FRANKLIN W. OLIN COLLEGE OF ENGINEERING

Learning from Bones

An Introduction to How We Learn About Our Past Through Human Remains

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Table of Contents

Introduction

Hello, and welcome to Learning from Bones. The goal of this paper is to teach you about how forensic anthropologists and bioarchaeologists learn from bones. Forensic anthropologists and bioarchaeologists both fall under the broader disciplinary umbrella of anthropology. But who are anthropologists, anyway, and why do they have a bunch of bones? Anthropology is defined by the American Anthropological Association (AAA) as “the study of humans, past and present” (1). Anthropologists draw on a variety of disciplines in their attempt to understand all human cultures, past and present, and their goal is to use the information they gain to solve problems (1). In order to study humans of the past, it is necessary to look at what humans have left behind. Often, the only thing left behind of actual human bodies is bone, or fossils of bone, so anthropologists study those bones to learn about humans of the recent and distant past. There are four primary subdisciplines of anthropology:

Physical Anthropology

Physical anthropologists pursue information about human variation from the perspective of human evolution and adaptation. In order to study this, they look to our ancestors, via the remains of past humans and the study of non-human primates. They study the biology (including genetics, epigenetics, etc.) of living humans, and how that contributes to behavior and the development of societal processes. They also combine the study of biological and cultural processes to investigate growth, development and behavior, and what causes disease and early death (1).

Archaeology

Archaeologists study the past via material cultural remains. They find remnants of human habitation or other interaction, and they use it to learn about humans of the past. They work with a variety of remains, such as pottery, stone tools, animal bone, and remains of structures. They seek to understand previous human experience, in terms of things like food source, interaction with the environment, societal structure, and more. Similar to other anthropological disciplines, archaeology studies the commonalities between and the differences within ancient cultures (1).

Cultural anthropology

Cultural anthropologists seek to understand current societies, or how varied individuals come to together to form a functioning societal entity. They are interested in studying differences and similarities between and within societies, focusing attention on race, sexuality, class, gender, and nationality (1). They learn about different aspects of how people interact with other people and with their environment through participating within the culture they are studying. They live with the subjects they are studying in order to learn about how they deal with things on a day to day basis, as well as overarching themes of behavior, such as problems of knowledge, truth, power, and justice (1).

Linguistic Anthropology

Linguistic anthropologists study how language reflects people's behaviors and beliefs. Language, an essential part of how we communicate, influences our behavior on the small scale, such as how we think about ourselves, and the large scale, such as how societies are structured. Language is what allows humans to communicate within and between generations of individuals, and allows us to share our personal view of world with other people in a way that they will understand. Linguistic anthropology also aims to understand how aspects of linguistics may shape social injustices, and how linguistics can affect social change (1).

These four subdisciplines cover the majority of anthropological research. As described above, each of these disciplines has even more divisions within its overarching themes.

This paper will explore methods within forensic anthropology, which generally falls under physical anthropology, and bioarchaeology, which falls between archeology and physical anthropology. The primary difference between forensic anthropologists and bioarchaeologists is what they hope to learn from human remains, or the questions that they attempt to address through their work. Forensic anthropologists, as the name implies, deal with criminal investigations into current remains, as well as remains from the more distant past. Their investigations are primarily concerned with determining basic information about an individual, such as sex, age at death, stature, cause of death, and identity (if the death was recent). Bioarchaeologists are traditionally more interested in learning information about the society that the individual was a part of, such as social status and rankings, diet, pathologies, burial practices, and more. Behavioral patterns are often much more difficult to interpret from individual specimens, because the impacts of different behaviors can be so varied.

Finding Bones and Fossils

In order to study bones of our ancient past, they must first be found. The context in which a bone is found contributes a great deal to its interpretation. Everything about an excavation site must be well documented, because it might provide insight when interpreting the finds. Even with today's technology, truly accurate documentation remains a challenge in the field (2). Even something that might be seen as relatively basic, such as the vertical and horizontal position (also known as the provenience) of a find with respect to the area being excavated, is incredibly tedious to record. Imagine you are digging up hundreds of items, and every time you find one you have to record its exact position, measuring each time. It takes a massive amount of manpower and computational power to truly map out a dig site.

Relative and absolute positions are both important for determining information about the item that has been found. Absolute positioning, such as latitude and longitude of the site, can give the investigator a general idea of what population their bones may be from (2). Investigators can make estimations based on current or previously identified local populations, as well as known migration patterns (2). Position of bones in relation to other items at the site, or relative to the top of the ground, can also tell a great deal about a bone. It is generally accepted in archaeology that layers of things get deposited in chronological order, so if something is below something else, it is older (2).

Not only can they tell relative age of bones from their deposition, but they can also gain some insight as to the absolute age of the bones. Over time, due to different climate conditions, weather, etc. different layers of rock and soil get deposited on the ground. The location of a bone within these layers, or strata, can give insight into the absolute age of the bone as well as other information (2). The other components of each stratum, such as the composition of soil, previous vegetation, microbial life, and more, can supply the investigator with more information about the bones found (2).

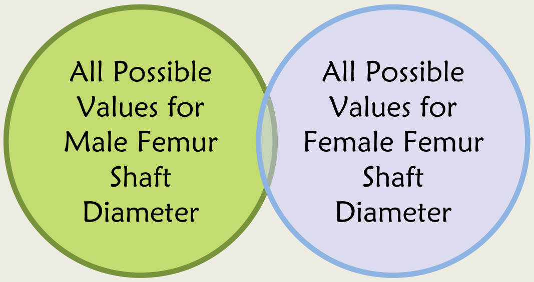
Interpreting Remains

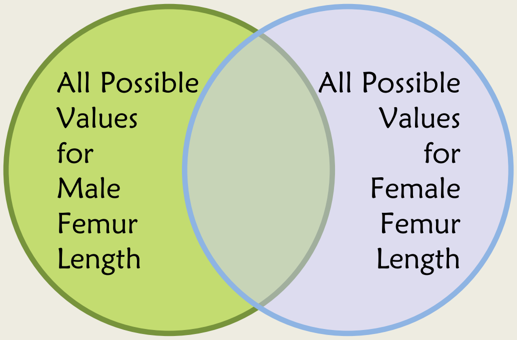
Once a set of remains is found, first the decision must be made whether a set of remains found is human at all! This is done primarily by assessment of the bone's morphology: essentially, does it look human? The humanness of a bone is often relatively straightforward to a trained eye (3). Once a decidedly human skeletal remain is found, the initial step towards garnering information from it is applying the context in which it was found. As described previously, there is a variety of information inherently associated with finds from an archaeological excavation. This context is important, because a lot of information that can be gained from bones is dependent on comparing them to a reference population. The location that a bone is found in can be one aspect of context that helps to classify it into a reference population, such as if a bone is found in an area that known populations have inhabited. If a bone is found in a particular stratum, this might suggest a specific time period to choose a reference population from. Categorization of a bone into a reference population can also be based on certain aspects of the bone itself, such as size and certain other morphological traits. Reference populations are well characterized populations within which the average and deviation of many specific traits are well known (3).

There is, however, an inherent circularity within this classification, and this is where the judgment and experience of the primary investigator comes into play. The primary investigator is the forensic anthropologist or bioarchaeologist currently analyzing a bone. They may have participated in the recovery of the bone from an archaeological dig site, or they may be looking at a bone from a collection acquired by other archaeologists. In order to garner information from remains the bones are compared to a reference population, but in order to classify them into a reference population something must be known about the remains. For example, in order to determine whether a bone is male or female, it must be classified into a population, such as Native American individuals from the early 1900s. However, in order to classify a bone into this population, versus another population that may be reasonable (for example, European immigrant individuals from the 1900s), certain information must be known about it.

Once a bone is classified into a specific reference population, a set of individuals with several well characterized features, the primary investigator can begin to compare the various features, such as size or shape of certain areas, of a bone to known information about the reference population. Generally, the primary investigator will look at the overall size of each bone, as well as features that are specific to each type of bone. Examples of specific features are given later, in the example section.

The primary investigator can then use the comparison between their sample and the reference population to draw conclusions about age, sex, size, etc. These conclusions are based on where the sample falls within the spread of variation of the reference population. The features that are measured in order to make these assumptions are specifically chosen because they have maximum variation between groups, and minimum variation within groups. The more variation there is within a group, the more likely it is that the end of the spectrum of variation overlaps the spectrum of variation for another group. The following diagrams are examples that represent the total of variation between different groups for two different features:





The first trait has a small amount of variation within each sub population, male and females, and a large amount of variation between each sub population (little overlap between the sets of values). The second trait has large amount of variation within each sub population, and less variation between sub populations (large amounts of overlap between the sets of values). If a femur was found and assessed based on femur length, it would be more likely to have a value that might fall within the variation of both subpopulations, and thus could not be specifically classified. It is therefore important to try to find traits that overlap as little as possible between groups (3).

This also makes it more difficult to assess more complex traits, such as diet, diseases, childbirth, etc. because there is so much variation within groups' responses to these phenomena, as well as ill-defined skeletal consequences of these traits. In these cases, the context in which a bone was found, such as in the presence of domesticated vegetation, likely plays an even greater role than in the investigation of more basic traits.

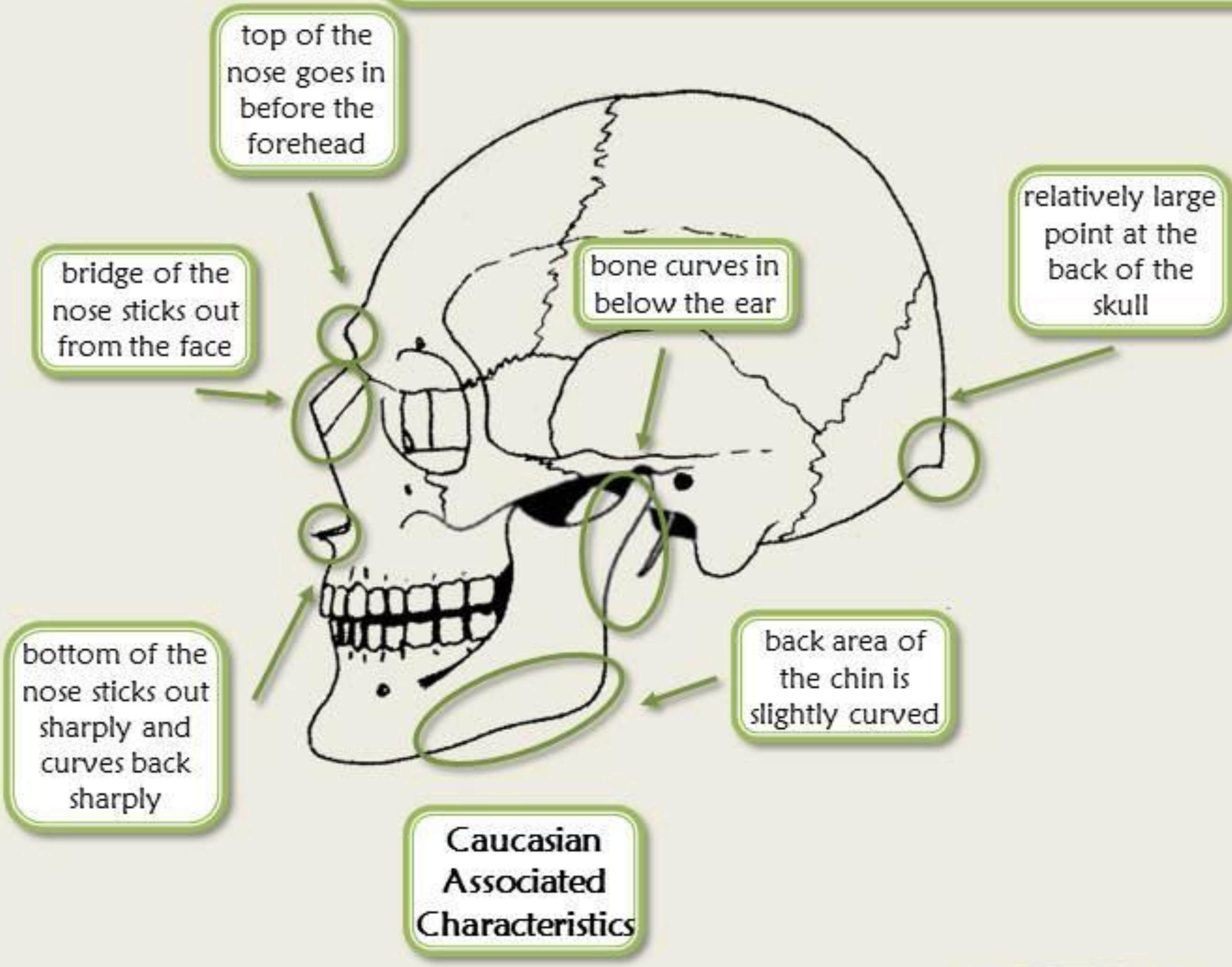
Examples

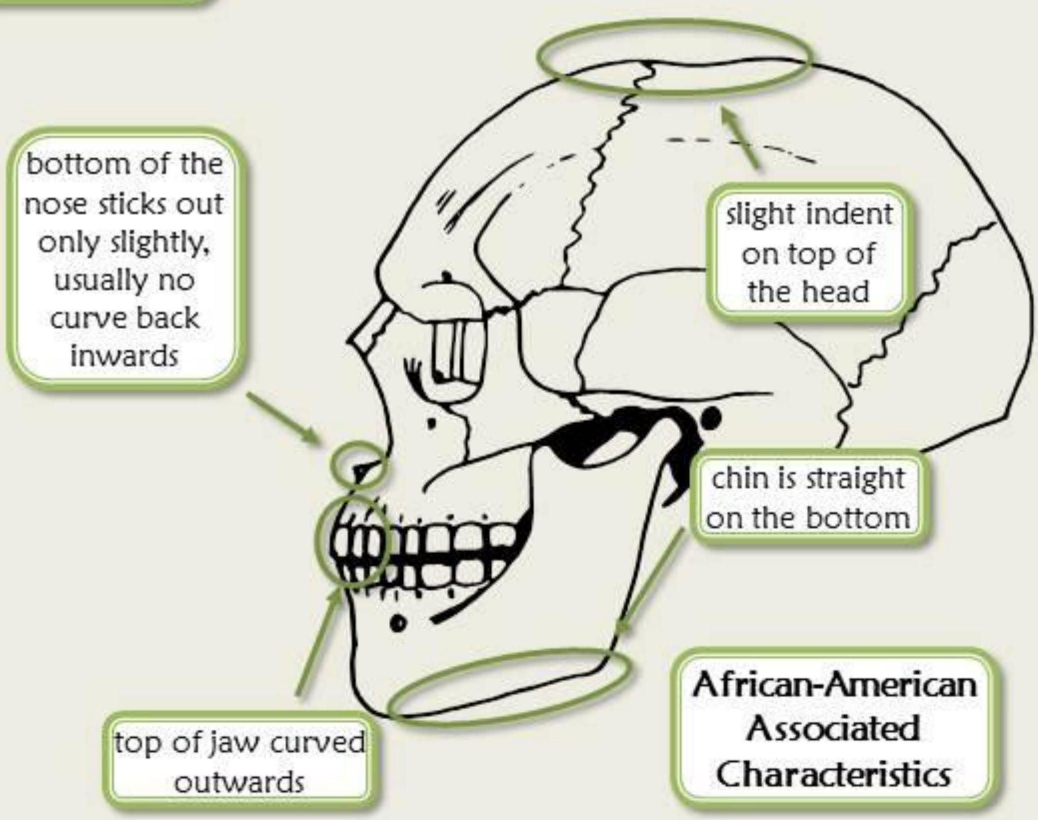
Each bone or fossil found might have any number of features that could be analyzed by a forensic anthropologist or bioarchaeologist to determine specific information about an individual or society to which that individual belonged. The following section describes a few examples of traits that can be investigated by measurements of certain features on specific specimens. This section should give a small insight into the vast amount of knowledge that has been accumulated about variation between and among traits of different bones, as well as the complexity of determining certain facts about individuals.

The first thing that is determined about a bone found at a dig site is what species it belongs to. It is often the case where it is relatively simple for a trained eye to determine whether a bone is human, based on the fact that our morphology is relatively different from most animals, and often investigators have a basic idea of what kind of remains they should be finding (e.g. an investigator is unlikely to find the bones of an ape naturally deposited in United States). There are a few cases, though, in which this determination can be surprisingly difficult. For example, the bones of a bear paw can look deceptively like a human hand (3). Also, if the remains are fractured, or if there are infant remains, they can be accidentally attributed to the remains of small animals. However, it is often the case that with careful examination by an expert, morphology will yield enough evidence to determine if remains are human or not.

The following is information about how an investigator might go about determining traits from specific bones found at a dig site:

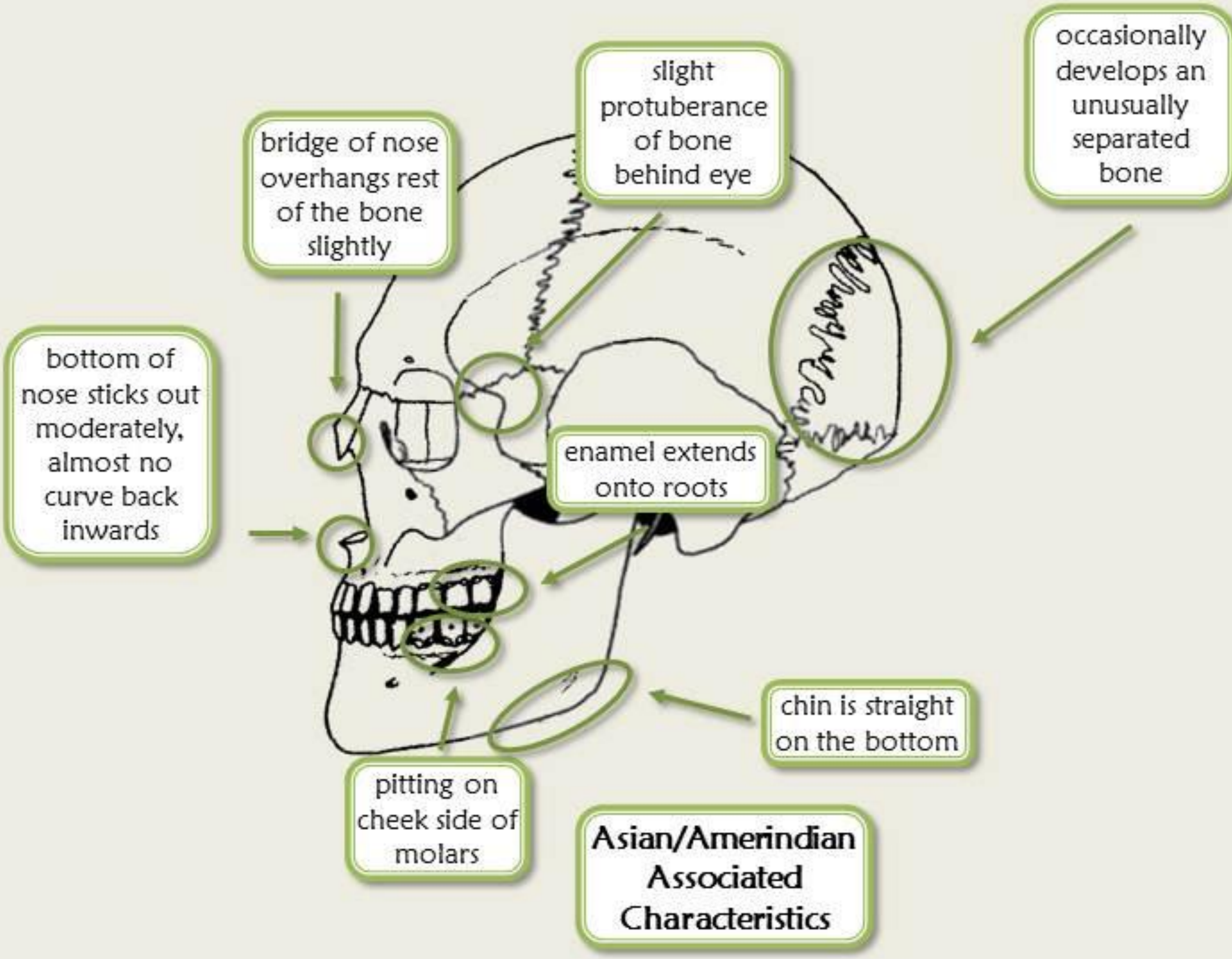
Skull: Assessing





Images from: Klepinger, Linda. (2006) *Fundamentals of Forensic Anthropology*. Hoboken, NJ: John Willey and Sons, Inc.

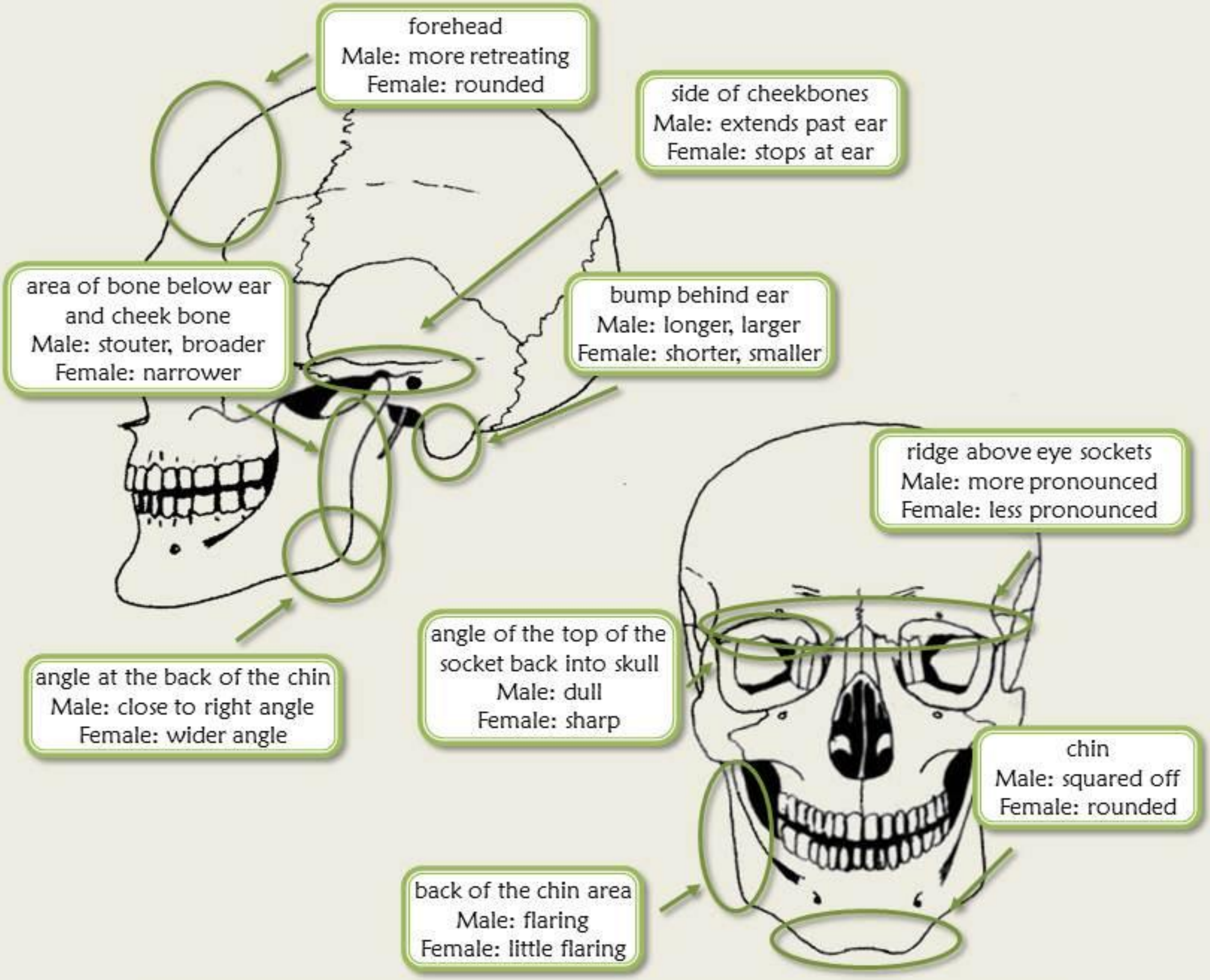
Ancestral History



Something that is often useful to forensic anthropologists, and may sometimes be of interest to bioarchaeologists, is the ancestral history of the subject to whom remains belong. Certain genetic markers have been shown to cluster into five major groups that generally correspond to geographic regions: Africa, Eurasia (Europe and West, Central, and South Asia), East Asia, Oceania, and the Ameircas (3). However, genetic variation does not always contribute to phenotypic variation, and phenotypic variation is not always the results of genetic variation. This means that looking at the morphology of a skeleton is not as accurate as being able to test the DNA, but it is still possible to obtain some clues as to the individual's ancestral history. The majority of skeletal features that are indicative of a certain ancestry are located on the skull, and a few of those features are noted here (3). It is also possible to get some information about ancestral history based on femur morphology, but variation in the femur is even less telling than the variation on the skull.

Images from: Klepinger, Linda. (2006) *Fundamentals of Forensic Anthropology*. Hoboken, NJ: John Willey and Sons, Inc.

Skull: Assessing Sex

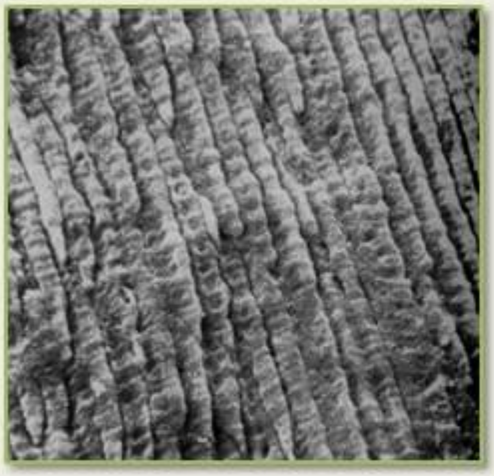


After the pelvis and femur, the skull may be used to determine the sex of an individual. However, due to a large amount of variation between individuals of a given population, the method is not entirely reliable. For any given population, there may exist a series of measurements of various features, some of which are described above, that can help investigators form equations that can predict the sex of an individual within a given level of confidence. These equations are based on measurements of the population and the value of each feature is given a weight based on how often that feature is an accurate predictor of sex. However, it is also possible for highly experienced investigators to "eyeball" it, which can yield an accuracy of about 75-85% (3).

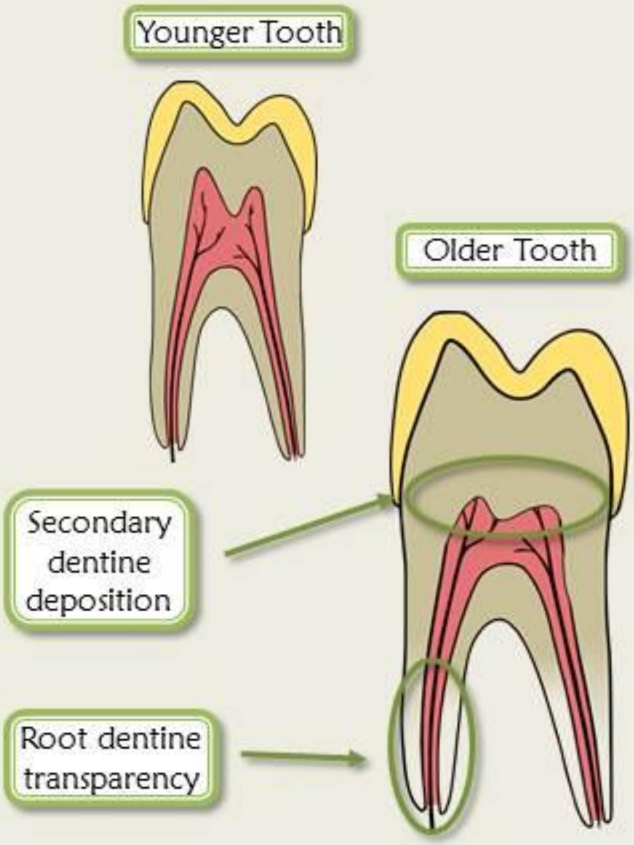
Images from: Klepinger, Linda. (2006) *Fundamentals of Forensic Anthropology*. Hoboken, NJ: John Willey and Sons, Inc.

Teeth: Assessing Age

Daily Enamel



The Later Years



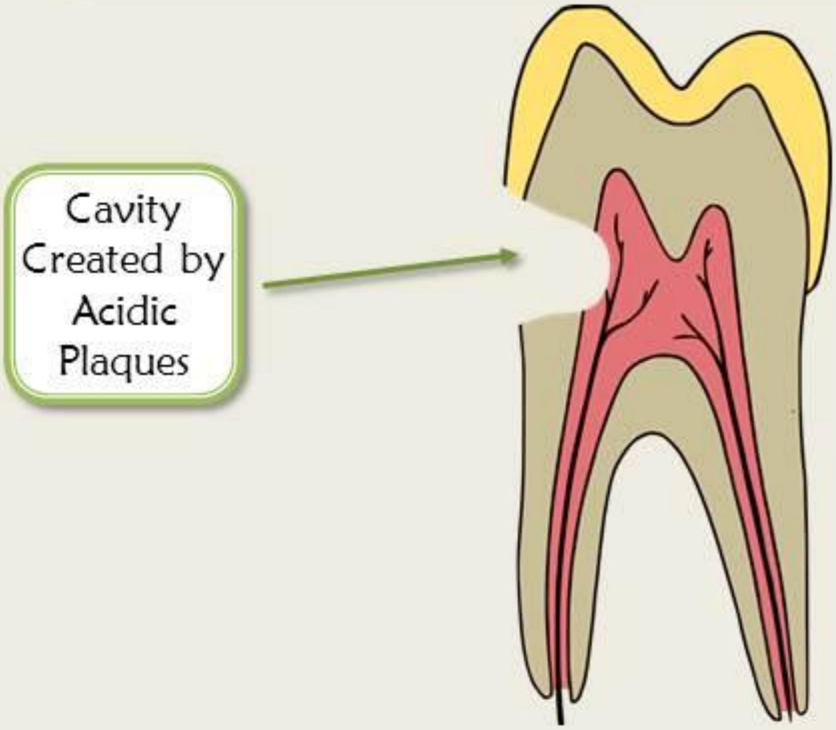
Teeth are seen as the gold standard for assessing the dental age at death of a particular individual. Dental age corresponds to particular points in development, but is only loosely associated with chronological age. There are several methods by which investigators can determine age based on teeth recovered from a dig site. Enamel is the hard covering on the outside of the crown of every tooth, and it is deposited on a daily basis. This regular, daily deposition allows investigators to track the precise age of a subject if the enamel is in good enough condition (4).

Other factors are also useful in assessing the age of an individual who is between the ages of 30 and 80. Traditionally this age range is difficult to assess by other methods, so any insight that can be gained is an improvement. The primary trait that is assessed in the transparency of the dentine in the roots of the tooth. Dentine is another tissue located in teeth, below the enamel and surrounding the inner cavity filled with pulp and nerves. Upon aging, some tubules in the dentine empty and become transparent. The amount of transparency in the dentine is one of the most accurate predictors of age (4). The amount of secondary dentine, or dentine deposited in later years after initial tooth formation, also correlates vaguely to age, and can be used in conjunction with root dentine transparency (4).

For remains from young children, they can also look at eruption of teeth, but this is not particularly accurate.

Images from: Cull, Peter, ed. (1989) *The Sourcebook of Medical Illustration*. Parthenon Pub. Group. And Hillson, Simon. (2005) *Teeth*. New York, NY: Cambridge University Press.

Teeth: Assessing Diet



Inferences Made about Diet Based on Stable Isotopes (6, 7, 8)

Isotope	Area of Tooth Analyzed	High Levels	Medium Levels	Low Levels
^{13}C	collagen and carbonate from enamel	tropical grasses (e.g. maize)	marine plankton	other terrestrial plants
^{15}N	collagen from enamel	carnivorous; legumes; marine food source		terrestrial food source

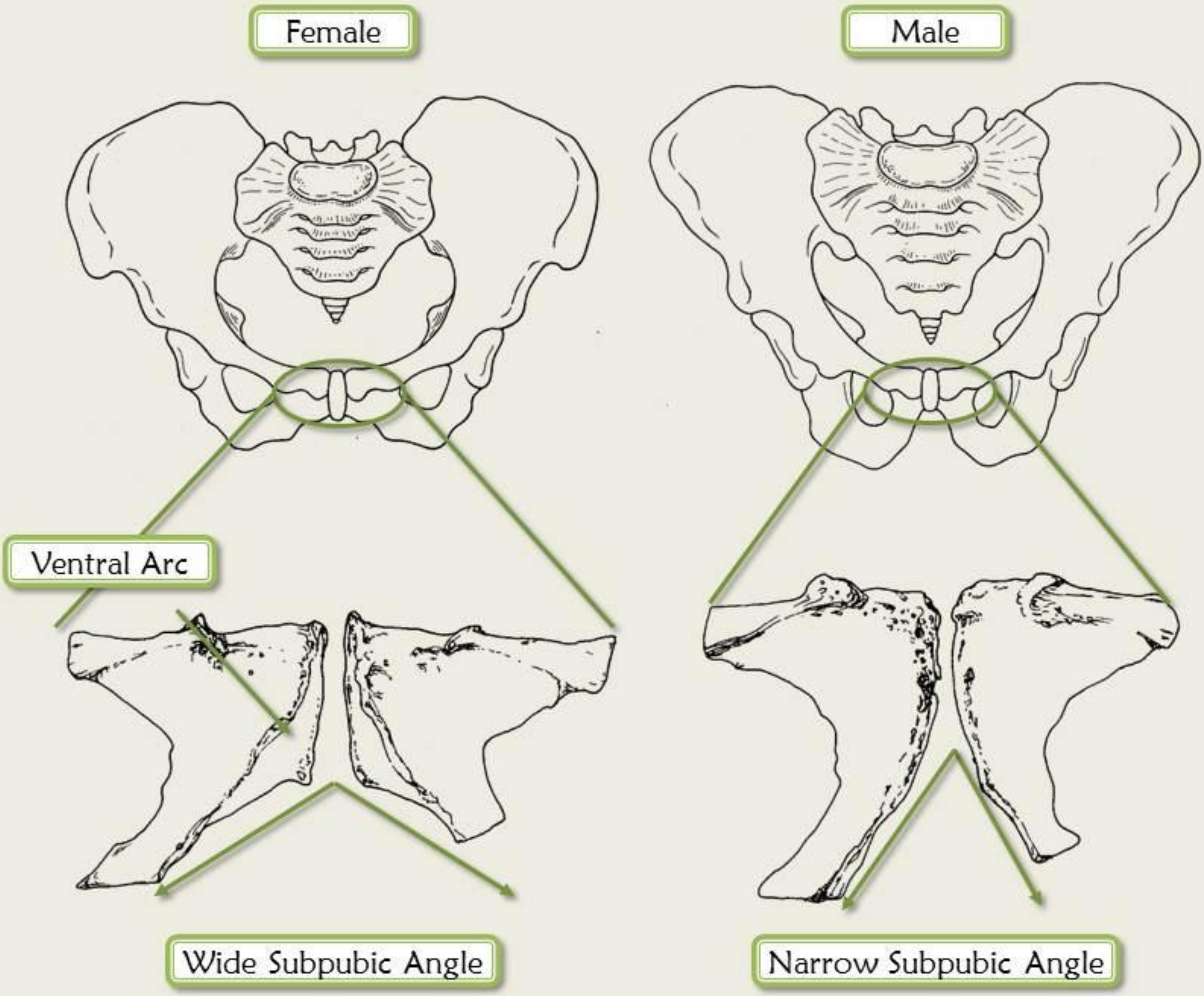
Not only are teeth the gold standard for assessing age of an individual, but they can also tell us more than most other skeletal structures about more abstract parts of an individual's life, such as diet. The amount, and pH of long term plaque can yield insight into the total amount of carbohydrates in an individual's diet (4). Acidic plaque implies higher levels of carbohydrates, whereas basic plaque implies higher levels of amino acids (4). The more acidic plaques are, the more they damage the teeth below them, which means that more sugar consumed leads to more cavities (4).

Investigators can also learn about the type of food consumed by individuals by analyzing the amount of certain isotopes found in different areas of the tooth. Common elements in life, such as carbon and nitrogen, and slightly less common elements, such as strontium, have isotopes that allow identification of particular sources of food or water. Carbon and nitrogen specifically can help distinguish between the primary source of nutrition coming from aquatic based life or terrestrial plants (4).

Strontium levels in groundwater vary across different geographic regions, so investigators can compare the level of strontium in a tooth to levels in the groundwater near where the tooth was found, or they can compare levels across different regions of the tooth that represent different periods in the individual's life (4).

Images from: Cull, Peter, ed. (1989) *The Sourcebook of Medical Illustration*. Parthenon Pub. Group.

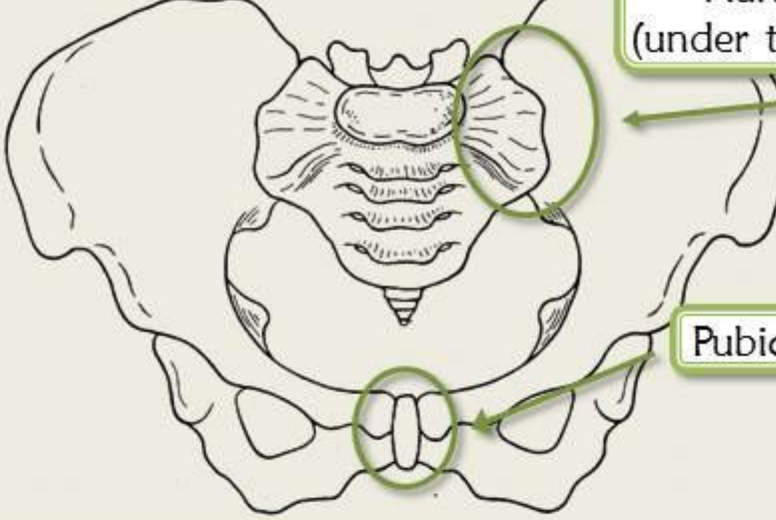
Pelvis: Assessing Sex



The pelvis is often thought of as the gold standard for assessing sex of an individual (3). The pressures of child bearing have forced changes in the female pelvis that do not appear in males. There are three main features that are used to assess sex, as shown on the pictures above. The presence of an arc along the edges of the pubis (due to remodeling of pelvic bone) is distinct to mature females. This ventral arc is one of the most accurate traits used to assess the sex of an individual, yielding up to a 96% accuracy rate (3). However, it has been suggested that this level of accuracy heavily depends on the expertise of the investigator. Adding other traits, such as subpubic angle, as well as the width of the pubis, increases accuracy, especially with less experienced investigators (3).

Images from: Cull, Peter, ed. (1989) *The Sourcebook of Medical Illustration*. Parthenon Pub. Group. And Sutherland, Leslie, and Suchey Judy. (1991) "Use of the ventral arc in pubic sex determination." *J Forensic Sci.* 36(2):501-11.

Pelvis: Assessing Age



Suchey/Brooks Method for Determining Age Based on Pubic Symphysis

Male

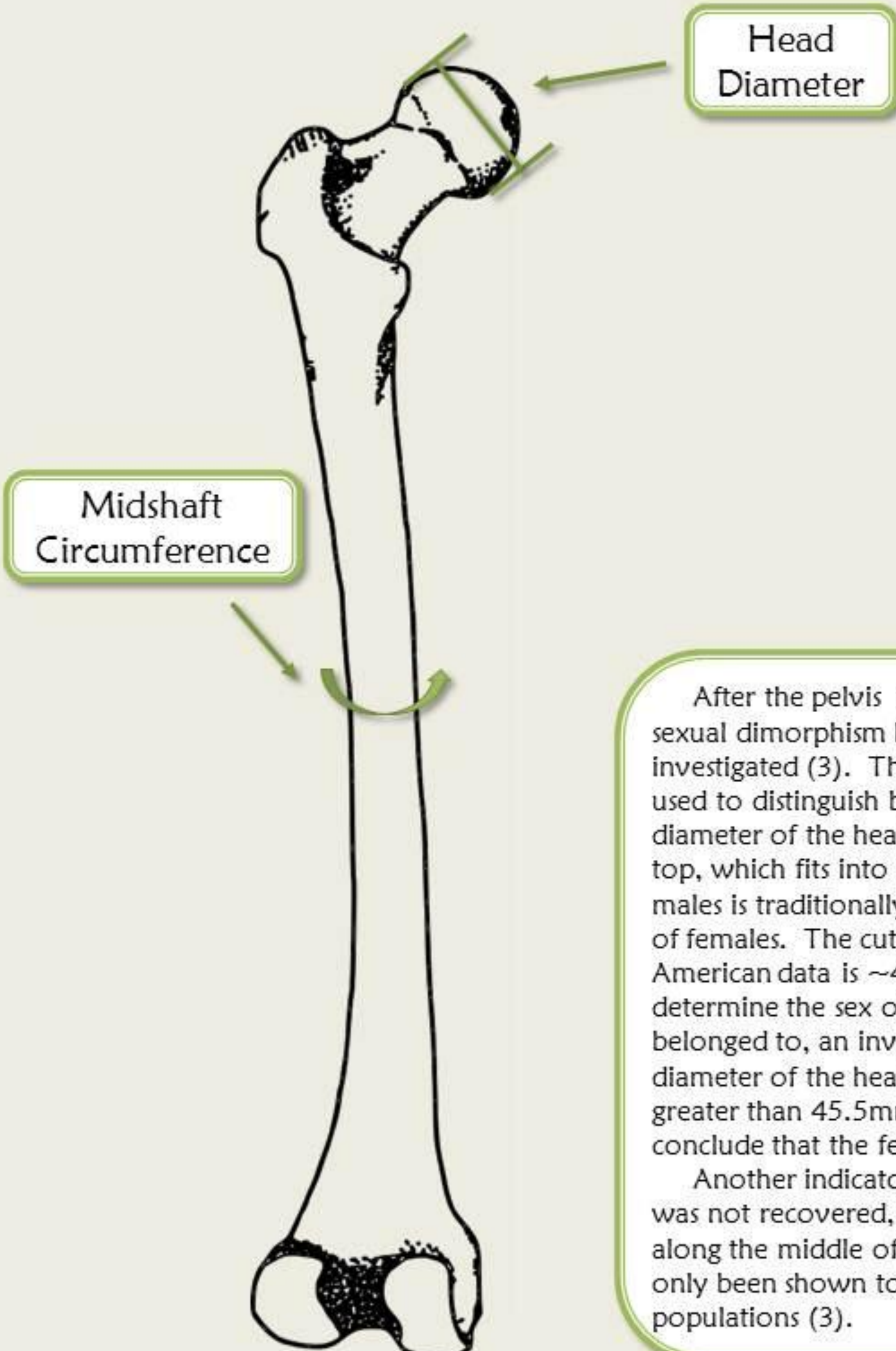
Female

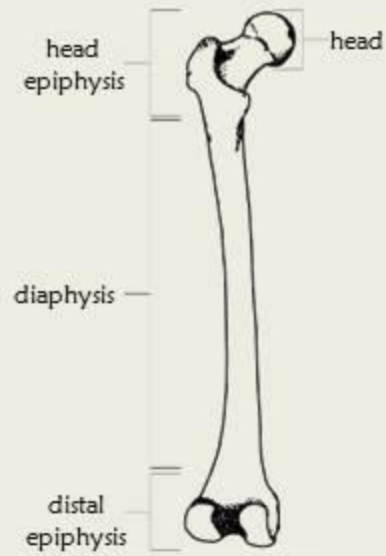
There are two regions of the pelvis that have been relatively well studied for determining age. These regions are the face of the pubic symphysis, or the part in the front that joins the left and right half, and the auricular surface, which is a small area on the inner side of the big flat part of the bone. Both of these regions change in morphology over the course of an individual's life. The pubic symphysis also turns from cartilage into bone (3).

The morphology of these two areas, however, is hard to assess without a trained eye. The pubic symphysis looks less wavy and more oval as an individual ages (10). The auricular surface looks less grainy and more dense as an individual ages (11). The methods used to assess them involve grading certain aspects of morphology, then categorizing a sample into one of five or six phases. However, neither of these two methods has been full defined to include the full spectrum of variation (3).

Images from: Cull, Peter, ed. (1989) *The Sourcebook of Medical Illustration*. Parthenon Pub. Group. And Sheridan, Susan G. "Pubic Symphysis Morphology." Byzantine St. Stephen's. University of Notre Dame. <http://www.nd.edu/~stephens/index.html>.

Femur: Assessing Sex



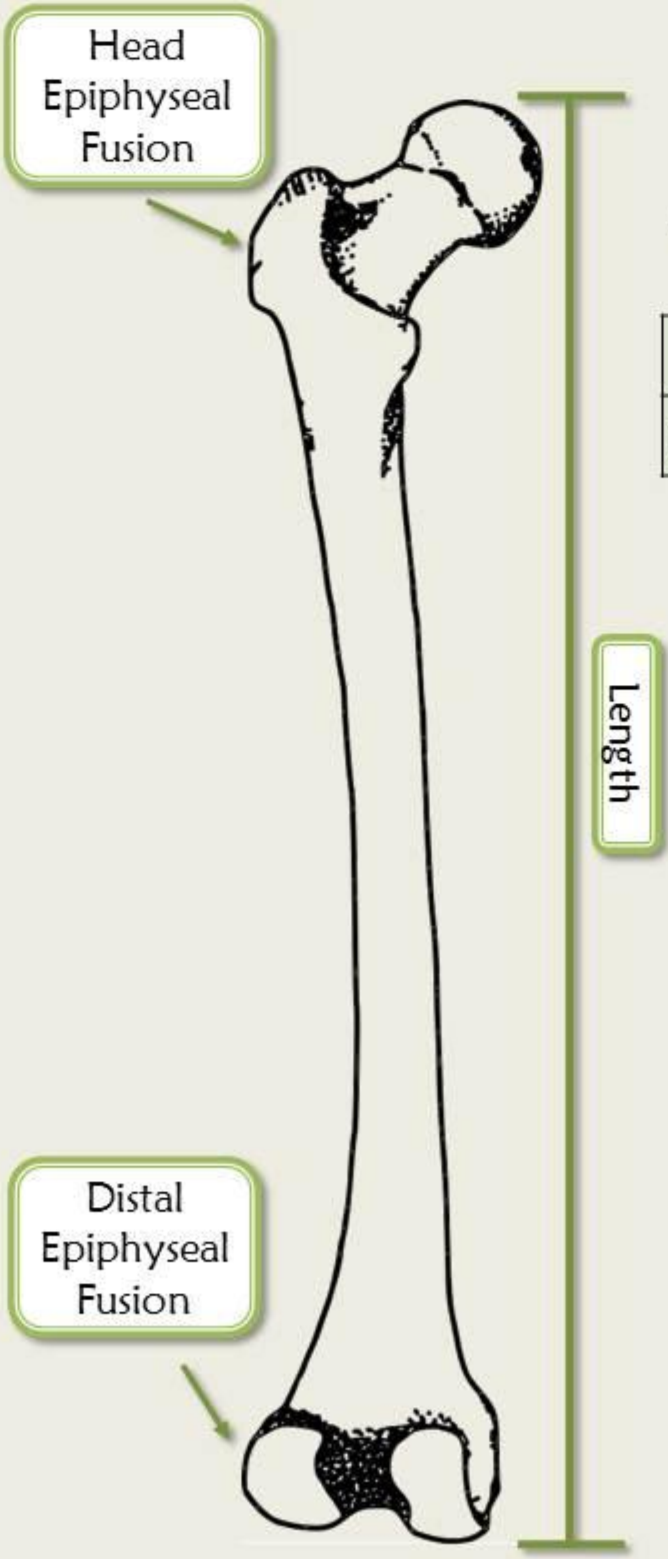


After the pelvis the femur is the bone whose sexual dimorphism has been most thoroughly investigated (3). The primary way that femur is used to distinguish between males and females is the diameter of the head (3), or the knobby bit on the top, which fits into the pelvis. The head diameter of males is traditionally larger than the head diameter of females. The cutoff point best fit to modern American data is ~45.5mm (3). So in order to determine the sex of the individual that a femur belonged to, an investigator would measure the diameter of the head and if the diameter was greater than 45.5mm, the investigator might conclude that the femur belonged to a male.

Another indicator that has been used, if the head was not recovered, is the circumference of the bone along the middle of the shaft. However, this has only been shown to be effective for particular sub populations (3).

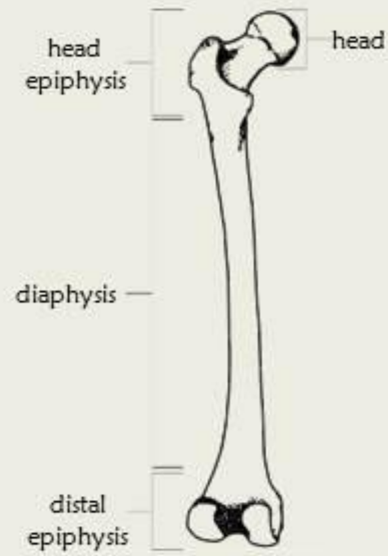
Images from: Weaver, Timothy. (2003) "The shape of the Neandertal femur is primarily the consequence of a hyperpolar body form." *PNAS.* 100(12):6926-6929.

Femur: Assessing Age



Age (in years) of Head and Distal Epiphyseal Fusion

		Beginning of Fusion	Fusion Complete
Males	Head	14	19
	Distal	14	20
Females	Head	12	16
	Distal	12	18

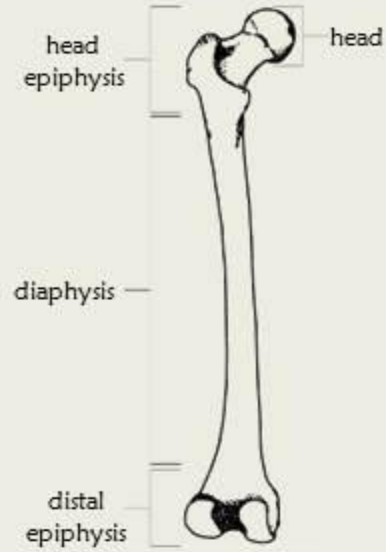


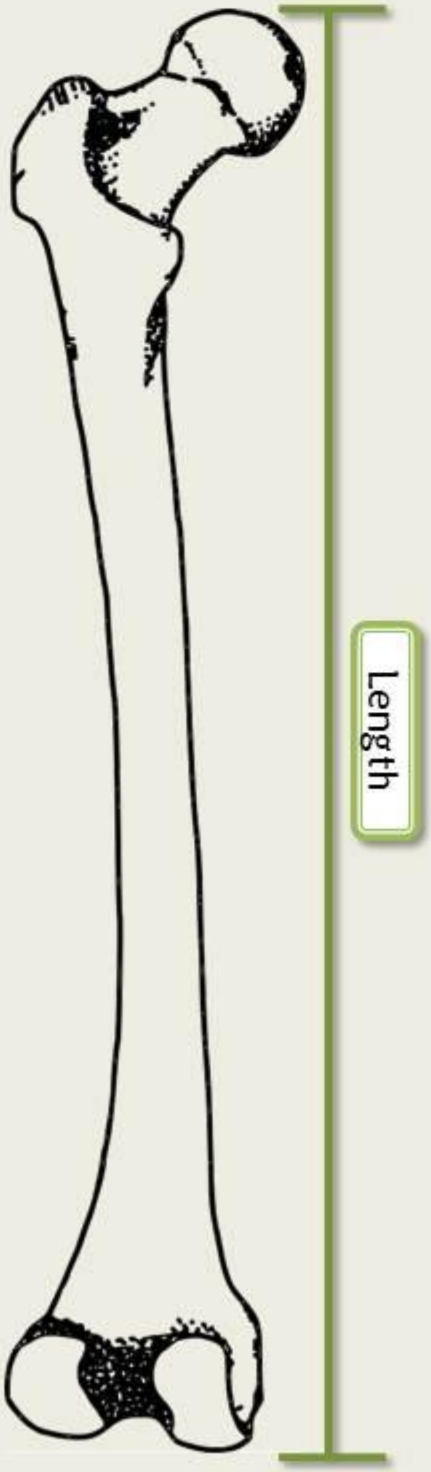
The femur can also be used in gaining an assessment of the age of the individual to whom it belonged. However, it is only effective to predict the age of an individual whose age of death was approximately 20 or less. The length of the femur has been shown to directly correlate with age up until age 12 (3).

Within the femur, as with most long bones, there are three distinct regions, the head epiphysis (or the top knob area), the diaphysis (the middle), and the distal epiphysis (the bottom knob area). Before early adolescence, each of these regions is partly bone, but separated by plates of cartilage. As individuals progress through adolescence, the bony (or ossified) top and bottom regions begin to fuse with the bony middle regions. The progression of this fusion can be used to predict the age of males from 14-20, and females from 12-18 (3).

Images from: Weaver, Timothy. (2003) "The shape of the Neandertal femur is primarily the consequence of a hyperpolar body form." *PNAS.* 100(12):6926-6929.

Femur: Assessing Stature





The femur along with other long bones, can be used in estimating the stature of an individual, given the individual's sex (3). This estimation of stature is based entirely on the length of the femur. There are a variety of equations that an investigator might use to estimate height based on the length of the femur, but many also involve the length of other bones as well. Seen below are an example of equations that use only the length of the femur to estimate stature. These equations were developed by measuring the length of the femur of a large number of individuals of known age, then creating regression curves to estimate the relationship between age and length (3).

Equations to Convert Femoral Length to Stature

	Equation (cm) (3)
White Males	2.38*length of femur + 61.41
Black Males	2.11*length of femur + 70.35
White Females	2.47*length of femur + 54.10
Black Females	2.28*length of femur + 59.76

Images from: Weaver, Timothy. (2003) "The shape of the Neandertal femur is primarily the consequence of a hyperpolar body form." *PNAS.* 100(12):6926-6929.

Other Analysis Types

Aside from measuring or otherwise assessing a variety of morphological traits, there are several other ways an anthropologist might learn from a bone. They might, for example, look at the bone chemistry. As discussed above for teeth, ratios of different stable isotopes can yield information about diet and geographical location.

Ratios of radioactive isotopes, specifically ^{14}C, can tell us about the absolute age of a bone. This is based off of the idea that we all have a certain amount of radioactive ^{14}C that we obtain from the atmosphere by way of carbon fixation by plants, and that ^{14}C decays at a very specific rate. Once an organism is dead, it is no longer incorporating radioactive isotopes into itself, and the radioactive isotopes already present begin to decay steadily. This means that we can estimate the absolute age of an organism by examining the ratio of ^{14}C to the normal, stable, isotopes of carbon (^{13}C and ^{12}C). The half-life of ^{14}C is 5730 years, so 5730 years after an organism dies, it should have half the ratio of ^{14}C to stable carbon isotopes as compared to a living organism (2). Due to limitations in our detection methods, carbon dating can only accurately measure of the age of things that are between 400 and 50,000 years old (2). This is great for bioarchaeologists, but not particularly useful to forensic anthropologists if they are studying more contemporary subjects.

Another identification agent, which has mainly come into prominence in recent years, is DNA sequencing. DNA is most easily sequenced from more recent human remains, but can be sequenced from remains up to, potentially, 100,000 years old (13). Currently, however, the oldest sequenced hominid DNA is from samples that are approximately

40,000 years old (13). This DNA from earlier hominids can give us information about the evolution of humans from distinct ancestors. The DNA analysis of more recent humans can tell us about the evolution and large scale migration patterns of current humans. As new ways to interpret sequences of DNA are emerging, DNA analysis will begin to yield even more interesting information about disease, diet, behaviors, etc. However, we are not yet at a point where DNA sequencing of current humans can serve as more than a unique identifier or potentially display predisposition for certain diseases.

Summary

Forensic anthropologists and bioarchaeologists use a variety of methods to investigate human remains, including observation of morphological variation, analysis of stable and radioactive isotopes, application of context that remains are found in, and DNA analysis. There is a great deal beyond what I have mentioned that goes into the classification and determination of traits from skeletal remains, but it would be impossible to fit it all. This paper should have provided a taste for what an investigator might look for in a set of remains to determine age, sex, ancestral history, or diet. Though what is listed here may seem relatively straight forward, classification of remains are often severely complicated by fragmentation of sample or limited information about a reference population.

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