Sex and Height Determination by Foramen Magnum Morphometry using Multiplanar Reconstruction (MPR) CT Skull Images

Dr. Suraya Hanim Binti Mohamed Annuar

Dissertation is Submitted in Partial Fulfillment of the Requirement for the Degree of Master of Medicine (Radiology)

SCHOOL OF MEDICAL SCIENCES

UNIVERSITI SAINS MALAYSIA

2016

Sex and Height Determination by Foramen Magnum Morphometry using Multiplanar Reconstruction (MPR) CT Skull Images

Researcher:

Dr. Suraya Hanim Binti Mohamed Annuar

Supervisor/Co-Researcher:

Assoc. Prof. Dr. Mohd Ezane Bin Aziz

Contents

ACKNOWLEDGEMENT

بسم الله الرحمن الرحيم

I would like to express my gratitude to my supervisor Associate Profesor Dr. Mohd Ezane Aziz for the useful guidance, comments, remarks and engagement through the learning process of this master thesis. Furthermore, I would like to thank other lecturers, staffs and fellow colleagues for the support on the way conducting this study. I would like to thank my beloved family, who have supported me throughout entire process, both by keeping me harmonious and helping me putting pieces together. I will be grateful forever for their love.

ABBRAVERATION

CT	**Computed Tomography**
FM	**Foramen Magnum**
GE	**General Electric**
LC	**Length of condyle**
LFM	**Length of foramen magnum**
MBD	**Maximum bicondylar distance**
MDCT	**Multi-detector computed tomography**
MPR	**Multiplanar Reconstruction**
PACS	**Picture Archiving and Communication System**
SD	**Standard deviation**
WC	**Width of condyle**
WFM	**Width of foramen magnum**

LIST OF TABLE AND FIGURES

List of figure:

List of tables:

ABSTRACT

Introduction:

Radiological forensic is a specialised area of medical imaging using radiological technique for identification of human and also for ante or post mortem purposes. Radiological imaging of human remains become important in forensic field in determining sex, age, ethnicity, stature and in fact, cause of death.

Objective:

The aim of this study is to determine the relationship between sex and height with foramen magnum (FM) morphology using multiplanar reconstruction (MPR) computed tomography (CT) scan of the skull.

Material and Method:

Total of 104 CT scan of the skull were selected using randomised sampling, i.e. 52 samples for each gender. Images were analysed using PACS viewing application on grey-scale monitor. Seven variables of FM morphology were measured on MPR skull images. Comparison between FM morphology and sex, and correlation with height were analysed using statistical test.

Results:

There is statistically significant difference between males and females for all measurements, with p value < 0.05. The males have larger value than female, in all FM measurements. However, fair degree of correlation between FM parameters and height ($0.257<r<0.495$; $P<0.05$) was observed in this study.

Conclusion:

FM measurements are very useful in studying sexual dimorphism in forensic investigations, but less helpful to determine height of an individu.

ABSTRAK

Pengenalan:

Forensik radiologi adalah bidang pengkhususan di dalam bidang pengimejan perubatan menggunakan kaedah radiologi bagi indentifikasi manusia dan juga bertujuan untuk mengenal pasti punca kematian secara *ante* atau *post* mortem. Input dari pengimejan radiologi ialah dalam mengenal pasti jantina, umur, etnik, ketinggian dan juga punca kematian.

Objektif:

Tujuan kajian ini adalah untuk menentukan kaitan antara jantina dan ketinggian dengan morfologi *Foramen Magnum (FM)* melalui teknik *rekontruksi multiplanar (MPR) imbasan tomografi berkomputer (CT) tulang tengkorak*.

Bahan dan Kaedah:

Sebanyak 104 imbasan tomografi berkomputer tulang tengkorak telah dipilih secara persampelan rawak, iaitu 52 sampel bagi setiap jantina. Imej-imej dianalisa dengan perisian PACS menggunakan paparan monokrom. Tujuh pemboleh-ubah berkaitan morfologi FM telah diukur ke atas imej rekontruksi multiplanar. Perbandingan antara morfologi FM dan jantina, serta korelasi dengan ketinggian dianalisa menggunakan ujian statistik.

Keputusan:

Hasil kajian menunjukkan perbezaan ketara dalam statistik ($p < 0.05$) bagi kedua jantina untuk semua ukuran morfologi FM. Namun begitu, perkaitan antara morfologi FM dengan ketinggian adalah sederhana.

Kesimpulan:

Analisis ukuran FM sangat berguna di dalam mengenal pasti jantina dalam bidang forensic, tetapi kurang membantu dari segi menentukan ketinggian individu.

INTRODUCTION

Identification of the human remains is the most essential part of forensic anthropology. There are multiple established scientific identification methods, such as fingerprint, dental, anthropological, genetic, and radiological examination. It is most often based on assesing sex, age, stature, and ethnicity or traits. Skeletal part of human body is usually used as it the only remains that can withstand extreme weather climate and chemical exposure. Many studies have been done in different skeletal parts, such as bone of extremities, different part of skull vault and pelvic bones (Lynnerup 2013). A lot of forensic anthropological methods for aging and sexing have been around for more than hundred years and become part of basic toolbox for forensic anthropology.

For age evaluation, the fundamental methods in forensic is that biological age more or less follows chronological age. Chronological age is the calendar age, which we identify our age in years; as biological age refers to how aging affects body and how this changes being observed. Human soft tissues also has aging phenomenon but it is more complicated and difficult to discern in useful way compared to odontological or skeletal part. Same as sex evaluation, it mainly based on skeletal by identifying sex-characteristic and specific morphology, although the primary sex characterization is determined by sex chromosomes in genetic study. Some established data has been used, for example pelvis, which turn out to be the bony structure with most marked sexual dimorphism: female pelvis has wider and flater dimension whereas male pelvis is higher and narrow (Lynnerup 2013). Other features evaluated in pelvis are the shape of obturator foramen, subpubic angle sharpness and ischiopubic angle. These features makes the pelvis, the most reliable bones for sex identification.

Radiograph has long been used for forensic identification of human remains since it was introduced in 18th century. Same as other forensic method, radiological forensic anthropology is also widely used in sex identification, age estimation and more importantly has a role for establishing the cause of death. The comparison of ante and post morterm radiographs are one of acurate methods of identification (Thali, Brogdon et al. 2002). As the radiology field evolves, multi-detector computered tomography (MDCT) scan is highly used for this purposes and the application has become broad, not just confined to postmorterm study particularly in determining the cause of death or injury, now it is even used to investigate accidental injury and non accidental injury (Kudlas and Odle 2010).

Besides reliablity of pelvic bone morphology that has been used for forensic identification, skull vault or craniofacial anthropology has been used for the same purpose. The measurements of skeletal bones mainly neuro-cranium and viscero-cranium are often used for human population morphological studies of age estimation, sex determination, stature, ethnicity which are relevant aspects of forensic investigations and anthropological examination of unknown individuals. The human occipital condyles are unique bony structures connecting the cranium and the vertebral column. It is the only articulation between the occipital bone and the atlas hence an important part of the cranio-vertebral junction (Selma Uysal, Gokharman et al. 2005).

As for the foramen magnum is the largest opening located in the median plane of the cranial cavity. The foramen belongs to the posterior cranial fossa and connects it with the base of the skull and with the vertebral canal. The structure is completely surrounded by 4 principal components of the occipital bone: the supra-occipital part of the squama posteriorly, the basilar part anteriorly, and by two lateral parts on the right and left sides (Burdan, Szumiło et al. 2012).

The integrity of occipital condyles is of vital importance for the stability of the cranio-vertebral junction. In the last two decades, the cranio-vertebral junction has been the focus of a variety of anatomical and biomechanical studies. Today, the newer neuro-imaging techniques have increased the interest for aggressive craniovertebral surgeries. Space occupying lesions ventral to the spinal cord at the level of foramen magnum can be surgically reached using a ventral or dorsal approach. The ventral approach has a lot of difficulties and a high rate of morbidity therefore necessitating the increasing trends of dorsal and lateral trans-condylar approach which requires partial or complete resection of the occipital condyles for access to the ventral and ventro-lateral areas of the foramen magnum. Therefore, knowing the anatomy and analyzing the morphometric aspects of occipital condyles is extremely important as it will help the neurosurgeon in the planning of surgical intervention involving the skull base safe and easier due to the increasing trends for transcondylar approach (Nagar and Kumar 2014).

Study performed previously on determined sexual dimorphism by measuring specific bony landmarks on the cranial base, such as axial length of the occipital condyle, showed significant outcome (Murshed, Çiçekcibaşi et al. 2003). Another study also described that significant difference between male and female condyle area and also the foramen magnum width (Selma Uysal, Gokharman et al. 2005). Similarly in a study done by Galdames et al, showed foramen magnum dimension has significant difference in both sexes (Galdames, Russo et al. 2009). Shape of foramen magnum also has been describe by other researcher, but no correlation can be demonstrated in relation to ethnicity or sex (Murshed, Çiçekcibaşi et al. 2003).

In Malaysia, foramen magnum has not been studied in determined sex, and there is none of the earlier mentioned articles study the correlation of the foramen magnum morphology in relation to stature such as height.

The purpose of this study is to assess the foramen magnum (FM) using multiplanar reconstruction (MPR) measurements from computered tomography (CT) brain images, and determined whether morphometry of the FM can be used for sexing and height correlation.

STUDY PROTOCOL

General Objective:

To assess the foramen magnum based on multiplanar reconstruction CT measurements.

Specific objectives:

To determine the association of foramen magnum (FM) morphometry with gender.

To determine correlation between FM morphometry and body height.

Research design:

- Retrospective study will be used to obtain data sample of CT scan brain.

Population and Sample:

- Source population will be patients underwent CT scan brain in HUSM.

- Letter of permission from the Director of Hospital USM (as required during Ethical meeting on 24th April 2015 obtained) for using the patients' images.

Inclusion criteria

- All CT brain done from January 2013 until December 2013.
- Adult patients from 12 years old and above.
- Diagnostic quality image.

Exclusion criteria:

- Patient with congenital defect of the brain or spine.
- Patient with previous operation to the skull or spine.
- Patients who are involved with trauma to the base of skull and spine.
- Patients with carcinoma or acquired pathology to foramen magnum.
- Patients with trauma or acquired pathology which can alter height.
- The method and measurement used here will be based on the modified method developed by UYSAL ET AL.

Sampling method:

All samples will be randomly obtained retrospectively and images will retrived from the picture archiving and communication system (PACS) in Department of Radiology into diagnostic workstation with GE Centricity PACS Universal Viewer version 5.0PACS where the source population were patients underwent CT scan brain in Hospital Universiti Sains Malaysia, using Siemens Somatom Plus4, 128 slices multidetector.

Sample size estimation:

Objective 1:

To determine the association of foramen magnum (FM) morphometry with gender.

Sample size calculation made based on study performed by Suazo et al., using T- test in PS software:

- α : 0.05
- P : 0.8
- Δ : 1.5
- σ : 2.6
- M : 1
- n= 48 + 4 (10% drop off) : 52 patient each gender
- total: 52 x 2 = 104 subjects

Objective 2:

To determine correlation between FM morphometry and body height.

No literature reviews available for sample calculation.

In conclusion, based on largest sample size calculated, total sample size of 104 patients are required for this study.

MANUSCRIPT

Introduction:

Identification of the human remains is the most essential part of forensic anthropology. There are multiple established scientific identification methods, such as fingerprint, dental, anthropological, genetic, and radiological examination. It is most often based on assesing sex, age, stature, and ethnicity or traits. Skeletal part of human body is usually used as it the only remains that can withstand extreme weather climate and chemical exposure. Many studies have been done in different skeletal parts, such as bone of extremities, different part of skull vault and pelvic bones (Lynnerup 2013). A lot of forensic anthropological methods for aging and sexing have been around for more than hundred years and become part of basic toolbox for forensic anthropology.

For age evaluation, the fundamental methods in forensic is that biological age more or less follows chronological age. Chronological age is the calendar age, which we identify our age in years; as biological age refers to how aging affects body and how this changes being observed. Human soft tissues also has aging phenomenon butit is more complicated and difficult to discern in useful way compared to odontological or skeletal part. Same as sex evaluation, it mainly based on skeletal by identifying sex-characteristic and specific morphology, although the primary sex characterization is determined by sex chromosomes in genetic study. Some established data has been used, for example pelvis, which turn out to be the bony structure with most marked sexual dimorphism: female pelvis has wider and flater dimension whereas male pelvis is higher and narrow (Lynnerup 2013). Other features evaluated in pelvis are the shape of obturator foramen, subpubic angle sharpness and ischiopubic angle. These features makes the pelvis, the most reliable bones for sex identification.

Radiograph has long been used for forensic identification of human remains since it was introduced in 18th century. Same as other forensic method, radiological forensic anthropology is also widely used in sex identification, age estimation and more importantly has a role for establishing the cause of death. The comparison of ante and post morterm radiographs are one of acurate methods of identification (Thali, Brogdon et al. 2002). As the radiology field evolves, multi-detector computered tomography (MDCT) scan is highly used for this purposes and the application has become broad, not just confined to postmorterm study particularly in determining the cause of death or injury, now it is even used to investigate accidental injury and non accidental injury (Kudlas and Odle 2010).

Besides reliablity of pelvic bone morphology that has been used for forensic identification, skull vault or craniofacial anthropology has been used for the same purpose. The measurements of skeletal bones mainly neuro-cranium and viscero-cranium are often used for human population morphological studies of age estimation, sex determination, stature, ethnicity which are relevant aspects of forensic investigations and anthropological examination of unknown individuals. The human occipital condyles are unique bony structures connecting the cranium and the vertebral column. It is the only articulation between the occipital bone and the atlas hence an important part of the cranio-vertebral junction (Selma Uysal, Gokharman et al. 2005). As for the foramen magnum is the largest opening located in the median plane of the cranial cavity. The foramen belongs to the posterior cranial fossa and connects it with the base of the skull and with the vertebral canal. The structure is completely surrounded by 4 principal components of the occipital bone: the supra-occipital part of the squama posteriorly, the basilar part anteriorly, and by two lateral parts on the right and left sides. The foramen is clinically important since the following structures pass through it: the medulla, meninges, accessory spinal nerve, dural sinuses, as well as the vertebral, posterior and anterior spinal arteries. Since all of the bone elements are well palpated and visible during various radiological examinations, they are also important landmarks for neurosurgeons, radiologists, other physicians, and anthropologists (Burdan, Szumiło et al. 2012).

Study performed previously on determined sexual dimorphism by measuring specific bony landmarks on the cranial base, such as axial length of the occipital condyle, showed significant outcome (Murshed, Çiçekcibaşi et al. 2003). Another study also described that significant difference between male and female condyle area and also the foramen magnum width (Selma Uysal, Gokharman et al. 2005). Similarly in a study done by Galdames et al, showed foramen magnum dimension has significant difference in both sexes (Galdames, Russo et al. 2009). Shape of foramen magnum also has been describe by other researcher, but no correlation can be demonstrated in relation to ethnicity or sex (Murshed, Çiçekcibaşi et al. 2003).

In Malaysia, foramen magnum has not been studied in determined sex, and there is none of the earlier mentioned articles study the correlation of the foramen magnum morphology in relation to stature such as height.

The purpose of this study is to assess the foramen magnum (FM) using multiplanar reconstruction (MPR) measurements from computered tomography (CT) brain images, and determined whether morphometry of the FM can be used for sexing and height correlation.

Methodology

1.1 Study design:

The study was approved by our institutional research ethical committee. All samples were obtained retrospectively where the source population were patients underwent CT scan brain in Hospital Universiti Sains Malaysia, using Siemens Somatom Plus4, 128 slices multidetector. Samples were from the CT brain images of adult patients (12 years and above) done from January 2013 until December 2013. Patient with either congenital or acquired defect of the brain or spine, patient has skull and spinal defect either due to trauma or previous surgery were excluded. Patient with underlying bone or brain tumour within skull and long bones which can altered the morphology of skull and patient's height were also excluded. From these data, a randomized selection was used to obtain required sample.

1.2 Image Analysis:

CT scan images were retrieved from the picture archiving and communication system (PACS) in Department of Radiology into diagnostic workstation with GE Centricity PACS Universal Viewer version 5.0. The images were displayed on Barco 5 Mega Pixel grey scale monitor. Images were post processed using multiplanar reconstruction tool and viewed in bone setting. All measurement done in axial plane, with zoom factor of 2.0. The axial plane image was choosen in reference of mid sagittal plane with point is taken from the basion to opisthion. Measurements taken using point to point measurement tool.

The measurement methods were based on previous study done by Uysal et al with some modification. All seven measurements that included were (illustrated in figure 1-2):

1. Length of left occipital condyle (LLC): The maximum length of left condyle along the long axis from the edges of the articular surface.

2. Length of right occipital condyle (LRC): The maximum length of right condyle along the long axis from the edges of the articular surface.
3. Width of left occipital condyle (WLC): The maximum width of left condyle from the articular edges along a line perpendicular to the long axis.
4. Width of right occipital condyle (WRC): The maximum width of right condyle from the articular edges along a line perpendicular to the long axis.
5. Maximum bicondylar distance (MBD): The maximum distance between the lateral edges of the articular surfaces of the condyles.
6. Length of the foramen magnum (LFM): The maximum internal length of the foramen magnum along the midsagittal plane.
7. Width of the foramen magnum (WFM): The maximum internal width of the foramen magnum perpendicular to the midsagittal plane.

Inter-observer validity test was done for FM measurements. FM readings were taken from two observers, Observer A (Researcher) and Observer B (Radiologist) on ten subjects. These reading were validated with inter-item correlation. The result indicates best inter-item correlation Table 1.

1.3 Statistical Analysis:

All statistical analysis done using SPSS software for Window version 19. Normality of the variables and equal variance assumption were checked prior to analysis (figure 3-11). Paired t-test was used to compare right and left FM. Mean values of two independent variables were compared using independent t-test. The P value of less than 0.05 was taken as statistically significant.

The Pearson Correlation Coefficient test was use to study the corellation between two variables. The correlation coefficient, r, reflects the strength of the linear relationship between two variables. To get a feeling for strong or weak correlations, correlations from 0 to 0.25 (or -0.25) indicate little or no relationship, those from 0.25 to 0.50 (or -0.25 to -0.50) reflects a fair degree of relationship; and those from 0.50 to 0.75 (or -0.50 to -0.75) a moderate degree of relationship, while correlations over 0.75 (or -0.75) reflect a strong relationship.

Results

A total of 104 samples had been selected for this study. The demographic data of these samples is presented in Table 2. Their mean age was 48 years old (SD 16) with minimum and maximum age of 17 and 80 years old, respectively. Majority of the participant were Malay (97.1%), only a small percentage of Chinese (1.0%) and Indians (1.9%) were successfully selected for this study. There were 50% of male and female subjects in this study. The mean heights of participants were 161.62 cm (SD 8.84), with minimum and maximum height of 143 cm and 178 cm respectively.

The general FM morphormetry of participant were shown in Table 3. The mean right LC of participants was 2.34cm (SD 0.22), with minimum 1.77cm and maximum 2.88cm. While mean of left LC was 2.34cm (SD 0.22), with minimum 1.88cm and maximum 2.98cm. The mean right WC of participants was 1.15cm (SD 0.12), with minimum and maximum value was 0.94cm and 1.49cm, respectively. Meanwhile, mean of the left WC was 1.16cm (SD 0.13), the minimum value was 0.85cm and maximum was 1.72cm. There were no significant differences between right and left WC and LC as shown in Table 4. The mean MBD of participants was 4.87cm (SD 0.35), with minimum and maximum mean WC of 4.15cm and 5.94cm, respectively. The mean LFM of participants was 3.45cm (SD 0.62), with minimum and maximum LFM of 2.81cm and 4.02cm, respectively. The mean WFM of participants was 2.95cm (SD 0.24), with minimum and maximum WFM of 2.43 cm and 3.64 cm, respectively.

Statistical analysis done using student t-test for association of FM with gender. The mean of LC, WC, MBD, LFM and WFM between male and female were compared (Table 5). The analysis indicated statistical significant differences among all the parameters, and male showed larger parameters than female.

There was significant fair degree of correlation between FM parameters and height (0.257<r<0.495; P<0.05) as shown in Table 6.

Discussions

Identification of skeletal and decomposing human remains is one of the most difficult skills in forensic medicine. Sex determination is also an important problem in the identification. If almost all the bones composing the skeleton are present, sex estimation is not difficult. The study of anthropometric characteristics is fundamental importance when solving problems related to identification of human remains. Cranio-metric features are included among these characteristics, which are closely connected to forensic medicine since they can be used to aid in identifying an individual from a skull found detached from its skeleton. Sex estimation can be accomplished using either morphological or metric methodologies (Uthman, Al-Rawi et al. 2014). In his study, the FM measurements showed significant difference in each gender with the mean length of FM 32.9 cm (SD 2) in female and 34.3 cm (SD 2) in male with p value < 0.001. Similar finding was noted in previous study which showed significant difference of FM dimension between male and female ($p < 0.001$) in Eastern-European adult (Burdan, Szumiło et al. 2012). Another study also showed that gender influenced the width of the foramen magnum ($p < 0.05$) but not the length (Manoel, Prado et al. 2009).

A study performed among Nigerian population has shown that mean bicondylar distance in males was 49.9 mm (SD 3.4) and in females it was 47.6 mm (SD 4.5), which was statistically significant ($p <0.05$)(Kataba 2014). Another study using dry human skull signify all dimension of the left occipital condyle was statistically significant to determine sex (Nagar and Kumar 2014). All of these different FM morphologies has statistical significant in current study to determine gender.

Another interest in anthropology and forensic medicine is to determine individual stature from skeletal remains. However, in current study, it only show significant fair degree of correlation between FM parameters and height ($0.257<r<0.495$; $P<0.05$). This also proven in other study that showed linear correlations between foramen magnum sizes and individual body height, was weakly positive (Gruber, Henneberg et al. 2009). The study used femur length as a representative indicator for individual height's, which may not be the true representation of height. In comparison to current study, which used standardised measuring tool for each sample's height (Appendix, page 31). Despite of the standardised measuring tool that has been used, the results show no correlation of the FM morphology in individual height.

For stature determination, the two principal methods are anatomical and mathematical. The anatomical method involves measuring all of the skeletal elements that contribute to height and then adding a constant. The mathematical method is based on the correlation between bones and body parts and stature (Dedouit, Savall et al. 2014). Anatomical structure and morphology of the foramen magnum and the occipital condyle, may not contribute much to stature or specifically height. In other hand, some of research that studied the skull morphology showed significant result in estimating individual stature mainly the height. A study done among North Indian population showed cephalometric measurements are highly correlate with stature ($p < 0.001$) (Krishan 2008). Anthropology study of the skull dimension and maxillary teeth in correlation to height that has been done previously showed significant correlation in both entity (Kalia, Shetty et al. 2008). Therefore, we can conclude that the FM morphometry may not be used as strong predictors for individual stature as compared to long bones and cephalometric measurement.

Overall results showed that sexual determination or estimation can be achieved by foramen morphology including the left and right occipital condyle dimension in current study and other previous studies. Although there is poor to fair correlation in all measurements to estimate stature, it may due to poor contribution of the FM itself toward human stature. In view of small sample size, these results may not represent our true adult population. Therefore, recommendation for further study of these FM measurements in larger sample, and to see the specificity to determined sex is highly suggested.

In a nutshell, identification of skeletal and other human remains is one of the most challenging tasks in forensic medicine. The craniofacial which includes the FM component, have the advantage of being composed largely of hard tissue, which is relatively indestructible. The reconstructed CT images can provide reliable measurement of these dimensions. The objective of our study to see the correlation of FM morphology for sex identification and heights has been achieved. However Further study of accuracy using FM measurements with larger samples size is necessitated.

Referrences

Burdan, F., et al. (2012). "Morphology of the foramen magnum in young Eastern-European adults." Folia morphologica **71**(4): 205-216.

Dedouit, F., et al. (2014). "Virtual anthropology and forensic identification using multidetector CT." The British journal of radiology **87**(1036): 20130468.

Galdames, I. C. S., et al. (2009). "Sexual dimorphism in the foramen magnum dimensions." Int J Morphol **27**(1): 21-23.

Gruber, P., et al. (2009). "Variability of human foramen magnum size." The anatomical record **292**(11): 1713-1719.

Kalia, S., et al. (2008). "Stature estimation using odontometry and skull anthropometry." Indian Journal of Dental Research **19**(2): 150.

Kataba, A. (2014). Biometric And Morphologic Characteristics Of The Skull, University of Zambia.

Krishan, K. (2008). "Estimation of stature from cephalo-facial anthropometry in north Indian population." Forensic Science International **181**(1): 52. e51-52. e56.

Kudlas, M. and T. Odle (2010). "The State of Forensic Radiography." Radiologic technology **81**(5): 484-490.

Lynnerup, N. (2013). "Forensic anthropology and human identification." Scandinavian Journal of Forensic Science **19**(1): 16-38.

Manoel, C., et al. (2009). "Morphometric analysis of the foramen magnum in human skulls of Brazilian individuals: its relation to gender." Braz J Morphol Sci **26**(2): 104-108.

Murshed, K. A., et al. (2003). "Morphometric evaluation of the foramen magnum and variations in its shape: a study on computerized tomographic images of normal adults." Turkish Journal of Medical Sciences **33**(5): 301-306.

Nagar, M. and A. Kumar (2014). "Human Adult Occipital Condyles-A Morphometric Analysis." RESEARCH AND REVIEWS: JOURNAL OF MEDICAL AND HEALTH SCIENCES **Volume 3** (Issue 4).

Selma Uysal, R., et al. (2005). "Estimation of sex by 3D CT measurements of the foramen magnum." Journal of forensic sciences **50**(6): 1310-1314.

Thali, M. J., et al. (2002). Forensic radiology, CRC press.

Uthman, A., et al. (2014). "Evaluation of foramen magnum in gender determination using helical CT scanning." Dentomaxillofacial Radiology.

Figures and Tables

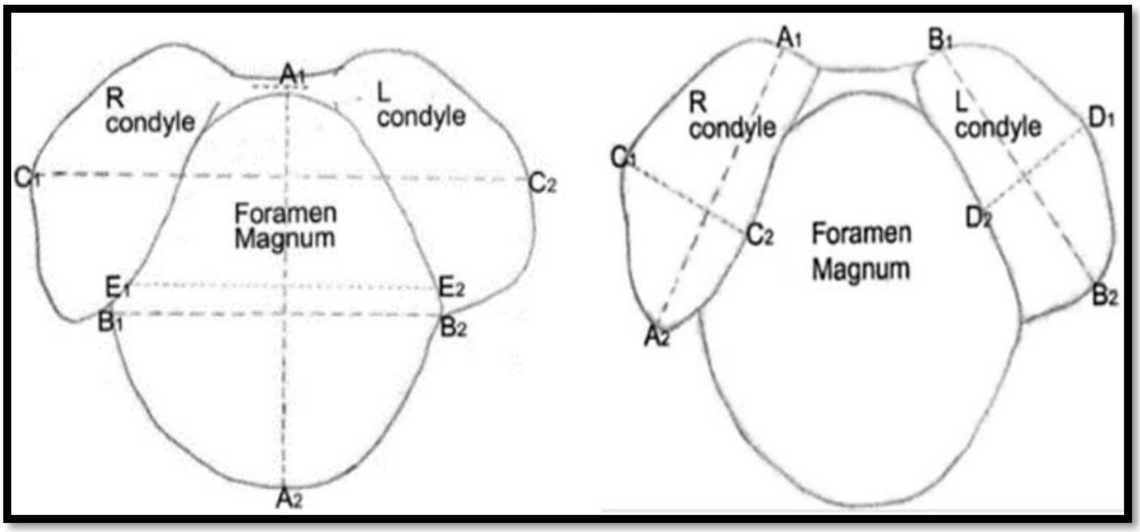

Figure 1: Measurement method for FM morphology.

Length foramen magnum LFM (A1–2); Width foramen magnum WFM (B1–2); Maximum bichondylar distance MBD (C1–2); Length of right chondyle LRC (A1–2); Length of left chondyle LLC (B1–2); Width of right chondyle WRC (C1–2); Width of left chondyle WLC (D1–2)

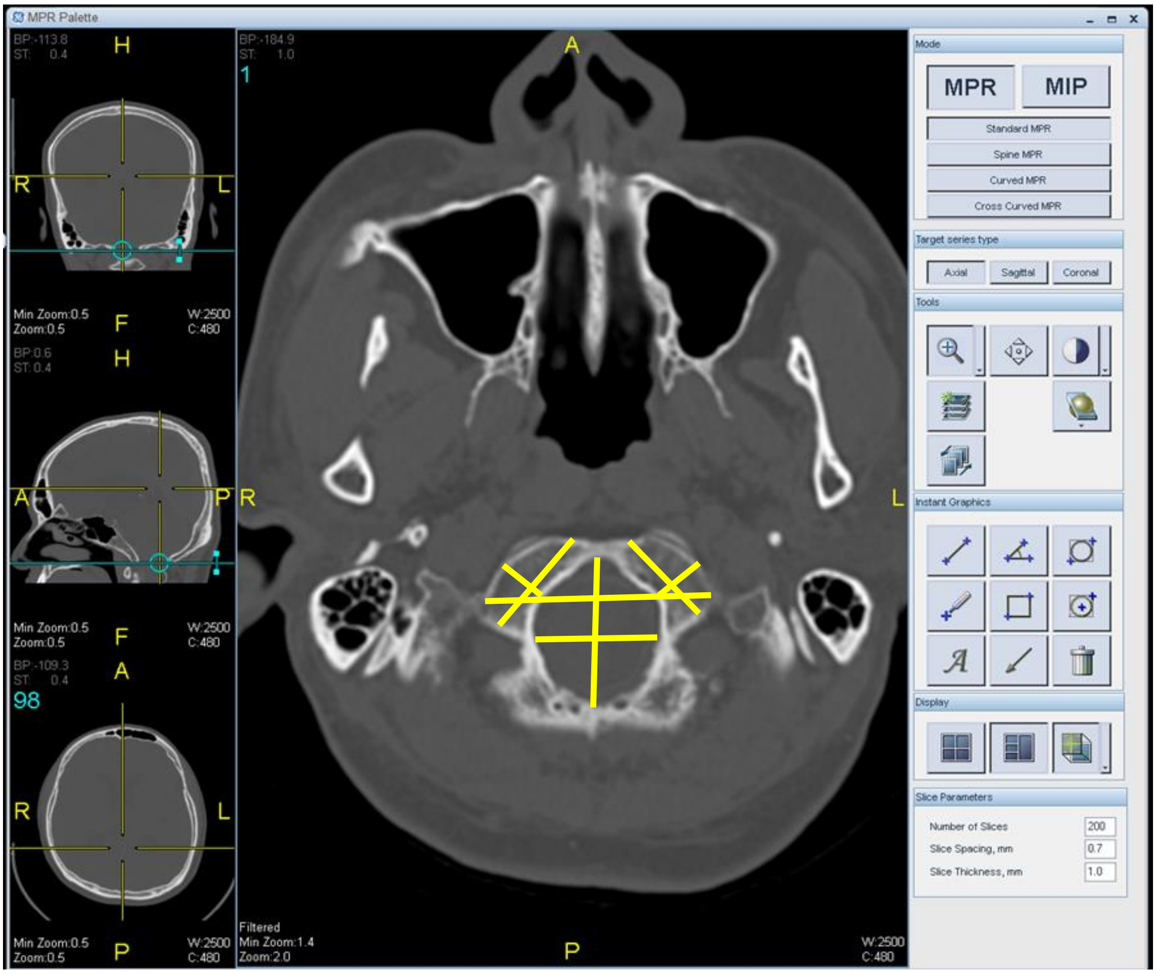

Figure 2: Measurement of FM morphology in MPR CT brain image

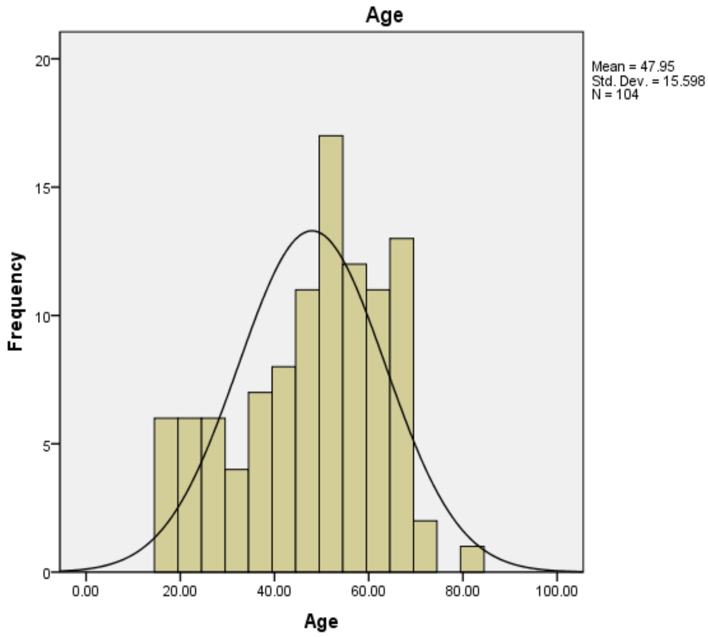

Figure 3: Normality test graph for age

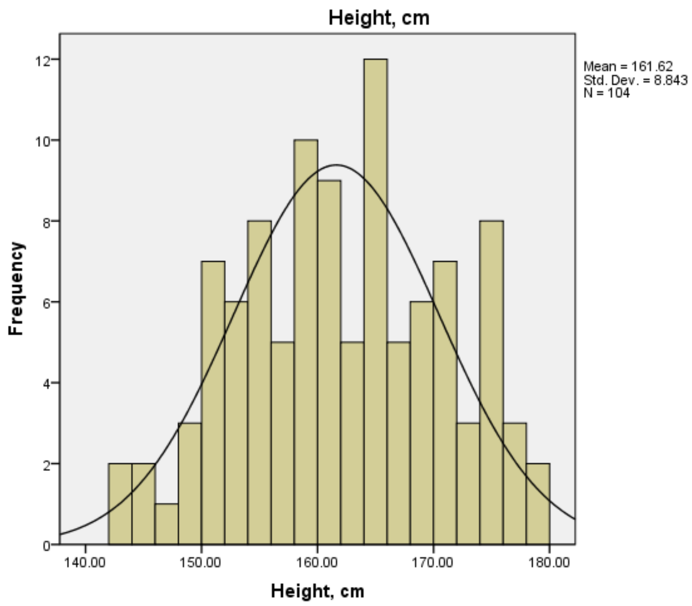

Figure 4: Normality test graph for height

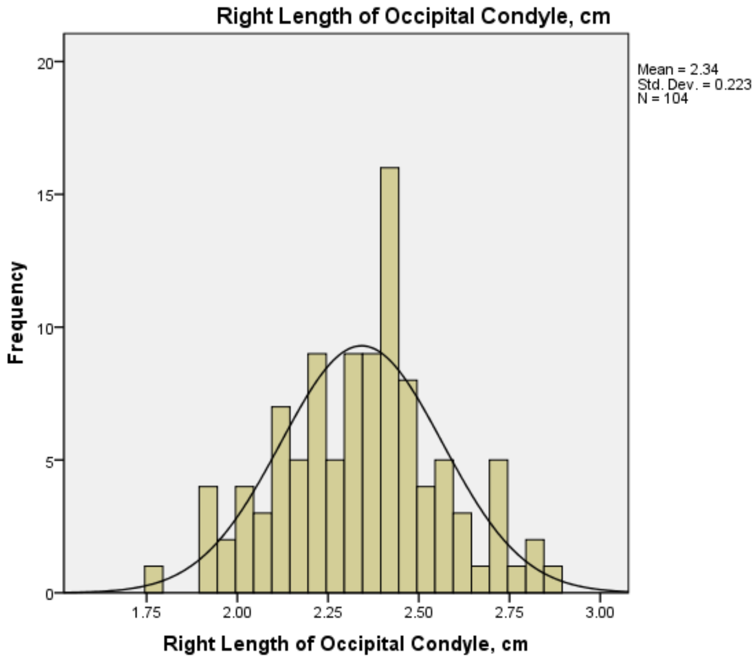

Figure 5: Normality test graph for right LC

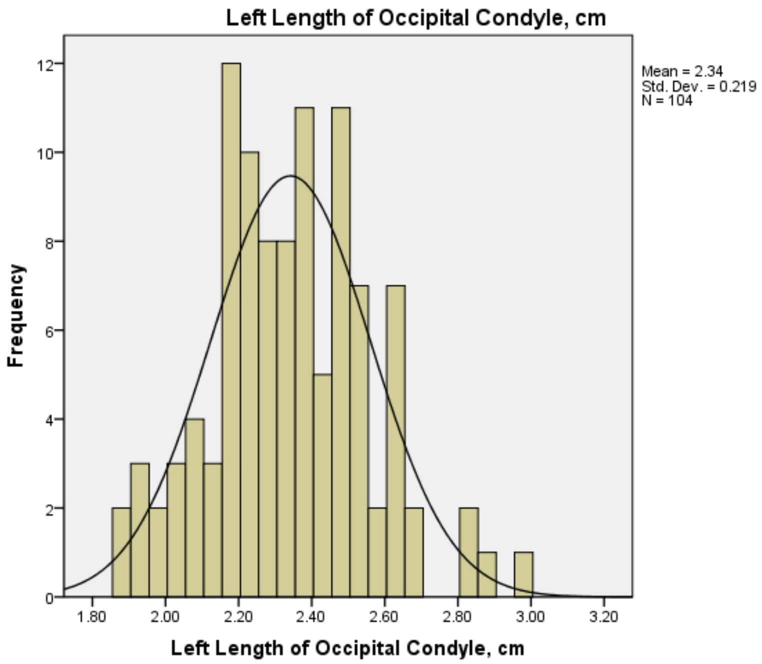

Figure 6: Normality test graph for left LC

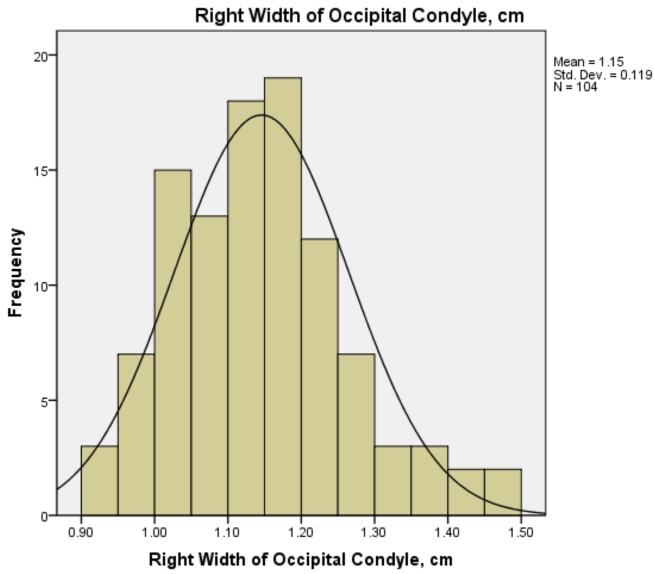

Figure 7: Normality test for right WC

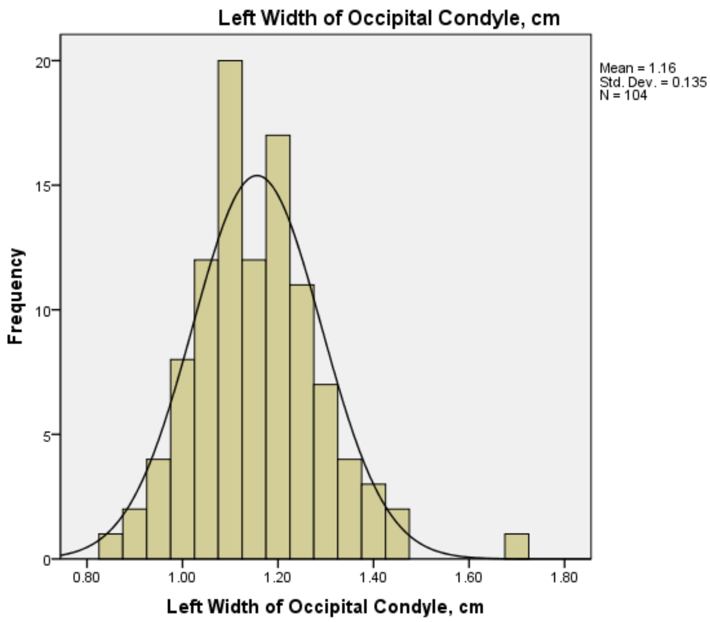

Figure 8: Normality test graph for left WC

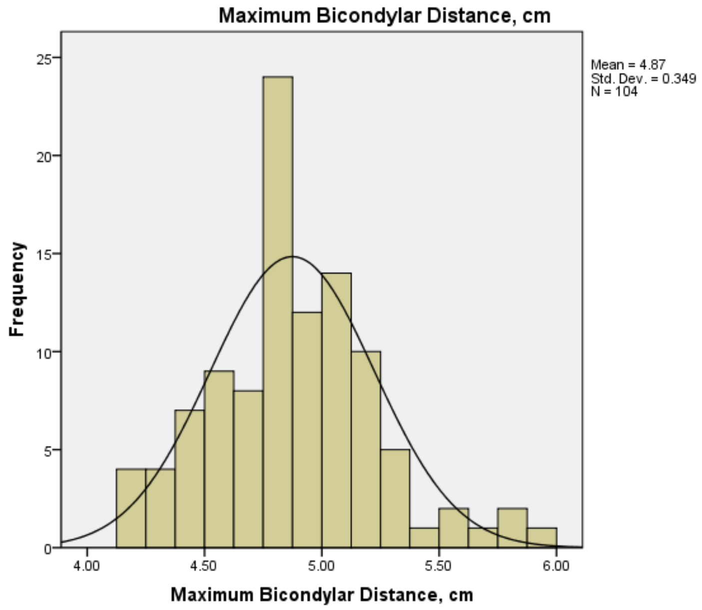

Figure 9: Normality test graph for MBD

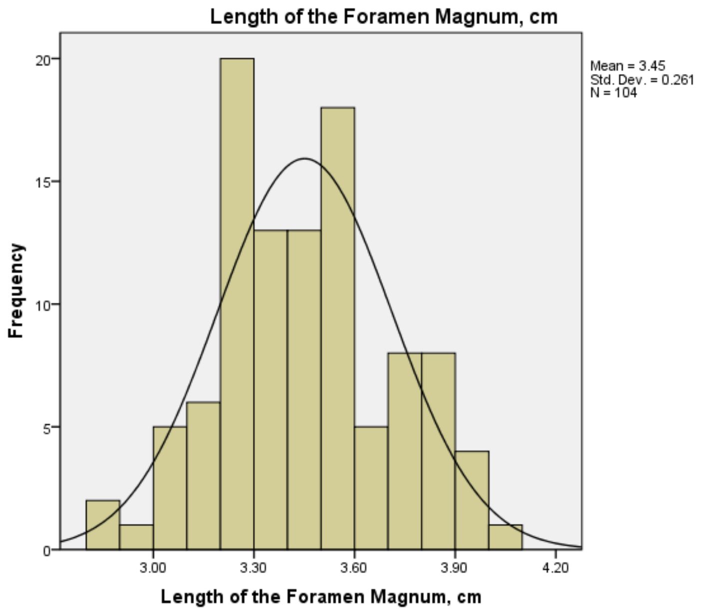

Figure 10: Normality test graph for LFM

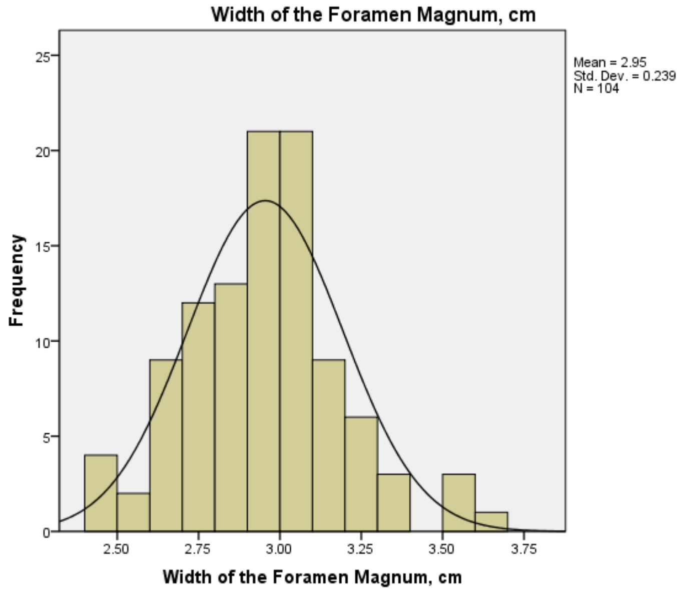

Figure 11: Normality test graph for WFM

Table 1: Inter-class correlation of FM morphology between two observer:

Variables	Observer	Mean	Std. Deviation	Correlation	P value
Right LC	A	2.3230	0.32142	0.980	<0.001
	B	2.2860	0.28496		
Left LC	A	2.2270	0.24208	0.892	0.001
	B	2.2480	0.25538		
Right WC	A	1.1240	0.14539	0.968	<0.001
	B	1.1240	0.14781		
Left WC	A	1.0790	0.16347	0.882	<0.001
	B	1.1040	0.13842		
MBD	A	4.7390	0.38573	0.988	<0.001
	B	4.7620	0.37118		
LFM	A	3.3040	0.31387	0.903	<0.001
	B	3.2540	0.28001		
WFM	A	2.8290	0.27303	0.979	<0.001
	B	2.8590	0.30245		

LC: Length of Occipital Condyle; WC: Width of Occipital Condyle; MBD: Maximum Bicondylar Distance; LFM: Length of the Foramen Magnum; WFM: Width of the Foramen Magnum

Table 2: Demographic data of samples

	Frequency, %	Mean	Std. Deviation	Minimum	Maximum
Age		47.95	15.60	17.00	80.00
Ethnic					
Malay	101 (97.1%)				
Chinese	1 (1.0%)				
Indian	2 (1.9%)				
Gender					
Male	52 (50%)				
Female	52 (50%				
Height, cm		161.62	8.84	143.00	178.00

Table 3: FM morphometry in adult population

		Mean	SD	Minimum	Maximum
LC, cm	Right	2.34	0.22	1.77	2.88
	Left	2.34	0.22	1.88	2.98
WC, cm	Right	1.15	0.12	0.94	1.49
	Left	1.16	0.13	0.85	1.72
MBD, cm		4.87	0.35	4.15	5.94
LFM, cm		3.45	0.26	2.81	4.02
WFM, cm		2.95	0.24	2.43	3.64

LC: Length of Occipital Condyle; WC: Width of Occipital Condyle; MBD: Maximum Bicondylar Distance; LFM: Length of the Foramen Magnum; WFM: Width of the Foramen Magnum; df: degree of freedom

Table 4: Paired sample test for right and left condyle morphometry.

	Mean	Std. Deviation	Std. Error Mean	95% CI		t	df
				Lower	Upper		
LC (Right - Left)	.00057	.09368	.00918	-.01764	.01879	.063	103
WC (Right - Left)	-.01028	.07363	.00722	-.02460	.00403	-1.425	103

LC: Length of Occipital Condyle; WC: Width of Occipital Condyle; CI: Confidence interval; df: Degree of freedom.

Table 5: Association of Foramen Magnum (FM) Morphometry with Gender

	Gender	Mean	Std. Deviation	Mean Difference	t-Stasttic (df)	P value
Right LC, cm	Male	2.3885	0.21301	0.092	2.142 (102)	0.035*
	Female	2.2963	0.22536	.		
Left LC, cm	Male	2.4021	0.22150	0.121	2.906(102)	0.004*
	Female	2.2815	0.20116	.		
Right WC, cm	Male	1.1762	0.12339	0.061	2.674 (102)	0.009*
	Female	1.1154	0.10784	.		
Left WC, cm	Male	1.2065	0.13327	0.101	4.102 (102)	0.000*
	Female	1.1056	0.11721	.		
MBD, cm	Male	5.0113	0.35186	0.274	4.334 (102)	0.000*
	Female	4.7371	0.29056	.		
LFM, cm	Male	3.5321	0.23898	0.162	3.328 (102)	0.001*
	Female	3.3698	0.25801	.		
WFM, cm	Male	3.0573	0.22129	0.205	4.838 (102)	0.000*
	Female	2.8519	0.21158	.		

LC: Length of Occipital Condyle; WC: Width of Occipital Condyle; MBD: Maximum Bicondylar Distance; LFM: Length of the Foramen Magnum; WFM: Width of the Foramen Magnum; df: degree of freedom; Student t-test; P<0.05 indicates statistically significant.