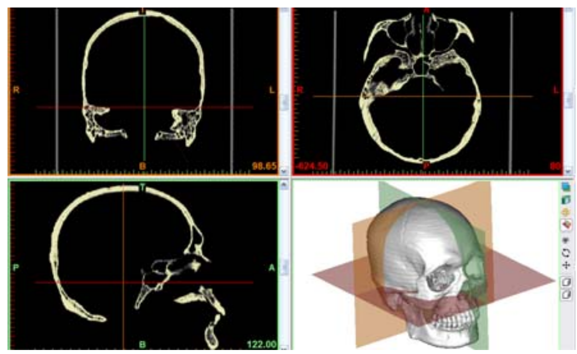

Fig. 2 Three-dimensional reconstruction of skull in medical imaging software using data obtained from computed tomographic data

Measurement of 3D craniometric data

To determine the craniometric data in the present study, the first step was to define the anatomical landmarks which can be classified as median and bilateral types as shown in Fig. 3. All landmarks used in the present study were based on the traditional definition[12,13] with the modification into 3D model. The most prominent anatomy in 2D/3D views were selected to state the proper position of each anatomical landmark. The second step was to calculate the craniometric parameters, which were derived from the two and three coordinate points for linear and angular measurements respectively. The measurement data was then exported into the Microsoft Office Excel file (*.xls) for the statistical analysis.

Statistical analysis

For statistical analysis, craniometric measurements were reported using descriptive statistics *i.e.* mean (μ) and standard deviation (SD). The investigation of different craniometric data between male and female was analyzed with an unpaired t-test. A p-value < 0.05 was considered to be statistical significant difference. In addition, the linear regression and correlation analysis were performed to investigate the pairwise correlation of each craniometric parameter.

Results

All parameters obtained from the three-dimensional craniometric measurement of 91 specimens between male and female are presented in Table 1. The results showed that the dimensions of the male were larger than those of the female craniometric data.

Table 2 presents the comparison of craniometric data between the computerized technique in the present study and previous reports[4,13] that were based on the traditional measurement technique. It was found that the craniometric results were slightly different between each study due to different measurement techniques and source of specimens.

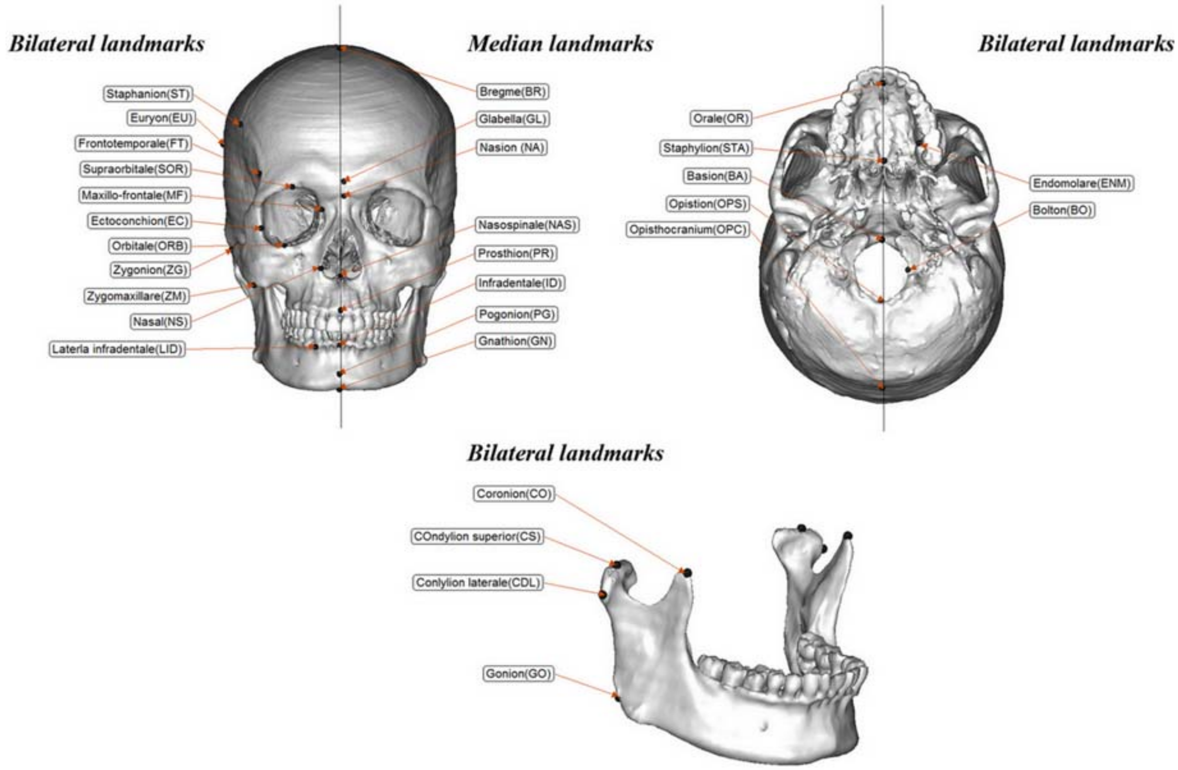

Fig. 3 The anatomical landmarks used in this study which classified as median and bilateral landmarks

In addition, the linear regression and correlation analysis of craniometric parameters in male and female are presented in Table 3 and 4, respectively. It found the relationship between pairwise craniometric parameters that can be classified into 2 groups. The first group is the pairwise between each contralateral sides of each craniometric parameter, while the second group is the pairwise correlation of each craniometric parameter.

Discussion

The present study revealed a new method of three-dimensional evaluation of the craniometric study of skull using computed tomographic (CT) and medical imaging techniques. To the authors' knowledge, no previous reports have described such a craniometric study of Thai skull with this advanced method. The major advantage is to investigate the craniometry of the skull in the digital format without physical measurement and destructive specimen. It enabled the authors to easily assess the three-dimensional anatomical landmarks for the craniofacial morphology. In addition, the inter-landmark distances and angle measurement were automatically calculated between the three-dimensional coordinates of the skeletal structure without magnification errors and head positioning. Although, some studies reported that the accuracy and reliability of 3D CT landmark identification system were no statistical significant difference from the physical measurement with $p > 0.05$[10,18]. However, several studies reported the advantages of 3D cephalometric study based on the medical imaging software as a reliable tool to obtain the valuable information[7,8,16,17].

In the present study, as shown in Table 1, it has revealed that there was a statistical significant difference between male and female. This was consistent with the previous studies that the skull dimensions of males were larger than those of females. However, there were some overlapping ranges which were unable to define definite gender[4,13].

Considering each parameter, it was found that 25 of 32 parameters showed statistical significant difference between males and females, especially, the maximum cranial length, basian-bregma height, nasion-basion length, nasion-bregma length and

Table 1. The results of Thai craniometric data male and female for each parameter

Measurement	Landmark	Male		Female		p-value
		Mean (μ)	SD (σn-1)	Mean (μ)	SD (σn-1)	
Max. cranial length (mm)	*GL-OPC*	173.09	4.74	165.15	6.61	****
Max. cranial breadth (mm)	EU_l-EU_r	144.13	5.45	140.83	5.40	**
Min. frontal breadth (mm)	FT_l-FT_r	94.71	4.97	91.54	4.64	**
Max. frontal breadth (mm)	ST_l-ST_r	115.61	7.08	113.68	6.68	NS
Basion-brema height (mm)	*BA-BR*	138.48	4.97	132.29	5.18	****
Nasion-basion length (mm)	*NA-BA*	101.54	3.65	95.96	3.33	****
Foramen magnum length (mm)	*BA-OPC*	36.78	2.14	34.29	2.35	***
Foramen magnum breadth (mm)	BO_l-BO_r	30.71	2.05	28.90	1.89	***
Nasion-bregma length (mm)	*NA-BR*	112.88	4.14	107.15	5.84	****
Facial length (mm)	*BA-PR*	95.95	5.70	93.06	5.44	*
Bi-orbital breadth (mm)	EC_l-EC_r	97.22	3.60	93.73	3.47	***
Bi-zygometic breadth (mm)	ZG_l-ZG_r	133.21	4.91	127.31	4.79	****
Maxillary breadth (mm)	*ZMl -ZMr*	104.47	5.19	98.75	5.09	***
Upper facial height (mm)	*NA-PR*	70.17	4.35	65.78	4.13	***
Orbital breadth-left(mm)	EC_l-MF_l	40.95	1.86	39.36	2.30	***
Orbital breadth-Right (mm)	EC_r-MF_r	41.43	1.75	39.66	2.00	***
Orbital height-left (mm)	ORB_l-SOR_l	36.30	2.35	34.45	2.42	***
Orbital height-right (mm)	ORB_r-SOR_r	36.22	2.37	34.79	2.17	***
Anterior interorbital breadth (mm)	MF_l-MF_r	21.35	2.09	20.87	2.16	NS
Nasal breadth (mm)	N_l-N_r	27.28	2.08	27.20	2.07	NS
Nasal height (mm)	*NA-NAS*	52.57	3.02	49.53	2.68	***
Palatal length (mm)	*OR-STA*	41.84	3.79	41.82	4.00	NS
Palatal breadth (mm)	ENM_l-ENM_r	39.03	2.96	37.82	2.13	*
Bi-coronion breadth (mm)	CO_l-CO_r	97.95	5.17	93.91	4.56	**
Bi-condylar breadth (mm)	CDL_l-CDL_r	122.89	5.32	118.27	4.99	**
Bi-gonion breadth (mm)	GO_l-GO_r	99.90	4.78	93.62	5.90	***
Coronion height-left (mm)	CO_l-GO_l	62.29	4.88	57.35	4.59	***
Coronion height-right (mm)	CO_r-GO_r	62.72	5.38	57.62	4.79	***
Mandibular angle-left (deg)	CS_l-Go_l-GN	112.37	5.37	112.88	5.66	NS
Mandibular angle-right (deg)	CS_r-Go_r-GN	112.54	5.61	112.05	5.73	NS
Mandibular body length-left (mm)	GO_l-PG	91.63	4.85	87.18	4.99	**
Mandibular body length-right (mm)	GO_r-PG	91.93	4.73	87.72	5.20	**
Max. mandibular length-left (mm)	CS_l-PG	119.01	5.99	113.96	4.57	**
Max. mandibular length-right (mm)	CS_r-PG	119.75	5.89	114.63	4.73	**
Notch length-left (mm)	CO_l-CS_l	35.42	2.86	34.50	4.24	NS
Notch length-right (mm)	CO_r-CS_r	35.13	2.87	34.01	4.14	NS
Ramus height-left (mm)	CS_l-GO_l	58.11	5.07	55.38	4.58	*
Ramus height-right (mm)	CS_r-GO_r	58.26	4.86	55.65	4.52	*
Symphysic breadth (mm)	LID_l-LID_r	20.55	1.81	20.93	1.70	NS
Symphysic height (mm)	*GN-ID*	31.63	3.75	29.48	3.07	*

Significance levels: ****$p << 0.001$; ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; NS-no statistical significance

bizygomatic breadth parameters (****$p << 0.001$). The following parameters *i.e.* foramen magnum length, foramen magnum breadth, bi-orbital breadth, maxillary breadth, upper facial height, orbital breadth, orbital height, nasal height, bi-gonion breadth, coronion height showed the relative high statistical significant difference (***$p < 0.001$) while the other following parameters *i.e.* max. cranial breadth**, min frontal breadth**, bi-coronion breadth**, bi-condylar breath**, mandibular body length**, max mandibular length**, facial length*, palatal breadth*, ramus height* and symphysic height* also showed statistical

Table 2. The comparison craniometric data between present studies and previous reported[13,4]

Measurement	Sex	Present study n	Mean	SD	Ninprapan[13] n	Mean	SD	Sangvichien[4] n	Mean	SD
Max. cranial length (mm)	M	56	173.09	4.74	32	169.16*	8.08	66	175.68*	6.83
	F	35	165.15	6.61	22	165.82	5.74	35	168.80*	7.18
Max. cranial breadth (mm)	M	56	144.13	5.45	31	143.58	6.02	65	145.82	5.20
	F	35	140.83	5.40	22	140.56	6.00	35	144.66*	5.59
Min. frontal breadth (mm)	M	56	94.71	4.97	32	93.57	4.81	66	81.73*	5.58
	F	35	91.54	4.64	22	91.97	4.02	35	77.80*	6.27
Max. frontal breadth (mm)	M	56	115.61	7.08	31	114.56	7.73	65	121.92*	6.55
	F	35	113.68	6.68	22	111.46	6.41	35	119.20*	6.33
Basion-brama heigth (mm)	M	56	138.48	4.97	32	135.37*	6.02	66	142.09*	5.35
	F	35	132.29	5.18	22	131.73	4.60	35	135.86*	5.67
Nasion-basion length (mm)	M	56	101.54	3.65	-	-	-	66	101.77	4.10
	F	35	95.96	3.33	-	-	-	35	94.57	4.43
Foramen magnum length (mm)	M	56	36.78	2.14	32	35.39*	2.99	65	32.42*	3.10
	F	35	34.29	2.35	22	34.76	2.08	35	31.06	2.66
Foramen magnum breadth (mm)	M	56	30.71	2.05	32	30.68	2.26	66	27.04*	2.22
	F	35	28.90	1.89	22	30.10	2.64	35	25.83	1.88
Nasion-bregma length (mm)	M	56	112.88	4.14	-	-	-	66	110.65*	4.96
	F	35	107.15	5.84	-	-	-	35	106.96	5.51
Facial length (mm)	M	56	95.95	5.70	-	-	-	66	95.78	5.60
	F	35	93.06	5.44	-	-	-	35	89.77	6.01
Biorbital breadth (mm)	M	56	97.22	3.60	32	96.80	4.18	66	96.79	4.07
	F	35	93.73	3.47	22	95.21	3.43	35	92.09	3.56
Bizygometic breadth (mm)	M	56	133.21	4.91	32	130.99	5.30	66	136.33*	5.75
	F	35	127.31	4.79	22	125.32	5.68	35	127.54	5.39
Maxillary breadth (mm)	M	56	104.47	5.19	-	-	-	-	-	-
	F	35	98.75	5.09	-	-	-	-	-	-
Upper facial height (mm)	M	56	70.17	4.35	32	68.07*	4.99	66	67.12*	4.94
	F	35	65.78	4.13	19	65.89	4.55	35	62.14*	5.44
Orbital breadth-left (mm)	M	56	40.95	1.86	32	41.54	2.15	66	40.10*	1.89
	F	35	39.36	2.30	22	40.56*	1.29	35	38.09	2.25
Orbital breadth-right (mm)	M	56	41.43	1.75	32	42.10	2.21	-	-	-
	F	35	39.66	2.00	22	40.96*	1.64	-	-	-
Orbital height-left (mm)	M	56	36.30	2.35	32	36.57	2.87	66	33.44*	2.33
	F	35	34.45	2.42	22	35.84*	1.82	35	32.89	2.28
Orbital height-right (mm)	M	56	36.22	2.37	32	36.17	2.63	-	-	-
	F	35	34.79	2.17	22	35.42	2.33	-	-	-
Anterior interorbital breadth (mm)	M	56	21.35	2.09	32	19.70*	2.11	66	15.30*	2.43
	F	35	20.87	2.16	22	19.96	2.93	35	14.04	2.01
Nasal breadth (mm)	M	56	27.28	2.08	32	27.41	1.86	-	-	-
	F	35	27.20	2.07	22	26.85	1.63	-	-	-
Nasal height (mm)	M	56	52.57	3.02	32	50.25*	3.48	-	-	-
	F	35	49.53	2.68	22	48.19	3.31	-	-	-
Palatal length (mm)	M	56	41.84	3.79	31	45.16*	3.39	-	-	-
	F	35	41.82	4.00	21	43.27	3.95	-	-	-
Palatal breadth (mm)	M	56	39.03	2.96	29	36.99*	3.55	-	-	-
	F	35	37.82	2.13	19	36.75	3.16	-	-	-

* Statistical significance $p < 0.05$

Table 3. The correlations coefficients for pairwise correlation of Thai male craniometric parameters (n = 56)

Parameters	Linear regressionequation	Correlation coefficient (r)
Mandibular angle*	y = 0.976x + 2.862	0.934
Max.Mandibular length*	y = 0.893x + 13.39	0.910
Mandibular body length*	y = 0.876x + 11.63	0.897
Coronion height*	y = 0.970x + 2.240	0.881
Orbital height*	y = 0.865x + 4.790	0.858
Orbital breadth*	y = 0.774x + 9.716	0.821
Ramus height*	y = 0.761x + 14.03	0.794
Notch length*	y = 0.775x + 7.657	0.772
Bi-zygometic breadth (x) vs. Bi-condylar breadth (y)	y = 0.743x + 23.944	0.710
Upper facial height (x) vs. Symphysic height (y)	y = 0.624x - 12.53	0.707
Bi-orbital breadth (x) vs. Orbital breadth right (y)	y = 0.342x + 8.161	0.702
Max. cranial breadth (x) vs. Bi-zygometic breadth (y)	y = 0.585x + 48.86	0.650
Facial length (x) vs. Palatal length (y)	y = 0.425x + 1.026	0.640
Basion-brema height (x) vs. Nasion-bregma length (y)	y = 0.509x + 42.26	0.612
Nasal height (x) vs. Upper facial height (y)	y = 0.853x + 25.30	0.593
Bi-coronion breadth (x) vs. Nasion-basion length (y)	y = 0.384x + 63.94	0.575
Anterior interorbital breadth (x) vs. Bi-condylar breadth (y)	y = 1.291x + 95.54	0.514

* Contralateral parameter: left side (x) vs. right side (y)

Table 4. The Correlations coefficients for pairwise correlation of Thai female craniometric parameters (n = 35)

Parameters	Linear regressionequation	Correlation coefficient (r)
Mandibular body length*	y = 0.957x + 4.292	0.918
Ramus height*	y = 0.893x + 6.17	0.907
Orbital breadth*	y = 0.773x + 9.211	0.891
Max.Mandibular length*	y = 0.922x + 9.513	0.890
Coronion height*	y = 0.927x + 4.446	0.888
Notch length*	y = 0.848x + 4.735	0.868
Orbital height*	y = 0.759x + 8.623	0.847
Mandibular angle*	y = 0.841x + 17.05	0.832
Upper facial height (x) vs. Symphysic height (y)	y = 0.647x - 13.422	0.772
Facial length (x) vs. Palatal length (y)	y = 0.566x - 10.91	0.770
Bi-orbital breadth (x) vs. Orbital breadth left (y)	y = 0.508x - 8.312	0.767
Min. frontal breadth (x) vs. Max. frontal breadth (y)	y = 1.090x + 13.84	0.758
Nasion-bregma length (x) vs. Ramus height (y)	y = 0.610x - 10.09	0.745
Maxillary breadth (x) vs. Bi-orbital breadth (y)	y = 0.469x + 47.36	0.689
Nasal height (x) vs. Upper facial height (y)	y = 1.043x + 14.10	0.677
Upper facial height (x) vs. Symphysic breadth (y)	y = 0.298x + 1.167	0.643
Bi-zygometic breadth (x) vs. Max.Mandibular length right (y)	y = 0.610x + 36.64	0.639
Max. cranial breadth (x) vs. Max. frontal breadth (y)	y = 0.774x + 4.586	0.626
Bi-gonion breadth (x) vs. Mandibular body length left (y)	y = 0.520x + 38.47	0.615
Foramen magnum breadth (x) vs. Foramen magnum length (y)	y = 0.750x + 12.60	0.603
Max. cranial length (x) vs. Nasion-basion length (y)	y = 0.302x + 46.01	0.600
Basion-brema height (x) vs. Ramus height right (y)	y = 0.688x - 35.04	0.596
Bi-condylar breadth (x) vs. Bi-zygometic breadth (y)	y = 0.562x + 61.26	0.566
Anterior interorbital breadth (x) vs. Bi-coronion breadth (y)	y = 1.345x + 65.84	0.558

* Contralateral parameter: left side (x) vs. right side (y)

significant difference (** $p < 0.01$, * $p < 0.05$). However, the other 7 of 32 parameters didn't show the statistical significant difference *i.e.* maximum frontal breadth, anterior inter-orbital breadth, nasal breadth, palatal length, mandible, angle, notch length, and symphysic breadth.

As shown in Table 2, it was found that the craniometric data from the present study and the report from Ninprapan[13] were quite similar while the report from Sangvichien[4] was quite different with statistical significant difference ($p < 0.05$). This is due to the different craniometric measurement techniques and source of specimens, especially, the report from Sangvichien[4] which was based on the anatomy of Thai skulls in the central region of Thailand while the present study and report from Ninprapan[13] were based on Thai skulls in the north-eastern region of Thailand. It can depict that the craniometry of the people in the northeast region is different from the people in the central region with statistical significant difference.

The authors also investigated the relationship between each craniometric parameter in males and females separately using the linear regression and correlation techniques. This is due to the statistical significant difference of craniometry between males and females. The pairwise correlations of craniometric parameters were found differently between males and females as shown in Table 3 and 4. However, in both male and female craniometric data, the high correlation coefficients occurred in the bilateral anatomy but they were not strong enough to conclude the facial symmetry of each contralateral side. Regarding the linear regression analysis and scatter plot of pairwise parameters (as shown in Fig. 4, 5), the linear equation can be obtained. On the other hand, the equation to predict the other pairwise parameter can be used. The confidence interval of each equation depends on the correlation coefficients. If it gets closer to $\pm$ 1, the relationship between each pairwise is stronger. This linear regression equation is very useful to predict the craniometric parameters in the forensic medicine.

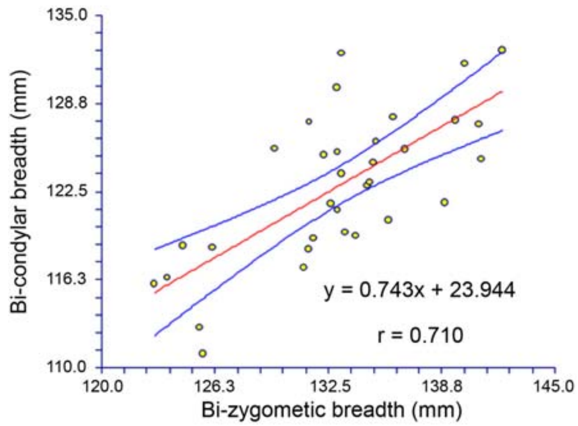

Fig. 4 Scatter plot and 95% confidence interval bands of the bi-zygometic breadth (x) and the bi-condylar breadth (y)

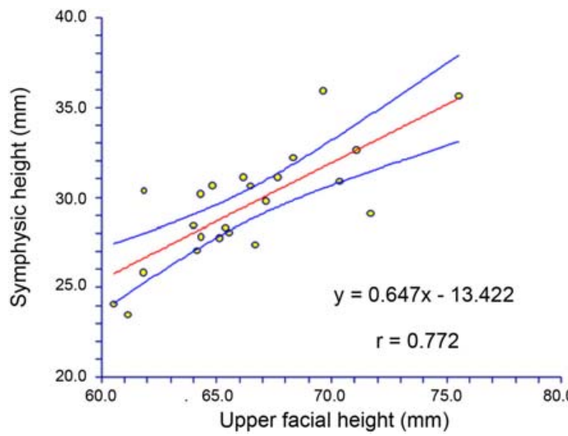

Fig. 5 Scatter plot and 95% confidence interval bands of the upper facial height (x) and the symphysic height (y)

Conclusion

The present study has demonstrated an advanced technique based on computed tomographic and medical imaging methods, which is very useful to analyze the craniometric study in digital format without physical measurement and destruction to the specimen. The conclusion can be drawn that the craniometric data of Thai males are larger than Thai females with statistical significant difference. In addition, the craniometric data based on Thai skulls in the northeast region is different from the people in the central region with statistical significant difference.

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การศึกษาทางกายวิภาคในกะโหลกศีรษะคนไทยแบบ 3 มิติ โดยอาศัยข้อมูลภาพถ่ายเอกซ์เรย์คอมพิวเตอร์

สุภกิจ รูปขันธ์, สุรสิทธิ์ ปิยะศิลป์, ณัฏฐภูมิ วัฒนาปฐิมากุล, ยุพาพร แก้วพรม, กฤษณ์ไกรพ์ สิทธิเสรีประทีป

ในการศึกษานี้ได้เสนอวิธีการใช้ข้อมูลการถ่ายภาพเอกซ์เรย์คอมพิวเตอร์แบบ 3 มิติ เพื่อประเมินหาข้อมูลทางกายวิภาคกะโหลกศีรษะคนไทย โดยทำการศึกษาในกะโหลกศีรษะแห้งคนไทย จำนวน 91 ตัวอย่าง จากภาควิชากายวิภาคศาสตร์ คณะแพทยศาสตร์ โรงพยาบาลศรีนครินทร์ มหาวิทยาลัยขอนแก่น วิธีการนี้ทำให้สามารถกำหนดจุดสำคัญทางกายวิภาคแบบ 3 มิติ ในรูปแบบดิจิตอลโดยปราศจากการวัดโดยตรง จากผลการศึกษาพบว่าข้อมูลทางกายวิภาคกะโหลกศีรษะคนไทยเพศชาย มีขนาดใหญ่กว่าเพศหญิงด้วยความแตกต่างทางสถิติอย่างมีนัยสำคัญ โดยเฉพาะอย่างยิ่งค่าความยาวสูงสุดของกะโหลกศีรษะ, ระยะความสูง brasion-bregma, ความยาว nasion-brasion, ความยาว nasion-bregma และความกว้างของ zygoma ($p << 0.001$) และยังพบว่าข้อมูลทางกายวิภาคกะโหลกศีรษะคนไทยในภาคตะวันออกเฉียงเหนือมีความแตกต่างจากคนไทยในภาคกลาง นอกจากนี้ความสัมพันธ์เชิงเส้นจากพารามิเตอร์แต่ละคู่จะมีประโยชน์ในการทำนายข้อมูลกะโหลกศีรษะคนไทยในทางนิติเวชศาสตร์