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Sex Determination by Pelvis: A Mini Literature Review

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Abstract: ***An endeavor involving the application of physical anthropology in the context of civil or criminal cases is forensic anthropology. Determination of sex is the matter of absolute attention for a forensic anthropologist as it is the first step towards positive identification process after discovering the skeletal or bone remains of human origin. Pelvic Girdle is the most sexually dimorphic part of human skeleton which estimates the result with an accuracy of 95% and along with sacrum i.e. pelvis it estimates the sex with 98% accuracy and it decomposes slowly than other parts. Sex can be estimated by skeletal remains only in adults as the marked variations on bones be in terms of morphology or size are visible only after attaining puberty. Methods involved in sex estimation process are Morphological, Metric and Radiological. The Morphological method accords the result by considering the morphological sexual traits on pelvis and in contrary the Metric method involves measurement of bones and indices. Metric recipe should be applied in combination with Morphological results as Morphometric in order to get more accurate results. Whereas, in radiological recipe radiographs of collected remains are taken from which certain measurements and morphologic observations can be carried out. Quantitative and statistical analysis can be done using these mentioned methods. Skeletal features may vary with population. Bones are very frail in nature so, in turn, cannot be collected fully thus when fragmented remains are collected the morphometric method is of ultimate importance in the estimation process.***

Keywords: Anthropology, Metric, Morphological, Morphometric, Pelvis, Radiological, Sex determination, Skeletal.

I. INTRODUCTION

Forensic anthropology is a multidisciplinary endeavor involving the application of biological or physical anthropology in investigation of civil or criminal cases by analyzing the skeletal, decomposed or fragmented unidentified human remains [1, 2, 25, 53]. A forensic anthropologist can conjure the biological profile of an individual by determining age, sex, stature, ancestry, time since death, cause of death, and certain other unique features from the collected unidentified remains [25, 54]. Sex determination is simply identifying the skeletal parts or it's remains as male or female. Determination of sex is crucial for all stages of identification [14]. In context of forensic anthropology, sex estimation is far reaching for generating the accurate biological profile of an unknown in process of positive identification [2]. This procedure is more reliable if there is a complete skeleton for inference which is not so common in most cases [12].

Determination of sex can be established by applying these primary approaches such as morphological, metric and radiological. However, these three methods have different precision levels of sex determination. Machine learning methods can be applied to pelvic dimensional data collected using a metric or radiological recipe for gender estimation to achieve greater accuracy in the determination process [20]. Morphological methods rely on evident sexual traits on bones which are genetically controlled; specialized skills are needed in application of this recipe in order to get desired accuracy. The results using this method are accurate and clear but dependent on the observer [50]. On the other hand, the metric method assesses the result by measuring the particular characteristics present on bones and it should be used along with the morphological recipe in order to get desired accuracy. Metric approach is least observer dependent and more decisive and easier. Morphometric method as the name says involves the methodologies of both Morphologic and the Metric recipe [3]. This is adapted to estimate prominent results particularly when fragments of bones are collected in place of complete skeleton or bone. It is difficult to recover a complete skeleton or bone from the scene of crime in forensic cases but in turn charred, fragmentary, or damaged remains are recovered in most cases [13]. In radiological approach radiographs and imaging techniques such as MRI and CT scans of collected skeletal parts or remains are taken from which certain dimensions vital for sex determination and morphological traits can be measured and examined and further observations can be carried out.

A basin shaped association of two hip bones, a sacrum along with a coccyx bone is pelvis and the two hip bones all alone can be termed as pelvic girdle. The aspects of sexual dimorphism for a pelvis be it in terms of morphology or size, is chiefly due to the phenomenon of parturition in females or to deliver the foetus [41]. Pelvis estimates the result with an accuracy of 98% and the pelvic girdle alone can estimate the result with 95% accuracy [1, 35]. Pelvic girdle is the most sexually dimorphic part of human skeleton [16]. The os cox or the hip bone is considered one of the most reliable indicators for sex identification because the pattern of sexual dimorphism is common to the entire human race [1, 4, 8] whereas, the sacrum bone represents some principal sexual differences of which prime are of the metrical values. The pelvic bones together with the sacrum, called the pelvis, become a rich source of sex determination. Various parameters of pelvis essential for sex determination are discussed in this paper. A progressive evolutionary change can be observed in the magnitude of the pelvic sex differences in modern humans but the pattern of sexual dimorphism has not evolved in modern beings and must have been present in the ancestors of man [19].

Parameters such as weight and roughness of the bones involved, os coxae shape, pelvic brim, pelvic inlet, greater sciatic notch, acetabular fossa position, periauricular sulcus, ischial tuberosity, sub-pubic angle, sub-pubic concavity, shape of obturator foramen, shape of sacral body etc. are discussed under the morphological approach. The diameter of acetabular fossa (Vertical and horizontal), indices such as Ischiopubic, sacral index and angles of greater sciatic notch, total innominate length, length and width of each pelvic bone component, greater sciatic notch breadth, length and breadth of the sacral bone, breadth of S1 vertebrae and more are reviewed under the metrical and radiological approach.

Skeletal characteristics vary among populations, each population should have specific metrical and morphological standards to optimize the accuracy of forensic identification [11, 37]. Therefore, it is difficult to use a uniform method or criterion for sex determination [9]. The ability to determine gender from unidentified skeletal remains or bones is important, and methods of doing this on various bones or remains of the human skeleton have been extensively researched. The results of various studies and research have uncertainties due to the recipes used, the origin of the sample, the condition of the sample (burnt, fractured, gross) etc. that make them unique [1].

A basin shaped framework embodying two hip bones, a sacrum and coccyx is called pelvis [43, 46] shown in **Figure 1**. This bony framework expresses the lower limbs along the axial skeleton, upholds and mainstays the vital visceral organs such as intestines, urinary bladder and the in lying sex organs.

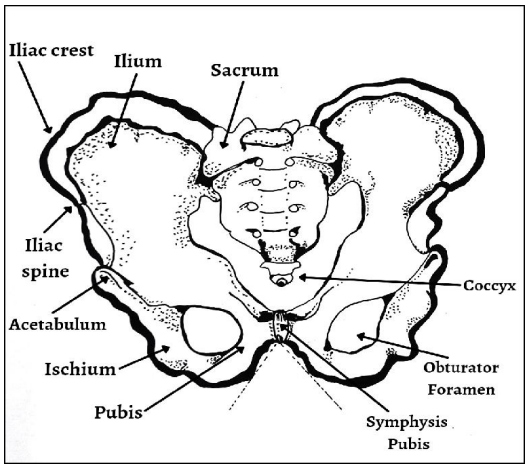

Figure 1 Pelvis Diagram

Apart from this it also serves a variety of purposes such as weight balancing; as it transfers the weight from upper body to lower limbs especially during locomotion and sitting position, provides the attachment point to various 0muscles and ligaments [41]. The hip bone or Os coxae are formed by fusion of three bones that are ilium, ischium and pubis [4, 43, 46]; collectively they form a structure called pelvic girdle. Pelvic girdle in sync with the sacrum and coccyx is termed as pelvis. The antero-lateral portion of the pelvis is mainly contributed by the two hip bones whereas the sacrum and coccyx are positioned posteriorly. All three parts of os coxae fuse to form a cavity called acetabulum where the head of the femur fits to form the ball and socket joint.

The ilium bone is the widest and largest of the three components and is supero-lateral in position. This bone primarily accounts for the width of the hip. Indispensable landmarks are present on the ilium bone; iliac crest, iliac fossa, gluteal surface bearing gluteal lines.

The falcate and upper outline of the ilium is known as iliac crest and it's anterior termination features the anterior superior iliac spine and inferior to it is the anterior inferior iliac spine, these are the attachment points for thigh muscles and posteriorly the iliac crest curves downward to form posterior superior iliac spine and posterior inferior iliac spine is present no muscles and ligaments attached to these points but sometimes due to these a depression can be seen in lower back. A groove can be observed on the iliac bone that is adjacent and parallel to the inferior surface of the sacroiliac joint [28].

The anterior termination of the iliac crest is anterior superior iliac spine and inferior to it is the inferior iliac spine and are the attachment points for thigh muscles and posteriorly the iliac crest curves downward to form posterior superior iliac spine and posterior inferior iliac spine is present no muscles and ligaments attach to these points but sometimes due to these a depression can be seen in lower back. The ala comprises two surfaces, the inner which bears the iliac fossa and the outer one that bears the iliac spine. At the posterior margin of the lower ilium is a U-shaped indentation present called greater sciatic notch which is present between the posterior inferior iliac spine. Greater sciatic notch is resistant to fragmentation and can also be assessed in poorly preserved bones [56].

Ischium bone is positioned postero-inferiorly and the basal tuberous part of this component is called the ischial tuberosity which mainly accords the weight of the body primarily in sitting position and also serves as attachment point for posterior thigh muscles. And the posterior margin of the ischium above the ischial tuberosity is the lesser sciatic notch. The ischial spine separates the greater sciatic notch from the lesser sciatic notch. It mainly comprises the body, superior ramus, inferior ramus and the ischial spine. Whereas, two pubic bones join anteriorly to form pubic symphysis and similar to ischium it also bears a body, superior, inferior ramus. The inferior pubic ramus extends downward to join the ischial ramus to form ischiopubic ramus. The inverted V-shape formed as the ischiopubic rami from both sides come together at the pubis symphysis is called the sub-pubic angle.

Sacrum is a large triangular shaped bone wedged between two pelvic bones and forms the posterior wall of the pelvis [40, 47]. Body of sacrum consist of base, apex and four surfaces; two are auricular surfaces that are lateral in position and articulates with the auricular part of ilium, one anterior and one posterior surface are positioned as their name says and provides the attachment point to pelvic ligaments and muscles.

The coccyx/tail bone is articulated to the inferior end of sacrum bone. Joints of the pelvis include; the Sacro-iliac joint between the sacrum and two iliac bones; sacrococcygeal symphysis between the sacrum and coccyx; pubic symphysis; and the lumbo-sacral joint between the between the lumbar vertebrae of the vertebral column and the sacrum bone.

Pelvis can be divided in two parts that are: Greater or true pelvis which is located superiorly and resides the upper abdominal viscera whereas the second part; lesser or false pelvis is located inferiorly and resides the pelvic cavity and pelvic or lower abdominal viscera.

The boundary between the greater and lesser pelvis is pelvic inlet and its size is determined by its edge or brim; the shape and size of the birth canal is determined by the pelvic inlet only. Generally, the females have a wider pelvic inlet as compared to the males. The end of the lesser pelvis marks the pelvic outlet. The pelvic brim (also known as the pelvic inlet) forms the superior margin of the lesser pelvis, separating it from the greater pelvis. The large opening in the antero-inferior hip bone between the ischium and pubis is the obturator foramen.

II. MATERIALS AND METHODS

The process of Sex determination ensnares three methodological approaches:

A. Morphological Method

Morphological or descriptive estimation of sex is entrenched by simply observing the expressive sexual traits which advances on the pelvic bones only after attaining the stage of puberty. Agile results with high accuracy are administered using this recipe if a skilled observer is experienced enough [25, 50].

Diversified discernible features are considered and discussed under this method. This expressive sexual dimorphism is mainly due to the body's reproductive system, organ support, and adaptive differences between the two sexes. The morphological features present in the human skeleton can complete the process of gender assessment with some degree of reliability [1, 3]. In a study of Balkan populations by Durić et al. it has been stated that morphological sex differences in the pelvis are significant enough to determine gender with 100% accuracy [36].

There are features such as bone shape, the shape of some landmarks that can only be accessed morphologically and features that are difficult to measure [25, 26, 49].

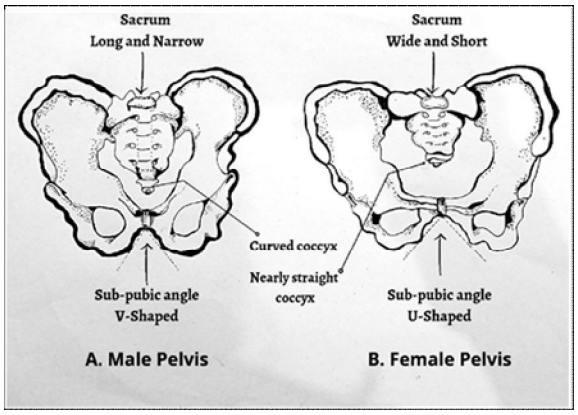

Figure 2 Morphological difference between Male and Female Pelvis

Longer, robust, rugged with marked muscular insertions, aforesaid girdle is generally observed in males as compared to Short and wider girdle of females to assist child birth or parturition [44]. Heart shaped brim or pelvic inlet is present in males while circular or elliptical which is larger and deeper is present in females to assist birthing. Refer Figure 2 and Table 1 for sex differences between males and female pelvis. Sub pubic concavity is greater in females as the sub pubic angle is considerably much wider and U-shaped in females that is more than 90 degrees; usually about 70 degrees in approximation and V-shaped is present in males [41, 52]. Greater sciatic notch is deeper and narrow in males as compared to females. There's a significant difference in shape of pubic body generally triangular shaped in males and rectangular in females. The acetabular fossa parades distinctions in terms of its position, in males it is positioned lateral or anterolateral while in females it stands anteriorly. The obturator foramen is generally oval shaped in males, while triangular shaped in females. While the periauricular sulcus is well defined and prominent in females but implicitly absent in males. Sacro-iliac joints are large in males while small in females. These differences result in determination of accurate sex by the skilled expert.

Sacrum in case of females is short, wider resulting into a wider and cylindrical pelvic cavity and is more curved posteriorly with less pronounced promontory whereas is longer, narrow, straighter with a pronounced promontory in males [28]. Pelvic constitution, pelvic outlet morphology, greater sciatic notch, auricular surface of the bones is considered the most likely morphological features for the gender evaluation process [14]. Morphological or any other approach to gender assessment is not dependent on one trait [7]. The size of the greater sciatic notch, posterior angle has been considered effective parameters in morphological approaches in various studies, where the shape of the obturator foramen is not found to be a reliable discriminator of sex [16]. Considering the shape of the obturator foramen as oval in males and triangular in females, Bierry et al. in a study of 104 adult pelvic bones, gender was determined with an accuracy of 84.6% [42].

From various researches and studies certain parameters showing some population specific standards in terms of sexual differences has been observed. In a previous study of an Iranian population, it has been marked that in males the right and the left hip bones were J-like and J-shaped, respectively; in females the right and the left hips were L-like and L-shaped, respectively [1]. So, many of the characteristics vary with the population and are population specific [1, 7, 8]. A significant number of studies considered both racial and population attributes in order to determine gender. Refer Table 1.

B. Metric Method

Metric method implies the measurement of bones. This approach determines the result with high accuracy, ensures easy repeatability, inexpensive, non-complicated, no special skills are required. Metric methods assess the same results of growth and development of males and females as morphological methods but remove the potential for observer's subjectivity. Parameters under metric criteria are being measured using a caliper scale or any other similar apparatus as demonstrated in Figure 3. Measurements are taken using some standard techniques. The accuracy of metric method also depends on the statistical method used [25] and the evaluation techniques. Length of all three individual components of pelvic bone and the total in-nominate height can be measured as demonstrated in Table 2.

Similarly various other parameters such as breadth of each component of the pelvic bone, sacral index and other, can be measured using such standard metric criteria and analysis can be carried out.

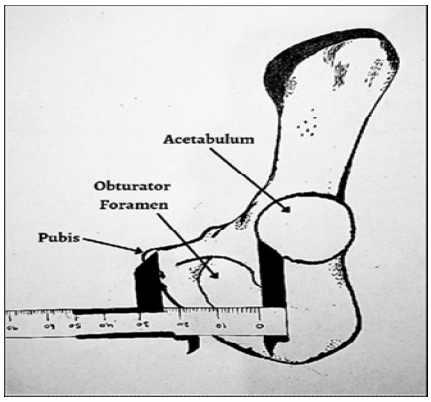

Figure 3 Part A and Part B Distance measurement between highest point of pubic tubercle to anterior rim of acetabulum (using the Metrical method)

The sacral index can be calculated using the sacral dimensions which is the total sacral width x 100 divided by the total sacral length. Indices and angles of greater sciatic notch are known to be highly sexually dimorphic [10] in various research studies and are vital for the sex estimation process. In a previous study of Balkans population the width of sciatic notch is found to be the least significant parameter for sex estimation [36]. Generally, the acetabular diameter and width of pubic ramus are significantly higher in males as compared to females. It has been found that the greater sciatic notch is greater in the female pelvis while the depth of the sciatic notch was greater in the male pelvis [16]. Male has greater sacral height and S1 vertebra, while the female has wider sacral alar and anterior breadth. The distance between the posterior inferior iliac spine and the ischial spine is generally shorter in males than in females and the depth of the greater sciatic notch is greater in males than in females [15]. Many researchers have focused on the need for statistical population-specific data for methods based on measurement, as there are many differences in the body built in different populations [8, 37]. For example, in a study of North American population, the range of the Ischio-pubic index it is 73-94 (mean 84) for the male, 91-115 (mean 100) for the female, and the angle of greater sciatic notch is 26-50° (mean 38°) and 61-93° (mean 74°) for male and female, respectively [7] and it can be different for some other population as per their standard values recorded. In a study by Akhlaghi et al. it has been found that the acetabular diameter (vertical and horizontal) and greater sciatic notch dimensions are found to be the vital parameter for the estimation process with a precise level of accuracy and the superior and inferior pubic ramus width and dimensions of obturator foramen are not found to be the parameters of precise level for estimation process [1]. Hadihalilovi et al. in a study of Bosnian population considered greater sciatic notch in their study by using a metric approach to calculate its depth and wet Lidth, the vertex of its width, and its index and found that there are differences in the mean values of Greater sciatic notch width on the male hip bones (53.94 mm and 57.8 mm), and a slightly smaller difference on the female bones (58.3–58.5 mm and 60.65 mm) [14]. Pelvic height is found to be a useful parameter in the process of gender estimation with a precise level of accuracy [5]. Singh et al. in a study of 200 samples from an Indian population, found that the posterior angle of the greater sciatic notch estimates the sex with an accuracy of 75% for the left and 88% for the right male hip bones and 92% for the left and 100% for the right female hip bones [24].

The metric method is found to have more ambiguous results in some studies when used alone, so it should be used in combination with that of the morphologic method that is called morpho-metric [3] in order to get desired accuracy. Ambiguous results are evident in cases when one or a few traits or parameters are considered for the process of gender assessment. Ninrat et al. examined the skeleton of the deceased using morpho-metric gender estimation techniques in central Thailand and found that the antero-posterior diameter of the first sacral vertebra is a reliable parameter for estimating gender with an accuracy of 82.1%, but when the combination of more than one parameter such as antero-posterior first sacral vertebrae diameter, alar index, sacral height and sacral bone width is considered together, an impressive discriminant data with a strong accuracy rate of 97.4% is prepared [17].

The sex estimation process mainly relies on the statistical data generated by keeping in mind the population standards so, various online application systems are being used to generate the population models for sex estimation and contains the desired properties for the investigation of sexual differences. One such method of machine learning with high accuracy rates is CADOES which can achieve accuracy of 92% considering any 3 parameters and increase the accuracy up to 95% with 6 parameters of critical importance in gender estimation [20].

C. Radiological Method

This technique involves the use of Radiographs and the precise imaging techniques. It's a non-invasive method [25]. A typical radiograph is an impression produced on a sensitive surface by using X-rays or similar radiations. Here radiographs of the skeletal parts are taken and the factors that are vital for the estimation process are measured on these radiographs by using X-ray viewing box, pencil, protractor and a ruler or software can be used for carrying out measurements by using the radiographs, as shown in Figure 4. Angular and linear measurements can also be made using some precision software [6]. Various factors that aid in determination of gender are measured on radiographs such as sub-pubic angles, pubic angles, length of pelvic bones (ilium, ischium, pubis), sacral length and width, transverse diameter of first sacral vertebrae, and the ala index by dividing the ala length by transverse diameter of first sacral vertebrae, multiplying by 100 and one the utmost important parameter the sacral index can be calculated by using sacral length and breadth.

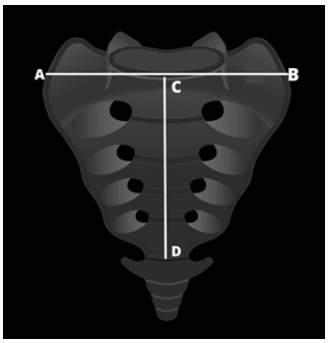

Figure 4 Measurement of Ventral Straight width (AB) and Ventral length (CD) of Sacrum

After measuring all the factors comparison is done with standard population data and estimation is carried out. Radiographs can be measured using tools from certain image measurement precision software. When compared to histological and biochemical methods, radiographs are more accurate, and cost-effective [6]. Sacral index is considered to be one of the most accurate parameters for gender estimation [10]. Various other factors can be measured using the radiographs and then sex determination can be carried out by applying metric approach or statistical analysis of the data measured and collected. The data can be measured using precision software, or the conventional methods. This recipe is useful in cases of large-scale studies or inference. Radiographs or more precise imaging techniques such as magnetic resonance imaging and computed tomography may be used to transfer and store digital data, rather than actual physical material, to obtain an expert opinion in the investigation [22]. Using radiological application, a specific detailed three-dimensional (3-D) model of skeletal elements or bones can be generated to analyze the morphological features of skeletal elements and measure the metric values of the same. Magnetic resonance imaging with three-dimensional (3-D) radiographs has been found to be the best and most effective method for the measurement and morphological estimation of skeletal elements or bones in the gender estimation process. Using the Magnetic Resonance Imaging the anterior sacral length and posterior sacral length were found to be the best parameters for sex determination with an accuracy rate of 71.9% and 71.5% respectively in an Egyptian Population [21]. Hayashizaki et al. stated that image processing tools such as the Fourier transform can be used to analyze the curved shape of bones [27].

III. RESULTS AND DISCUSSION

Gender estimation is the key area of forensic anthropology. Pelvis is the most optimal skeletal part for the gender estimation process with high accuracy and reliability. Forensic anthropologists are constantly striving to improve sex identification methods through the development and improvement of new methods of sex determination to make it more precise and admissible in court of law. The three main methods used for sex estimation process are morphological, morphometric and radiological.

From various studies it has been concluded that; chances of getting ambiguous results are generally higher when any solitary recipe is used. In some previous researches it has been found that chances of getting ambiguous results is more in the case of metric or measuring approaches when used alone. While the application of morphological approaches in the estimation process come up with less ambiguous results. Morphological methods give better results with higher accuracy when the complete pelvis or skeletal part is administered, although the level of precision decreases when fractured, charred, mutilated and disfigured parts or remains are discovered [25]. There is no such difference in the accuracy of sexing in the morphological and metric approaches when the whole bone is present for the assessment process.

Numerous researches have overlooked the morphological approaches in sex estimation process but it is also observed that sex differentiation on the basis of morphologic sexual traits visible on bones are not all alone enough to estimate the sex accurately in various cases. Though when both these methods are combined and applied as morphometric, then it culminates the high level of accuracy and consistency in sex determination process. Much prominent metrical values and morphological characters can be calculated and observed respectively by using radiological methods or imaging techniques such as X-rays and imaging techniques like CT scan, MRI, refer Table 3.

Radiological films demand the execution of a radiograph shaped with a definite shape of the bone. Radiological methods and imaging techniques can estimate precise dimensions using specific formulas that are important for the sex determination process [11, 39]. Radiographs and images can be stored digitally [11].

When a single attribute is considered for the estimation process, the potential for error and uncertainty is high, so the sex determination process does not depend on a single attribute or parameter. Bruzek (2002) in a study found that the accuracy obtained in the sex determination process is higher when the sets of traits is considered; he considered two sets of traits, one is simple and the other is complex, simple features such as composite arch or ischiopubic determines the sex with an accuracy between 60–80%, however complex features (periauricular surface, greater sciatic notch, inferior pelvis) lead to a more reliable sex determination. When all these five traits are considered together the results achieved are very homogeneous and these sets when considered can raise the accuracy up to 93-98% [7].

Skeletal characteristics vary among population, each population should have specific metrical and morphological standards to optimize the accuracy of forensic identification [8, 11, 37]. Nowadays, certain precision software is developed, modified and used to collect statistical population data. The accuracy of sex determination depends on the traits or parameters considered, the methods applied, the racial difference and the assessment technique used. In a research study two empirical techniques for gender estimation that are Discriminant Function Analysis (DFA) and Back propagation Neural Network (BPNN) using pelvic bones and patella were compared and it has been found that higher accuracy can be achieved in gender estimation process using BPNN as compared to DFA [2].

In a study by Meindl et al. it has been observed that the chances of misclassification of female skeletons are usually less, however the male skeletons can be occasionally misclassified [45]. According to NOVOTNY, perfect accuracy of sexing the pelvic bone can be achieved by considering a combination of 2 types of morphological and 4 types of morphometric features in the pubis, ischium and greater sciatic notch [38]. The use of a combination of osteoscopic and osteometric methods is recommended when it is difficult to determine gender in one or the other category [14]. The morphology of the skeletal part or remains is unclear in cases where burned and fragmented or mutilated remains are recovered, in such cases morphometric estimation is important [40, 48]. Molecular methods such as molecular sex typing using multiplex PCR can be used for gender estimation when no such method is in use [55].

It is difficult to administer any particular estimation method due to existing racial differences as it is evident in previous studies of the sex of skeletons from unknown subjects and it has been observed that metric methods can lead to more ambiguous results. It parades the ambiguousness of a particular recipe. Another can be, both right and the left hip bones generally do not accomplish the outcome with same accuracy in sex determination process.

IV. CONCLUSION

Sex determination by skeleton or its remains play an admirable role in forensic and anthropological investigations. Various bones of skeleton are dedicated towards this process of estimation but the pelvic bone produces gilt-edge results in sex determination process with the highest accuracy of 95% alone. Sex estimation is of foremost importance for developing the biological profile of an individual, it's the first step towards the positive identification process. The main issue with the pelvic bone is that it is frail in nature so primarily are collected in fragmented, charred or damaged conditions in maximum cases. In such cases no particular method serves the purpose of estimation with consistency and higher accuracy but in turn keeping in mind the aspects of all the methods can result in an estimation process with a high level of accuracy and consistency. Moreover, not all anthropometric recipes used are in favor of a single sex.

The main criterion for accurate sex estimation process is being discussed in this paper. Not any single recipe, be it morphological or metrical or radiological, is consistent or gives accurate results due to racial differences as the results may vary with population, region etc. So, any single criteria or method is not all alone able to estimate accurate results therefore the results should be interpreted by considering all the available parameters.

Table 1 Parameters and their sexual dimorphism

Parameters	Male	Female
General	Heavier, Rough and Rugged	Lighter, Smooth and Gracile
Sub-pubic angle	V-shaped	U-shaped, obtuse
Sub-pubic concavity	Minimal or absent	Greater and prominent
Obturator foramen	Oval and large	Triangular and small
Acetabulum	Laterally directed and large	Antero-laterally directed and small
Periauricular sulcus	Implicitly absent	Prominent
Greater Sciatic notch	Narrow and Deep	Wide and shallow
Pubic Symphysis	Higher	Lower
Ischio-pubic rami	Flat and blunt	Sharp and narrow edge
Pelvic Brim	Heart Shaped	Elliptical or circular
Shape of pubic body	Triangular	Rectangular
Sacroiliac joint	Large	Small
Sacrum	Long and narrow	Short and wide
Sacral Promontory	More pronounced	Less pronounced

Table 2 Parameters and their measurement techniques using metric recipe

Parameters	Measurements
Iliac Length	It is measured using a caliper from the extreme end of the iliac bone to the closest point on the acetabular rim.
Ischial Length	From extreme point of the ischium to the acetabular rim
Pubic Length	From inner edge of the obturator foramen to mid of the pubis symphysis
Height of pubic symphysis	From topmost to the lowermost point of the pubic symphysis
Total innominate height	From the most superior point of the iliac crest to the most inferior point of the ischial tuberosity
Greater sciatic notch breadth	Measured from the base of the ischial spine (may be wasted in most samples) to the posterior inferior iliac spine
Acetabular diameter	Diameter of the acetabulum is reviewed, vertical acetabular diameter that is maximal diameter measured in superior-inferior order, Horizontal acetabular diameter expressly the maximum diameter measured horizontally
Anterior length of sacrum	From midpoint of the promontory to the mid of the inferior end of the sacrum
Anterior breadth of sacrum	Distance between two auricular surfaces
Maximum breadth S1	It can be measured on the superior surface of the sacrum.

Table 3 Parameters and their measurement techniques using radiological method

Parameters	Measurements
Sub-pubic angle (degree)	Two tangent lines are drawn from the lower brim of pubic ramus and their point of intersection in the lower middle part of inter-pubic disc is measured as angle.
Pubic angle (degree):	Two tangent lines drawn from the middle part of the pubis symphysis to the longitudinal axis of the superior and inferior pubic ramus are measured as an angle.
Length of pubis:	Measured from the point of reference of acetabulum to mid midpoint of pubic symphysis.
Ischiopubic index	Length of pubis by the length of ischium multiplied by 100.
Minimum width of pubis body	Distance between the internal margin of pubic symphysis and the inner edge of obturator foramen.
Mid Width of pubis body	Distance between mid-point of pubic symphysis and the inner edge of obturator foramen
Maximum length of sacrum	Measured by taking two points at the upper part of the auricular surface anteriorly.
Transverse diameter of first sacral vertebrae	Measured by taking the lateral most point of each side of the first sacral vertebrae.

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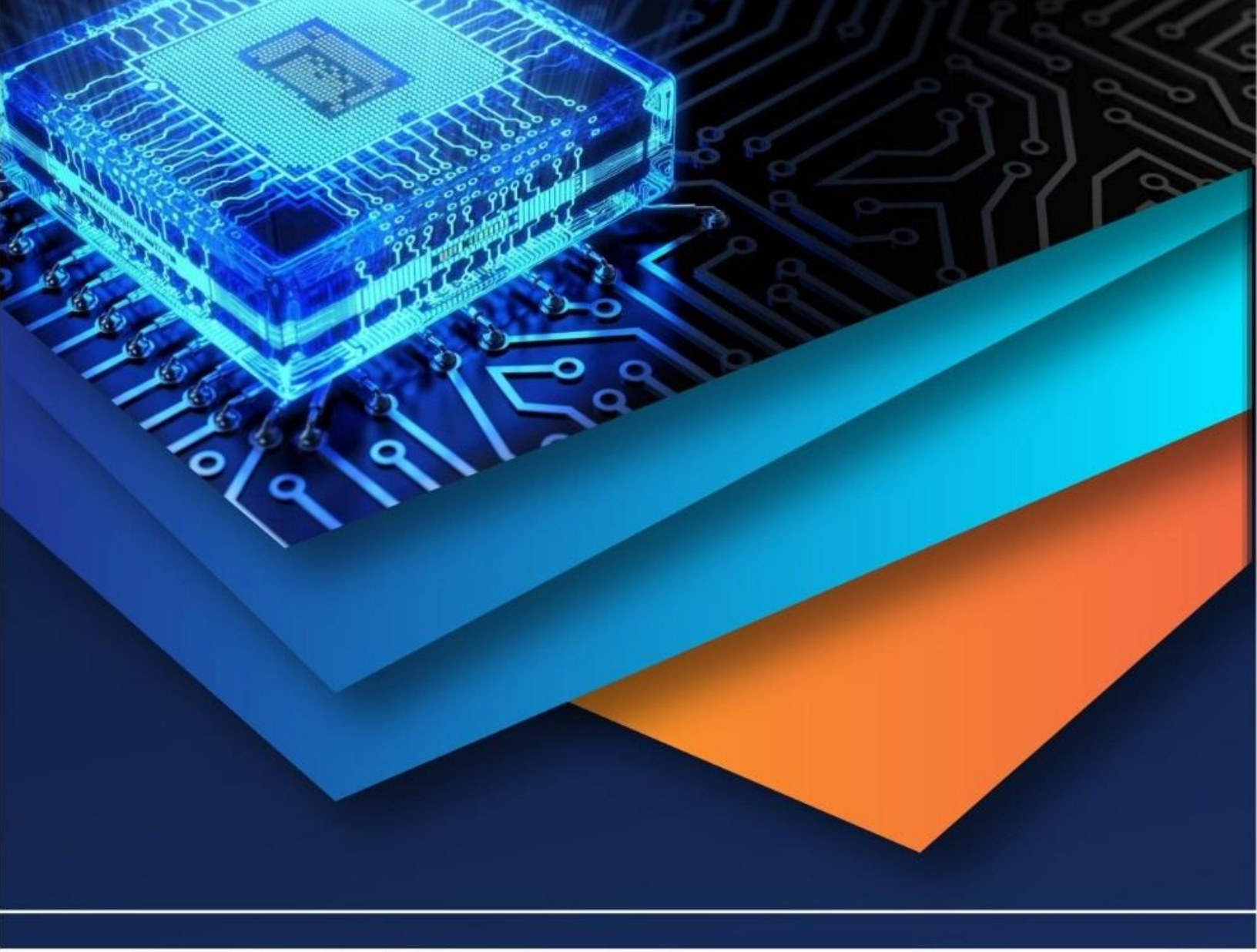

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