Forensic Anthropology

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Abstract

Forensic Anthropology, a subdiscipline of Physical Anthropology, practices various methodological aspects for the welfare of society, especially for law and authority. In the modern era, medico-legal aspects use the old age features and concurrently realise the shift towards state-of-the-art. Forensic anthropologists, like other forensic professionals, share their knowledge and views and gather physical evidence for cadavers, associate pieces or matters and identify living ones. This chapter depicts the meaning, scope, and some application of forensic anthropology systematically. Here the growing concern of Forensic Anthropology is also discussed.

Keywords

Forensic anthropology · Forensic anthropologist · Human identification · Skeletal remains

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21.1 Introduction

Anthropology is the study of human kind in every space and time through applying knowledge for the welfare of humankind. Its holistic stance is unique as it studies about the bodily features, ecological behaviour/responses, societal aspects, historical occurrence, and cognitive aspects of human being, as well as treat human as whole; physically like a biological being and intellectually as a social creature (Kehoe 2013). Broadly speaking it gathers the evidence about variation, evolution and facts linked to the human and its society. Though an interdisciplinary science it synthesizes the knowledge with both theoretical and application perspective for the welfare of humanity. The term Anthropology came from the Greek words *'anthropos'* which means 'human' and the word *'logos'* which means 'thought' (Britannica 2021). Physiques of Anthropology are built with the platform of knowledge with different dimensions encircling a number of subjects and their tributaries. Its identity as a major discipline, can broadly be categorized into subsequent subdivisions or branches (Fig. 21.1).

21.2 Forensic Anthropology

As a sub discipline, Forensic Anthropology is classified under Physical or Biological anthropology. The American Board of Forensic Anthropology (ABFA) describes the discipline by the definition- 'the application of the science of physical or biological anthropology to the legal process' (American Board of Forensic Anthropology 2021). Forensic anthropology is an inter-disciplinary arena that pleats evidences of human remnants for the purpose of medico-legal exploration, especially for an

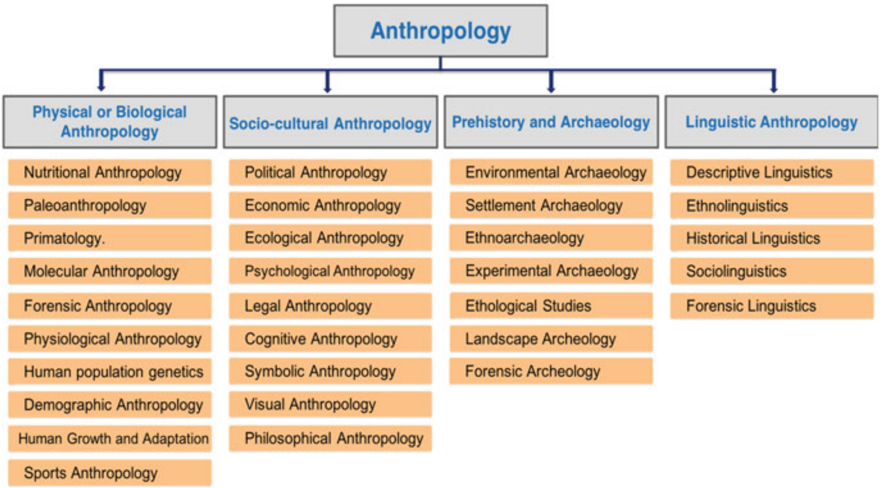

Fig. 21.1 Different specialized areas of study in Anthropology

identification perspective. From the goal point of view, forensic anthropology is a discipline comparable with forensic pathology and considered as more multidisciplinary (Cattaneo 2007). Similarly from the methodological point of view, the discipline of forensic anthropology enriches itself from different slants of biological anthropology, forensic sciences and medicine. Forensic anthropologists are professional experts in the skeletal morphology of human beings, proficient in human anatomy, osteoarchaeology, and in biological anthropology (OBE 2003). This multidisciplinary field working in corresponding with other disciplines like taphonomy, archaeology, anatomy, odontology, pathology, biology, osteology, entomology and botany (James and Nordby 2002).

21.2.1 Sub-Fields of Forensic Anthropology

The major sub-fields of Forensic Anthropology are mentioned in Fig. 21.2.

21.2.1.1 Forensic Osteology

Forensic Osteology is a sub-branch of forensic anthropology that deals with different issues like the facial reconstruction and superimposition, bone pathology, and archaeological investigations; provide evidences that either confirm, or support in determining the identity from the skeletal remains of an individual associated to different mysterious or natural death cases, a suicide, homicide victims, and remains of a mass disaster (Scheuer 2002). As, all the matters associated to the legal arena, levels of accuracy need to be greater than comparable to other disciplines. The word osteology is derived from the Greek words *"osteon"*, which means bone and *"logos",* which means knowledge. It is the scientific study including structure, function, development and variation of bones of the skeleton. Human Osteology focuses on the morphology of the human skeleton and incorporates information about the names, placement, visible features of bones and articulations of bones with other bones etc.

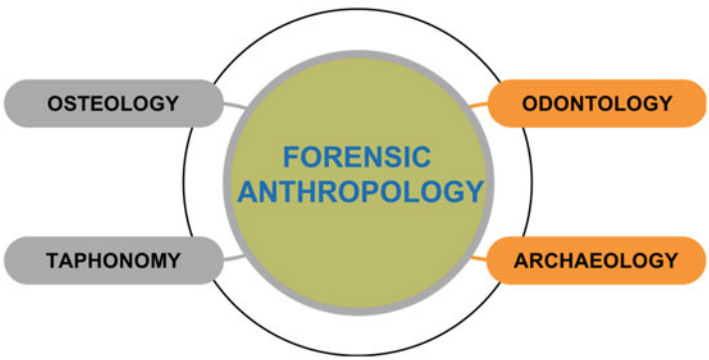

Fig. 21.2 Sub-fields of Forensic Anthropology

There is always a challenge for the forensic scientist in identification of deceased through their skeletal remains. Hence having knowledge of human osteology is important in positive identification of the individual from its skeletal remains. An expert forensic anthropologist identify a human skeleton as whole or in fragmentary remains. Skeletal remains are used for determining the demographic characters of the deceased including race, age, sex and stature. Study of human osteology also helps in understanding what is called normal in the human skeleton, and by knowing these standards, differences can be identified which help in positive identification of the deceased and also give information relating to the cause and manner of death.

21.2.1.2 Forensic Odontology

Forensic Odontology is the application of the science of dentistry in legal matters. The examination, assessment, management and demonstration of dental evidences are done by Forensic odontologists for civil or criminal proceedings for legal perspective (Avon 2004). Roughly speaking the sub-discipline alienated into 3 major fields based upon the activities, i.e. criminal, noncriminal or civil and research (Cameron et al. 1974; Neville et al. 2002). It is the science behind the practice of dentistry. Forensic odontology basically uses the science of dentistry to identify a person from the dental evidences left by him/her (i.e. bite marks, dental remains etc.).The forensic anthropologist is the first person to see the dental evidence, chart them, and report the evidence but for accurate results, the final analysis is done by an expert odontologist.

The importance of dental evidence in a forensic analysis is very high. The teeth have an outer layer of enamel that makes it the hardest and most durable substance of the human body. Hence they are highly resistant to physical and chemical influences such as high temperature, decomposition, desiccation, or long-term submersion in water etc. Having almost similar composition, teeth are more resilient then bones, thus sometimes dental evidences are the only human remains recovered from forensic scenes. Another important aspect is the pattern of dentition which is unique in every human being exactly like the fingerprints. This unique character of human dentition makes it important evidence when it comes to identification of a person. Apart from identification, dental evidence can also help in the determination of age, race and medical history of an individual.

21.2.1.3 Forensic Taphonomy

The word Taphonomy comes from the Greek word *"taphos"* which means burial or grave and *"anomy"* which means law. Taphonomy is a sub-field of forensic anthropology basically studied under the science of paleontology. The procedures linked with decay of cadaver are study in Forensic taphonomy (Tibbett and Carter 2009). Or it can be said that Forensic taphonomy is the study of the events (such as postmortem changes and interval, decomposition, mummification, saponification etc.) that happens to an organism after its death to the point of its recovery. The postmortem changes, decomposition of the body and the factors affecting such changes are studied in this discipline. Most of the changes occur to the body after death is due to natural factors such as temperature, plant, animals, soils, weather,

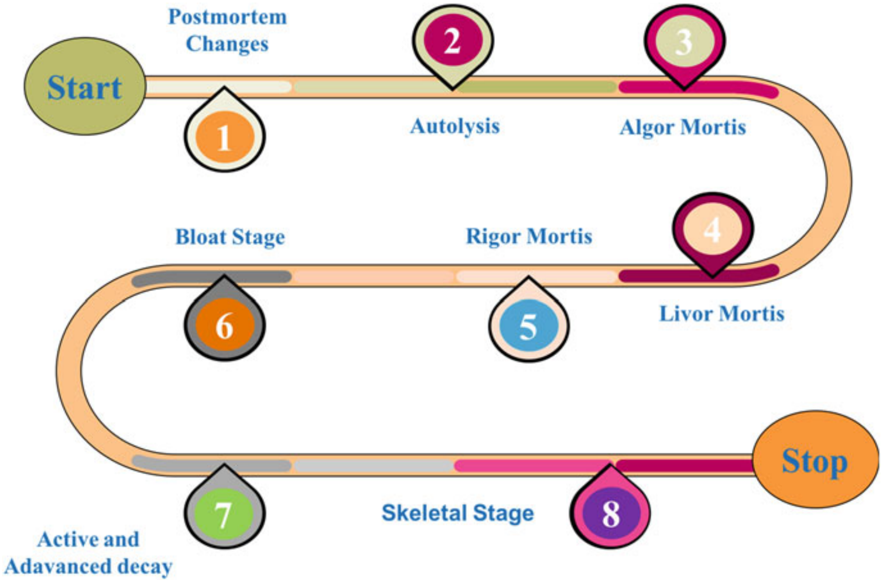

Fig. 21.3 Stages of Decomposition

gravity etc. Studying the specific role played by each of these natural factors is important in understanding and establishing the present state of the collected skeletal evidence. This also helps to focus on unusual patterns of dispersal or removal of evidence that indicates any human intervention (i.e. removing/moving remains to hide evidence). Taphonomy, on the basis of studying the condition of skeletal remains at the time of its recovery help to determine the circumstances surrounding the death, assessment of post-mortem interval and how long the body remains has been at the location of its recovery.

Taphonomy involves the study of all peri- and post-mortem processes including stages of decomposition mentioned below (Fig. 21.3).

The difficulties in estimating the postmortem interval (PMI) increase with the older human remnants. Particularly in the case of PMI the knowledge of forensic anthropologist is very limited, only confined to the dry bone; whether the bones belong to archaeological period, old, or very recent. It is a very difficult question for forensic anthropologists that 'time since death' is to be answered due to the lack of effective methods for the evaluation of the PMI. Even in some cases, it is impossible to say whether it is a forensic case or from earlier populations.

21.2.1.4 Forensic Archaeology

An essential set of methodologies in the discipline of Archaeology dealing with different buried remnants, evaluating and recording a graveyard and the close surrounding setting associated to them (Haglund 2001; Schmitt 2001; Tuller 2012; Wright et al. 2005). Forensic archaeology is placed at the juncture of various evidential regimes that articulate diverse and often contradictory prospects for different archaeological works (Crossland 2013). It is a sub-field of forensic anthropology in which archaeological theories and methods are applied to solve medicolegal issues. The Forensic Archaeologist uses various methods and techniques of archaeology in the investigation of a crime scene with the purpose to identify and reconstruct the crime scene. The major duties of a Forensic archaeologist are to assist in crime scene recovery and evidence collection that includes searching, locating, surveying, sampling, recording and interpreting relevant evidence, as well as the recovery and documentation of human remains and associated evidence.

The objective of Forensic archaeology is to properly investigate the crime scene using an archaeological approach. It includes selecting a precise detection or recovery strategy which will provide maximum data and evidence from the crime scene while minimizing the alterations of the scene and evidence. Another objective of Forensic archaeology is the proper recovery, systematic storage and recording of all evidences (such as human remains and associated materials) which helps in determining the manner of death, reconstructing the scene and identifying the post-depositional taphonomic processes and ultimately identifying the deceased. A proper chain of custody is to be maintained from point of recovery to accession by the appropriate agency. Diverse studies of the recent past have encouraged different new scenarios by the growth of forensic archaeology (Buchli and Lucas 2002).

21.3 Need of Forensic Anthropologist

Forensic anthropology has emerged extensively as an important field of study in last several decades. Different cases related to individual identification like the severely decayed body remnants, burned, maimed and disrupted are solved or assisted with the help of forensic anthropologist. Conventionally speaking the forensic anthropologist investigates the recovered human remnants to examine the bones associated with human or not, species recognition, time intervals from death and age at death, taphonomic history, sex, ancestry, height and not least to other sorts clues to identification and to spot the foul plays (Blau and Ubelaker 2016; Stewart 1951; Ubelaker 2018). The major concerning areas called upon the forensic anthropologist are the inquiries associated with criminal cases, like homicide, natural deaths with unknown causes, mass fatalities and different accidents; issues linked with non-criminal events i.e. numerous deaths in natural calamities; an inquiry into genocide and war crimes (Randolph-Quinney et al. 2011); estimate the age of a living individual related to immigration cases or asylum status and matter with legal accountability (Scheuer and Black 2007). As the present century expects a high perception of risks associated with mass fatality, accidents, terror outbreaks and different natural calamities (Thompson and Black 2006), which needs more methodological inventions and collaborations with forensic anthropologists. Different other methods like the techniques of facial approximation and/or photographic superimposition are used by the forensic anthropologists in different circumstances (Stephan 2016; Ubelaker 2015, 2018) for facial recognition. The expanded theoretical concept and their practicality in medico-legal field encourage the forensic anthropologist to solve issues like age determination and identification of living being (Black et al. 2010; Fenger et al. 1996; Sauer et al. 2012).

21.4 Historical Background: Development of the Forensic Anthropology as Discipline (World and India)

The field of Forensic Anthropology, which is an application of skeletal biology to medicolegal investigation, first emerged in the late eighteenth century in the European continent. Forensic anthropology is a relatively young subfield of biological anthropology, which is said to have its roots in the American continent during the nineteenth century. The development in the field of Forensic Anthropology majorly occurred in these two subcontinents. Academically the development of forensic anthropology rooted back to European centres of comparative anatomy closely linked to physical anthropology (Spencer 1982; Stewart 1979; Ubelaker 2009). Among key early scholars, Jeffries Wyman (1814–1874) known for forensic anthropology testimony (Ubelaker 2018) (Table 21.1).

21.5 What a Forensic Anthropologist Do

The ultimate aim is to establish or rebutting the personal identification with the confirmation through specifics knowledge of morphological characteristics, development and variation in human bodies (Randolph-Quinney et al. 2011). This is not a single task undertaken by the forensic anthropologist but must recognize the cause of the death along with the personal identification (Cattaneo 2007) wherever necessary. All these purpose are fulfilled with four elementary biological principles, i.e. biological sex determination, developmental or skeletal age estimation, assessment of living stature and establish the ethnic or racial affiliation (Klepinger 2006); followed by secondary examinations wherever applicable. The secondary investigation deals with identification of different macroscopic and microscopic marks like the trauma, scar marks, chronic pathological alterations in soft and hard tissue, modification found in human body and proof of surgical intercessions (Black and Thompson 2007; Clarkson and Schaefer 2007; Eugænia Cunha 2006). Broadly speaking the present day forensic anthropologist not only deal with the dead but also to identify and age approximation of a living one, hence become a crucial in medico-legal investigation.

Here we try to discuss the work of a forensic anthropologist with reference to explain three broad aspects, i.e. A. Identification/investigation associated with dead individuals/scattered remains and B. Identification/investigation associated with the living one C. New emerging trends in forensic anthropology.

Table 21.1 shows a timeline view of developments and personalities behind the major contribution to literature and developments in the field of Forensic Anthropology from world context

S. No.	Year/time	Personality/ organization/ region	Description of work	References
1	1684	François Bernier	François Bernier's ''new division of earth by the different species or races which inhabit it". Classified world population into 4 races-considered as first racial classification	Stuurman (2000)
2	17th centurt	J. Sigismund Elshwltz (1623–88 AD)	The word anthropometry was first used in the seventeenth century by him for his graduation thesis entitled "Authropometria"	Venkatachalam (2008)
3	1775–1899	European scholars	Foundation work related to forensic anthropology by estimation of living stature	Beddoe (1888), Manouvrier (1893), Orfila and Lesueur (1831), Pearson (1899), Rollet (1888), Sue (1755) and Topinard (1885)
4	1859	Paul Broca (1824–1880)	Founded world's first official organization of physical anthropology in Paris, the *"Société d'Anthropologie de Paris"*. Initiated study and training in comparative skeletal anatomy and developed instruments (e.g., the stereograph, osteometric board and goniometer) for the quantification of skeletal measurements	Sapweb (n.d.)
5	1878-1905	Dwight (1843 AD–1911 AD)	Father of American forensic anthropology. He published many literatures that build an initial foundation for forensic anthropology and skeletal biology	Stewart (1979b) and Dwight, (1878a, b, 1881, 1890a, b, 1894a, b, 1905)
6	1883	Alphonse Bertillon (1853–1914)	Known as Father of Criminal Identification, Devised a criminal identification system based on measurement of	Bertillon (1853–1914)

(continued)

Table 21.1 (continued)

S. No.	Year/time	Personality/ organization/ region	Description of work	References
			physical dimensions of the body such as arm, foot length etc. In 1884, Bertillon's Anthropometric Identification System which later called as Bertillonage is announced to be used in all of the french prisons and accepted as a popular criminal identification technique	
7	1897–1903	Wilder (1864 AD–1928 AD)	Trying to establish academic bridge between American and European scholar with respect to forensic anthropology. Published literature on dermatoglyphics and facial approximation techniques	Wilder (1897, 1902, 1903) and Ubelaker (2018)
8	1918	Wilder and Wentworth	Published manual on personal identification (fingerprint analysis and facial approximation)	Wilder and Wentworth (1918)
9	1924	N. Pan	An Indian anatomist was first to study the length of long bones and their proportions to body height in Indian population and observed that males have larger length of long bones as compared to females	Pan (1924)
10	1932	Ales Hrdlička	First attempt on cranial/ photograph comparison in a legal context was done	Ubelaker (1999)
11	1939	Krogman (1903–1987)	Published "guide to the identification of human skeletal material"	Krogman (1939)
12	1972	American Academy of forensic sciences (AAFS)	Newly section named "physical anthropology" was formed by AAFS	Pickering and Bach (2009)

(continued)

Table 21.1 (continued)

S. No.	Year/time	Personality/ organization/ region	Description of work	References
13	1989	Surinder Nath	Indian anthropologist published an book "an introduction to forensic anthropology"	Nath (1989)
14	2003	Establishment of forensic anthropological Society of Europe (FASE)	FASE was established as a subsection of the international academy of legal medicine	Forensic Anthropology Society of Europe (n.d.)
15	2005-2009	L'Abbe et al. Hunt and Albanese; Dayal et al.	World-wide skeletal collections from different geography and people	L'Abbe et al. (2005), Hunt and Albanese (2005) and Dayal et al. (2009)
16	2008	SWAGANTH establishment	Scientific working Group for Forensic Anthropology (SWGANTH), was formed under joint sponsorship of FBI laboratory and Department of Defense Identification Laboratory (DDIL) with the objective to develop and spread best practice guidelines and standards for forensic anthropological investigations	Forensic-Science Anthropology-Subcommittee (n.d.)

21.5.1 The Stages/Scenario of Forensic Human Identification Process Conducted by a Physical Anthropologist: A Brief View

21.5.1.1 Initial Assessment of Skeletons

Some are the general question arise after collection of Skeletal Evidence from different areas:

- Whether the collected evidence is a skeletal material (i.e. bone or tooth) or some other material?
- Whether the collected evidence belongs to human or non-human decedent?
- Whether the collected evidence belong to a single or more persons (i.e. what is the number of victims)?

21.5.1.1.1 Is the Evidence, Skeletal Material or Not?

Ans: For a forensic anthropologist, the determination of skeleton remains during evidence collection is not considered as easy in every cases. Identification of skeleton remains can be done on the basis of thorough visual examination of different morphological features. But sometimes it is difficult to recognize skeleton remains when the bones are found in fragments or due to taphonomic processes which may degenerate the recognizable morphological features of the bones. Also in cases of burning, especially within a confined space (e.g. house fires) it is difficult to distinguish skeleton material from other materials (such as wood, plastic, mineral, shell or metal) due to intermixing of bone fragments with other burned materials (such as furniture, appliances, building material etc.).

In cases where the determination of skeleton material is not possible by thorough visual examination following techniques could be used,

- **Radiography:** Skeleton remains due to their high mineral content are more radiopaque, which can differentiate them from commonly encountered non-mineralized materials.
- **Microscopic Analysis**: Using a high magnification microscope identification of skeleton material can be done by locating microstructures such as trabecular bone, Haversian system, layers of bones etc.
- **Elemental Analysis:** Most accurate but destructive technique. Skeleton remains can be identified by their elemental analysis using techniques like SEM/EDS, XRF(non-destructive analysis).
- **Alternative Light Source (ALS):** Due to the fluorescence property of the collagen protein of the bones, identification of the bones can be done using a short wavelength alternate light source.

21.5.1.1.2 Is the Skeletal Evidence Belongs to Human Skeleton or Not?

Ans: After identification of the collected evidence as skeleton material the next question arises is what the origin is? Is it belonging to a human or some other animal? Again answering such questions is easy for an expert anthropologist on the basis of gross visual examination of the morphological features. Due to differences in locomotion, growth and development, there are numerous differences exist between a human and animal skeleton (Table 21.2). But, certain taxa may be difficult to discriminate because of resemblances in structure, size, or quality; particularly the mammalian species such as cows, bears, deer, large dogs and pigs (Randolph-Quinney et al. 2011). But still certain exceptions are there where some animal bones resemble to humans and hence difficulty arises in differentiation (Table 21.3). Another problem in differentiation comes when scattered/ fragments of bones are found which lack the presence of diagnostic morphology.

Determination of origin of the skeleton (i.e. human or non-human) can be assessed by following methods:

- **Macroscopic Method**: Includes visual and radiographic examination of the skeleton, with attention to the shape, size as well as stage of growth and development of the skeleton. E.g. at macrostructural level cancellous bone of

Table 21.2 Differences between human and non-human skeleton

Bone	Human	Non-human
Skull	Rounded, globular, non-projecting face, anterior foramen magnum	Elongated front to back, projecting snout, posterior foramen magnum
Vertebral column	S-shaped curve, bifurcated spinous process in cervical vertebrae, sharp, point inferior in thoracic vertebrae	Little variation in vertebrae size, some have elongated spinous process which forms shoulder hump
Thorax	Broad and shallow, high degree of curvature, well defined costal groove on internal and inferior aspect of human ribs	Narrow and deeper, costal grooves are absent in non-human mammalian skeleton
Pectoral girdle	Clavicle is elongated, scapula is triangular and elongated supero-inferiorly	Clavicle is reduced or absent, scapula is longest Medio-laterally
Pelvic girdle	Pelvis is wide and broad, illium is short and flaring,	Narrow and elongated illium, pelvis is fused along pubic symphysis
Long bones	Long bones are more gracile and smoother, less complex joint surface, rounded and large femoral and humoral heads	More defined morphology of non-human mammal joint surfaces, smaller size of head of femur and humerus

Table 21.3 Bones of human and non-human origin that resembles each other

Non-human bone	Human bone
Raccoon baculum (penis bone)	Clavicle bone (young child)
Long bones of the birds	Metacarpals/metatarsals (adult), long bones (infant)
Tortoise carapace (dorsal shell) and plastron (ventral shell)	Cranial bone (infant or child)
Bones of Hindpaw of bear	Bones of human foot

non-human origin is more homogeneously distributed then the bone of human origin.

- **Microscopic or Histologic Method**: Such method help in case of burned, fragmented or weathered bones. In these methods microscopy (Cuijpers 2006) is used to compare the microstructures of the bones. E.g. at microstructural level human bones contain Haversian system of arrangement (i.e. concentric rings oriented around the long axis of the bone) whereas non-human bones are arranged in more linear form (i.e. non-Haversian system).
- **Biochemical/immunological Method**: Includes protein based methods (e.g. protein based RIA and solid-phase double antibody RIA) (Lowenstein et al. 2006; Ubelaker et al. 2004) where protein is extracted from bone's organic matter and combined with rabbit antisera pre-exposed with sera of selected animal species (e.g. human, bear, goat, dog etc.). Species-specific antibodies are then combined with protein-antisera and show precipitin reaction and thus species can be determined.
- **DNA Analysis**: This method gives the most accurate result (Guglich et al. 1994) but is comprised of a complex procedure and also not so economical and hence is

used when other methods are not effective. mtDNA cyt-b gene (the specific coding regions) is also useful for taxa differentiation (Linacre and Lee 2016; Matsuda et al. 2005).

21.5.1.1.3 Is the Skeletal Evidence Belongs to a Single or More Persons?

Ans: Once the origin of the skeletal material is determined, the next problem that a Forensic anthropologist faces is the determination of the number of deceased from whom the skeletal material comes from or in other words identifying the number of victims. The process of identifying the number of individuals from the commingled skeletal remains is called the determination of a minimum number of individuals (MNI). The process involves the following steps.

- The first step of analysis involves the arrangement of collected skeletal remains or fragments in anatomical order (i.e. arrange remains into left side and right side elements into complete skeleton).
- The next step is identifying duplicates or duplicating segments of bone. E.g. if two right femur bones are present it means the remains belong to two individuals as no single human has two right femur bones.
- Differentiation can also be made by visual analysis of the remains by checking the size of the elements with each other. E.g. if two complete femur bones are identified, both are different in size. Then it's indicative of the presence of more than one person.
- Another way of segregation between remains is done by checking the compatibility of the bones with each other on the basis of age, sex, robusticity, or configuration.

In 2001, a formula was developed to determine the probable number of individuals (PNI) from commingled skeletal remains by West and Giles (Klepinger 2006). They create the formula by taking the Lincoln Index approach in mind.

$$\mathrm{PNI} = (R \times L)/P$$

where 'R' = Number of right side elements, 'L' = Number of left side elements and 'P' = Number of matched pair of elements.

Formula for small samples and small number of pairs:

$$\mathrm{PNI} = (L + 1)(R + 1)/(P + 1) - 1$$

Formula if no right-left pairs are found:

$$\mathrm{PNI} = (R + 1)(L + 1)$$

Besides this, other new methodologies, like the use of pair-wise maximum likelihood models, recording of distinct anatomical sutures, DNA analysis and Geographical Information System (GIS) -based statistical models will be useful to mentioned above matter (Adams and Byrd 2006; Adams and Konigsberg 2004, 2008; Outram et al. 2005).

21.6 Determination of Demographic Characteristics

Forensic anthropologists have an important role to provide enough information regarding the human skeletal remains. The law enforcement agency by using that information and matching it with a missing persons file, can lead to a positive identification of a person. The information or data required for positive identification of individual from skeletal remains include determination of the four principle components that together makes up the biological profile of an individual. These basic demographics are

1. Ancestry.
2. Sex.
3. Age.
4. Stature.

This text provides in depth knowledge regarding determination of the above mentioned components of the biological profile which leads to the positive identification of an individual from its skeletal remains.

21.6.1 Determination of Ancestry

Classification of a population is done on the basis of geographical region of origin. People of different geographic location have significant morphological as well as cultural differences between them and it is due to the climate and environment where they lived for ages. People get these different morphological traits from their ancestors. These ancestral traits provide a means to classify people for identification purposes in forensic anthropology. Groups of physical traits differ in frequency from one major region of the world to another and help to determine ancestry. Variation in genotype and phenotypic characters among human population group are shaped by the geography and culture (Klepinger 2006). The genetic variation among inter-individuals inside a population account for about 93–95% of and that differences between major population groups (inter-population) account for only 3–5% (Rosenberg et al. 2002).

Forensic Anthropologist, tend to classify individuals into three major groups:

1. **Caucasoid:** It includes Europeans, inhabitants of South-Western Asia and North Africa.
2. **Mongoloid:** It includes rest of inhabitants of Asia (i.e. Chinese, Japanese, and Koreans etc.).
3. **Negroid:** It includes rest of inhabitants of the continent of Africa.

Ancestry can be traced by different indicators, which are discussed below.

21.6.1.1 Skeletal Indicators

Racial/ancestral association in forensic investigation are conceded out using metric and morphological methods both, on the cranial and postcranial skeletons (Barker et al. 2008; Craig 1995; Gilbert 1976; St Hoyme and Iscan 1989; Walker 2005). The differences are associated to the morphology of the human skeleton as well and hence classifying an individual on the basis of these morphological variations at the skeletal level plays an important role in the identification of individual's ancestry. The variations can be studied under following types:

(a) **Nonmetric Variation in Skeletal Morphology**: It includes morphological variation in various part of the skeleton (i.e. skull, dentition, postcranial bones etc.) that can be visually identified. Table 21.4 shows Non-metric racial traits.

Table 21.4 Morphological variations in skeleton of different race

Elements of difference	Caucasoid	Mongoloid	Negroid
Skull			
Facial profile	Orthognathic	Orthognathic	Prognathic
Nasal spine	Large, long	Medium, tilted	Little or none
Nasal aperture	Narrow, elongated	Medium, rounded	Broad
Nasal sill	Single, sharp	Single, sharp	Double, guttered
Skull shape	Rounded	Square	Narrow, elongated
Forehead	Raised	Inclined	Small, compressed
Orbits	Triangular	Small, round	Square
Palatal shape	Parabolic, triangular	Elliptical, rounded	U-shaped, square
Palatal suture	Not straight	Straight	Not straight
Cranial sutures	Simple	Complex	Simple
Chin	Square, projecting	Blunt	Retreating
Skull length	Short	Long	Long
Skull breadth	Broad	Board	Narrow
Skull height	High	Middle	Low
Sagittal contour	Arched	Arched	Flat
Dentition			
Maxillary incisors	Blade shaped	Shovel shaped	Blade shaped
Maxillary molars	Carabelli's cusp	Simple, 4 cusps	Simple, 4 cusps
Dentition	Crowded	Not crowded	Not crowded
Postcranial bones (femur)			
Anterior curvature	More curved	Straight	Straight
Proximal diaphysis shape	Round	Anteroposterior flattening	Round
Intercondylar notch depth	Shallow	Undetermined	Deep

Table 21.5 Metric indexes to differentiate between skeleton of various races

Index	Formula	Caucasoid	Mongoloid	Negroid
Cephalic index (CI)	(maximum transverse breadth of skull)/(maximum anteroposterior length of skull) × 100	75–79.99	80–84.99	70–74.99
Skull height index (HI)	(height of the skull)/(length of the skull) × 100	71	75	72
Nasal index (NI)	(width of nasal aperture)/(height of nasal aperture) × 100	46	50	55
Brachial index	(length of radius)/(length of Humerus) × 100	74.5	–	78.5
Crural index	(length of tibia)/(length of femur) × 100	83.3	86.5 (Indians)	86.2
Humero-femoral index	(length of Humerus)/(length of femur) × 100	69	–	72.4
Intermembral index	(length of Humerus + radius)/(length of femur + tibia) × 100	More than 72	–	Less than 70.5

Other than the above-mentioned variation, few differences are also there such as,

- Mongoloids have the largest teeth among the three races.
- Third upper molar is absent in Mongoloids.
- Mongoloids have an extra tubercle on mandibular premolars (i.e. Dens Evaginatus).
- Negroids have extra lingual cusp in the mandibular molars (i.e. Tuberculum intermedium).
- Mongoloids have long pointed canines and also have a condition of Taurodontism (i.e. Bull tooth).
- Caucasoid population has a small additional cusp at the mesiopalatal line angle of maxillary molars (i.e. Carabelli's cusp).

(b) **Metric Variation in Skeletal Morphology**: Metric variations are the differences related to measurements. People of different races have different body measurements (i.e. height, length, breadth and width) using these variations multiple indexes (i.e. cephalic index, brachial index, nasal index etc.) are formed which help to differentiate between races of individuals. Some of the indexes use to differentiate between races along with their formula and approximate values are mentioned in (Table 21.5).

Skull can be classified into three categories on the basis of Cephalic Index,

1. **Dolicho-cephalic:** When the CI is 70–74.99, then they are long, narrow-headed person or dolichocranic. E.g. Negroid, Aborigines, Aryans etc.
2. **Mesati-cephalic:** When the CI is 75–79.99, then they are medium or average headed person or mesocranic. E.g. Caucasoid, Indians etc.

3. **Brachy-cephalic:** When the CI is 80–84.99, then they are short, broad, round headed person or brachycranic. E.g. Mongoloids.

Below the Table 21.5 shows various indexes related to person of different racial backgrounds.

21.6.1.2 Cultural Indicators

The forensic anthropologist always seeks for the cultural indicators associated with the body remains of also with living individuals and connect them to their ancestry/ race. These indicators are the customs, jewelleries, different body modification (as that practises by specified groups all over the world) and materials with religious significances. E.g. hole in ear lobe is common among adult Brahmins and Kshatriyas in Hindu community. Other cultural Modification marks are imprinted on skin includes permanent and semipermanent tattoos, cutting marks, beads and rings implant sub-dermally and piercing trans-dermally respectively and also scarifications has significance potentiality for personal identification purpose. Also surgical inventions or modifications were performed as a part of cultural or religious/ aesthetic and cosmetic purpose either by trained medical practitioner or by non-medically trained persons. E.g. penis circumcision by the Jews and Muslims all over the world. These kind of crucial indicators are comparable to different ethnic groups of different geography during the legal investigation. The major issues/ drawbacks associated to these practises are seen due to the availability of these crucial witnesses due to preservation point of view. Also in present globalised world the modern lifestyle promote/distribute different ethnic wears and practises among the natives, hence creates misconception to the investigation agency if they found any such evidences.

21.6.1.3 Molecular Indicators

With the advancement in DNA based identification methods, allows forensic anthropologist to adopt such techniques where the traditional methods (osteological investigation) are not suited to identification confirmation of evidential remains. The cases like the identification of mass disaster victims, totally burnt individuals with limited body residues fragmented body parts of skeletons and ancestry of an orphan can be solved by DNA analysis. The drawback is associated with the biological samples, which immediately start the degradation after the death of an individuals. To compare the ancestry a proper sophisticated DNA data base is needed, which now lacks to even in different developed nations.

21.6.1.4 Somatoscopic Indicators

These indicators are different somatic features that can be seen to the naked eyes. Those are the skin tone type, eye-fold pattern, hair pattern and colour etc. These characters helps the physical anthropologist to trace the ancestry to the respective family or with an ethnic group or to conclude in personal identification.

21.6.2 Determination of Sex

After estimation of ancestry of an unidentified skeleton the next step is the determination of its sex. The skeleton remains serves best in the estimation of sex until most of the bones are available for analysis. Sexual dimorphism or expression of phenotypic differences between male and female of the same species have the ability to differentiate between male and female skeleton. Due to this condition of sexual dimorphism male and female skeleton have prominent morphological differences (i.e. in size and architecture).

Estimation of sex from bone morphology is not so reliable in immature skeletal cases, where the molecular analysis, i.e. amelogenin marker testing consider as reliable alternative irrespective of age and where the skeletal remains are fragmentary or incomplete (Baker 2016; Ostrofsky and Churchill 2015; Ubelaker 2019). Sex is an important component of the biological profile of a missing person. In most of the cases the sex can be reliably estimated from pelvis and found difficult in cases where the pelvis is damaged or completely absent (Abdel Fatah et al. 2014; Michel et al. 2015). Different researches established substantial population variation in appearance of sexual dimorphism seen in human skeleton (Brzobohatá et al. 2015), and published literature for specific data based on the sex differences (Spradley et al. 2015).

In general speaking, an adult male human skeleton is larger in size and more strongly built than female skeleton. The difference in size between male and female skeleton is about 8% i.e. female skeleton is about 92% the size of male skeleton. Male skeleton exceeds the female skeleton in height, weight and breadth. The bones of male skeleton are longer, thicker and have more prominent attachment of muscles. On the other hand the architecture of both male and female skeleton also varies greatly. One of the reason of difference in architecture is that female gave birth due to which they have wider pelvis (i.e. to accommodate passage of infants) than males of comparable size.

A forensic anthropologist, classify two categories of methods to differentiate between male and female skeleton,

Non-metric (microscopic or visual analysis) Methods**,** involve examination of morphological features of bones that vary between male and female (i.e. pelvis, skull, long bones etc.). These methods are more accurate to identify the sex of the skeleton. The entire skeleton can be used to assess the sex, but some of the major bones like skull, pelvis, long bones play major role in establishment of sex because they show prominent difference in male and female skeleton. Table 21.6 shows accuracy of sex determination based on skeletal remains.

According to the above data, pelvis is the best single bone which gives 95% accuracy in sex determination. Table 21.7 shows features of pelvis that are diagnostic of sex.

After pelvis, another sex differentiating bone is the skull that gives around 92% accuracy in sex estimation. Table 21.8 shows various differentiating feature of male and female skull.

Table 21.6 Accuracy in sex determination based on skeletal remains

Skeletal remains	Accuracy in sex determination
Pelvis	95%
Skull	92%
Long bones	80–85%
Skull + pelvis	98%
Long bones + pelvis	98%
Entire skeleton	100%

Table 21.7 Differentiating features of male and female pelvis

Features	Male pelvis	Female pelvis
General appearance	Massive, rougher, prominent muscular markings	Less massive, slender, smoother, muscular markings are not prominent
Shape	Deep funnel	Flat bowl
Body of pubis	Narrow, triangular	Broad, square, pits on posterior surface
Acetabulam	Large (52 mm diameter), more forwardly directed	Small (46 mm diameter), more laterally directed
Preauricular sulcus	Generally absent, if present narrow, shallow	Better developed, broad, deep
Iliac auricular surface	That is not elevated from the surrounding bone	That partially or completely elevated
Ischio-pubic ramus	Broader and less everted	Sharp, often everted with ridge
Greater sciatic notch	Deep, small, narrow	Shallow, large, wide
Obturator foramen	Large, oval, base upwards	Small, triangular, apex forwards
Ischial tuberosity	Inverted	Everted
Ilium	High and vertical	Low and flaring
Subpubic angle	V-shaped, sharp angle (70^0–75^0)	U-shaped, rounded, broader angle (90^0–100^0)
Pelvic inlet	Heart shaped	Circular or elliptical shaped
Pelvic outlet	Smaller	Larger
Pelvic cavity	Conical, funnel shaped	Broad, round
Subpubic contour	Straight	Concave
Auricular surface	Raised	Flat

Other bones such as mandible, sacrum, scapula, clavicle, long bones (i.e. humerus, radius, ulna, femur, tibia) also have differentiating features in male and female skeleton that can also be used for the assessment of sex from the skeletal remains.

Metric Methods**,** involve estimation of sex on the basis of measurement of bone lengths, width and breadth. Table 21.9 contains certain indexes that tell about the sex from the skeletal remains.

Table 21.8 Differentiating features of male and female skull

Features	Male skull	Female skull
General appearance	Large, heavy, rugged, marked muscular ridges	Small, light, thin walls, smooth
Forehead	More retreating, irregular, rough, less rounded	Vertical, rounded, full, infantile, smooth
Mastoid process	Large, round, blunt	Small, smooth, pointed
Cranial capacity	1450–1550 cc	1300–1350 cc
Orbits	Square, small	Rounded, large
Frontal and parietal eminence	Less prominent	Prominent
Zygomatic arch	Prominent	Not prominent
Supraorbital ridges	Thick, rounded, more pronounced	Sharp and less pronounced
Suprameatal crest	Present (extends)	Absent (no extension)
Nasal aperture	High, thin,sharp margins	Lower, wider, rounded margins
Palate	Large, U-shaped, broad	Small, parabolic
Foramen magnum	Relatively large, long	Small, round
Mental eminence	Large projection	Small or no projection
Glabella	Prominent	Less prominent

Table 21.9 Diagnostic Indexes for determination of sex

Index	Formula	Average value in male	Average value in female
Ischiopubic index	Length of pubis/length of ischium × 100	73–94 (average 75)	91–115 (average 100)
Sciatic notch index	Width of sciatic notch/depth of sciatic notch × 100	145	166
Sternal index	Length of manubrium/length of body × 100	46.2	54.3
Chilotic line index	Sacral part of chilotic line/pelvic part of chilotic line × 100	More than 100	Less than 100
Sacral index	Transverse diameter of base of sacrum/ anterior length of sacrum × 100	Less than 114	More than 114
Kimura's base wing index (alar index)	Width of wing (ala of sacrum)/width of base (transverse diameter of body of S1) × 100	65	80
Corporobasal index	Breadth of body of first sacral vertebra/ breadth of base of sacrum × 100	More than 42	Less than 42

21.6.3 Determination of Age/Age at Death

Human skeleton can also be used to estimate the age of the deceased at the time of death. In case of unidentified skeletal remains, once the age is determined, the law enforcement agency can narrow down their search and this information will limit the pool of potential matches with missing individuals and identification of the individual can be done.

Forensic anthropologist can determine the age from skeletal remains by in-depth understanding of the nature, sequence and timing of skeletal changes throughout a lifetime. A Forensic anthropologist provides the estimated age in a range, because there is no method or clue present which allows the determination of exact age from the skeletal remain. The age range will be narrow (i.e. 1–3 years) in case of younger person (i.e. 15–25 years) and will widen (i.e. 5–10 years) as the age of the person increases or in case of an older (i.e. 40 years and above) person. The most accurate age determination is done for infants and children.

Until the sub-adult age (i.e. from infant to children to adolescents) there are many biological changes going on the body including in the bones that are occurring at regular times and rates and hence estimation of age in subadults is quite precise (i.e. Age range is narrower). At the age of biological maturity the number and rate of developmental changes in the body decreases as during this age (25–35 years) the body is in maintenance phase. After the age of 40 years, the developmental change ceases. Estimation of age in adults (i.e 40 years and above) are based basically on the degenerative changes (i.e. breakdown, wear and tear of skeleton) that vary person to person and hence age range is broader (i.e. 5–10 years) in adults as compared to subadults (i.e. 1–3 years).

Determination of Age from skeletal remains in subadults, depends upon growing characteristics of the bones and teeth whereas in adults (i.e. 40 years or more) it depends upon the degenerative changes in the bones. The features that are used to establish the age from skeletal remains are mentioned below,

21.6.3.1 Determination of Age from Dentition

Age of an individual can be determined from its dentition. The stages of dental development (i.e. formation, mineralization, and eruption of the deciduous and permanent dentition) are the most relevant processes for age estimation. Eruption of teeth and dental ageing are said to be the most precise method of age estimation upto the juvenile period (i.e. 15 years) because dental development starts early in the sixth fetal week and does not complete until the early adulthood. Tables 21.10 and 21.11 shows time of eruption of deciduous and permanent dentition respectively.

Period of mixed dentition, is the time when both the deciduous and permanent teeth are present in the jaw and this is the most informative period for determination of the age, usually it is between 6–11 years, but may persist until 12–13 years. Table 21.12 represents the number of teeth with age.

By following the information given in Table 21.9, estimation of age can be done on the basis of presence of different numbers and types of teeth in the dental evidence of the skeletal remains.

Other methods of estimation of age from dental evidence include,

1. **Stack's Method:** This method helps in estimating the age of the fetus and infants from the weight of erupting teeth. Stack derived a regression line of weight of

Table 21.10 Eruption time of deciduous teeth

S. No.	Tooth	Eruption time	No. of teeth
1.	*Central incisor*		
	• Lower	6–8 months	2
	• Upper	7–9 months	4
2.	*Lateral incisor*		
	• Upper	7–9 months	6
	• Lower	10–12 months	8
3.	First molar	12–14 months	12
4.	Canine	17–18 months	16
5.	Second molar	20–30 months	20

Table 21.11 Eruption time of permanent teeth

S. No.	Tooth	Eruption time	No. of teeth	
			Permanent	Deciduous
1.	First molar	6–7 years	4	20
2.	Central incisor	6–8 years	8	16
3.	Lateral incisor	8–9 years	12	12
4.	First pre-molar	9–10 years	16	8
5.	Second pre-molar	10–11 years	20	4
6.	Canine	11–12 years	24	0
7.	Second molar	12–14 years	28	0
8.	Third molar	17–25 years	32	0

Table 21.12 Number and types of teeth present at various age

Age (in years)	No. of teeth	Type of teeth
2–5	20	All deciduous
6	21–24	20 deciduous, 1–4 first permanent molars
7–9	24	12 permanent—8 incisors, 4 molars 12 deciduous—8 molars, 4 canines
10	24	16 permanent—8 incisors, 4 molars, 4 premolars 8 deciduous—4 second molars, 4 canines
11	24	20 permanent—8 incisors, 4 molars, 8 premolars 4 deciduous—4 canines
12–14	25–28	Eruption of second permanent molars
14–17	28	All permanent
17–25	29–32	Eruption of third permanent molars

growing dental tissues with respect to age. Table 21.13 shows the weight of dental tissues with respect to age.

2. **Boyde's Method:** This method is basically used to determine the age of dead infants. This method estimates the age of the dead infant on the basis of counting the number of cross striations (i.e. incremental lines) in the enamel of the teeth.
3. **Gustafson's Method:** A method for estimation of age between 25–60 years using dental evidence. By microscopically examining the physiological age changes

Table 21.13 Weight of dental tissue with respect to age

Age (in weeks)	Sum of teeth weight (in mg)
28 (prenatal)	60
40 (prenatal)	460
2 (postnatal)	530
30 (postnatal)	1840

(i.e. wear and tear) in each of the dental tissue, age of an individual is determined. This method is useful in determining the age from a dead body or skeletal remains because the methodology requires extraction of tooth from the jaw. After extraction, the longitudinal section of central part of the tooth is taken for assessing following physiological changes,

(a) Secondary dentin.
(b) Cementum Apposition.
(c) Root Resorption.
(d) Attrition.
(e) Periodontosis.
(f) Root transparency.

By assessing the above given changes, age of the deceased is determined (Table 21.14).

1. **Miles Method:** He derived a method of estimation of age at death from the dental remains. The method involves measuring the thickness of enamel and dentin from neonatal line and divided it by appropriate daily rate of formation.
2. **Radiocarbon Analysis of Tooth enamel:** On the basis of levels of radiocarbon present in tooth enamel, the year of tooth formation can be determined.
3. **Chemical Analysis:** Chemical methods are also useful for determination of age from skeletal remains. These methods are destructive but can produce precise results. Some of the chemical method includes,
   (a) **Estimation of Nitrogen content in tooth enamel** (Increase with age).
   (b) **Estimation of Carbonate content** (Decreases with age).
   (c) **Estimation of Copper, selenium, lead and iron ions** (Increases with age).
   (d) **Amino Acid Racemization:** Most reliable destructive method for dental age estimation. With age the L-form of amino acid transformed to D-form by racemization. By estimation of extent of racemization of amino acid in the tooth enamel and crown dentin, age can be estimated. Out of all amino acid Aspartic acid has one of the fastest racemization and hence used to estimate age from dental tissues.

21.6.3.2 Determination of Age from Ossification of Bones

Ossification is the process where soft bone tissues become hard and calcified. The process of ossification starts around the sixth and seventh week of embryonic development and continues until 25 years of age (except in case of ossification of

Table 21.14 Ossification of bones with age in human male

Bone	Ossification centres	Age of appearance of ossification	Age of complete ossification
1. Sternum	Manubrium	5th month of IUL	60–70 years
	1st sternebrae	5th month of IUL	14–25 years
	Second and third sternebrae	7th month of IUL	14–25 years
	4th sternbrae	10th month of IUL	14–25 years
	Xiphisternum	3rd year (after birth)	40–45 years
2. Clavicle	Medial end	15–17 years	20–22 years
3. Scapula	Coracoid base	10–11 years	14–15 years
4. Hyiod	Greater cornu	–	40–60 years
5. Sacrum	–	–	20–25 years
Upper limb	Head	1 year	Conjoint epiphysis in three bones at age of 5–6 years and union with shaft at 17–18 years.
6. Humerus	Greater tubercle	3 years	
	Lesser tubercle	5 years	
	Capitulum	1 year	At 14–15 years, all three fuses with the shaft.
	Trochlea	9–10 years	
	Lateral epicondyle	10–11 years	
	Medial epicondyle	5–6 years	16 years
7. Radius	Upper end	5–6 years	15–17 years
	Lower end	1–2 years	17–19 years
8. Ulna	Upper end	8–9 years	15–17 years
	Lower end	5–6 years	17–19 years
9. Carpals	Capitate	At birth	2 month
	Hamate	3 month	14–16 years
	Triquetrum	3 years	6–7 years
	Lunate	4 years	6–7 years
	Scaphoid	4 years	5 years
	Trapezium	4–5 years	6 years
	Trapezoid	5 years	7 years
	Pisiform	9–12 years	–
Lower limb	Ischiopubic rami	–	7 years

Table 21.14 (continued)

Bone	Ossification centres	Age of appearance of ossification	Age of complete ossification
10. Hip bone	Triradiate cartilage	–	12–14 years
	Iliac crest	15–16 years	19–21 years
	Ischial tuberosity	16–17 years	20–22 years
11. Femur	Head	1 year	17–18 years
	Greater trochanter	4 years	14–15 years
	Lesser trochanter	14 years	15–17 years
	Lower end	At birth	17–18 years
12. Tibia	Upper end	At birth	17–18 years
	Lower end	1 year	16–17 years
13. Fibula	Upper end	4 years	17–18 years
	Lower end	2 years	16–17 years
14. Tarsals	Calcaneum	5th month of IUL	17–18 years
	Talus	7th month of IUL	–
	Cuboid	9th month of IUL	–

cranial sutures, sternum and hyoid bone). Ossification starts centrally in an epiphysis and spread peripherally. The centre of ossification in most of the bones appears during the seventh to 12th week of embryonic development. At about 11th to 12th week of embryonic development there are around 806 centres of ossification which decreases to 450 during the birth. The disappearance of ossification centres shows that ossification centres unites with adjacent centres and forms an adult bone and finally an adult human skeleton consists of 206 bones.

Ossification of bones is a relevant method to estimate the age in the subadults as this process continues until the age of 25 years. Table 21.16 shows the age at which these ossification centres appear and unite to complete the ossification in a human male. In females the union of epiphyses occurs 1 year earlier.

Fusion of joints can also be used for age estimation before 25 years of age, because all the joint get fused in 25 years. Table 21.15 shows the approximate age of fusion of various joints.

21.6.4 Determination of Age from Skull Suture Closure

The human skull is not a single bone but it is composed of several major bones which are joined together with the help of fibrous joints known as the suture. These sutures help the skull bones in movement during the birth process and act as expansion joints. Closure of cranial sutures is said to be a reliable method of age estimation

Table 21.15 Age of fusion of various joints

Joint	Approximate age of fusion
Elbow joint	16 years
Ankle joint	16–17 years
Hip joint	17–18 years
Shoulder joint	18 years
Knee joint	18 years
Wrist joint	18 years

Table 21.16 Closure age of various sutures of the skull

Suture	Age of closure
Posterior Fontanelle (occipital)	At birth to 6 months
Anterior Fontanelle (bregma)	1 ½–2 years
Two halves of mendible	1–2 years
Metopic suture (between frontal bones)	2–4 years, may extend to 6 years or remain unfused
Bassiocciput and basisphenoid	18–20 years in female, 20–22 years in male
Coronal suture (between frontal and parietal bones)	Lower half in 40–50 years, upper half in 50–60 years
Lambdoid suture (between occipital and parietal bones)	45–50 years
Sagittal suture (between right and left parietals) Posterior one third in 30–40 years, anterior one third in 40–50 years, middle part in 50–60 years	
Parieto-temporal	60–70 years

between 25–40 years of age. The human skull contains sutures on the inner and outer surfaces known as **endocranial** and **ectocranial** sutures respectively. Closure of sutures on the outer surface (i.e ectocranial sutures) is useful in estimation of age at death whereas the inner sutures (i.e. endocranial sutures) are said to give a rough estimate of age at death. Closure of endocranial sutures begin 5–10 years earlier than the ectocranial sutures. The palate also contains sutures known as the palatal sutures which are also used in age estimation. Table 21.16 shows the ages at which different sutures closes.

The above given information is utilized to estimate the age at death and the most precise age estimation is done from sagittal suture followed by lambdoid suture and then from coronal suture. Closure of all sutures indicates that the age is above 60 years.

Other method of age estimation from skeletal remains include,

21.6.5 Determination of Age Based on Changes in Pubic Symphyseal Surface

The pubic symphyseal surface starts changing from 18 years of age. This surface at young age is an undulating surface, at 25–40 years the surface become granular and become eroded around 60 years. These alterations in the pubic symphyseal surface with ageing are the best single criteria to determine the age at death for the individuals of 30—50 years of age.

21.6.6 Determination of Age Based on Changes in Morphology of Mendible

Morphological features of the mendible bone can be utilized to estimate a rough outline regarding the age group (i.e. infant, adult and oldage) of the individual. Mendible bone's morphology changes with time like the body is shallow at infancy which become thick and long during the adulthood and in old age again become shallow. The angle of Ramus with the body is obtuse (about 140°) at infancy which become less obtuse during adulthood and again become obtuse at oldage. The mental foramen moves towards the alveolar margin with age.

21.6.7 Determination of Stature from Skeletal Remains

From the four principle components of a person's biological profile or demographics (i.e. ancestry, sex, age, stature) stature is the fourth component of importance. Estimation of stature along with other demographics from the skeletal remains will help the law enforcement agency to identify the person. The word stature is derived from Latin word "*statura*" which means height or size of the body and the Latin verb "*stare*" which means to stand. Stature of a person relates to its standing height.

Estimation of stature from skeletal remains can be done by following methods,

(a) **Anatomical or full skeleton method**: It is a rarely used method also known as full skeleton method. This method involves taking vertical measurements of all the bones that contribute to stature (i.e skull, vertebrae, scapula, long bones, tarsals etc.) using calipers and osteometric boards. After taking the measurements, stature is estimated by adding the measurements of all bones along with a correction factor for soft tissue. This method gives high accuracy but from a forensic point of view it is bit impractical. As this method requires measurements of all bones and it is quite difficult to recover a full skeleton because usually incomplete skeletons and fragmentary remains are recovered from the scene.
(b) **Mathematical or Regression method:** This is the most commonly used method for stature estimation. Based on the principle that components of the skeleton grow in an orderly manner along with the growing human body and hence have a specific relationship with the increasing height of the body. The mathematical relationship between body height and various bones that contributes to the stature (i.e humerus, radius, ulna etc.) is devised in the form of regression formula. This formula consists of a multiplication factor which is different for different bone along with correction factor for soft tissues and is

Table 21.17 Long bones with their respective multiplication factors for stature estimation

Bone	Multiplication factor (approx.)
Femur	3.6–3.8 (3.7)
Tibia/fibula	4.48
Humerus	5.30
Radius	6.7–6.9
Ulna	6.0–6.3 (6.1)

used to estimate the stature from different bones. From the forensic perspective the regression method is better as single bone is sufficient to estimate the stature but it is better to have combination of bones as they provide more accurate results than single bone. Regression formulas are derived for various long bones as they give better results. **Karl Pearson's regression formula** is the most commonly used method for estimation of stature from long bones. For e.g. the formula for stature estimation from femur is,

$$\text{Stature} = 81.306 + 1.88 \times F \text{ (Length of femur in males)}$$

Table 21.17 shows multiplication factors for calculation of stature from various long bones.

Sex and race of individuals should be taken into account while applying these methods. Long bones of lower limb gave more accurate result than long bones of upper limb. Apart from long bones studies have been done for the estimation of stature from non-long bones such as calcaneus bones, metatarsals, size and shape of foot and hand, parts of vertebral column etc.

Other methods used for Stature estimation include,

- Radiographs to study stature and bone lengths of living and recently deceased person.
- Multislice CT scans to determine regression formula between stature and bone (i.e. sacrum) length.
- Magnetic resonance imaging (MRI) also been used in few studies.

21.7 Identity Markers Related to Individual and Its Life History

Personal identity of the deceased may judge more appropriately by difference skeletal marks acquires by live events. Certain type of erosions like the depressions, scars and pits on the dorsal surface of the pubic bones that adjacent to the pubic symphyses portion observed more often in female's pelvis than the opposite sex. Radiographic examination are carried out during forensic post-mortem to examine the pathological and non-pathological marks acquired by the deceased and the ante mortem radiographic report should compare to the previous one in case of availability, either confirm or exclude in identification point of view (Murphy and Gantner 1982). Some characters are unique to a single individual. Some of them are secure characteristics as they control by genetics itself, or acquired due to the addition, removal, or alteration of bodily tissues i.e. in ontogeny and phenotypically become plastic/fix (Randolph-Quinney et al. 2011). Such type of individualities are ascend upon intervention in development naturally or intesionally, through accident, or intended alteration, with the aim that those are suitably becomes a mark of identity to an individual. These are the pathological effects of any disease or trauma, surgical mediation for therapeutic or cosmetic tenacities and uniqueness in soft tissue or in bones; and such signs should provide a resilient evident for establish discrete identity. Joint replacement surgery/ orthopedic plating, breast augmentation in female, use of cardiac pacemakers, or other life supporting surgical maneuvers (having manufactures mark/number) are certain types of surgical interventions that left some imprints permanently, useful as personal identification purpose.

21.8 Trauma Analysis

Forensic anthropologist are expert to access the bone's response with respect to any type of trauma. Systematic analysis of skeletal remains for knew the timing and mechanism of skeletal trauma give clues to relevant forensic questions. That involve careful observation, documentation and interpretation with proper scientific methods and principles. For trauma analysis forensic anthropologist through assessing the timing of occurrence of the trauma (antemortem, post-mortem/perimortem) and the mechanism responsible for the occurrence of the trauma (like the projectile, blunt, sharp and thermal) (SWGANTH 2011). This needs an interdisciplinary approach and brings methodologies from disciplines like osteology, taphonomy, anatomy, physics, materials engineering, biomechanics and ballistics. Not only the trauma associated with the bones but with the cartilages are recruited to forensic anthropologists. They carefully restructure the fragmented bone, study the pattern of any fracture, characteristics of the wound, and lastly the nature of tool as well as the minimal force that should responsible for the trauma (Love and Wiersema 2016).

21.9 Craniofacial Reconstruction

When the other methods are failed to identify the unknown human remnant Forensic facial reconstruction can be useful to identification purpose. Forensic facial reconstruction is a quick, non-invasive as well as effectual method that made facial reconstruction, useful for individual identification from skeletal remains and also in archaeological research (Gupta et al. 2015). The techniques are varied from two dimensional (2D) drawings to three dimensional (3D) clay models (Abate et al. 2004; Yadav et al. 2010). Based on antemortem snaps and the skull the former model requires an artist and a forensic anthropologist to work on the facial reconstruction (Yadav et al. 2010). Accurate identification allows the legal agencies to make a list of alleged victims'. A 3D techniques called as Anatomical Russian Method used for reconstruction of face of fossilized skulls (Kähler et al. 2003). For facial recognition of an individual the combination Manchester method has been considered as the best and most precise one (Short et al. 2014).

21.10 Identifying Living Individuals

Forensic anthropologist also involve in the matter of identifying the living being, but facial identification is quite difficult (Fraser et al. 2003). It is quite a different aspect in the field of forensic identification, which study the human diversity and attempt to construct and verify morphological characteristics to understand the differences in physiognomy of one from other. They collect the CCTV footages and reconstruct the face of the suspects who involves in crimes like robberies and assaults etc. proper attention should be given to verify the falsification arises by projective geometry during the measurement of the dimension of the real items seen at crime surroundings (Criminisi et al. 1999). Traditional literature use conventional anthropometry (i.e. indices and facial characters) in for verify the resemblance in between the two individuals (Halberstein 2001). The 3D models of the person are examined to check matching of different facial landmarks and outlines, for an efficient analysis on 2D image (Fraser et al. 2003; Yoshino et al. 2001). Most recently the with technological shift improvement in 3D image acquisition technology will enable the researcher to achieve 3D-3D facial superimposition goal (Gibelli et al. 2017).

21.11 Determining the Age of Living Individuals (Imputability, Migration Issues and Pedo-Pornography)

The issues related to the individual's identification arises, when there is no documental evidence present near the person. This kind of concerns related to the victims of war survivals, persons associated with illegal migration and children survived in mass disaster cases. Other issues arises with the culprit, whose age is not known to the law enforcement agencies, hence issue arises with the type of court proceedings either for underage or adults. Forensic anthropologist with radiological, anthropological, and odontological investigations determine whether they belongs to underage or adult after the ancestry tracing, as the somatic growth differ with the geographical areas and ethnicity (Cattaneo 2007; Eugénia Cunha and Cattaneo 2006). Where the person ≥18 years old then CT examination of collar bones is necessary to construct the accurate age (Schmeling et al. 2006). A recent method is called as exfoliative cytology (EC) is considered as unique, use noninvasive technique, that involving simple, and based on the pain-free collection of intact cells from the oral cavity for different microscopic examination (Nallamala et al. 2017).

Child pornography is a type sexual exploitation, where the victims are the children/ underages. The issue associated to the pedoponography is quite difference, where the age calculation are performed with the help of 2D images over anthropological assessment. The facial and secondary sexual characteristics are extremely variable and do not represent chronological age, even the rate of sexual maturation is vary with geography, hence considered as a novel and very tough aspect of age estimation (Gehlen et al. 2005; Greil and Kahl 2005; Parent et al. 2003). Now other new methods of age estimation used 'Iris Ratio' (Machado et al. 2017) and face (Ratnayake et al. 2014) as indicator that capable with the potentiality for forensic applications, especially to the crimes like the child pornography and child abuse issues.

21.12 Positive or Confirmed Identity and Exclusion

The important step of any forensic investigation is to conclude its own way. Proper identification in the forensic anthropological investigation complete with the two-step procedure. Formerly, the features which are found are match in between the recovered remains and the antemortem feature/evidences of the missing person. The later step must clarify any differences which exists and explain the uniqueness of the common attributes. When the commonly found features are properly umpired as unique and the differences are reconciled successfully, a positive identification result will be established, otherwise exclusion is concluded.

21.12.1 Human Right Issues and Forensic Anthropologist

Forensic anthropology apply scientific knowledge as well as methodologies to solve law and justice related issues. The problem not only associated with the individual identification and identify the foul play in crimes but also with humanitarian and issues with human right. Forensic anthropologists identify the missing persons and helps in detect crime and take part to give justice against the culprit for of any crimes. Human rights in forensic anthropology is the specific application of forensic anthropology to the cases with mass killing or genocide has occurred intensively in a large scale. Forensic anthropologists associated to the human rights work are recruited by federal agency to gather precise evidence related to any war, genocide, human trafficking and child abuse. The first ever involvement of international forensic anthropologist into human rights inquiries started in 1984 by the American Association for the Advancement of Science (AAAS) sponsored forensic anthropology experts responded to Argentina's request regarding the support of forensic experts in unearthing and identifying thousands of individuals who missed during the period of 1976 and 1983.

21.12.2 Case Studies/Famous Case Histories

- In 1849, The Parkman Murder (Killgrove 2016), known to be the first case that originates Forensic anthropology in America. Two anatomists Oliver Wendell Holmes and Jeffries Wyman at Harvard University investigate the Murder of the prominent physician Dr. George Parkman who was killed by a chemistry professor at Harvard named John W. Webster. The conviction was done on the basis of investigation done by the two anatomists by examining the segmented body parts for stature estimation and comparing the dentures found in the furnace.

- In 1897, The Luetgert Case (Murderpedia n.d.), become another famous case in which Adolph Luetgert, a Chicago based sausage producer was accused of killing his wife and attempting to dispose of the remains by cooking them in a potash vat in the factory. George A. Dorsey, an anthropologist, investigated the case and recovered small fragments of bones and a ring (belongs to Luetgert's wife) from the vat. On examination he found that the small fragments were from a human hand, foot and rib, hence stated Luetgert as guilty and gave testimony in court which helped in conviction of Adolph Luetgert. His testimony was sternly challenged by other specialists, and Dorsey left his contribute further to the study of forensic anthropology.
- In April 1997, The Marty Miller Case(Casto 2016), is an incident that happen in a quite rural area of upstate of New York. Marty Miller shot his daughter with a shotgun which fatally wounded her. After this incident Marty ran into the woods behind his house, in spite of a massive manhunt, he was not seen again. This incident became something of a legend in the community due to the notoriety of the missing suspect. Marty was an enthusiastic outdoorsman and know the survival techniques in the forest. As a fugitive, he could be quite dangerous and people feared of his reappearance. After 4 years in December 8, 2001, a hunter found a human skeleton at a remote place into the woods and called to the police. The New York Police investigated the scene and recover the skeletal remains along with other important evidences (such as clothes, wallet, eye glasses, wrist watch, shotgun etc.) and send the evidences to Forensic Anthropology Lab at Binghamton University where anthropologist using methods of identification through skeletal remains helped in positive identification of the deceased as Marty Miller.

Case Study 1: Ancestry Estimation

In 2012, a scattered human remain was found along a hill side in Northern California. The skeletal remains found were highly fragmentary and incomplete. Due to carnivore scavenging the pelvic features are not clear but the intact skull was located which is then used for assessment of ancestry. Although the age estimation was not easy task due to scavenging but cranial sutures and osteophytic lipping on vertebral column gave an idea that the decedent was of 40+ years and on the basis of maximum length of ulna, the stature was estimated as 6 ft. ±4.5 in. Apart from these findings law was interested in ancestry of the decedent to narrow down the search from the pool of missing persons hence they compared 16 measurement of cranium with the sample group of male and found the results as:

– Fordisc 3.0 classified it as white male.
– High posterior probability value $p = 0.984$ indicated it as white male.
– Typical value $p = 0.366$ indicated the skull as white male.

After all the above mentioned findings it was identified by DNA analysis that the remains was of a 54 year old white male with a stature of 6 ft. 3 in. and the result is consistent with the above findings.

Case Study 2: Sex Estimation
In 2006, a nearly complete human skeleton is recovered from grave in Northern California. The deceased remains showed male pelvic traits such as a narrow sub-pubic angle, absence of a ventral arc, a narrow sciatic notch etc. The cranial features like mastoid process temporal lines, supraorbital region indicated the skeleton to be of male sex. On comparing the postcranial measurement with statistics of Forensic Anthropology Databank (i.e. Fordisc 3.0) it was suggested that the skeleton was of human male. It was later identified that the remains were of a 26 year old white male with living stature of 5 ft. 8 in.

Case Study 3: Age Estimation
In 2008, human remains from a cemetery in Northern California were exhumed; the decedent's age was estimated to be of 6.0 ± 2 years. This age was estimated by seeing the dental eruption, dental development and epiphyseal union in the skeletal elements which were surprisingly in a good preserved state with clearly visible features even after 30 years of the body being buried. The maxillary and mandibular first molars were almost erupted and permanent central incisors were in process of eruption. Apart from this even the degree of fusion of vertebral column, early stage development of several epiphyses and length of limb bones indicated the age of the decedent to be approx. 6–8 years. Later the individual was identified as 6 year old child from American Ancestry.

Case Study 4: Stature Estimation
A different case of carnivorous scavenging of human skeleton was discovered in Northern California in 2008. The estimated biological profile said, descendent was an adult male of European ancestry and was of about 50–80 years of age. The skeleton was heavily degraded but the case was solved on the basis of postcranial elements. Osteometric data was collected from left long bones of upper and lower limbs, clavicle, and scapula. The data then entered into Fordisc. Using the formula derived for twentieth century white males the stature is estimated. The result concluded that the stature is best estimated using the maximum lengths of bones like clavicle, femur and tibia.

The combination of the measurements of these bones was used in regression formula which generated the stature as 67 ± 3.3 in. with 95% confidence level. Later the profile matched closely with a missing individual's file and descendent was identified as 70 years old white male with a stature of 68 in.

Case Study 5: Human or Non-human
In this case, a partly skeletonized leg was discovered in a river in Northern California. Local law enforcement sent it to an archeologist, pathologist and veterinarian for identification to which the archeologist and pathologist identified it as

human right leg but the veterinarian identified it from a non-human origin. The leg was attacked by a saw which caused dismemberment of the bone. The law enforcement searched for the other remains of the skeleton for 3 days considering the skeleton to be of a human. On searching a complete left femur and proximal two thirds of a tibia and fibula were found which is then identified to be of a black bear. In this case much time and money would have been saved if the case was handed to the forensic anthropologist and not to the experts of three different streams who had the conflicting opinion.

21.12.3 Concluding Remarks and Future Prospects

Forensic anthropologists work in humanitarian and medico-legal issues with the primary aim of establishing the identity. Traditionally, the forensic anthropology begins from human anatomy and focuses majorly on osteological evidences. With the ongoing research and increasing need of forensic anthropologists in world scenario the branch become more liberal in accepting methodological collaborations and make the investigation effective. Over time forensic anthropologist makes the discipline as a unique one, at its standpoint. In the present scenario, new experimental trends in forensic sciences focus on trauma analysis, taphonomy, examination of isotopes, time since death and visual interpretation are going on to meet the demand in the identification process. The current trend of forensic anthropological research and teaching progressively attracts the best and dedicated students through graduate and post-graduate studies as an applied discipline with problem-oriented interdisciplinary approaches. During the investigation by the forensic anthropologist number of ethical issues faces by them, brings a challenge when establish the study conclusion. The future perspective will focus on, but not least to utilization of interdisciplinary techniques, expansion of new centres and laboratories, introduce new school programs, and enhanced understanding on the variation of global population Lastly it can be said that in this age of 'necronominalism' the personal identification of deceased is important as much as like the identity of a living.

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