Chapter

Forensic Osteology and Identification

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Abstract

Every human corpse is unique. There are different religions in different parts of the world which adopt a variety of ways to dispose of corpses. Dead bodies can be found unattended, dug up, mutilated by the perpetrators of crimes, and eaten by wild animals in lonely unattended places. In these situations, forensic anthropologists or anatomists are consulted by the state authorities to help them to provide justice to the deceased person. The first and foremost scientific information desired by authorities is identification of the corpse, cause of death of the human body and weapon used, if applicable. Identification can be done by studying the bones of the human corpse during autopsy examination and if unknown skeletal remains are all that is available, examination of each bone is required. Forensic anthropologists or pathologists are asked to identify race, sex and age as important parameters of the identification. In this chapter, we will enumerate various parameters for identification. We will discuss race, age and sex from various bones as part of forensic oesteology.

Keywords: bones, index, skull, femur, ossification centre, race, age, sex, skull, pelvis, mandible, rhomboid fossa

1. Introduction

The human corpse is more than a utilitarian object; it has sacred meaning. Every religious faith has beliefs pertaining to the treatment of corpses and there are laws that govern the treatment and the burial of the dead. While these laws have recognized the corpse's instrumental value as an object for scientific study, clinical teaching and commercial gain, they generally accommodate the desire to respect the remains [1].

Forensic experts, in particular anthropologists, frequently are asked to examine unknown corpses before final rituals for identification in medico-legal cases. Identification is the determination of the individuality of a person. This can be for either a living or dead person. Various parameters for identification of human dead bodies are enumerated below.

1. Race

2. Sex

3. Age

4. Stature
5. Teeth
6. Hair
7. Religion
8. Fingerprints
9. Footprints
10. Tattoos
11. Scar marks
12. Anthropological factors

A thread that binds parameters such as race, sex, age and stature is human osteology or forensic Osteology. Bones and teeth of the skeleton resist putrefaction or decay. Hence they are a cornerstone for the determination of individual existence. Scientists employ their knowledge of the human skeleton in interpreting the bones and thus help in identification.

Human forensic osteology is the study or application or knowledge of human bones in the field of forensic science to assist the administration of justice.

In this chapter, we will mainly consider race, age and sex parameters.

2. Race

Human bone measurements play vital role in the determination of race. The important bones that are useful for race determination are the skull and the long bones of the limbs. Various indexes are given for these.

Index is defined as a percentage expression of the ratio of a smaller dimension over the larger one.

2.1 Cepahalic index

The cephalic index (CI) is calculated from the skull according to the following equation:

$$(\text{cephalic width}/\text{cephalic length}) \times 100 \quad (1)$$

Cephalic length is the distance between the most anterior and posterior point of the outer table of the skull or occipitofrontal diameter (OFD). Cephalic width is the distance between the outer skull tables at the widest points of the skull or biparietal diameter BPD [2]. Cohens [3] classifies race on the basis of cephalic index as dolichocephaly (long headed) up to 75.9 e.g. Pure Aryans, Caucoids and Negroids, mesocephaly (round headed): 76.8–80.9 e.g. in few Caucoids (Europeans) and Mangoloids, and brachycephaly (Short headed): 81.0–85.4 e.g. Mongoloids, with hyperbrachycephaly exceeding 85.5 e.g. Kyushu of Japan.

2.2 Nasal index

Nasal anthropometry is the study of proportion, shape and size of the nose in human beings. The nasal index is the ratio of nasal width to nasal height multiplied by 100.

$$\text{Nasal Index} = \text{Nasal Width} * 100/\text{Nasal Height} \quad (2)$$

It also exhibits sexual differences and has become an important tool in forensic studies. The general shape of the nasal base has long been broadly classified as the leptorrhine or long/narrow nose, the mesorrhine or medium nose and the platyrrhine or short broad nose [4].

Leptorrhine: Lesser than 70. Caucoids
Mesorrhine: 70–85 Mangloids
Platyrrhine: greater than 85; Negroids

In a study in Nigeria on Igbo and Yoruba males and females, it was observed that both had the same type of nose Platyrrhine, but differences still existed. The report showed that the Igbo males and females had mean nasal indices of 95.8 ± 0.44 and 90.8±0.61 respectively while the Yoruba males and females had mean nasal indices of 90.0±0.38 and 88.1±0.47 respectively. The Igbo (Total) had mean nasal indices of 94.1 ± 0.37 while the Yoruba (Total) had mean nasal indices of 89.2±0.30. The mean nasal indices of Igbo males and females were significantly higher than those of Yoruba males and females [5].

3. Age

Age determination from humans is one of the important tasks desired by law enforcement agencies for medico-legal cases. Absolute or chronological age is the number of years an individual has lived since birth. In other words, it is the age that is mentioned on the passports or other important documents of the person. Biological age is the age of the person gauged from the physical wellbeing of the person [6]. Environment, health conditions, exercise, yoga and healthy eating habits affect the biological age, not the chronological age. The difference between chronological and biological age is minimal in juveniles, but it increases afterwards [7].

In fetuses and children, age can be estimated from the appearance of ossification centres, development of bones and eruption and calcification of the teeth. There are approximately 806 ossification centers at the 11th prenatal week, 406 ossification centres at birth and 206 bones in the adult. The ossification centres enlarge in size and joints to nearby ossification centres and thus give rise to the bones in the adult skeleton [7]. A fetus' age is best given in lunar months although it is also given in weeks of pregnancy. In decomposed fetal bodies, it is best to have the fetal body X-rayed [8]. But in skeletonised fetuses, various bones dissociate, thus X-rays are not helpful. The presence of the primary ossification centre of the talus, calcaneum, cuboid and the secondary ossification centre in the femur and tibia around the knee joint point toward full term pregnancy [9]. The major ossification centres appear [10] as follows:

At Birth: calcaneum, talus, femur distal end, tibia proximal end, cuboid, humerus head.
At Second Month: capitate, hamate, lateral cuneiform.
At 3 month: femus head, capitulum, tibia distal end.
At 6th month: fibula distal end.
At 7th month: humerus, greater tuberosity, radius distal end.

At 10th month: triquetrum.
At 11th month: third finger-first phalanx, first toe-second phalanx.
At 12th month: second finger-first phalanx, fourth finger-first phalanx, first finger-second phalanx.
At 13th month: third toe-first phalanx, second metacarpal, medial cuneiform.
At 14th month: fourth toe – first phalanx, second toe – first phalanx fifth toe-second phalanx.
At 15th month: third metacarpal, second toe-second phalanx, fifth finger-first phalanx.
At 16 month: fourth toe-second phalanx, fourth metacarpal.
At 18th month: fifth metacarpal, second, third and fourth finger-second phalanx.
At 20th month: first toe-first phalanx, middle cuneiform [10].

Fetal age can be determined by crown heel length (CHL). According to Hasse's rule which is a crude method to determine fetal age, in the first 5 months of fetal life, the square root of crown heel length measured in cm, will give the age of fetus in months. As with the Morrison rule, after five months of fetal life, the crown heel length in cm is divided by the number five to reach the fetal age in months.

In the mandible and maxilla, the primary centre of ossification appears at 6 weeks, while in frontal bones ossification begins in 6–7 weeks, and in the temporal bone, ossification appears in 7–8 weeks. In occipital bone, ossification centre appears in 8–10 weeks of intrauterine life [11].

The appearance of secondary ossification centre [11] appear as shown in **Table 1**.

In adult skeletonised remains, epiphyseal closure or fusion is more commonly seen than ossification centres. This process of closure usually starts from 12 to 14 years and chronologically happens earlier in females as compared to males.

Stevenson [12] described four stages of fusion as follows:

1. First Stage or No fusion: On gross examination of skeletal remains, there is a clear cut hiatus in between the epiphysis and diaphysis. The margins of the epiphysis and diaphysis is serrated or saw-toothed.

2. Second Stage or Beginning of fusion: There is a clear cut line in between the epiphysis and diaphysis. The first phase hiatus is replaced by formation of new bone leaving only a line of separation. The saw-toothed appearance of margins in the epiphysis or diaphysis as evident in the first stage, is also blurred or lost.

3. Third stage or recent union: The clear cut line in the second stage is as appreciable as the fine line. This stage is sometimes difficult to appreciate.

4. Fourth stage or stage of complete union: This stage represents complete fusion. Sometimes, a very faint epiphyseal line is appreciable throughout life.

Loth [13] described that the order of epiphyseal closure of various joints is as follows. First the elbow is followed by the hip, followed by the ankle, followed by the knee, followed by the wrist, and last in the shoulder joint.

3.1 Sternum

The sternum is made of the manubrium, body of the sternum and the xiphi-sternum. The body of the sternum is the middle-most part and is composed of four parts. The fusion of the sternum is variable. Different authors have expressed

Sr. No.	Bones Parts	Age
	Shaft	Birth
	Medial Epicondyle	12–14
	Lateral Epicondyle	19–20
	Humeral shaft	Birth
	Humeral head	2–6 months
	Humeral Capitulum	By 1st Year
	Humeral Greater Tubercle	6 months-2 years
	Humeral Lesser Tubercle	4+ years
	Humeral medial epicondyle	4+ years
	Humeral Trochlea	8 year
	Humeral Lateral Epicondyle	10th year
	Radius Shaft	Birth
	Radial distal Epiphysis	1–2 years
	Radial head	5th year
	Radial styloid process	8th year
	Ulnar shaft	Birth
	Ulnar distal Epiphysis	5–7 years
	Ulnar styloid process and olecranon	8–10 years
	Pelvis	Birth
	Femoral shaft	Birth
	Femoral distal epiphysis	Birth
	Femoral Greater trochanter	2–5 years
	Femoral lesser trochanter	7–12 years
	Tibial Shaft	Birth
	Tibial proximal epiphysis	Birth
	Tibial Medial Malleolus	3–5 years
	Tibial Tuberosity	8–13 years
	Fibular Shaft	Birth
	Fibular distal epiphysis	9–12 years

Table 1.
Showing appearance secondary ossification Centre from bones.

different views. Sternebra are numbered from upwards to downwards as 1 to 4. Sternebra 3 fuses with 4 between the ages 4 and 15. Sternebra 2 fuses with 1 and 3 by the ages of between 11 and 20. The manubrium fuses with sternebra 1 by between the ages of 15 and 25 years [7]. The xiphoid fuses with sternebra 4 in older age.

Garg [14] conducted a radiological study on 150 living subjects by doing lateral view X-rays of the sternum in the age group of 35–65 years whose exact age is known by available official documents and where the entire sternum was intact without disease and deformity. He concluded that complete fusion of the xiphisternun with the body of the sternum occurred by 56–59 years and only 40% manubrium fused with body of sternum by 65 years.

Mean Closure Value	Mean Age	SD	Range	Age Category
0.4–1.5	28.6	13.08	15–40	Juvenile-young adult
1.6–2.5	43.7	14.46	30–60	Young-middle adult
2.6–2.9	49.1	16.40	35–65	Young-middle adult
3.0–3.9	60	13.23	45–75	Middle-old adult
4.0	65.4	14.05	50–80	Middle-old adult

Table 2.
Showing estimation of age by cranial suturel closure [6] by mean Acsadi score.

3.2 Cranial sutures

Cranial sutures are extensively studied by different authors for age estimation. Cranial Sutures usually fuse in adult life except the metopic suture. The metopic suture fuses by the age of 1 to 4 years. The fusion of the cranial suture in adult life is studied both endocranially and ectocranially. Cranial sutures are assessed in three sections or parts: palate is also studied along with endocranial and ectocranial study of cranial sutures.

Recently also the method devised by Acsadi and Nemeskeri [6] has been widely used. They studied sagittal, coronal and lambdoid sutures for the purpose of age estimation. They divided the coronal suture into three parts, the sagittal suture into four parts and the lambdoid suture into three parts – in total 16 sections. Then they studied closure of sutures and gave scores as follows:

Score 0: Open suture.
Score 1: Suture line is closed but clearly visible and continuous.
Score 2: Suture line is thinner and may be interrupted by complete closure at places.
Score 3: At the suture line, only pits are available.
Score 4: Suture is completely obliterated.

Each of 16 sections described above was examined and awarded scores and a mean value was calculated, then that mean closure value was compared by the **Table 2** given below and the mean age was calculated and the age category was noted.

In young adult life, the incisival palatine suture is closed with activity seen at transverse and posterior palatine suture. The anterior palatine remains completely open. In middle-aged adult life, the incisival transverse and posterior palatine suture are closed. The interior palatine remains partially open. In old age, all palatine sutures are fused [15].

There are many more bones from which age can be found. The bones described here are the bones which are frequently examined by forensic anthropologists.

4. Sex

In humans, it is very difficult to determine sex from skeletal remains. Until adolescence, the human skeleton is immature and starts maturing at puberty or adolescence and thus attains complete maturity in adulthood. Thus, sex determination with accuracy in young to adult life is difficult as many factors overlap.

Sr. No	Bones Available	Accuracy of Sex determination by Krogman [16]	Accuracy of Sex determination by Stewart [17]
1	Entire Skeleton	100%	90–95%
2	Pelvis + Skull	98%	—
3	Pelvis + Long Bones	98%	—
4	Skull Alone	98%	80%
5	Pelvis alone	95%	—
6	Long bones only	80%	—
7	Skull + mandible	—	90%

Table 3.
Showing accuracy of sexual identification from bones.

Krogman [16] studied a sample of 750 adult skeletons (white and black, male and female) from the Harmann-Todd collection and Stewart [17] also determined sex and found as shown in **Table 3**.

Sex can be determined by two methods – morphological and metric. The morphological method of assessing sex is by reference to the differences in skeletal remains on the basis of gross examination. It relies on the specific bony traits and muscular markings etc. to differentiate the skeletal remains. The advantage of the morphological method is that sex-specific bony characteristics remain unique in spite of population variations. But gross examination of morphological characteristics of the skeleton has disadvantages such as inter- and intra-observer errors, observer experience, and standardization and statistical analysis problems. This gross morphological method of determining sex is challenged by modern morphological methods such as the geometric morphometric technique [18] and elliptical Fourier analysis [19].

Earlier in the gross morphology technique, the skeletal remains are observed in two dimensions and now by reference to the geometric morphometric technique, the shape differences are first observed and then quantified in three dimensions digitally. Thus, this technique reduces the inter- and intra-observer errors. This new technique works well at a population level but it is very difficult to apply to individuals. Nowadays, a number of sex dimorphic characters are studied morphometrically and then statistically analyzed by discriminant function analysis, logistic regression and neural networking.

4.1 Pelvis

4.1.1 Morphological assessment

The human pelvis consists of 3 bones namely the hip bone, the sacrum and the coccyx. The hip bone consists of 3 parts i.e. the ilium, the ischium and the pubis. The pelvis is the most sexually dimorphic bone of the human skeleton as it determines the sex very accurately. The pelvis is the most widely studied bone to determine sex from unknown skeletal remains. As Krogman [20] has identified, the pelvis can identify correct sex in 95% (**Table 3**) of cases from unknown skeletal remains. **Table 4** enumerates classical morphological sex differences from pelvis.

Phenice [21] studied 275 adult individual already sexed pelvises from the Terry collection with three visual traits named the ventral arc, the subpubic concavity and the medial aspect of ischiopubic ramus and found sex with 95% accuracy. He also

Sr. No	Characters of bone	Male	Females
1	Pelvis as a whole	Massive, rugged, marked muscle sites	Less massive, gracile, smoother
2	Symphysis	Higher	Lower
3	Subpubic angle	V-shaped (<90°)	U-shaped: rounded;broader divergent obtuse angle (>90°)
4	Subpubic shape	Convex	Concave
5	Pubic bone shape	Triangular	Rectangular
6	Ventral arc	Absent, not well	Well defined
7	Obturator foramen	Large, often ovoid	Small, triangular
8	Acetabulum	Large, tends to be directed laterally	Small, tends to be directed anterolaterally
9	Greater sciatic notch	Smaller, close, deep	Larger, wider, shallower
10	Ischiopubic rami	Slightly everted	Strongly everted
11	Sacroiliac joint	Large	Small, oblique
12	Auricular surface	Raised	Flat
13	Postauricular space	Narrow	Wide
14	Preauricular sulcus	Not frequent	More frequent, better developed
15	Postauricular sulcus	Not frequent	More frequent, sharper auricular surface edge
16	Ilium	High, tends to be Vertical	Lower, laterally divergent
17	Iliac tuberosity	Large, not pointed	Small or absent, pointed or varied
18	Sacrum	Longer, narrower, with more evenly distributed curvature; often 5 or more segments	Shorter, broader, with tendency of marked curvature at S1–2 and S2–5; 5 segments the rule
19	Pelvic brim,or inlet	Heart shaped	Circular, elliptical
20	True pelvis, or cavity	Relatively smaller	Oblique, shallow, spacious

Table 4.
Shows classical morphological sex differences from pelvis.

found that the ventral arc is the least ambiguous and medial aspect of the ischiopubic ramus as the most ambiguous trait among the three traits studied.

Kelley [22] observed after applying the Phenice technique in 392 mature pelvis of both sexes from collection from University of California, Berkeley and Sacramento State University that the Phenice method of sexing with three virtual traits is very reliable and also found that fewer intermediate features are present with the ventral arc and if intermediate features are present in two or all the three traits, then the pelvis is of the female sex.

Bruzek [23] found 95% accuracy in sex determination by using a new visual method taking into account five traits of the hip bone, namely the preauricular sulcus, the greater sciatic notch, the composite arch, the morphology of the inferior pelvis and ischiopubic proportions.

Bytheway [24] studied thirty-six traits digitally of 200 African and European American male and female adult humans' coxae and showed that sex and size have a significant effect on shape for both European Americans. The discriminant analysis

shows that sexing accuracy for European Americans is 98% for both males and females, 98% for African American females, and 100% for African American males.

Iscan and Derrick [25] developed a gross assessment method for sex determination using the sacroiliac joint with three structures which included the post-auricular sulcus, the postauricular space and the iliac tuberosity. They found these to be highly accurate in determining sex.

4.1.2 Metric assessment

There are multiple studies suggesting various indices to access sexual dimorphism.

4.1.2.1 Turner pelvic index

Turner [26] described the shape of the pelvic inlet based on the conjugate diameter (anteroposterior diameter) and transverse diameter of pelvic inlet. It is also known as the Brim Index.

$$\begin{aligned} \text{Brim Index} &= \text{Turner Pelvic Index} \\ &= (\text{Conjugate diameter (anteroposterior diameter} \\ &* 100/\text{transverse diameter of pelvic inlet}) \end{aligned} \tag{3}$$

On the basis of the index, Turner divided inlet into three classes as follows
Platypellic = less than 90 (90 not included)
Mesatipellic = 90 to 95 (both 90 and 95 included)
Dolichopellic = greater than 95 (95 not included)

He found that the brim index in males is somewhat lower than in females.

4.1.2.2 Ischiopubic index (Washburn index)

The ishchiopubic index is given by Washburn [27]. It is calculated as follows

$$(\text{Pubic length} * 100/\text{Ischial Length}) \tag{4}$$

Both lengths can be measured with a vernier caliper from the point in the acetabulum where the ilium, ischium and pubis fuse, which may be a notch, raised or irregular area in the acetabulum. The caliper should be held parallel to the long axis of the bone. The author also suggested that the index alone will determine sex from skeletal remains of any one particular population race by up to over 90%. However, overlapping may occur in the skeletal remains of different races as found in white males and black females (**Table 5**).

Population	Male	Female
White	73–94 (83.6 ± 4)	91–115 (99.5 ± 5.1)
Black	71–88 (79.9 ± 4)	84–104 (95 ± 4.6)

Table 5.
Showing ischiopubic index in white and blacks.

4.1.2.3 Sciatic notch index

The sciatic notch index is given by dividing the hundred times width of sciatic notch with its depth.

$$(\text{Width of the sacrum}/\text{diameter of sacrum}) * 100 \quad (5)$$

In adult males: 145; in adult females: 166.
In the male fetus: 4–5; in the female fetus: 5–6.

4.1.2.4 Chilotic line index

The chilotic line index is obtained by dividing the hundred times length of the sacral part of the pectineal line with the pubic part of pectineal line.

$$(\text{Sacral part of pectineal line}/\text{pubic part of pectineal line}) * 100 \quad (6)$$

In males: the CLI is greater than 100, In females: the CLI is less than 100.

These indexes are not used routinely. Nowadays, discriminant function analysis is used by anthropologists. This was first used by Howells [28]. He worked on Gaillard's skeletal collection (75 males, 69 females) and took four parameters, ischial and pubic lengths and the index obtained from it, he took four measurements of the greater sciatic notch and acetabular region. These included sciatic height, cotylosciatic length (shortest distance from acetabular rim to greater sciatic notch), cotylopubic length (from acetabular rim to pubic symphysis) and the difference between SS-SA, in which SS is the distance between the anterior superior iliac spine and the closest point on the greater sciatic notch, and SA is the distance between the anterior superior iliac spine and the closest point on the auricular surface (**Table 6**).

In another study, Dixit [29] observed twelve measurements and five indices from 100 human hip bones of unknown sex of Indian origin. Each of the hip bones was classified as male, female and intermediate on the basis of morphological characters. Afterwards discriminant function analysis was done and it was observed that sex can be accessed with greater accuracy from parameters such as the

From Howells [28]	**Male**		**Female**	
Dimension (mm)	**Mean**	**S.D.**	**Mean**	**S.D.**
X1 Ischial length	96.9	5.65	89.3	5.00
X2 Pubic length	93.2	6.48	97.0	5.31
X3 Ischiopubic index	96.2	3.81	108.7	4.18
X4 Sciatic height	41.0	4.80	47.1	5.32
X4 Cotylosciatic length	40.1	3.13	37.2	3.97
X5 Cotylopubic length	29.7	2.71	24.8	2.63
X6 SS-SA	1.4	3.88	−7.7	4.33
Discriminant Function Formulae			Section Point	% Correct
$Y = 0.7717X1–0.636X2$			11.3	97.8
$Y = 0.8285X6 + 0.517X7–0.1148X4–0.1819X5$			9.2	93.1
$Y = 0.4514X6 + 0.3253X7 + 0.6071X1–0.0993X4–0.1345X5–0.05421X2$			9.3	96.5

Table 6.
Showing discriminant function coefficients for determining sex from the Os Coxa.

acetabular height (vertical diameter) and indices 1 (total pelvic height/acetabular height), 2 (midpubic width/acetabular height) and 3 (pubic length/acetabular height). Pelvic brim depth, minimum width of ischiopubic ramus and indices 4 (pelvic brim chord * pelvic brim depth) and 5 (pubic length * 100/ischial length) were also good discriminators of sex. The remaining parameters used in the study were not significant as they showed a lot of overlap between the male and female categories. The results indicated that one exclusive criterion for sexing was index 3 (pubic length/acetabular height).

4.2 Sacrum

The sacrum is a large flattened triangular bone formed by the fusion of five sacral vertebrae and forming the posterosuperior part of bony pelvis. It articulates on either side with the corresponding innominate or hip bone forming sacroiliac joint. Morphological and metric differences of sex determination are given in the **Table** 7.

4.2.1 Sacral index

The sacral index [30] is given by dividing the hundred times length of anterior superior breadth of the sacrum at the first sacral vertebrae with anterior length of sacrum. The anterior length was measured along the midline from the antero-superior margin of the promontory to the middle of antero-inferior margin of the last sacral vertebra. The anterior superior breadth was measured between the lateralmost points of the ala of the sacrum.

$$\text{Sacral Index} = (100 * \text{Anterior superior breadth of sacrum}/\text{Anterior length of the sacrum}) \quad (7)$$

The study [30] also calculated the demarcating point (DP) which increases the accuracy by 100%. The range of sacral index in male is 80.7–106.4 and in females is 93.1–108.8 and DP for sacral index in males is less than 90.29 and in females is greater than 112.43.

In a study [31] done on 150 fully ossified dry human sacrums (59 male and 91 females), it was observed that the mean straight length of sacrum in the male and in the female was 104.27±5.76 mm and 92.82±7.59 mm respectively. The mean width of sacrum in the male and the female was 99.51±5.80 mm and 102.98±6.69 mm respectively. The mean sacral indices were 95.42±3.14 and 111.27±7.66 in males and females respectively.

Sr. No	Trait	Male	Females
1	Size and shape	Longer, Narrower	Shorter, wider
2	Curvature	More evenly distributed	Curvature not seen in the upper half, lower half curves suddenly
3	Sacral Promontry	Well marked	Less marked
4	Body of first sacral vertbra	Larger	Smaller
5	Sacroiliac articulation	Large, Extends to 2.5to 3 vertebrae	Small, Extends to 2 to 2.5 vertebrae

Table 7.
Showing difference in human sacrum with respect to sex.

4.2.2 Kimura base wing index

Kimura [32] examined 300 sacrums (103 Japanese sacra from the Yokohama City Medical School, 100 American whites and 97 American blacks) and obtained the transverse width of the sacral base, transverse width of the wing and the index as follows.

$$\text{Kimura base wing index} = (100 * \text{transverse width of wing}/\text{Breadth or transverse width of Ist sacral vertebra}) \quad (8)$$

The Kimura base wing index is also known as the Alar Index. In males it is less than 65 and in females: it is more than 80.

Patel [33] observed that the sacral index results are more reliable than the Kimura base wing index.

Valojerdy studied 153 dry human sacrums of Indian origin [34], and found that the size of the articular surface was studied in sacro-iliac joints. He found that the articular surface on sacral and iliac surfaces in males is longer and larger in surface area than in females.

4.2.3 Corporo-basal index

The corporo-basal index is the transverse diameter of body of the sacrum S1 when the breadth of the sacrum is 100

$$\text{Corporo} - \text{basal Index} = (\text{Transverse diameter of body of S1} * 100/\text{Maximum breadth of sacrum}) \quad (9)$$

Maddikunta [35] studied 60 adult sacrums from Telengana, India (27 male, 33 female) and calculated the corpora-basal index and demarking point and observed that the range in males is 39.0–53.77 and in females is 27.43–32.67 and the demarking point in males and females is >57.81 mm and <32.02 mm respectively.

4.3 Skull

Th skull is very important for aging and sex differentiation. Sexing can be done with the help of morphological as well as metric characters. As Krogman [16] has identified, if only the skull is available from bony remains, sex can be given correctly up to 98% of the time (**Table 3**). Differences in male and female skull on the basis of morphological characters are given below in **Table 8**.

Buikstra et al. [15] concluded that five traits of the skull should be regarded as able to differentiate sex:

i. Robusticity of the nuchal crest,

ii. Size of the mastoid process,

iii. Sharpness of the supraorbital margin,

iv. Prominence of the glabella, and

v. Projection of the mental eminence

S. No	Feature	Male skull	Female skull
1	General appearance	Larger, heavier, rugged, marked muscular ridges	Smaller, lighter, walls thinner, smoother
2	Forehead	Receding, irregular, rough, less rounded	Vertical, round, full, infantile, smooth
3	Cranial capacity	More capacious (1450–1550 cc)	Less capacious (1300–1350 cc)
4	Glabella	Prominent	Less prominent
5	Supraorbital/Superciliary ridge	Prominent	Less prominent
6	Frontonasal junction	Distinct angulation	Smoothly curved
7	Orbits	Square, rounded margins, small	Rounded, sharp margins, large
8	Frontal and parietal eminence	Less prominent	Prominent
9	Zygomatic arch	Prominent	Not prominent
10	Occipital area (Muscle markings and protuberance)	Prominent	Not prominent
11	Mastoid process	Large, round, blunt	Small, smooth, pointed
12	Digastric groove	Deep	Shallow
13	Condylar facet	Long, narrow	Short, broad
14	Palate	Large, U-shaped, broad	Small, parabolic
15	Foramen magnum	Relatively large, long	Small, round
16	External auditory meatus	Bony ridge along upper border prominent	Often absent

Table 8.
Showing morphological differences in male and female skulls.

The above features are examined independently and scores 1 to 5 is given. A score of 1 is definitely female, 2 is probably female, 3 is ambiguous, 4 is probably male and 5 is definitely male.

Rogers [36] examined 46 identified skulls from a cemetery in Belleville, Canada. He examined 17 morphological features of the skull commonly used to determine the sex of unknown skeletal remains. He observed that traits such as nasal aperture, zygomatic extension, malar size/rugosity, and supraorbital ridge are the most useful; chin form and nuchal crest are the second most useful followed by mastoid size as a tertiary consideration; nasal size and mandibular symphysis/ramus size rank fourth; forehead shape ranks fifth; and palate size/shape are sixth. Skull size/architecture provides an internal standard to assess the relative sizes of other traits.

4.4 Mandible

The mandible is a very important bone in sex determination. Stewart [17] observed that if the mandible along with the skull are the only available bones out of skeletal remains, sex can be determined with 90% accuracy. The projection of mental eminence is one of five characteristics suggested by Buikstra and Ubelakar [15] for sex discrimination (**Table 9**).

Loth [37] examined a sample of 300 mandibles from the Dart collection with known sex. 100 showed bony pathologies and tooth loss. Thus these pathological samples of mandibles were not considered in main study. Of the remaining 200,

S. No	Feature	Male mandible	Female mandible
1	General appearance	Larger, thicker	Smaller, thinner
2	Chin (symphysis menti)	Square or U-shaped	Rounded
3	Angle of body with ramus	Less obtuse (< 125°), prominent	More obtuse, not prominent
4	Angle of mandible (gonion)	Everted	Inverted
5	Body height at symphysis	Greater	Smaller
6	Ascending ramus	Greater breadth	Smaller breadth
7	Ramus flexure	Rearward angulation of the posterior border of ramus	Straight ramus
8	Muscular markings	Prominent	Not prominent

Table 9.
Showing morphological differences for sex determination from mandible.

normative samples consisted of 116 males and 84 females. After careful macroscopic examination, Loth discovered a new trait known as flexure at the level of the molar occlusal surface in adult males. It is a male developmental character that is developed after adolescence. Females retain the straight juvenile shape of the mandibular ramus. Since male develop distinct angulation of the posterior border of mandibular ramus, it usually appears near the neck of condyle or along with gonial prominence or eversion. In the sample of 200, sex was able to be determined in 99% of mandibles. The same parameter was also applied to discarded or pathological samples of mandibles; it yielded 91% accuracy in sex determination.

Kemkes-Grottenthaler [38] investigated the reliability of two mandibular traits: ramus flexure and gonial eversion. The study was done on two samples, one of forensic (N = 153) and one of archeological provenance (N = 80). It was observed that for ramus flexure, male accuracy was only 66%, while female accuracy was even lower (32%). Overall accuracy was 59%. For gonial eversion, a similar picture emerged (75.4% for males, 45.2% for females and 69.3% overall accuracy). Both these indicators are affected by intra- as well as inter-observer bias.

With the development of multiple discriminant function analysis, formulae for various populations have been published taking into consideration various intercorrelated dimensions as well as the degree of difference between sexes.

4.5. Scapula

The scapula is not widely used for sex discrimination. However, a few studies are available. Iordanidis [39] has taken into account scapular height and breadth, total length of the spine and width of the glenoid cavity, calculated by upper and lower limit for discriminating between each sex (**Table 10**).

Traits	Male	Female
Scapular Height	>157	<144
Scapular Breadth	.106	<93
Total Length of spine	>141	<128
Width of glenoid cavity	>29	<26

Table 10.
Showing sex determination by scapula measurements (from Iordanidis [39]).

4.6. Clavicle

The clavicle is also used very rarely in the discrimination of sex from skeletal remains. However, recently a number of authors have show, interest in the clavicle for sex discrimination.

The costoclavicular (rhomboid) ligament joins the first rib anterior to the clavicle to give stability to the pectoral girdle. During this process, sometimes it leaves a depression known as the rhomboid fossa or tubercle or roughened impression, deep fossa or no trace at all. Rogers [40] found correlation with the rhomboid fossa and sex. If the rhomboid fossa is present on the clavicle, the clavicle is of male sex.

5. Conclusions

Forensic osteology is an important part of identification for the criminal justice system. In the past, we talked about morphological ways of sexing more then metric methods and now neural networking is coming for sexing. Further studies must be done so that we can enrich our knowledge.

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Conflict of interest

No conflict of interest is present.

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