HUMAN PALEONTOLOGY AND STRATIGRAPHY: THE USE OF HOMININ FOSSILS AS BIOSTRATIGRAPHIC MARKERS

Andrea Di Cencio
Geology and Paleontology, Italy

Keywords: *Ardipithecus*, *Australopithecus*, biostratigraphy, evolutionary trends, Hominidae, Homininae, hominins, *Homo*, *Kenyanthropus*, *Orrorin*, *Paranthropus*, *Sahelanthropus*.

Contents

Summary

The period since the early 1990s is important for findings in the area of paleoanthropology. The topic of human evolution fascinated scientists since Linnaeus (1758); the findings of new genera and new species enabled the reconstruction of evolutionary trends. These trends lead to the identification of the unique living species *Homo sapiens*, starting from the time of split between hominins and chimpanzees. The history of hominin evolution is very long. Over time the entire group took several evolutionary directions, showing a high adaptive capacity to the changes of the paleoenvironmental conditions. The evolutionary trend was characterized by first occurrences, i.e., appearance of new genera and species, and last occurrences, i.e., their extinction. These data permitted us to reconstruct a chronostratigraphic scale starting with fossils of hominins and their tools, a scale correlated with the official schemes used to dating the last ten millions of years. The evolution of hominins was strictly connected to paleoecological systems that are characteristic of the environment where hominins lived. The succession of species and genera, or group of them, permits us to observe a sub-division of geological time following the rules of biostratigraphy.

1. Introduction

The systematic taxonomy for the genus *Homo*, our genus, has been the subject of academic attention and debates since the time of its institution, by Linneaus, in 1758. Numerous scholars thereafter, especially from the end of XX century, have worked on the right placement of genus *Homo* in the subfamily Homininae (family Hominidae, order Primates), starting from the several fossils that were found in rocks worldwide. The hominin paleontological record is incomplete and fragmentary, with regards to both the fossilized bones and tools and the distance between paleontological sites. This last feature makes it hard to recognize a right succession of geological records giving sufficient chronological data to set the age of fossils and their stratigraphic connections.

The fragmentary condition of paleontological records can be an issue in relation to the correlation among different species, and their consequent identification. The literature reports a number of studies on the effort to re-organize the numerous species belonging to several genera inside Homininae (Linnaeus, 1758; King, 1864; Dubois, 1894; Schoetensack, 1908; Woodward, 1921; Dart, 1925, 1948; Oppenoorth, 1932; Broom 1938; Leakey, 1959; Leakey *et al*. 1964, 1995, 1999, 2001; Arambourg and Coppens, 1967; Groves and Mazak, 1975; Alexeev, 1986; White *et al*. 1994, 2003; Brunet *et al*. 1995, 2002; Bermudez de Castro *et al*., 1997; Asfaw *et al*. 1999; Haile-Selassie, 2001; Senut *et al*., 2001; Mallegni *et al*. 2003; Brown *et al*. 2004; Berger *et al*. 2010; Curnoe, 2010).

The present chapter aims to summarize the state-of-the-art of the paleontological theories about the evolutionary trend of hominins, and their link with possible biostratigraphic markers. The present chapter also introduces a brief description of basic nomenclature used for the bones of hominins so as to understand the terms used to confront and compare the species. Previous studies about the evolution of hominins are also going to be discussed. Moreover, basic information about biostratigraphic and its importance for hominin fossils and tools are given. Biostratigraphy is the science which groups the sedimentary rocks depending on their paleontological content. The biozone is the fundamental unit of biostratigraphy, it is delimited by bio-events (or biohorizon) and it defines bodies of layers that are characterized by their distinctive fossil species. The succession of biozones gives the biostratigraphic scale which is perfectly correlated with chronostratigraphic schemes to date rocks.

The biostratigraphic method is very useful for dating marine rocks using nanno-plankton or foraminifera. The little dimension of nanno-fossils permits us to have a very high definition of biozones and the bioevent may be easily dated in an absolute way (Garzarella, 2012). When the bio-horizons are dated in million of years, the corresponding biozones identified become biochrons (from the Greek *bios* = life; and *khronos* = time). Biochron is the span of time in which are deposited the sediments of biozone. Biozones, and so biochrons, are named after the marker fossil that characterizes that interval of time (Di Cencio, 2007).

When a biozone is defined by macro-fossils, bio-events are harder to date in absolute age and the succession of biozones gives a relative dating of rocks. Even though

biostratigraphy may be applied to continental fossils, some further considerations are necessary.

The paleontological discovery of continental fossils is discontinuous and lacking of data. The paleontological sites are geographically far from each other so that a relationship between them is not easily predictable. As a consequence, the concept of biozone changes, accommodating the incomplete character of paleontological record and emphasizing the taxonomic homogeneity and bioevents.

The difficulty in having a direct correlation between standard biozonations and continental ones lead to the definition of a specific biozone scale (Neogene mammal units) and a geochronological one (European Land Mammal Ages). They will be briefly introduced in the following.

Homininae evolved in upper Miocene. This group was part of geological history of the Earth in the last ten million of years. The question is: can hominin fossils be used like fossils of other big mammals in order to describe the age and the environment in which they walked?

2. Systematic Paleontology

In this section, some information about the bones of hominins, starting from the humans' bones, is given. It is not a description of every single species, but the starting point to understand those works describing species and genera belonging to Homininae. Here the attention is focused to indicate the number of species that existed and the evolutionary connection between them. Hominidae is the family that regroups every genus of anthropomorphic primates which lived on Earth since Late Miocene. It was split in two subfamilies: Paninae and Homininae. Most of genera of the latter are extinct and Homininae is actually represented only by genus *Homo*, with one species: *Homo sapiens*.

During the past, several genera, with more numerous species, showed enough similarity with the actual humans to be included inside the same subfamily. Only incomplete fossilized bones of other species of Homininae were found so that their description and classification became sometimes very hard. Entire skeletons are very rare, but even more difficult is to find bones with anatomical connections which may explain how the skeleton and the body of fossil work.

The word "hominids" is commonly accepted to indicate every species of "primitive humans". Formally "hominid" indicates every specimen belonging to family Hominidae, chimpanzees and bonobos too. On the other hand, the more specific term "hominin" can be used to indicate every specimen belonging to the subfamily Homininae.

2.1. Morphological Description

The nomenclature used to describe the bones of hominins is the same as that used for modern humans and other vertebrates. The skeleton of hominins may be divided into two parts: cranial and postcranial portions.

The cranial part is the group of the head bones: skull, jawbone, mandible and teeth (Figure 1). Every part of head may have its own shape and utility, so they show a particular morphology. The comparison between morphologies may indicate similarities, differences and, more importantly, potential evolutionary trends.

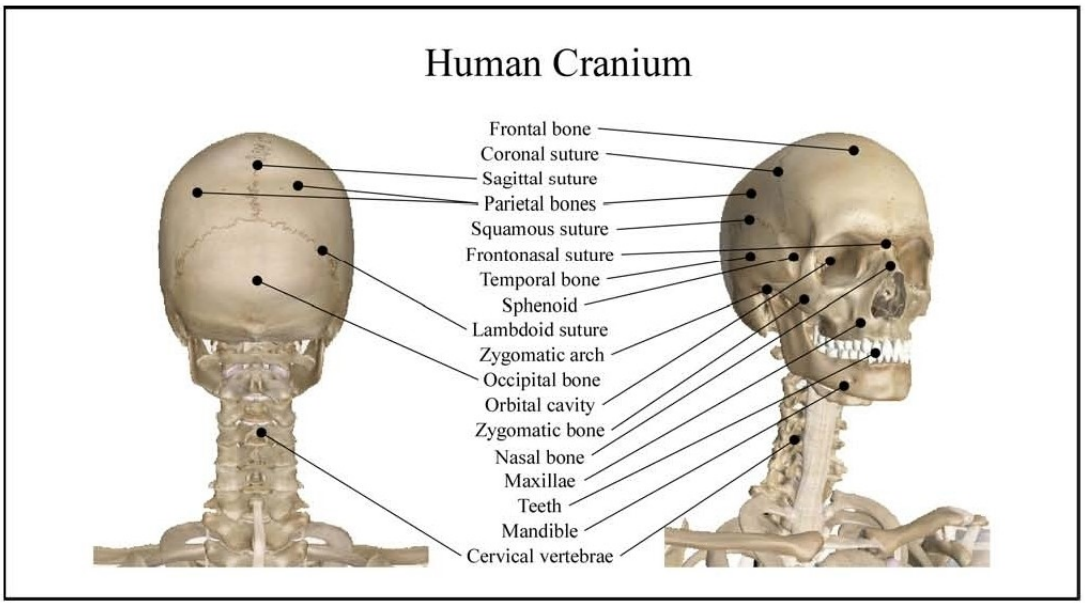

Figure 1. The list of most of bones of the head: cranial box, facial bones and neck. The images are taken and modified from the web site www.innerbody.com.

The general morphology of cranial box may give information about the shape of the upper side of face, how prominent the forehead is or the occipital and temporal sides. The bones of cranium are called: Frontal, Parietal, Temporal, Occipital and Sphenoid. These are flat bones that contain the brain; the inner volume represents the brain capacity of the species. These bones are separated by sutures: between Occipital and Parietal bones there is the Lambdoid suture, between the two Parietal, the Sagittal suture; between Parietal and Frontal, the Coronal suture; between Parietal and Temporal bones, the Squamous Suture; between Frontal and Nasal bones, the Frontonasal Suture. These sutures become more and more indented during ontogenesis to permit the young specimen to grow up and become adult. The Occipital bone contributes to posterior, lateral and inferior surfaces of the cranium. On it some features are recognizable: *foramen magnum*, the circular opening which permits the connection between cranial and spinal cavities; occipital condyles, articulated with the first cervical vertebra, the hypoglossal canal, between occipital bone and occipital; the external occipital protuberance and the jugular notch. The Parietal bones constitute the superior and the lateral surface of the cranium. Two temporal lines (superior and inferior) are developed on cranium starting from the extension of Zygomatic bone on Temporal bone. The Frontal bone is divided into frontal and orbital parts. On the frontal part may be distinguished the Frontal suture, usual childhood phase sutural line which often disappears around eight years of age; supraorbital margins, the edge of the frontal part on the superior border of the orbits; supraorbital foramen, at middle of supraorbital margin; superciliary arches, thickened ridges over supraorbital margins which supports

the eyebrows. The orbital part, the orbital surface, brings the lacrimal *fossa* that is the part where is allocated the lacrimal gland.

The Temporal bones constitute the lateral and inferior walls of the cranium. They are divided in three parts: Squamous, Tympanic and Petrous. The Squamous part forms the lateral surface and includes the Zygomatic process on the inferior part that with the Temporal process on Zygomatic bones composes the Zygomatic arch (cheekbone); mandibular *fossa*, the depression on the inferior base that articulates with the mandible; the articular tubercle, an elevation anterior of the mandibular *fossa*. The Tympanic part is the area around the external acoustic meatus. The Petrus part is the largest massive part of temporal bone in which the sense of hearing and balance are sided. The mastoid process which contains mastoid sinuses is located on it; together with styloid process to which ligaments and tendons are attached; the stylomastoid foramen is the area where the facial nerves pass; the jugural *fossa* together with the jugural notch Occipital bone form the jugural foramen; with the carotid canal; the foramen lacerum, between the Temporal and Occipital bones and the internal acoustic meatus.

The Sphenoid is a complex bone articulated with every other cranial bone. Although large, most of sphenoid is hidden by more superficial bones. On sphenoid, the body similar to a "Turkish Saddle" may be recognized. It forms an enclosure around the pituitary gland; the lesser wings, anterior extension, similar to wings of the Turkish Saddle; the greater wings, laterally to Turkish saddle; the pterygoid processes, the downward process on either side of body. The Ethmoid is an irregular bone that forms part of the orbital complex, floor of the cranium, roof of the nasal cavity and part of nasal septum.

Inside the cranium, the cranium *fossae* can be observed. They include: anterior cranial *fossa*, middle cranial *fossa*, posterior cranial *fossa*.

Several facial bones exist and their morphology affects the shape of the face. The Maxillae are the largest facial bones connected with upper jaw. The Zygomatic processes, the Orbital rim, the palatine processes and incisive canals are important features to be studied. The Palatine bone is a small L-shaped bone behind the nose. The nasal bones are two little bones articulated with Frontal bone and frontal processes of Maxillae. Zygomatic bones are the lateral rim of the orbit, they include the Temporal process, which with the Zygomatic process on temporal bones, forms the Zygomatic arch and the Zygomaticofacial foramen, an opening on the anterior surface of Zygomatic bone. Mandible is the lower jaw. The entire bone can be divided into a horizontal body and ascending rami. The ramus meets the body at the angle. Features of the ramus includes: condylar processes, coronoid processes, mandibular notch, mylohoyid line and mandibular foramen. The body includes: mental foramina and alveolar process.

The orbital complex is interesting to observe. The orbits are the bony recesses that enclose and protect the eyes. The orbital complex consists of the bones that form the orbit and include the Maxillae, lacrimal bone, Ethmoid, Palatine bone, Sphenoid, Frontal bone and Zygomatic bone.

Particular attention must be paid to dentition (Figure 2). Teeth of hominins may be found inside their location in mandible and in Maxillae, but, often they are isolated. This is due to the fact that teeth are allocated in jaws but not strictly connected or melded with jaws. Moreover, in every mammal there is a complete change of teeth, passing from child to adult phases, during puberty. The dentition presents its own nomenclature which is used to classify teeth and to relate specimens.

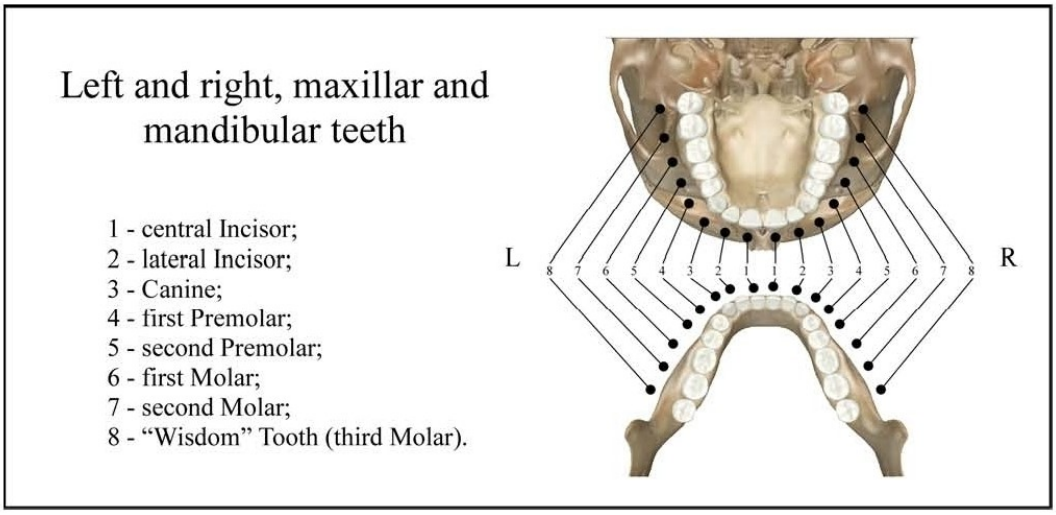

Figure 2. Dental numeration. The mandible is positioned in the same position of the reader in order to recognize teeth touching them during reading. The human mouth has 32 teeth: 8 Incisor (four upper and four lower); 4 Canine (two upper and two lower), 8 Premolars (four upper and four lower) 12 Molars (six upper and six lower, the third upper and lower Molars are named "Wisdom Teeth"). Figure taken and modified from www.innerbody.com.

Teeth are named by their set, arch, class, type and side. Teeth can belong to one of two sets: primary, or deciduous, and permanent, or succedaneous. The first are the teeth of children, the latter of adults. Teeth are maxillary or mandibular following their position inside the mouth, following the arch classification of teeth. The maxillar teeth are the superior ones, mandibular are the inferior ones. There are four classes of teeth: incisors, canines, premolars and molars. Premolars are found only in permanent teeth. Within each class, teeth may be further classified. Incisor are further divided into central (also indicated as first) and lateral (also indicated as second). Among premolars and molars, there are the first and second premolars, and first, second and third molars. This numeration is connected to left or right side in the mouth. For example, the "permanent mandibular left first premolar" is the fourth tooth starting from the centre of mouth, down and moving forward left. In the common use, teeth may be numerated starting from the centre of mouth: first, second, third, fourth teeth correspond to central incisor, lateral incisor, canine, first premolar, and so on.

Crown and root parts are recognizable on every tooth. The crown is completely covered by enamel, visible in the mouth and with all structures able to chew. The roots are the protuberances which allow the tooth to remain anchored to the Maxillae or Mandible. Maxillary molars have three roots, while mandibular molars have only two. The number

of roots may be important for the study of the evolution of teeth. For example, the upper fourth tooth, the maxillary first premolar, has generally two roots, but it has been observed that sometimes it presents only one root. It is calculated that the percentage of two/one root is 70% vs. 30%. Perhaps it is an evolutionary character. Important for the description of teeth is the number and shape of cusps, one for canine and two for maxillar first premolar, for example; the cingulum and the ridges.

In order to describe a tooth, terms which give the position of tooth inside mouth may be used: the mesial side and the distal side of tooth are respectively the side towards the middle of mouth and the side towards the temporal one; the labial (for incisor and canine) and cheek (for molars and premolars) side of tooth is the external one, the lingual side is the inner side of each tooth.

Starting from the mouth of modern human, and for extension in the mouth of every hominin's eight incisors are recognizable: four in the upper arch and four in the lower arch. Their function is to shear or cut food during chewing. They have no cusps. The permanent incisors are similar in shape to the primary ones.

The canine, both maxillary and mandibular, separate incisors from premolars. Their position reflects their dual function as they complement both the premolars and incisors during chewing process. Nonetheless, the most common action of the canines is the tearing of food. There is a single cusp on canines, and they resemble the prehensile teeth found in carnivorous animals. Premolars are found distal to canines and mesial to molars. They are divided into first and second premolars. There are no deciduous premolars, replaced by a deciduous molar. Molars are the most posterior teeth in the mouth. Their function is to grind food during chewing. The number of cusps, and thus the overall appearance, vary among the different molars and between people, so it cannot be a diagnostic specific or sub-specific character. There are great differences between the deciduous molars and permanent molars, even though their functions are similar. Permanent maxillary molars are not considered to have any teeth that precede them. The third molars, so-called "wisdom tooth", and it is actually considered a vestigial feature, often it is removed surgically and are often undeveloped in modern humans. The wisdom teeth, big and thick, are the remaining trace of a past in which the leaf diet requested some large and able teeth to long chewing activity.

The postcranial portion of hominid is the skeleton apart from the skull. In the postcranial portion the following part are recognizable: an axial part (Figure 3) and an appendicular part (Figure 4).

Moreover the described skull, the vertebrate column and rib cage belong to the axial part (Figure 3). The rib cage comprises twelve pairs of ribs and one sternum for a total of 25 separate bones. The rounded end of a rib is attached to a thoracic vertebra on the back, while a flattened end connects to the sternum, in the front. The upper first seven pairs of ribs are attached to the sternum, the 8^{th}, 9^{th} and 10^{th} are attached to the ribs above them, the 11^{th} and 12^{th} are the "so called" free ribs. The length of each rib increases from the first to the seventh and then decreases until the 12^{th}. The first rib is the shortest, broadest, flattest and most curved one.

The vertebral column has 33 separate vertebrae at birth that become 24 during a normal ontogenesis because some of them fuse together in the coccyx area. Five parts are recognizable on vertebral column: cervical vertebrae count 7 elements, thoracic vertebrae, 12, lumbar one, 5, sacral vertebrae count 4 to 5 elements and coccyx one count 3 to 4 elements. The connection between vertebral column and the skull is realized by the cervical vertebrae. Sacral and coccyx vertebrae are fused and are often called "sacral bone" or "coccyx bone". The sacral bone makes up the junction between the vertebral column and the pelvic bone.

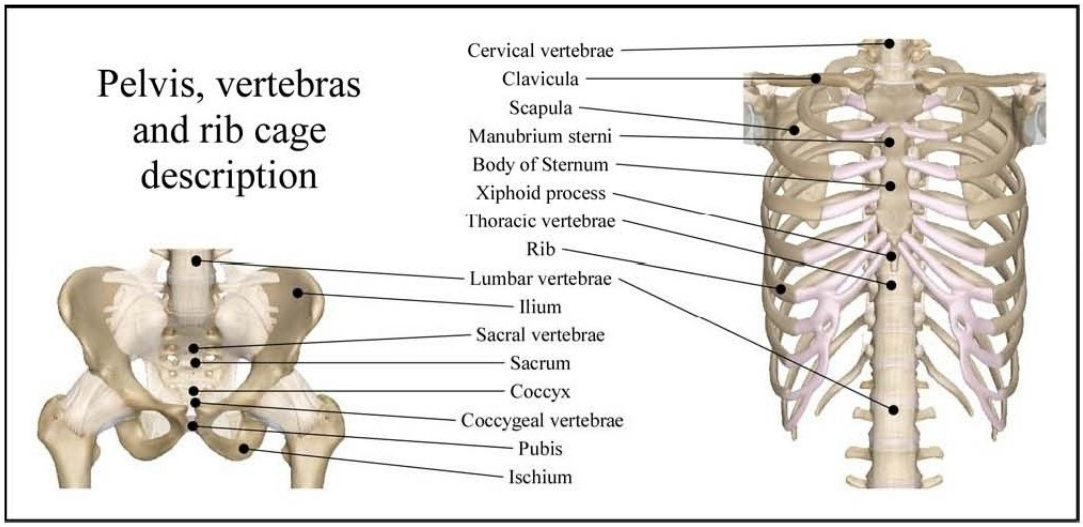

Figure 3. List of bones of axial portion of human skeleton, without the head. The rib cage is made of 12 pairs of rib connected as in the figure. The vertebral column has 24 vertebrae at adult stage. The pelvis is different in male and female, indicating the typical sexual dimorphism of more recent hominins and *Homo* in particular. Figure taken and modified from www.innerbody.com.

The appendicular skeleton (Figure 4) is the portion of postcranial parts which comprises limbs and their connection to the axial skeleton. The appendicular skeleton is divided in the pectoral girdles constituted by the left and right clavicula and scapula; arms and forearm which contains a humerus, ulna and radius; the hands are characterized by left and right carpals (wrist bones), metacarpals, proximal, intermediate and distal phalanges; the pelvis with a left and a right hip bone; thighs and legs constituted by left and right femur, patella (knee), tibia and fibula; feet and ankles formed by the left and right tarsals (ankle bones), metatarsals, proximal, intermediate and distal phalanges.

The study of the appendicular skeleton provided several hypotheses about the life and behavior of hominins. The length of long bones in the legs may indicate the inclination to bipedalism, while the shape and length of arms and forearms indicate what remains of arboreal life style. This latter habit is often correlated to the shape of pectoral girdles. On more ancient hominins, the funnel-shape of pectoral girdles confirms the arboreal or half-arboreal life style, a middle way between two very distant worlds. The comparative analysis of fossils of hominins, ancient and modern humans, indicates an evolutionary trend that starting from long arms, funnel shaped pectoral girdle and short leg moves towards longer legs, shorter arms and no funnel shaped pectoral girdle, meaning a

progressive distancing from the arboreal or wooden life style in favor of a "grassland" life style.

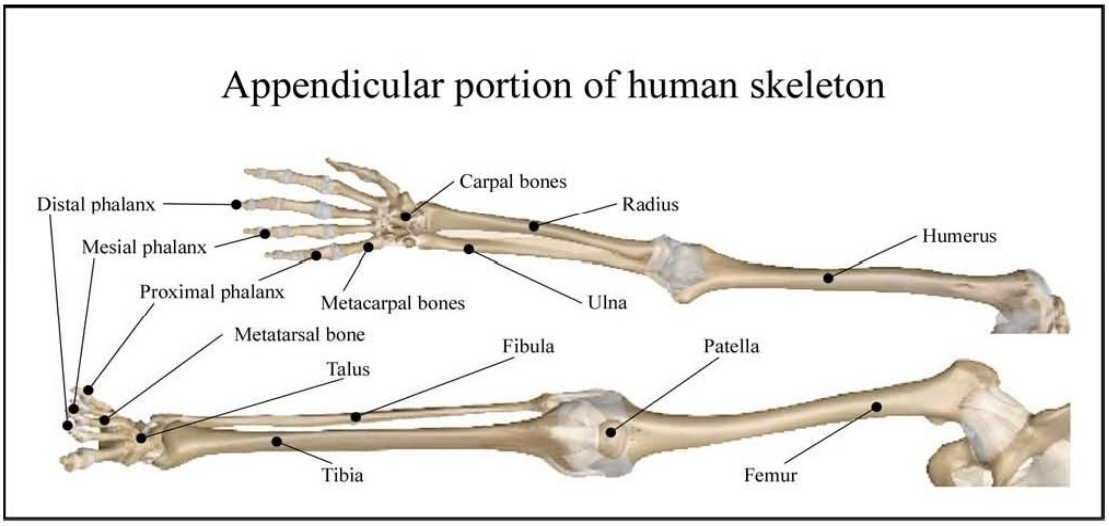

Figure 4. The list of bones of appendicular portion of human skeleton. The shape and the length of long bones, the position of bones of feet and hands, permit to understand the habit of life of hominins. Figure taken and modified from www.innerbody.com.

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Biographical Sketch

Andrea Di Cencio is an Italian Geologist and Paleontologist PhD, specialized in Biostratigraphy. He collaborates as freelance consultant with several universities (La Sapienza, Rome; "G. D'Annunzio", Chieti, Central Italy; Université de Bourgogne, Djion France, Université de Antananarivo, Antananarivo, Madagascar), Superhintendence of Cultural Heritage of Abruzzi and Tuscany and several museums (Natural History museum of Luxembourg, Luxembourg; "Giovanni Jack Pallini" Museum, University of Chieti, Italy; Paleontological Museum, University of Rome, Alto Aventino's Geo-Paleontological museum, Palena, Italy; Museo Paleontologico "Giuseppe Moretti" Paleontological Museum San Severino Marche, Italy; G.A.M.P.S. Paleontological Permanent Exhibition, Scandicci, Italy).