PELVIC CLASSIFICATION BASED ON DEEP LEARNING ALGORITHM ON CLINICAL CT SCANS IN MALAYSIAN POPULATION

YASMIN ARIJAH BINTI CHE YAHAYA

UNIVERSITI SAINS MALAYSIA

2023

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by

YASMIN ARIJAH BINTI CHE YAHAYA

Thesis submitted in partial fulfilment of the requirements
for the degree of
Master of Science (Forensic Science)

September 2023

ACKNOWLEDGEMENT

In the name of ALLAH, the kindest and most merciful, first of all I'm grateful to ALLAH Almighty, who bestowed me with health, abilities and guidance to complete the project in a successful manner. Foremost, I would like to express my sincere gratitude to my supervisor, Dr. Helmi Bin Mohd. Hadi Pritam, for the continuous support of my Master study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better supervisor and mentor for my Master study.

Beside my supervisor, I would also like to thank my co-supervisor, Dr. Ong Song Quan for his guidance, encouragement, insightful comments, and patience. I would also like to thank Dr Nurasmat Binti Mohd Shukri, the course coordinator for GTF 508 Research Project for giving us experience and opportunity to do this research. My sincere thanks also goes to Puan Nurfataha Binti Mohd Daud, staff at Radiology Department, for offering me opportunity and help during data collection in Radiology Department at Hospital Universiti Sains Malaysia.

Next, I would like to thank my parents, Che Yahaya Bin Yaakub and Siti Zaharah Binti Mamat for their endless love and support to me to keep going finishing this thesis. Thank you for sacrifices everything for me to have me further my study. Their love and care have been a constant source of strength and motivation. I would also like to thanks to my beloved husband, Mohd Baihaqi Bin Hashim for his endless love, tolerance, patience, and emotional support throughout my study journey. Last but not least, I would like to thank my bestfriend, Nurzaidah Anis binti Jamalludin, for always be there and for her constant encouragement during my research work

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
CT	computed tomography
DCNN	Deep Convolutional Neural Network
GTM	Google Teachable Machine
HUSM	Hospital Universiti Sains Malaysia
ML	Machine learning
ROI	Region of Interest
ROC	Receiver-Operating-Characteristics

LIST OF EQUATION

$$Precision = \frac{TP}{TP + FP}$$

$$Sensitivity = \frac{TP}{TP + FN}$$

$$Specificity = \frac{TN}{TN + FP}$$

$$Mean\ (x) = \frac{\sum x}{n}$$

$$Median = \frac{(\frac{n}{2}) + (\frac{n}{2} + 1)}{2}$$

$$Mode = l + \left(\frac{f_1 - f_0}{2f_1 - f_0 - f_2}\right) x\ h$$

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ABSTRAK

Anggaran jantina biologi dan umur rangka adalah penting apabila berurusan dengan sisa rangka. Oleh kerana manusia adalah dimorfik secara seksual, terdapat dalam rangka, muncul perbezaan ketara selepas umur akil baligh. Perubahan berkaitan umur juga boleh dikira dalam rangka, menjelma dalam pembentukan rangka hingga dewasa. Tulang pelvis adalah bahagian yang paling berguna dalam tubuh manusia untuk anggaran jantina dan umur. Dalam penyelidikan ini, kaedah Phenice telah digunakan untuk pengelesan umur dan anggaran jantina. Penggunaan rangkaian neural konvolusi dalam (DCNN) untuk anggaran jantina dan umur dinilai menggunakan imej yang dijana daripada imej tomografi berkomputer 3 dimensi yang dibina semula. Kajian ini menganalisis kaedah Phenice dengan mengaplikasikan imbasan CT 3D oleh algoritma pembelajaran mendalam untuk anggaran jantina dan pengelasan umur.

Imbasan CT ke atas 290 individu (179 lelaki dan 111 perempuan) yang terdiri daripada lingkungan umur 7 hingga 94 tahun penduduk Malaysia telah dianalisis oleh GTM (Mesin Boleh Ajar Google). Sampel telah dikumpulkan di Hospital Universiti Sains Malaysia (HUSM) bermula dari 2009 hingga Mei 2023. Tangkapan skrin imej 2D imbasan CT telah dibina semula kepada model 3D menggunakan Invesalius 3.1 dan PicPick untuk imej yang ditangkap untuk pembelajaran dan ujian. Model tersebut telah dipisahkan kepada empat ciri, iaitu arka ventral, lekuk subpubik, aspek medial ramus ischiopubic dan ciri keseluruhan kaedah Phenice. Untuk pengelasan umur, setiap ciri telah dibahagikan kepada dua kumpulan utama iaitu umur melebihi 20 tahun dan umur bawah 20 tahun.

Kaedah anggaran jantina Phenice menyediakan 98% ketepatan min manakala 88.3% dan 95% masing-masing untuk sensitiviti min dan kekhususan min. Walau bagaimanapun, kaedah

pengelasan umur Phenice hanya terpakai untuk umur sampel melebihi 20 tahun. Ia memberikan 97.75% ketepatan min, 93.95% untuk kepekaan min dan 95.7% kekhususan min. Untuk sampel di bawah umur 20 tahun, ketepatan, kepekaan dan kekhususan tidak boleh dikira kerana hasil daripada Mesin Boleh Ajar Google adalah ralat.

Penyelidikan ini menyimpulkan bahawa menggunakan Mesin Boleh Ajar Google memberikan ketepatan yang tinggi untuk anggaran jantina tetapi tidak berguna untuk pengelasan umur untuk sampel di bawah 20 tahun.

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ABSTRACT

The estimation of biological sex and skeletal age is vital when dealing with skeletal remains. As human are sexually dimorphic, are present in the skeleton, markedly after the age of puberty. Age related changes also can be quantified in the skeleton, manifesting in the formation of skeleton to adulthood. Pelvis bone is the most trustworthy part in human body for sex estimation and age classification. In this research, Phenice method will be utilised for the sex estimation and age classification. The utility of deep convolutional neural network (DCNN) for sex and age estimation was evaluated using images generated from reconstructed 3-dimensional computed tomography images. This study analysed the Phenice method by utilising 3D CT scans by deep learning algorithm for sex estimation and age estimation.

The CT scans of 290 individuals (179 males and 111 females) which comprised an age range from 7 to 94 years old of the Malaysian population were analysed by GTM (Google Teachable Machine). The sample was collected at Hospital Universiti Sains Malaysia (HUSM) starting from 2009 until May 2023. The 2D images screenshots of CT scans were reconstructed to 3D model using Invesalius 3.1 and PicPick for captured images for learning and testing. The samples have been separated into four features, which are the ventral arc, the subpubic concavity, the medial aspect of ischiopubic ramus and overall features of Phenice method. For age classification, each feature has been divided into two main groups which are age above 20 years old and age below 20 years old.

The Phenice sex estimation method provides 98% of mean precision while 88.3% and 95% for mean sensitivity and mean specificity respectively. However, the Phenice age classification method is only applicable for sample age above 20 years old. It gives 97.75% of mean

precision, 93.95% of mean sensitivity and 95.7% of mean specificity. For samples under 20 years old, the precision, sensitivity and specificity cannot be calculated as the result by Google Teachable Machine is error.

This research concludes that using Google Teachable Machine provide high accuracy and precision for sex estimation but not useful for age classification for sample below 20 years old.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In forensics and bioarchaeology, determining biological sex is one of the most significant conclusions that can be drawn from undocumented human remains. Age, ancestry, and stature estimation depend on sex determination because the sexes age differently, have some diversity in ethnic heritage morphology, and typically differ in height (Salim, 2012a).

Sex can be inferred from skeletal remains by biological anthropologists, forensic anthropologists, bioarchaeologists, and paleoanthropologists. To create an accurate biological profile from the human skeleton, sex estimation is essential since it affects the evaluation of other factors (e.g., stature and age). Sex and gender should not be used interchangeably in this context. Sex is a biological characteristic, but gender is a societal construct. The idea behind gender estimation is that male and female skeletons are different in terms of size and shape. Sexual dimorphism is the term used to describe this variation (Johnstone-Belford, 2016).

There is numerous technique that can be used for sex determination. The techniques used range from metric measurements of sexually dimorphic characteristics to visual evaluations of those same landmarks on the skeletal remains (Bruzek, 2002). The term "sexual dimorphism" describes the disparities in size and/or appearance between males and females (Bruzek, 2002).

The non-metric approach is morphological analysis. The ischiopubic ramus, subpubic concavity, and ventral arc are the three pelvic features that are visually evaluated when using the Phenice approach. With recorded accuracy rates ranging from 83% to 96%, the technique is simple and exact (Coelho & Curate, 2019). However, accuracy rates vary depending on the observer.

Quantitative methods, such as geometric morphometrics and machine learning, have made significant strides in the previous several decades and have been successfully used in Biological and Forensic Anthropology (Bove & Veneziano, 2022). Metric studies also produce incredibly high accuracy rates, comparable to research addressing pelvic morphology in the estimation of sex (Coelho & Curate, 2019). The hunt for new quantitative answers to the issue of predicting sex from the human skeleton has grown significantly because of those methods. Machine learning (ML) offers a versatile method for determining traits like sex from skeleton measurements, a method that is increasingly being used in the field (Bove & Veneziano, 2022).

1.2 Overview of Pelvic Girdle

The pelvis bone consists of three main bones, which are the right and left os coxa and the sacrum. The ilium, ischium, and pubis, which are the three bones that make up each os coxa, also merge occasionally once the child reaches the age of twelve (refer to Figure 1) (Byers, 2011).

Of the three pelvic bones, the ilium is the largest (Figueroa C. et. al, 2022). Comparatively speaking, it is positioned above the pubis and ischium. The rim of the superior ala is referred to as the iliac crest. The superior iliac spines in the anterior and posterior areas are where this crest comes to an end. The iliac fossa has a large bursa for the iliacus muscle that is located above it and is concave and incredibly narrow in the middle (Figueroa C. et. al, 2022). The medial surface's auricular surface for articulation with the sacrum is situated farther back. The pelvic brim is then defined by an oblique, forward-running arcuate line. (Figueroa C. et. al, 2022).

The term "ischium" refers to the inferior posterior portion of the hip bone. It consists of a superior body and an inferior ramus. The posterior inferior iliac spine, which protrudes from the bone at the posteromedial junction and concavely meets the ischial spine, creates the bigger

sciatic notch. This spine's concavity with the inferior ramus is known as the lower sciatic notch. The ischial tuberosity, which is situated at the inferior and posterior surfaces of the ischium, serves as the attachment point for the biceps, semitendinosus, and semimembranosus muscles. The ischial tuberosity's lateral half is joined to the sacrotuberous ligament (Figueroa C. et. al, 2022).

The pubis is the inferior and anterior portion of the hip bone. Its three primary components are the body, inferior ramus, and superior ramus. The superior ramus, made up of the lower obturator crest and the higher pectineal line ridge, helps form the acetabulum (Figueroa C. et. al, 2022). The inferior ramus of the pubis merges with the inferior ramus of the ischium. The pubis and ischium combine together to develop the obturator foramen, which permits the passage of major neurovascular systems. The pubic symphysis joint is formed in the midline by the joining of the left and right pubic bodies, which are both covered in a layer of hyaline cartilage and separated by a fibrocartilage disc (Figueroa C. et. al, 2022).

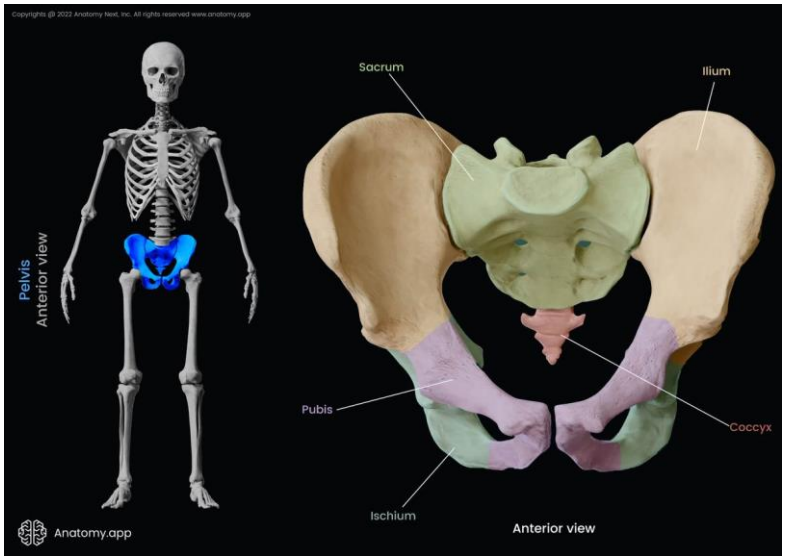

Figure 1 Anatomy of Pelvic Girdle (Figueroa C. et. al, 2022)

1.3 Overview of Phenice Method

Phenice (1969) method consisted of three features. The traits include the ventral arc, subpubic concavity, and medial aspect of the ischiopubic ramus ridge (Merrington & Mckeown, 2020).

The most forward aspect of the pelvic bone's pubic region has a curved bone line called the ventral arc (Figure 2). It clearly separates from the bottom edge of the bone, leaving a distinctive triangle appearance (Merrington & Mckeown, 2020). Additionally, it also slightly protruding ridge of bone that extends inferiorly from the pubic crest and bends laterally from the pubic symphysis on the ventral aspect of the pubis. The arc extends inferiorly to the subpubic concavity (Sandra Call et al., 2016).

The subpubic concavity is located in the area between the pubic region and the base of the pelvic bone, which should be viewed from the dorsal surface of the pubis. It is also described as lateral recurve, inferior to the pubic symphysis' lower margin (Figure 2) (Merrington & Mckeown, 2020).

The pubic symphysis, or the junction of the two pelvic bones, and the base of the pelvis, are separated by the ischiopubic ramus ridge (Figure 2). The ischiopubic ramus is located caudal to the symphyseal surface of the pubis (Merrington & Mckeown, 2020).

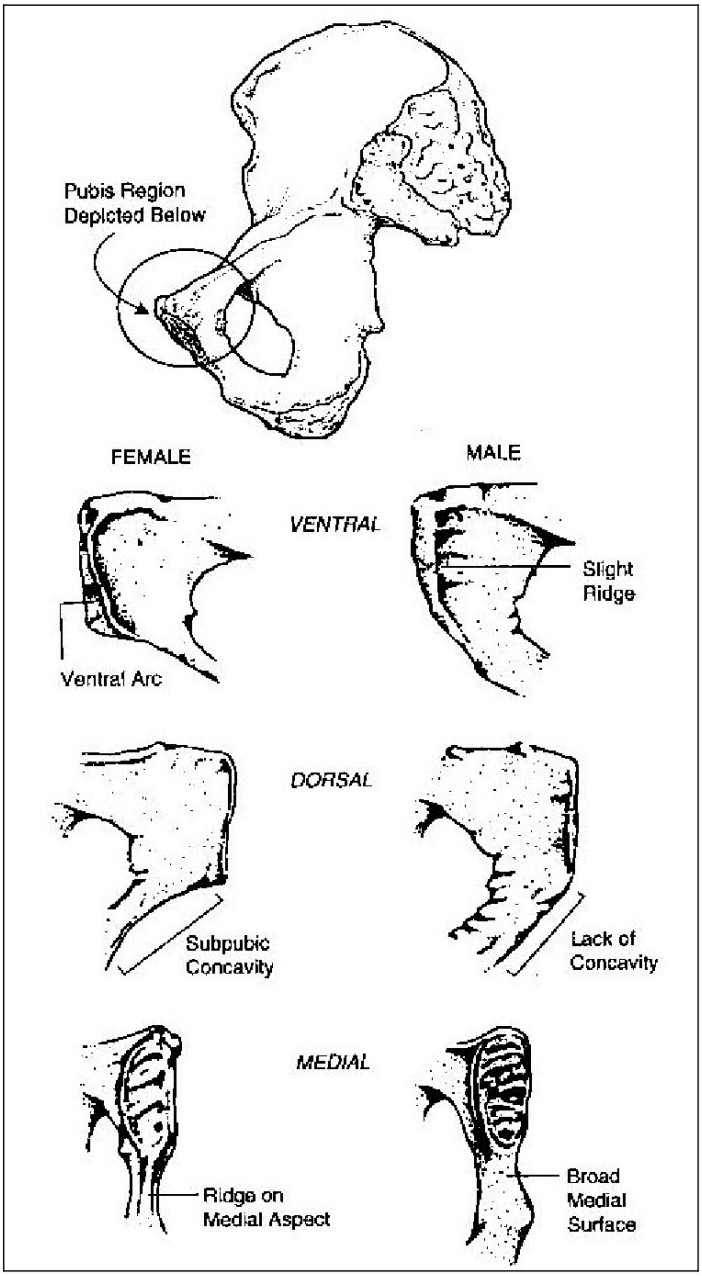

Figure 2 Ventral arc, subpubic concavity, and ischiopubic ramus ridge scoring guidelines (Blanchard, B.,2010).

1.4 Sex Estimation

In forensic investigations, personal identification entails recognizing unknown individuals from bone remains and intact body parts. To identify the age, sex, stature, and ancestry of the deceased, forensic anthropologists gather and analyse these remains (Verma et

al., 2020). Sex is a biological term used to describe sexually reproducing species and is based on the reproductive role and characteristics that have been found to display both intra and inter population variability (Krishan et al., 2016).

The skull and pelvis can be useful in sex determination and highly accurate as these body parts shoe sexual dimorphism in morphological features. Practitioners distinguish between estimating sex by physically examining skeletal features using nonmetric or metric methods and estimating sex by applying formulas based on skeletal measures. Experienced practitioners can differentiate sex by looking at nonmetric features of the pelvis. Males have cranial features and stronger muscular attachment points. Female skeletons are more gracile and smaller in size overall, despite the fact that their aggregate pelvic traits give rise to a broader pelvis in women. This morphology clearly relates to childbirth or parturition (Salim, 2012a).

As a result, the pelvic and postcranial bones yield the most accurate sex assessments. The most erratic and inaccurate sex determinations come from cranial features. The use of ordinal scoring systems, statistical methodologies, and the quantification of discrete trait morphology using geometric morphometric procedures that evaluate form differences are all responses to growing concerns about the subjectivity of nonmetric sex assessments. Because of the objectivity of osteometric data, a metric sex estimate is acceptable, but it can only be conducted if relevant reference samples are available. The most often employed statistical method for estimating sexual orientation is discriminant function analysis.

Additionally, before puberty, there is no skeletal sexual dimorphism that can be seen. Although attempts to create techniques for subadult sex estimation have had different degrees of success, it is often impossible to reliably estimate sex before the onset of puberty, especially when working with babies and young children.

1.5 Age Estimation

Age estimation is one of the most important aspects of forensic anthropology study. The biological profile of missing people represented by recovered bone fragments is very important and can be used as a marker for identification. Naturally, the presence of skeletal components and the age at which the specimen is shown as a whole influence the appropriate approach selection. The techniques used to establish the age of infant death, newborns, children, and other immature persons are different from those used to examine a mature person's bones (Olivares et al., 2020; Ubelaker & Khosrowshahi, 2019).

An appropriate technique must be applied for mature individuals if all the characteristics is met; the third molar is fully developed, the epiphysis of the iliac crest and sternal clavicle is fused, and the basilar synchondrosis is united. This is because, if those bones are fused, this indicates that the proximal tibia and other long bones, including the distal femur and distal radius, are merged as well, as these epiphyses are the last to united (Ubelaker & Khosrowshahi, 2019).

Numerous techniques exist for determining an adult's age, but some of them include evaluating the degree of cranial suture closure, general degenerative changes, pubic symphysis metamorphosis, osteophytosis,changes to the auricular area and acetabulum and development of the sternal rib ends (Ubelaker & Khosrowshahi, 2019).

Pelvic bone is one of the most common bones used for age estimation, particularly the pubic symphysis. In this study, we will only focus using features in the Phenice method. The Phenice method only applicable to bone that age more than 20 years old. Before the age of 20 in females, the subpubic concavity and ventral arc are not fully developed (Phenice, 1969).

1.6 3-Dimensional Analysis

With the incredible breakthroughs in technology, forensic anthropology has changed conventional techniques for age estimate to function with contemporary equipment. Imaging

technologies are commonly used in forensic anthropology cases. In their research, some forensic anthropologists are beginning to use increasingly sophisticated imaging techniques, such as computed tomography and three-dimensional (3D) surface scanning.

It is practical to gather sufficient forensic anthropological reference data from a modern population due to the widespread usage of computed tomography (CT) scanners in hospitals. Additionally, many morphological traits can be accurately depicted on their true skeleton counterparts using the CT-based three-dimensional (3D) reconstruction method. As a result, Forensic anthropologists may accept the virtual bone fragments produced by CT scanning as a practical alternative to traditional bone recovery in some cases.(Cao et al., 2022).

Because it provides more metric data about the specimen than conventional visual or interlandmark distance assessments, using 3D virtual bone is useful. Traditional visual analyses rely on the forensic anthropologist's knowledge to determine the size and shape of the bone just by looking at it.(Baca et al., 2022).

1.7 Significance of The Study

The study of determining sex using pelvis bone by Phenice method was widely used by many studies. However, there are little studies regarding the sexual dimorphism analysis using pelvis bone via 3D imaging deep learning in Malaysia. In addition, there are no studies that utilise Phenice method for age classification. Phenice (1969) stated that Phenice method must only apply to model age more than 20 years old. Thus, the significance of using deep learning algorithm is automation which can lead to higher accuracy and precision and to avoid bias among practitioners.

1.8 Problem Statement

Commonly, in determining the sex of pelvic bone, forensic anthropologist will evaluate the morphological features of the pelvis. However, in rare instances, they are forced to deal with the pelvis when bodies are found in poor condition after a catastrophe or as a result of carnivore scavenging. Because of this, sex assessment via the pelvis could be more difficult. The morphology method is also more subjective, and the accuracy rate are based on observer-dependant (Coelho & Curate, 2019). It also depends on the researcher's experiences and can lead to bias. In addition, the lack of database from Asian or Malay population causing little studies regarding sexual dimorphism and age classification using Phenice method. Next, the reliability of DCNN in storing and interpreting data is still a question. In order to improve upon routine morphological observation, it may be useful to develop additional objective approaches. In this study, using machine learning can reduce the risk of bias and less observer-dependant. The usage of the DCNN algorithm is easy and fast but requires little experience to use it. This study aims to train machine learning using deep convolutional neural network (DCNN) models for sex and age assessment based on 3D images of CT scans.

1.9 Research Objectives

1.9.1 General Objectives

i. The general objective of this is to analyse the performance of deep learning algorithm by machine learning technology on the pelvis bone by the Phenice method.

1.9.2 Specific Objectives

The specific objectives of this study are:

i. To evaluate the deep learning performance for sex estimation and age classification of the pelvis bone by using the Phenice method.

ii. To calculate the precision, sensitivity, and specificity of DCNN algorithm in machine learning in sex and age determination of pelvis using the Phenice method.

iii. To identify the region of the pelvic with the most reliable according to Phenice method.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Forensic Anthropology

The discipline of forensic anthropology uses anthropological theories and techniques, notably biological anthropology, and archaeology, to resolve disputes in the fields of medicine and law. Traditionally, the focus of forensic anthropology has been on the recovery and investigation of human remains. Along with looking for and locating the evidence, this work also estimates the amount of time since death, identifying the species, identifying the sex, ancestry, age at death, living stature, and recognizing any other features that could try to identify and track criminal activity. (Passalacqua et al., 2021; Ubelaker, 2018).

In addition to these duties, forensic anthropologists frequently support war crime and mass casualty investigations. Identifying victims of the terrorist attacks as well as those of aircraft tragedies like the US Air Flight 427 and the Arrow Air Flight 1285 disasters, in which the flesh was either completely burned off or severely mutilated, making conventional identification impossible, have been given to anthropologists as a task. Additionally, years after the actual event, anthropologists have assisted in locating victims of genocide in numerous nations(Mishra, 2022).

According to the American Board of Forensic Anthropology, forensic anthropology is the use of physical anthropology in the judicial system. In forensic anthropology, the fields of biological anthropology and archaeology come together in a medical-legal context. For the sake of this judicial procedure, the identification of skeletal human remains is crucial (Tallman, 2016).

Forensic anthropology focuses on individual variation across populations, physical anthropology investigates how external causes affect the bones and studies normal variation in the skeleton (Salim, 2012b; Yasar Iscan, 1983).

While biological anthropologists utilise their in-depth understanding of human skeleton variation to identify the remains, forensic anthropologists use archaeology techniques to recover human bones and other evidence from the field in a controlled manner. Identification of people who are no longer recognisable due to severe fire, decomposition, or skeletonization is the main objective of forensic anthropology (Salim, 2012).

2.2 Pelvic Girdle

2.2.1 Role of Pelvis in Sex Estimation

In forensic anthropology, accurate skeletal remains' sex evaluations are essential to identify an individual so that other biological factors like lineage, age, and stature may be established.

Byers (2011) claims that because it is the portion of the skeleton most impacted by childbirth, the pelvis has the highest concentration of traits that can be used to identify sex. Due to its extraordinary sex dimorphism, which is principally influenced by the functions of bipedal mobility and childbirth, the pelvis has historically been regarded as the most trustworthy of all human bones (Cao et al., 2022; Fukuta et al., 2020; Klales, 2020; Steyn & Işcan, 2008).

If the pelvis is fully developed, 95% accuracy can be attained, however, Bruzek reported that accuracy ranged from 59% to 96% (Steyn & Işcan, 2008). However, it is well known that skeletal traits differ throughout groups and that each population should have requirements to improve the accuracy of identification because of this regional heterogeneity. As a result, numerous studies utilizing a range of pelvic measurements and traits have been carried out globally, with various degrees of accuracy (Steyn & Işcan, 2008).

By experimentally analyzing the physical characteristics of the pelvis, forensic anthropologists typically estimate sex (e.g., ventral arc and subpubic contour). However, in rare instances, they are forced to deal with the pelvis when bodies are found in poor condition

after a catastrophe or because of carnivore scavenging. These might make estimating sex using the pelvis more difficult. Therefore, developing new objective techniques to complement normal morphological inspection may be advantageous (Cao et al., 2022).

A review of the literature reveals that genetics, obstetrics, the timing or trajectory of maturation, and surroundings are the four key elements that influence the morphological variance in the pelvis(Cao et al., 2022). These can be viewed as the immediate sources of variation, which also include maturation and surroundings, as compared to the evolutionary mechanisms that, in this case through genetics and obstetrics, develop and regulate diversity over a long duration (Cox, 2021).

Only a limited percentage of pelvic research to date has concentrated on elements that directly affect pelvic form. The characteristics that most identify the human pelvis from other primates are already evident in the fetus at this stage of development, and the ilium is fully developed by the time the child is eight years old. Rates of pelvic growth increase linearly from childhood to puberty, diminishing as the kid approaches adolescence. The pelvis lengthens and widens as a result of pubertal hormones; some regions of the pelvis grow relatively quickly, Others hardly alter from their pre-adolescent state, ultimately leading to sexually distinct morphologies (Cox, 2021). The male pelvis normally lengthens during puberty, whereas the female pelvis typically broadens, since the female real pelvis grows at a higher rate than the male. Similar to the pubis, the pubis grows more quickly in females than in males, making them overall wider and longer in females (Cox, 2021).

Numerous documented pelvic characteristics have been successfully employed throughout the years to identify sex. The pelvic inlet was traditionally employed. Puberty causes the female pelvic inlet to enlarge. Its shape evolves from a young adolescent elliptical form to a more open, rounded aperture. The larger elliptical, constrained aperture is nevertheless present in males(Anthropology, 2010). Increasing hormonal activity was first

thought to be the cause of this alteration in the female pelvic inlet. More recent research link changes in the pelvic inlet or pelvic canal to maternal-fetal growth connections and "functional modifications to particular movement styles." Along with the pelvic inlet, other measurements included the height of the pubic symphysis, the contour of the obturator foramen and the subpubic angle (Anthropology, 2010).

Growth makes the subpubic angle in women more acute than in men (Anthropology, 2010). The subpubic angle in men is V-shaped and less than 90^o while in females, it is more rounded and U-shaped (Byers,2011). This configuration appears to be related to childbearing and thus during birth, it allows more space for the head of infants (Byers,2011).

The obturator foramen grows more triangular, and the pubic symphysis gets shorter. The subpubic angle has the drawback that, while sex can be evaluated without the pelvis being fully articulated, it is best evaluated when it is (Anthropology, 2010). It might be argued that this means that using just one side does not produce the most accurate evaluation. Articulation is not always achievable due to the pelvic remnants' frequent fragmented nature. When looking at the height of the pubic symphysis, there is a second issue. Symphysis height could only be estimated due to the frequency of damage at the symphysis, otherwise, the pelvis would be disregarded from the analysis (Anthropology, 2010).

Other specific bones and structures, in addition to the pubis, help to distinguish between the sexes. Males and females have different obturator foramen shapes, which can be observed. In males, it has an oval contour or assumes an isosceles triangle configuration, whereas in females, it has a more equilateral triangular configuration (Byers,2011).

The larger sciatic notch, which varies similarly to the subpubic angle, is another characteristic that differentiates across sexes. Males have narrow, constricted notches, while females have large, open notches (Byers,2011).

The preauricular sulcus, pubis width, and the angle of the larger sciatic notch are more reliable characteristics that have been noted over time. The bigger sciatic notch, inferior section of the ilium, and pubic bone all expand wider in females as a result of the pelvic inlet's increased diameter (Anthropology, 2010). While the preauricular sulcus in males is absent or narrow (Byers,2011). There is no fixed rule as to which feature should be given a higher weight when features have intermediate levels, according to some researchers who have discovered that these traits tend to "display variable degrees of male and femaleness." (Anthropology, 2010).

The shape of the sacrum also shows differences between males and females. The females have wider and shorter sacrum, while males have longer and narrower bones (Byers,2011). When viewed laterally, the male sacrum has a more uniform curve, but the female sacrum has a distinct angle between segments two and three (Byers,2011).

There are few studies stated that, in the human skeleton, the os coxa is the bone that can most accurately predict sex, with an accuracy rate of about 90% when used alone (Anthropology, 2010). Both metric analysis of linear measurements and visual observation of anthroposcopic characteristics can be used to determine the sex using the os coxa, and both procedures have good accuracy rates (Anthropology, 2010; Bruzek, 2002).

The ossa coxae, according to Salim (2012), is the human skeletal component that is most sexually dimorphic because it must fit into the female pelvis to support the baby's comparatively big head during birthing. As can be seen in Figure 3, the female pelvis is typically wider than the male pelvis in all aspects.

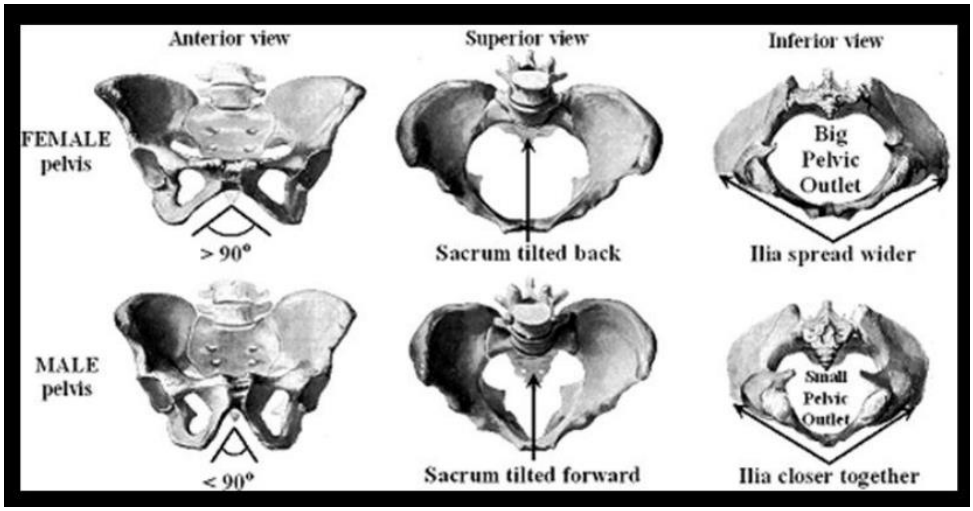

Figure 3 Comparison between male and female pelvis (Smithsonian Institute, 2017).

2.2.2 Other bones that can be useful to determine sex.

The skull can be used to determine sex, according to William and Rogers (2006), but its accuracy in doing so is only between 80 and 90% (Williams & Rogers, 2006). The skull of males tends to be larger and more robust than that of females, however, this isn't always the case; females can also be huge and robust, just as males can be graceful and dainty. The nuchal crest, mastoid processes, and brow ridges are sex indicators that are more developed in the male despite sexual dimorphism in the human skull being less prominent than in many other primates (Anthropology, 2010).

The long bones can be helpful in sex estimation studies as well. Males often have longer, more robust long bones than females do, and males also typically have greater muscle attachments. However, given the differences between the activities carried out by each sex, it is very likely that some females will get greater muscular attachments than males. Long bones may not always be the most trustworthy bones for use in sex identification unless they are used in conjunction with other bones due to variances in height among groups.

2.2.3 Role of Pelvis in Age Estimation

Identity loss is a common issue for both individuals and authorities, whether the person is alive or dead. In the lack of age information, the biological profile of unknown persons cannot be correctly recreated. Age can be calculated using the skeleton's growth, the dentition's development, or the skeleton's degenerative change (Priya, 2017).

Adults' ages can be calculated using indicators for the resorption, deposition, and remodelling of bone. The assessment of degenerative processes in adults is based on the body's normal ageing and wear and tear. Human behaviour and numerous environmental conditions can affect these processes. The remodelling process differs significantly from person to person, and the changes it produces are commonly undetectable and challenging to comprehend. Additionally, it's possible that these degenerative changes will occur at different times and in different ways in different populations (Priya, 2017).

According to reports, the estimated age for younger people has a narrower age range, but the estimated age for elderly people has a wider age range. This is explained by the fact that numerous biological changes take place for younger people at predictable periods and rates. The quantity and rate of developmental changes decrease after the person reaches biological adulthood. Middle age is probably the most difficult time to evaluate an adult's age since hormonal and metabolic changes result in a variety of transitions during this period (Priya, 2017).

According to Bartolini et al., 2018, there are two methods for age estimation, which are Risser theory and French (Fr) method (Bartolini et al., 2018). Risser sign use the iliac crest ossification process for evaluate skeletal maturation which is affected by scoliosis and said that it has been a very helpful tool for age assessment in forensic. However, due to the lack of research, it is not used for forensic purposes (Bartolini et al., 2018).

The first research of the Risser method's usefulness for forensic purposes in subjects between the ages of 10 and 30 years was conducted by Wittschieber et al. (2013). Both methods are suitable for age assessment for forensic reasons, the authors conclude, despite differences in some phases of ossification from Risser's theory. This is notably true for the age limit of 14, and the Fr method was up to 16 years (Daniel Wittschieber et al., 2013).

Priya (2017) stated that the pubic symphysis, the auricular surface of the ilium, the sternal rib eye, and the cranial sutures are the most common features used by forensic anthropologist to estimate age (Priya, 2017). The pubic symphysis is consist of a surface at which the two innominates anteriorly articulate. Based on the morphological changes found in the pubic symphyseal area for age estimate, different standards were created. Ageing charts were initially created using cadavers from various medical colleges. These samples included older people who may not have been in the best of health. The need to identify people who died in the Second World War brought age estimation using the pubic symphysis to light. These people, who came from the military, belonged to the younger age group, between 17 and 25, with most of them being male. Later, researchers investigated the age changes in the female pubic symphysis. One of the challenging elements is childbirth generates abnormal wear and tear at the pubic symphyseal area, which is one of the complicating issues experienced by females. Two conclusions were made: first, using male standards to estimate the age of the female symphysis is not recommended, and vice versa; and second, the in inconsistencies on the female symphysis caused by having children or not having children produced more variability. One of the most frequently utilized parameters for the goal of age assessment is the morphology of the face of the pubic symphysis, which has been described in the literature to vary with age. To determine age, Todd suggested a ten-phase procedure in 1920 for analysing the pubic symphysis (Priya, 2017).

2.3 Method for sex estimation

2.3.1 Metric Method

In forensic anthropology, metric method commonly used to determine sex because they are usually derived from the standard cranial and postcranial measurements (Tallman, 2016).

Metric procedures are said to be easier to repeat than morphological approaches since they rely on standardised osteometric markers or elements, according to researchers that support them. Metric approaches are also more objective than non-metric ones since it is generally simpler to locate osteometric landmarks consistently and because the evaluation is not based on judgement to a specific scale.

Metric estimation may be based on univariate statistics, where segmentation or cutting points for single measurements can produce estimates of sex that are reasonably quick and simple (Ferrer, 2022; Steyn & Işcan, 2008). Sex determination based on numerous measurements taken together might be examined using multivariate statistics, such as discriminant function analysis or linear regression (France 1998; Ousley and Jantz 2005; Slice and Ross 2009). As a result, metric approaches have low intra- and inter-observer error rates, are simple to teach and learn, and are open to statistical manipulation (Bruzek, 2002). Additionally, accuracy rates, probabilities, and error rates are typically included with metric techniques to sex estimation, which aid in meeting the Daubert criterion (Tallman, 2016).

Since the 1960s, numerous measures and discriminant functions have been successfully used to consistently detect gender from the cranium (Giles and Elliot 1963; Holland 1986; Ousley and Jantz 2005). Despite evidence indicating that postcranial measurements outperform cranial studies, anthropologists have traditionally held that the cranium is the second-best indicator of sex after the pelvis.

Because of the difficulty in measuring this bone, there are few methods for differentiate males and females from metric dimensions of the pelvis. The technique that has wide

acceptance is the ischium-pubic index, popularized by Sherwood Washburn (1948, 1949). This index was developed as a way of quantifying the longer, more stretched character of the pubic bone in females compared to males.

The two parameters needed to calculate the ischium-pubic index computations might be hard to obtain, despite the fact that it is an extremely accurate sex indicator (Byers,2011). The ilium, ischium, and pubis unite at the base point inside the acetabulum. This point, although difficult to perceive, is either a raised spot, an irregularity, or a notch inside the acetabulum. The inside surface of the os coxa can be observed as an additional way to locate this spot (Byers,2011). Where the pubis has fused to the ilium and ischium, a scar is frequently seen. The location inside the acetabulum can be reached by placing the thumb on this region and pinching the bone with the index finger. The two measurements then can be taken by holding the tip of a sliding calliper on this point in the hip socket and swinging it first to the end of pubic bone, and then to the bottom of ischium. The index is obtained by dividing the pubic length by the ischium length and multiplying by 100 to obtain a percentage (Byers,2011).

The accuracy rate of metric sex estimation using the pelvic bone can be more than 90%, making it more accurate than visual morphological studies. However, to evaluate all the landmarks suggested by the available literature, this approach needs a complete or almost complete pelvic complex. With a sex estimation accuracy of 96.5%, the ischio-pubic index was the most reliable (Rogers, 2009). Analysis and 90% accuracy were reached for the ischiopubic index, which uses measures of the pubis as a sex indicator (Rose Drew, 2013).

2.3.2 Traditional morphological sex assessment

Although many cranial and postcranial components can be measured to properly define sex (Navitainuck et al., 2021; Williams & Rogers, 2006). The most common method for determining sex in otherwise healthy individuals is through a visual assessment of any robust or gracile features present on the pelvis.(Phenice, 1969; Ubelaker, 2018). Due to the female capability for childbirth, the pelvic characteristics that are significant in sex evaluation are physically differ between females and males (Coleman, 1969; Jager & Eliopoulos, 2023; Phenice, 1969). Due to these growing variations, males have a tight and constricted pelvis while females have a wider and more flared pelvis. Furthermore, the sacrum is larger and demonstrates less anterior curvature in females than it does in males, who have a smaller sacrum and more anterior curvature. As a result, even though males may have larger and more robust pelvic bones, females show a slightly larger pelvic outlet.

The three methods for the visual evaluation of hip bone traits are the Phenice (1969) method, which uses three aspects on the pubis, the Iscan and Derrick (1984) method, which uses the posterior pelvis, and the Ferembach et al. (1980) method, which sex-identifies the entire pelvis based on an assessment of eleven traits (Bruzek, 2002). Although it is widely recognised that these methods provide adequate accuracy, few studies have looked at how well they perform in known-sex samples, and, surprisingly, the findings are typically overlooked (Bruzek, 2002).

In 1994, Standards for Data Collection from Human Remains recommended using Phenice's (1969) three charateristices, the ventral arc, subpubic concavity, and medial aspect of the ischiopubic ramus, coupled with the larger sciatic notch and preauricular sulcus, for pelvic sex estimation (Klales, 2020). The accuracy levels of the Phenice technique have shown erratic results, ranging from 59% (Bruzek, 2002) to 96% (Bruzek, 2002). This discrepancy results from the fact that observations should not be restricted to the pubis and that sexual

dimorphism of the overall hip bone should be considered. According to Bruzek (2002), the Phenice technique is most likely 80% reliable. Furthermore, in archaeological materials, pubic preservation rarely rises above 30% (Bruzek, 2002).

The method proposed by Iscan and Derrick gives an accuracy level of 90% but it cannot be regarded as equivalent to the results found with methods using the complete hip bone (Bruzek, 2002).

It has not been investigated whether the Ferembach et al. (1980) approach is accurate. Using a collection of eight characteristics related to the hip bone, Bruzek (2002) discovered that 93% of gender assignments were accurate. However, because this method relies on an ordinal scale of judgement, it calls for highly skilled observers with knowledge of morphological variety (Bruzek, 2002).

2.3.3 Phenice Method

The Phenice method has three features which are very useful for sex assessment. It was first described by Phenice (1969), which are the ventral arc, the subpubic concavity, and the medial aspect of ischiopubic ramus (Figure 2). According to Phenice (1969), males typically do not have the following characteristics: (1) a lateral curvature of the subpubic concavity; (2) an elevated ridge of bone on the medial aspect of the ischio-pubic ramus; and (3) an theventral arc is an elevated bone ridge that runs along the pubis' ventral surface. Therefore, the presence of the features is thought to indicate a female, whereas their absence suggests a man. When all three features did not indicate the same sex, Phenice claimed sex categorization accuracy is over 95% (Klales, 2020; Klales et al., 2012).

2.3.3.1 Traits Description

a. The Ventral Arc

"A slightly elevated ridge of bone that protrudes from the pubic crest and arcs inferiorly across the ventral surface of the lateral most extension of the subpubic concavity where it merges with the medial aspect of the ischio-pubic ramus" is how the ventral arc, which affects women, is described (Phenice, 1969). Males have a bony ridge on the ventral side of the pubis, but only females' pubic bones have a genuine ventral arc (Anderson, 1990; Phenice, 1969). However, due to its distinct direction and degree of angle, when this bony ridge is present, it can be used to discriminate between the sexes. The variation in the attachment point is the cause of the morphological variances in arc manifestation.

b. The Subpubic Concavity

According to Phenice (1969), the subpubic concavity is "a lateral recurve that appears in the female pelvis just below the lower edge of the pubic symphysis... [which] is missing in the male pelvis." Due to the female ischio-pubic ramus' concavity, which also results in a greater subpubic angle where the two innominates connect, females exhibit a more gracile characteristics when compared to males. According to Coleman (1969), the discrepancies between males and females in the subpubic angle are explained by developmental changes that take place throughout puberty. According to Coleman (1969), there are two elements that contribute to the various shapes of the ischio-pubic ramus: (1) the inferior edge of the ischial tuberosity grows horizontally in females while expanding inferiorly in males, and (2) variable directional growth at the ischial tuberosity (Coleman, 1969; Phenice, 1969).

c. The Medial Aspect of Ischio-pubic Ramus

The medial side of the ischio-pubic ramus, one of three markers for sex assessment, is the least distinct and known, according to Phenice (1969). According to the description by Phenice (1969), the male condition has a broad surface, whereas the female condition is characterized by a sharp ridge (Phenice, 1969). In addition to the ridge, the female version is also slimmer than the male form. The lengthening of the pubic bone during the adolescent growth phase may explain why females have a narrower surface, but little research has been done to determine why these sex differences exist (Phenice, 1969).

2.3.3.2 Method for Age Classification

Phenice does acknowledge that there may be ambiguity of the traits in some cases, as not every os pubis will be a perfect male or female. In some situations, the ventral arc may not be fully formed in females, or the subpubic concavity may present in males, or the medial aspect of ischiopubic ramus may be intermediate between the male or female morphology of bone. The ventral arc is likely to be the least ambiguous, and the medial aspect of the ischio-pubic ramus is highly ambiguous. However, Phenice (1969) stated that, when there is some ambiguity in the traits, there must be at least one feature that strongly indicates that the material is male or female. There is 96% accuracy at least if using one or two criteria that show the material is definitely male or female (Phenice, 1969).

Phenice method must only be tested on adult material or samples. This is because, the ventral arc and the subpubic concavity is not fully formed in females until 20 years old.