Drew University

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The Intersection of Art and Science: The Methods Behind Forensic Facial Reconstruction

A Thesis in Anthropology

by

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ABSTRACT

The field of Forensic Facial reconstruction is a relatively new process within the sciences. Despite how new it is, the field is widely known within the anthropological community for the ability to help identify unidentifiable individuals when other techniques or methods fail. However, due to the recent development of the field there are a number of issues within the discipline that stem from a lack of research. This thesis not only lays out the methodologies and underlying processes that exist within the field as well as reviews the literature surrounding them, but also aims to outline current issues within the field and even possit solutions, especially dealing with issues of accessibility. It also aims to analyze and test methods of 3D computerized reconstruction within free software, in order to determine which is the most useful and ultimately evaluate how adaptable they are. In order to do this, a 55 year old female skull was analyzed from the records of CT scans found within The Cancer Image Archive. Additionally, a method for this process of accessible computerized reconstruction was created using the online programs sketchfab, zbrush, and a popular animation software called Blender. Beginning with a historiography of the field, this thesis is composed of eight individual chapters that all add a unique perspective to the process and development of Forensic Facial Reconstruction.

ACKNOWLEDGEMENTS

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INTRODUCTION

WHAT IS FACIAL RECONSTRUCTION & THE DIFFERENCE BETWEEN RECONSTRUCTION AND APPROXIMATION

Craniofacial reconstruction is the process of recreating the antemortem likeness of an unidentified set of remains. It is a means for producing a facial surface from the skull and is often employed in the context of forensic investigation as well as the recreation of people from the past, ranging from ancient Egyptian mummies to bog bodies and even digital animations (Evison et al. 2016, p4; Wilkinson, 2010,). It can be used to identify unknown human remains when other techniques fail (Gupta et al. 2015). The process is generally conducted by an expert in anatomy, but the discipline involves many different areas of study including artistry, forensic science, anthropology, and osteology.

While the terms reconstruction and approximation are often used interchangeably it is important to note that they convey different meanings. Martin Evison explains that the "...term reconstruction is used to refer to both the process of restitution of a facial surface from that of the skull, as well as to the finished article" (Evison et al, 2016, p5) and that "Reconstruction, however, is an ambiguous term. It should not be taken to imply that the result is an exact likeness of the antemortem face. This outcome is probably impossible to achieve" (Evison et al, 2016, p5). Because of this difficulty, reconstructions are really only approximations, attempts to capture as much of the likeness as possible.

GOAL OF THIS UNDERGRADUATE THESIS

Facial reconstruction has fascinated me ever since I first heard about it. I was exposed to the concept through archeological reconstructions done on an Egyptian mummy in addition to forensic elements found within popular television shows. I always loved the idea of combining science and art. I am also fascinated with the process and am interested to see how much information this field can offer and how it can, as a result, influence forensic cases as well as the archeological record. With crime and detective television shows becoming more popular today, these methods are becoming much more known. However, they are not showcased correctly, with the processes being oversimplified or completely inaccurate. I am also interested in the different uses of facial reconstruction. While it is most commonly used in forensic cases, it is also an extremely valuable tool in the study of the archeological record. It not only gives life to ancient peoples or even other creatures, but it allows present day individuals to come "face to face" with their past.

The goal of this thesis project is to understand the method of forensic facial reconstruction from its birth to its current uses today, as well as to learn about the process involved in creating a face from just a skull, both manually and digitally. It will incorporate an overview of the current practices that exist within the field as well as a discussion of their benefits and drawbacks. I will also attempt a creation of my own, using the materials and methods I have researched. I hope to analyze the accuracies of the methods as well as to assess how understandable and accessible they are. I also hope to acknowledge some of the issues within the field and propose solutions such as the use of photogrammetry as a means to solve accessibility problems. Lastly, I hope this undergraduate thesis will serve as a great learning experience that will hone my research skills and give me practice for further work in this field in graduate school.

THE HISTORY AND DEVELOPMENT OF FORENSIC FACIAL RECONSTRUCTION

There have been and currently are many arguments surrounding the ethics regarding the dead and even the display of remains within museums. However, much can be learned through analysis of human remains - including the skull which can survive for centuries, even millions of years (Verzé, 2009, p5). Skulls also can provide an unrivaled means of identification that allow reconstructionists to solve forensic problems as well as generate interest and answer questions in a broader context. In the past, facial reconstruction from the skull was used for recognition of the deceased and more recently, for teaching anatomy (Verzé, 2009, p6). The earliest known usage of reconstruction methods dates back to the pre-pottery neolithic B culture circa 11,000 – 8,000 BP (Evison et al. 2016, p4). At this time, the inhabitants of Jericho, in the Jordan valley, would traditionally bury their dead under the houses in which they lived. They also followed the custom of separating the skull from the skeleton, often without the lower jaw and burying it separately (Verzé, 2009, p6). This absence of the mandible is not easily explained and can likely be attributed to a form of ancestor worship (Verzé, 2009, p6). These people became the first to reconstruct the face, using plaster to build on top of the skull. Excavations in 1953 revealed that nine skulls had faces built up in plaster over the bone, with cowry shells set into the eye-sockets to substitute as eyes (Verzé, 2009, p6: Evison et al. 2016, p4). After the plaster was applied the skin and any notable facial features, such as mustaches, were painted on the surface. These reconstructions are believed not to represent an ante-mortem likeness beyond "some features determined by the bony framework" (Strouhal 1973, p231). Other cultures have also experimented with facial modeling such as a skull from the New Hebridean Islands dating to AD 1700 (Verzé, 2009, p6). Despite these early attempts to recreate the face, nine millenia would pass before the first scientific attempts to reconstruct ante-mortem appearance were to arise (Evison et al. 2016, p4).

Throughout history, identification of the dead has been difficult. In the Middle ages the dead were left out along the street for identification by the public. This later became only the head, so as to avoid having decomposing bodies in the public spaces (Tyrell et al. 1997, p653). Death masks have been used by many different cultures in order to capture a realistic likeness of the dead. However, these masks were modeled on the superficial features of the face, ignoring the underlying structures of the anatomy and musculature (Verzé, 2009, p6). It also became complicated when the body began to decay and the process, such as bloating, caused facial deformities (Tyrell et al. 1997, p654). The main purpose of the death mask from the Middle Ages until the 19th century was to serve as a model for sculptors in creating statues and busts of the deceased person. Many of the techniques and knowledge that we have today comes out of a practice of anatomical study and dissection. In the Renaissance period, artists from northern Italy were the first to provide wax models for doctors and surgeons. This was because artists had the unique ability to reproduce what they saw from the 15th century tradition of human dissection for the purpose of anatomical study. Andrea Vesalius (1514-64) radically transformed anatomy teaching, making wax models commonplace in medical schools, and life-size waxes became substitutes for cadavers (Verzé, 2009, p8; Tyrell et al. 1997, p654). The field began to grow as empirical science became increasingly more relevant in the 18th and 19th centuries. Other artists such as Giulio Gaetano Zumbo (1656-1700), Abraham Chavet (1704-1790) and Ercole Lelli (1702- 1766) can be created with the foundation of the basic principles used in the discipline of facial reconstruction that is “from the shape and proportions of the skull can be inferred how the muscles were attached and shaped, defining the parameters of the face; anatomical correctness was important, rather than an exact likeness” (Verzé, 2009, p7). Ercole Lelli was an Italian painter of the late Baroque period. Starting in 1742, Lelli began to create anatomical models for the University of Bologna, where he would combine wax models with the actual human skeleton to create anatomical masterpieces for use in teaching. “He and his colleagues pioneered the development of scientific art and were the first sculptors to realize that the skeleton is the ideal frame upon which to build the musculature and the body" (Verzé, 2009, p7).

The face and the later development of methods began to gain importance in the 19th century. Before this period there were virtually no scientific methods for identifying the dead. Additionally, there was no justice system and the methods for prosecuting suspected criminals were rather crude and unethical. In ancient times, the manner of death was assumed by where the body was found and how the victim was found - rather than investigating the circumstances surrounding the death (Universal Class). For example, if a body was found within a body of water, it was assumed that the victim was drowned. Suspected motive and the word of others against possible murders took precedence over all else and when that failed, torture was readily available (Universal Class). Essentially, suspects would be tortured until they confessed. Suspects were subjected to other methods as well. One of these common methods was to throw the suspect into water and if he drowned then he must have been guilty (Verzé, 2009, p7). Other methods were to drag the suspect towards their presumed victim and he was proven guilty if the corpse's wounds bled (Verzé, 2009, p7). The application of anthropometry, or the early science of measuring the human body, became important in the 19th century as well. Anthropometry is the longest used measure of human variation. Through the analysis of morphological traits and characteristics the differences in human physical variety can be understood (Ulijaszek et al, 2010, p183). However, in the 19th and early 20th centuries anthropometry was used to create and validate racial typographies as well as assess the physical features of criminals (Ulijaszek et al, 2010, p184; Macdonell, 1901). Alfonse Bertillon (1853-1914) proposed a method of identification in 1879 using anthropological body measurements. This system involved the measurement of 11 specific points using calipers and other measuring tools (Yeshion, 2014, p46).

These points include: Length of left foot without shoe, Length of right ear, Width of right ear , Circumference of head, Circumference of right wrist, Length of left middle finger, Length of left little finger, Length from left elbow to end of middle finger, “Wingspan” measurement – tip of left middle finger to tip of right middle finger , Height, Length of trunk In addition to physical measurements. He argued that the odds of two people sharing the same measurements would be 4 million : 1 (Govan, 2020). Bertillon also recorded physical descriptors of the person (i.e., hair and eye color), including any unusual markings on the body (i.e., tattoos and scars). This was known as Portrait Parle or a speaking portrait that described many personal characteristics. Lastly, Alphonse included frontal and side-view photographs of each person, which we recognize today as mug shots (Yeshion, 2014, p46).

In order to understand forensic facial reconstruction it is first important to understand why human remains were collected and why they ended up in museum collections. This collection of human remains and their relationship to museums began can often be traced back to colonialism and the slave trade around the mid 1700s (Mancall, 2011). It is also important to note that before this date, private collections would have included human remains, however there were not many museums present before the 1700s. It began with European colonizers bringing American humans, both living and dead, to Europe in order to reform their behavior and make them indistinguishable from their European counterparts. Those captured were viewed as less civilized and less intelligent. Proceeding from this belief, early scientists worked to support their theories through studies of the remains. Massive repositories of human remains were collected and stored in so-called "bone rooms" for scientific study beginning in the mid-nineteenth century (Monza et al, 2019).

The history of these “bone rooms” is unfortunately linked to the history of the study of race. As bodies were found and preserved they were also studied. These bodies often offered opportunities for understanding prehistoric man but many people also used them to study and or prove scientific theories about race.

> “When new bodies were discovered, the first questions usually focused on the racial origin of the mysterious bodies and their relationship to the modern races of the Americas. While the age of these mummies made them an important rarity, the primary purpose for collecting and permanently preserving new skeletons was to fit them into the puzzle that was the taxonomy of race. Nineteenth-century scientific publications and debate about racial divisions seemed only to fuel popular desires to collect human skeletons and mummies. Museums in the United States, aiming to catch up with their older European counterparts, began collecting bodies in North America with heretofore unseen zeal” (Redman, 2016).

The science of comparative anatomy emerged in the second half of the 18th century, when Dutch anatomist and artist Petrus Camper, English surgeon and anatomist John Hunter and German Professor of Medicine, Johann Friedrich Blumenbach all developed quantitative methodology to distinguish between cranial types. This later became known as craniometry which used specific measurements of the skull and face to hierarchically rank different races - with those considered more inferior to be linked more closely to animals. The theory was that the measurements of the braincase, or length in ratio to width of the head, showed the intelligence of the individual- with smaller measurements showing a lesser intelligence. Additionally, the facial traits were analyzed, with traits commonly found in Africa and Asia, such as a sloping of the face - called prognathism, more closely linked to a lack of intelligence. In order to do much of this research, these physicians had to collect hundreds of skulls and remains from across the world. This kind of collecting became a common practice during this time in the 18th century with human remains being collected for their exotic or novelty value.

Additionally, the pseudoscience of phrenology became popular at this time. It was based on the idea that the brain was actually made of different organs that determined the shape of the skull - and therefore intelligence could be measured by analyzing measurements of the skull. This pseudoscience utilized both human remains and a great many replicated skulls and casts, many of which are still held in modern institutions. “Phrenology provided another market for human remains from across the world particularly because it often relied on the physical presence of the ‘head’ for assessment” (Clark, 2010, p9). “This market spread further than institutions of learning to institutions of medicine, in particular those treating mental illness” (Clark, 2010, p 8). Phrenology also provided methods that allowed untrained amateurs to take up the study and created an additional market for the collection of human remains (Clark, 2010, p 9).

With the rise of Charles Darwin's discoveries, the theories of phrenology fell out of favor. “To Darwin the ‘primitive’ races were not the degenerate offshoots of the Caucasians or separate species, but rather humans on a different step of the evolutionary ladder” (Clark, 2010, p 10). This created another reason to collect human remains, that being to find evidence of this evolutionary process.

ETHICS

Many of the ethical debates that surround this field and others like it take their root in the display of the dead. While this idea is less important in craniofacial reconstruction, the field does have its own ethical considerations. The main ethical questions that surround this field have to do with proper consent for the acquisition of documented data from known individuals, protection and proper storage of data, and appropriate scientific utilization of the data. This also means that the data used in creating methodologies should be taken from both deceased and living individuals, which will allow for a database for future applications and research. Ethics in facial reconstruction also involves the respect of both the living and the dead. According to the article Ethical and Legal Issues in Craniofacial Superimposition, written by three facial reconstruction specialists Sergio Damas, Oscar Cordón, and Óscar Ibáñez "The family is essential in this whole process, through the cooperation they can provide by making available photographs, personal details, and otherwise assisting in the identification process. It is undoubted that cooperation on the part of relatives in the collection of ante-mortem data enhances the quality and speed of identification measures. However, we must not forget that they may need psychological support, and we must be able to provide it in every situation. They also deserve to pay a last tribute to their dead, so we should do our best to enable it in every situation." (Damas et al, 2019). The respect and proper handling of the dead also plays an important role. The Universal Declaration on Bioethics and Human Rights aims "to promote respect for human dignity and protect human rights" (2012). Given these issues, we can say that victims are to be treated with dignity and respect. Everyone, dead or alive, deserves to be identified.

Other ethical concerns that have not been discussed as frequently within the field have to do with artistic bias. While the dead should be properly treated, they should also be properly represented, without outside influence. Professionals should do their absolute best to present the proper facial characteristics based on education, training and experience. They should comply with all relevant laws, regulations, and policies that relate to the acquisition, security, and use of data in this project and ensure that all scientific procedures meet professional standards. One other aspect of this, has to do with facial expression. It is important to accurately represent the individual, but this may become problematic with age and expression. As a result of this issue, the professional should use proper scientific data in order to accurately assess age and correctly represent it in the face. There is no one way to show age, especially when wrinkles can be unpredictable. Using data is the best source we have for this and should therefore be utilized.

THE USES OF FORENSIC RECONSTRUCTION TODAY

Anatomists were the first to attempt to create ante mortem likenesses of the dead. The modern methods grew out of a fascination with recreating the faces of famous individuals from the past. Hermann Welcker (1883) and Wilhelm His Sr. 1895) were the first to reproduce three-dimensional facial approximations from cranial remains (Wikipedia Selection for Schools, 2007; Verzé, 2009, p7). Welcker was an anatomist who used two dimensional techniques to provide orthogonal perspective drawings of skulls and death masks. He then superimposed these outlines of the drawings onto a real skull. He also compared the likeness of Rapheal's self-portrait with what was supposedly thought to be his skull and compared the skull with the death mask of Kant (Verzé, 2009. p7). Welcker is also famous for his research, as he was the first to document facial depths as a means of measuring and applying it as a technique for the the use of facial reconstruction (Verzé, 2009, p7).

Today forensic facial reconstruction is used in two principal contexts: forensic science and archeology. In the forensic context it plays an important role in identification of the dead where post-mortem deterioration has made this problematic. Sometimes forensic facial reconstruction is the only option when remains are badly decomposed or postcranial remains are not present (Rodriguez, 2018, p19). In archeology, it is used to create three-dimensional visual images of people from the past, from skeletal remains, mummified bodies, or bodies preserved in bogs (Wilkison, 2010).

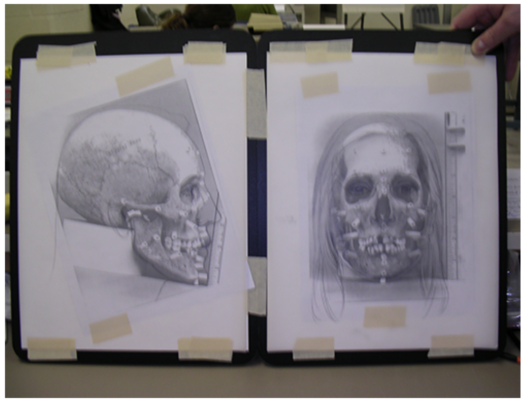
Facial reconstruction is a great asset to forensic cases, as it allows analysis and even identifications to be made when there is damage to the remains of the body, often due to animal scavenging, taphonomic processes and/or physical attacks such as those caused by grave robbers or ante mortem injuries to the remains. There are two methodologies that exist today, including two dimensional methods as well as three dimensional methods. These methods can be used in two ways; either manually, or through the use of digitization and software (computerized) (Gupta et al. 2015). There are three distinct techniques of 3D reconstructions, they are the Anatomical or Russian method, the Anthropometric or American method and finally the combination or Manchester method. This is also known as the British method. All three methods involve the collaboration of artists and forensic anthropologists (Gupta et al. 2015; Yadav et al. 2010, p39). The following section aims to explain and analyze each method.

TWO DIMENSIONAL METHODOLOGIES

2D Artistic Drawing

This is the most simple technique for recreating the face. It is based on the soft tissue depth of the face from both the frontal view and from the side (lateral) view. After the markers are placed, a line is drawn on a partially transparent overlay, creating a contour of the face (Abate et al. 2004; Yadav et al. 2010, p40). This will become a reference for the later drawing involving the anatomical and anthropological knowledge of an identikit artist[1] These artists know and understand the rules of the face, for example the width of the nose is the same distance as is the measurements from the inner corner of the eye to the outer corner and the placement of the corners of the mouth lie just below where the iris is located in the eye (Yadav et al. 2010, p40). This method is relatively fast (especially in comparison with other methods) and is suitable enough to provide rough identifications in the forensic context (Abate et al. 2004).

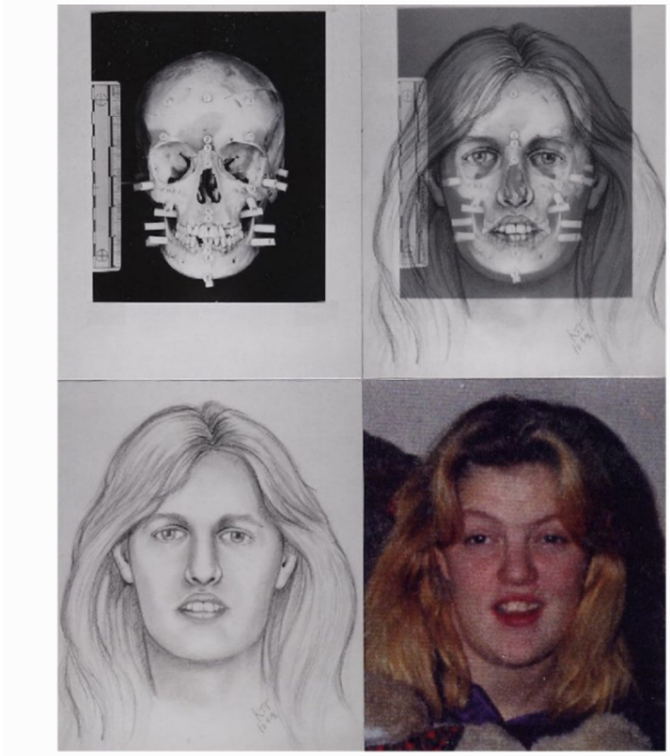
[1] An identikit is a graphical representation of one or more eyewitnesses' memory of a face, as recorded by a composite artist.



1.0 An example of a facial reconstruction using the 2D artistic drawing method

Photo/video Overlay

The main purpose of this method is to compare a face with a skull so as to identify similar features (Yadav et al. 2010, p40). This is done through image or video compositing (using video frames) of the skull and face (Abate et al. 2004). This technique is also known as craniofacial superimposition (CFS) where the image of the recovered skull is a superimposed over an ante mortem image of the suspected individual (Damas 2019; Ubelaker et al. 2019). The goals of this method are to determine exclusion or the skull definitely could not be the person, positive identification - where the skull definitely represents the person or if it is potentially possible that the skull could represent the person (Ubelaker et al. 2019). Unlike other methods, this technique involves a large number of very diverse approaches. Rather than following a uniform methodology, every expert tends to apply his/her own approach to the problem, based on the available technology and his/her own knowledge of human craniofacial anatomy, soft tissues, and their relationships (Ubelaker et al. 2019).



1.1 An example of a facial reconstruction using the photo/video overlay

THREE DIMENSIONAL METHODOLOGIES

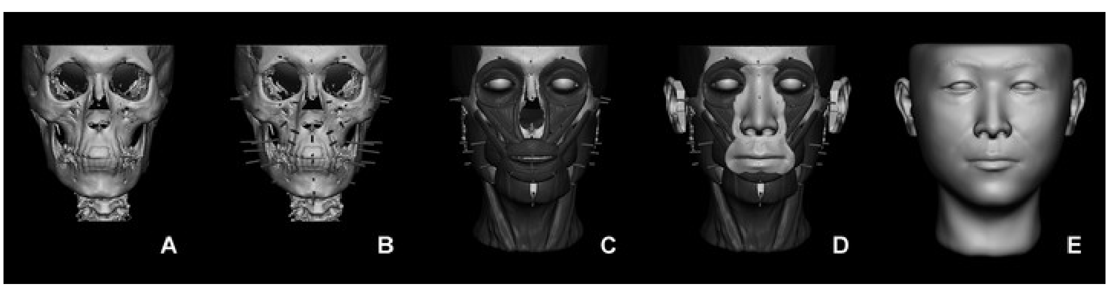
Manual Method

This method was first developed by Karen Taylor in Austin, Texas during the 1980's. In this technique, tissue depths are assessed in order to recreate the face from the underlying skull. The remains are first analyzed, and a biological profile is created. This is typically done by a forensic anthropologist rather than the artist. The skull is also analyzed and sex, age, and ancestry are evaluated - so as to add the associating tissue markers and traits. The real skull is then recreated typically through casts made of resin. Each facial soft tissue thickness marker or FSTT is then placed on the skull at specific landmarks and the muscles of the face are sculpted over it, using clay (Gupta et al. 2015; Yadav et al. 2010, p40; Galzi and Mullins, 2016, p4).

1.2 An example of a facial reconstruction using the manual method

Digital/Computerized Method

The first step in the computerized reconstruction process is digitizing the skull. This is most commonly done using CT scans as they are efficient and less expensive than handheld laser scanners, which are also popular for digitizing. CT or computerized tomography allows the individual to see anomalies and peculiarities that are not always visible to the naked eye (Yadav et al. 2010, p40). Once the 3D model has been made it is enhanced through the use of material shaders and textures (Abate et al. 2004). These methods have been criticized, with the results being stiff and smooth or unhuman like. However, the process is much faster and still has a high rate of identifications. Additionally, recent softwares and methods have made this process have made a high level of realism possible (Abate et al. 2004).



1.3 An example of a facial reconstruction using the digital/computerized method

METHODS OF MANUAL 3D RECONSTRUCTION

Regardless of the method used, forensic facial reconstruction procedures can be divided into three basic schools of thought (Kundu, 2021)

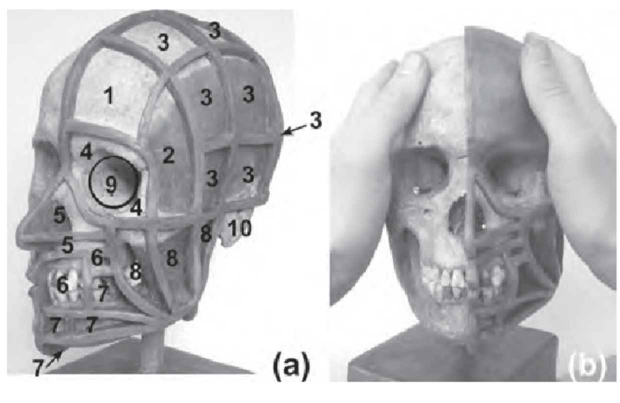
1. **Anthropometric American Method/ Tissue Depth Method:**

This method, also known as the tissue depth method, was developed by Wilton M. Krogman in 1946. This method focuses on the average depths of soft tissue from approximately 30 different landmarks on the skull (Gupta et al, 2015; Omstead, 2011; Kundu, 2021; Evison et al. 2016, p4) The method was commonly used for reconstruction by law enforcement agencies (Omstead, 2011). Measurements were obtained by the use of needles, X-rays and or ultrasounds. This technique is not preferred today, as it requires highly trained personnel (Dtsch Arztebl 2007). The foundational work for this methodology was done by His in 1895 and was later adapted further by two 19th century anatomists named Kollman and his colleague Büchly. Today, this method is primarily used by forensic artists working in the law enforcement environment because it is cheap and quick. Additionally, the average law enforcement agent does not have much anatomical knowledge or training and therefore this method is much more accessible.

1.4 An example of a facial reconstruction using the Anthropometric American Method/ Tissue Depth Method

2. Anatomical Russian Method:

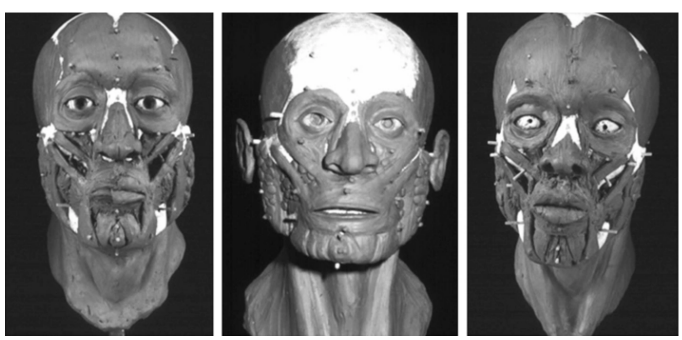
This method was developed by Mikhail Mikhaylovich Gerasimov in 1971. The main theory for this method was built on the accuracy of facial muscles. While it did not rely on soft tissue depths, facial muscles were used in the correct anatomical position (Gupta et al, 2015). In this method, different layers of muscles were layered in order to create depth, however this method is not preferred today because it is extremely time consuming and requires much more anatomical knowledge, even possibly a background in anatomy. The method has been used in the rebuilding of fossil faces, as there is no possibility to gather facial depth data on early human populations (Taylor, 2001).



1.5 An example of a facial reconstruction using the Anatomical/Russian Method

3. Combination Manchester Method/ British Method:

This method was developed by Richard Neave in 1977 and is currently the most widely used and accepted method today. So far, this method has been proven to be the most effective and accurate as it considers both soft tissue depth, as well as the correct anatomical positioning of facial muscles. Because of this inclusion of the previous methods, it is known as the combination method. Neave is a medical artist and is therefore knowledgeable in anatomy as well as art and therefore has been able to examine the muscle attachments and evaluate robustness in order to add to the accuracy of the reconstruction. Neave explained that this method "...Ensures that the hand of the artist does not and cannot influence the final shape of the head and face. The measurements still rule supreme" (Taylor, 2001). The first step in this method is to articulate the cranium with the mandible (assuming all parts are present.) Next, the cast skull is placed into an adjustable frame in the frankfort horizontal plane. The Frankfort Horizontal Plane is an anthropological standard position that closely approximates the natural position of the head in real life (Gupta et al, 2015; Taylor, 2001). Keeping the skull in this position limits distortion and therefore allows for a better, more accurate result. The position dictates that the orbitale (the lowest point on the margin or the orbit) is horizontally aligned with the porion (the most lateral portion on the roof of the external auditory meatus or ear hole) (Taylor, 2001). Once the skull is oriented correctly, facial markers are added. These can be added directly onto the skull or drilled in at a 90 degree angle typically using a 3mm drill bit (Gupta et al, 2015). The muscles are then added - with size and thickness determined by the underlying bony tissue. Once the muscles of mastication (chewing) and facial expressions are placed, prosthetic eyeballs (made of plaster or plastic) can be placed into the sockets. The rest of the facial features are then modeled onto the skull according to specific standards, measurements and individual characteristics of the face (Gupta et al, 2015).



1.6** An example of a facial reconstruction using the **Combination Manchester Method/British Method

UNDERLYING STRUCTURE

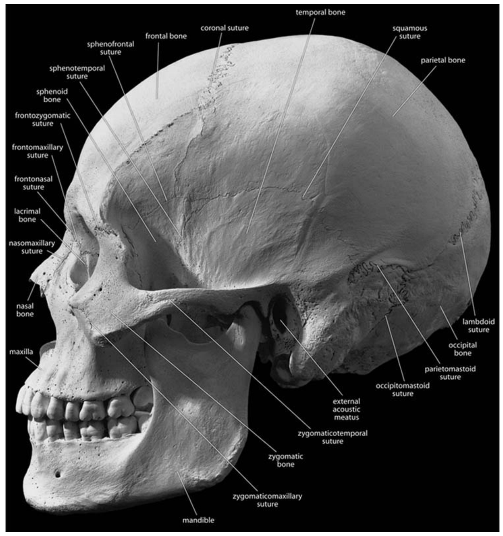
The human head is made of a number of different things, including: bones, complex musculature, fat, and skin. Each face is also unique in terms of shape and the kinds of features it contains, which may differ based on ancestry. Other important factors include age and skin wrinkles, as well as biological sex.

BONES OF THE SKULL

The skull is the most complex portion of the human skeleton. It is also one of the most useful tools in physical anthropology as it allows for the assessment of age, sex, and understanding of human evolution through hominid deveolpment and evolution. This complexity can best be understood by recognizing the widely different functions of the skull, including; protection of the brain, bony foundations for the senses (sight, sense, smell, taste, and hearing) and the formation of the framework for chewing apparatuses (White, 2000). The human skull can be broken down into two components: the neurocranium and the splanchnocranium. The neurocranium is the protective shell surrounding the brain and brainstem, for this reason it is also known as the braincase. The splanchnocranium is the face, derived from the pharyngeal arches or the gill arches of primitive fish ancestors (Taylor, 2001; White, 2000). Both of these regions are composed of multiple bones that interlock and fuse together through synarthrodial (immovable) seams called sutures throughout the process of growth and development (Taylor, 2001; White, 2000). However, the skull is commonly referred to as the cranium and the mandible. The skull is composed of 22 different bones, with 14 of them making up the face.

The frontal bone is located at the front of the neurocranium and forms the forehead and upper portions of the orbital cavity surrounding the eyes. It articulates with the parietal bones, maxillae, sphenoid, ethmoid, lacrimals, and zygomatics (White, 2000). It is also one of the largest and most robust cranial bones (White, 2000). One prominent feature of this bone is the supraorbital ridge or superciliary arch, which is the prominence above the orbits. It is often more noticeable in males (Taylor, 2001). The parietal bones are curved plates that compose the sides and roof of the cranial vault (Taylor, 2001; White, 2000). It articulates with the opposite side parietal bone as well as the frontal bone, temporal bones, occipital bone, and the sphenoid. In most, the parietal tuber also known as the parietal boss or eminence is the widest part of the head. The temporal bones form the transition between the cranial wall and base, as well as house the organs of hearing (White, 2000). They also form the upper portion of the jaw joints. It articulates with the parietal, occipital, sphenoid, zygomatic, and mandible. This bone also contains three important features: the mastoid process, the external auditory or acoustic meatus (ear hole), and a zygomatic process, which forms half of the zygomatic arch (Taylor, 2001). The mastoid process is an extension of bone behind the ear (White, 2000). It contains a roughened surface where several muscles attach including the sterno-cleidomastoideus, splenius capitis, and longissimus capitis (White, 2000). These muscles are important for the extension and rotation of the head (White, 2000). The external auditory meatus is an opening in the bone just above and in front of the mastoid process that determines the placement of the ear (Taylor, 2001). The Zygomatic process is a thin projection of bone which joins anteriorly with the zygomatic bone. Together they form the cheekbones, called the zygomatic arches (Taylor, 2001; White, 2000). The occipital bone is set at the rear of the cranium and forms much of the back and base of the skull. It articulates with the temporals, sphenoid, parietals, and the first cervical vertebra, called the atlas (Taylor, 2001; White, 2000). The occipital bone also serves as an important attachment site for the muscles of the neck, or the nuchal musculature, which attach at the superior and inferior nuchal lines as well as the external occipital crest (median nuchal line or nuchal crest) (Taylor, 2001; White, 2000). Another important feature of the occipital bone is the foramen magnum which is the large hole located in the back of the bone in which the brainstem (where the brain is connected to the spinal cord) passes. The maxillae are a pair of bones that form the dominant portion of the face. They form the upper jaw and hold the upper teeth roots. They also form most of the nasal aperture, most of the hard palate and the bottom portion of orbits. The nasal bones are small, thin, rectangular bones that create the upper part of the nose and the top margin of the nasal aperture. They articulate with the frontal bone, with each other, with the frontal process of the maxillae and the ethmoid bone (Taylor, 2001; White, 2000). The cranium also contains other bones such as the nasal conchae, ethmoid bone, sphenoid, and lacrimals, as well as the tiny auditory ossicles (malleus, incus, and stapes). However, these are not relevant for this project.

The mandible, or lower jaw, is the only truly separate bone of the human skull. It hinges with the temporal bones through the two condyles located posteriorly. This is known as the temporomandibular joint (TMJ). This movement allows the jaw to open, close, and rotate for the primary function of mastication, or chewing (Taylor, 2001; White, 2000). It is held to the cranium through tough bands of fibrous tissue called ligaments. It also holds the lower teeth and provides a site for muscle attachments. The mandible contains three other notable features including the ramus, the coronoid process and the condyles. The ramus (or ascending ramus) is the thin, upper portion of the bone that articulates with the cranial base. The coronoid process is the thin projection of bone on the anterior portion of the ramus. It acts as a muscle attachment for the temporalis muscle that closes the mouth. The two condyles, or heads, are the large, round prominences located at the end of the ramus. They connect the jaw to the cranium at the temporomandibular joint (TMJ).



1.7 A diagram of the bones of the face taken from White, 2000.

MUSCLES OF THE FACE

The face is an interesting part of the human body as it is almost always moving. This movement is created through the contraction and pulling of facial muscles. John Liggett states that “There are more than a hundred different muscles lying just below the surface of the face. These lie in many different directions, criss-crossing each other in a thousand different ways, making possible a rich variety of complex, subtle and beautiful movements” (Liggett, 1974). The facial muscles are divided into two groups based on their functions. These are muscles of mastication and muscles of expression, though some can perform both functions.

Muscles of the mouth (buccolabial group) (Hayes, 2017; Taylor, 2001; Gordana, 2021)

1. **Temporalis -** A fan shaped muscle that fills out the side of the head. The fibers converge as a tendon and pass through the zygomatic arch. Articulates posteriorly at the inferior temporal line of the zygomatic bone and inferiorly at the coronoid process of the mandible. It allows the mandible to rise and close as well as aids in the sideways grinding movement of the jaw. It can be felt when it contracts as the teeth are clenched.
2. **Masseter -** A thick, quadrilateral muscle composed of three layers: superficial, middle, deep. It attaches superiorly on the lower border of the zygomatic bone and inferiorly at the body and angle of the ramus. The function of this muscle is to

bring the back teeth together for grinding during the process of chewing. It can be seen and felt along the cheek when the teeth are clenched.

3. **Mentalis** - A conical bundle of muscle fibers located on either side of the ridge that runs vertically down the mental eminence of the mandible (called the symphysis menti). These fibers attach at either side of the symphysis menti and to the skin. They help move the lower lip. Activation of the fibers can be seen as it causes dimpling in the skin, which helps show the expressions of doubt and disdain. For this reason it is nicknamed the "pouting muscle."
4. **Orbicularis Oris -** Four (relatively) independent quadrants, each containing two fan shaped segments. The quadrants flow in a roughly circular direction, with no attachments to the bone. The muscle brings the lips together and aids in the outward motion - such as in kissing.
5. **Buccinator -** A thin, quadrilateral muscle located on the inside of the cheek - sometimes called the "trumpeter muscle." It attaches to the skull posteriorly above the upper molars of the maxilla and inferiorly below the lower molars, converging with the other muscles of the mouth. It compresses the cheeks when full of air, such as the motion of blowing as well as aids in chewing, keeping food from passing between the molars.
6. **Levator Anguli Oris -** An upside down triangular muscle that attaches to the maxilla just below the infraorbital foramen. It contains superficial fibers that insert into the nasolabial fold, a crease starting above the wing of the nose and framing the mouth. It raises the mouth corners to allow for expressions such as smiling as well as changes the depth and shape of the nasolabial fold.
7. **Levator Labii Superioris -** A thin muscle that starts above and crosses over much of the underlying levator anguli oris. Attaches above the infraorbital foramen and articulates with the orbicularis oris inferiorly. The muscle is associated with crying as it deepens the nasolabial furrow during expressions of sadness and/or seriousness. It also lifts the upper lip, squaring it.
8. **Depressor Labii Inferioris -** A quadrilateral muscle located between the symphysis menti and the mental foramen. The superficial fibers contain fatty tissue. Attaches inferiorly at the lower jaw and superiorly it intermingles with the other mouth muscles. The muscle pulls the lower lip downwards as well as outwards and is activated both during mastication and when showing the expression of irony.
9. **Levator labii Superioris Alaeque Nasi -** This muscle runs from the maxilla beside the nasal bone to blend with the orbicularis oris. It lifts the lip and wing of the nose.
10. **Risorius muscle -** A long and very thin muscle, the risorius acts to pull the corner of the mouth straight back. It originates in the fascia (though covering of the masseter muscle) and inserts in the skin at the corners of the mouth.

11. **Depressor anguli oris -** A triangular shaped muscle that mirrors to the levator anguli oris and crosses over part of the depressor labii inferioris and attaches at the modiolus. It attaches to the mandible laterally and depressor labii inferioris and the upper fibers blend at the modiolus. It functions to lower the mouth corners and shifts them laterally. It is associated with expressions of sadness and disgust.
12. **Muscles of the nose (nasal group):**

1. **Nasalis muscle -** .
2. **Levator Labii Superioris Alaeque Nasi -** The long, thin muscle runs alongside the nose and blends with the levator labii superioris and the orbicularis oris. It begins below the fronto-maxillary suture of the nasal wing and the medial part of the upper lip. This muscle dilates the nostrils and raises the upper lip. It is associated with weeping and expressions of disgust.
3. **Zygomatic Minor -** Runs from the zygomatic bone to the orbicularis oris at the corner of the mount. Associated with smiling and emotions of smugness, contempt, and or disdain.
4. **Zygomatic Major -** Runs from the zygomatic bone to the the orbicularis oris muscle at the upper lip. Associated with joy and laughter.
    a. These muscles originate at the zygomatic bone and together these muscles aid in the movement of smiling.

Muscles of the external ear (auricular group):

1. **Auricularis Anterior -** The action of the auricularis anterior is to draw the auricula (visible part of the ear, outside the head) forward and upward.
2. **Auricularis Posterior -** The action of this muscle is to draw the auricula backward.
3. **Auricularis Superior -** Is a thin, fan-shaped muscle that arises from the temporal fascia (connective tissue along the side of the head) and descends into the root of the auricle, or ear.

Muscles of the eyes (orbital group):

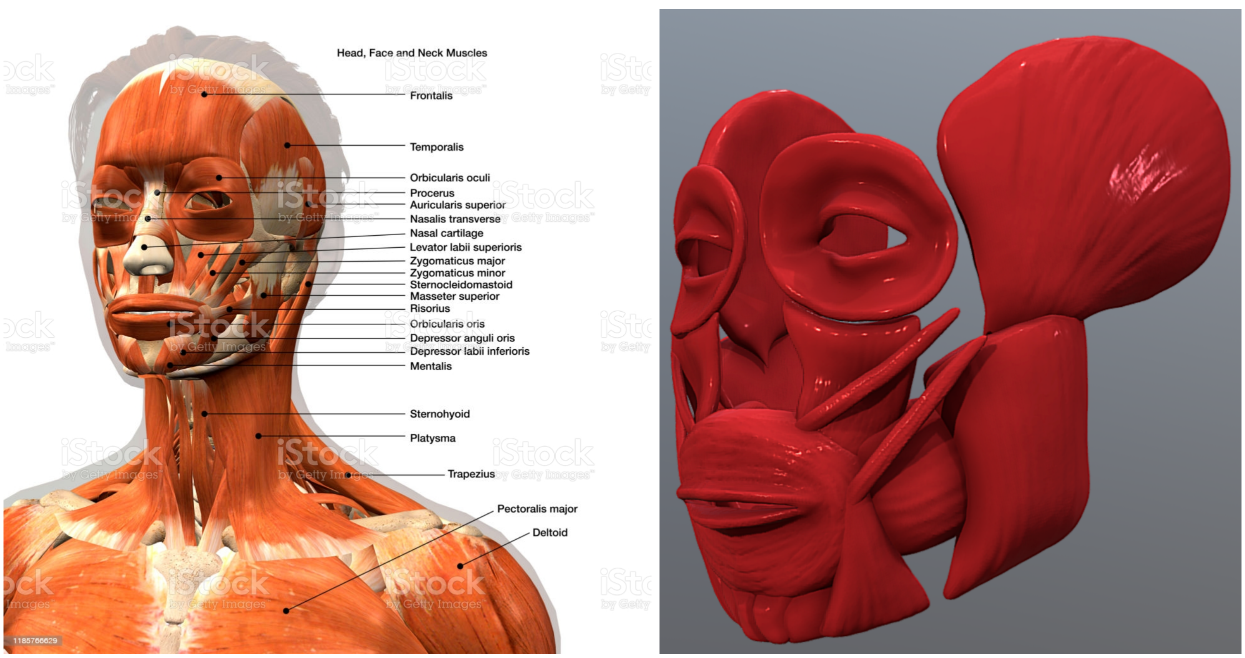
1. **Orbicularis Oculi -** This wide, flat shaped muscle forms much of the upper and lower eyelids. It consists of two parts, the palpebral and orbital. The orbital portion of the muscle is attached, only, at the medial walls of the orbital bones and wraps around the rest of the orbital rim to attach at the zygomatic and maxillary bones. This muscle closes the eyelids in actions such as winking, blinking, and squinting. It is also associated with expressions of emotion, such as laughter.
2. **Procerus muscle -** A small thin muscle that covers the nasal bones running in the same vertical direction as frontalis. When it contracts, pulling down the inner corner of the eyebrow area, small horizontal wrinkles are created across the upper brow ridge of the nose.
3. **Corrugator Supercilii -** A cone shaped muscle that pulls the inner corners o the eyebrows together and downward, creating small vertical creases above the nose.

a. The procerus muscle and the corrugator work together.

4. **Parotid Gland -** While this is not a muscle, the structure contributes to the full, curvedness of the cheek. It is instead the largest of the salivary glands and resembles an upside down pyramid in shape. Despite this, it can be highly variable in size and shape. It covers the zygomatic bone and extends to the external auditory meatus of the ear. It also covers the masseter muscle and sometimes can taper down to the base of the jaw.

Muscles of the cranium and neck (epicranial group):

1. **Occipitofrontalis (frontalis) muscle -** is a flat muscle that covers the forehead on the frontal bone. It's vertical fibers originate approximately at the hairline and insert in the skin under the eyebrows. It can raise the eyebrows straight up and creates horizontal wrinkles or furrows across the forehead.
2. **Platysma muscle -** This is the most superficial muscle of the neck, overlapping the sternocleidomastoid. It is thin and sheet-like in appearance. It attaches to the mandible as well as the skin and fat of the lower face and extends downward anteriolaterally.

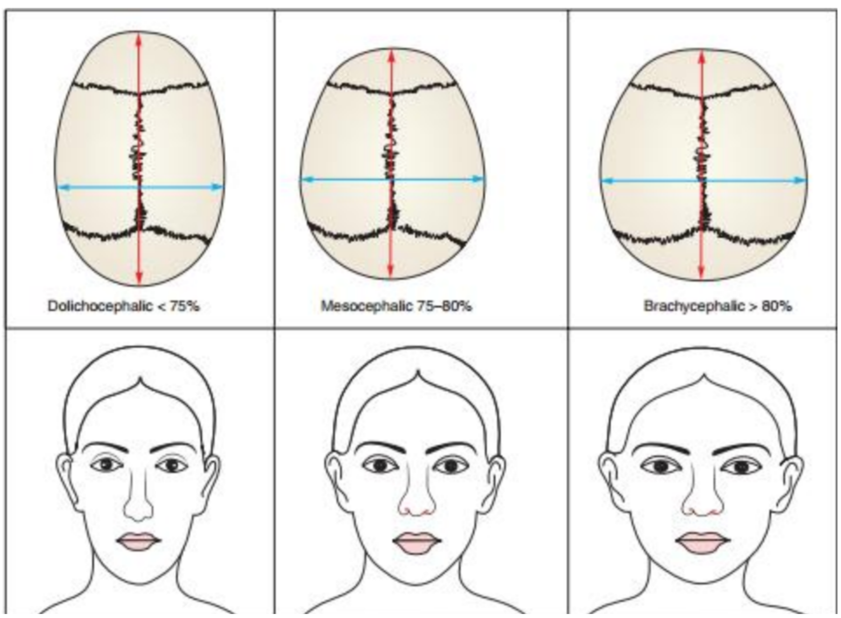


1.8 A labeled diagram of the facial muscles and a 3D model of the facial muscles from sketchfab

HEAD TYPE

Anatomists have further broken down the face and head into three distinct categories based on skull shape. The measurements used to determine each type of head are classified under the cephalic index (Taylor, 2001). It is also important to note that these head types do not identify specific individuals as do age, gender and ethnicity, but are present and vary across all races of people (Rodriguez, 2018). Burne Hogarth explains in the book *Drawing the Human Head* that "No one particular group of persons can be identified by a single head type classification or facial slope. Head form variations run through the individuals of all population groups" (Hogarth, 2002).

1. **Brachycephalic -** Relatively broad heads, wide skull and a medium to low positioning forehead. The facial features tend to be more compact and square.
2. **Mesocephalic -** Medium heads, described as intermediate-sized skulls with an oval-shaped face, and small facial structures.
3. **Dolichocephalic -** Relatively long and narrow heads. Foreheads are moderate to highly arched. High arches are associated with longer facial structures.



1.9 Diagram of the three different head types starting from Dolichocephalic, Mesocephalic, and finally Brachycephalic

RACIAL/ANCESTRAL GROUPS AND ETHNICITY

This can be a complex and problematic aspect of forensic anthropology as well as facial reconstruction. Karen Taylor includes a quotation from a 1968 encyclopedia that defines race as "One of the major zoological subdivisions of mankind, regarded as having a common origin and exhibiting a relatively constant set of physical traits such as pigmentation, hair form, and facial and bodily proportions" (Taylor, 2001; Landau, S.I., Brantley S. C., et al.. 1968). Race is based on appearance, while ethnicity is linked to cultural expression. Despite this, they are both cultural conflicts, used to characterize different and distinct people. Neither of these terms can be detected or measured in the human genome. Throughout the history of humanity there have been various genetic patterns that vary from time and place. Because of this, even if one accepts the terminology and categorization of "race" there was likely never a "pure" race because of the breeding and genetic mix of the human race. This is especially relevant today, as the ease of travel has allowed people to migrate around the globe causing genetic mixing and a greater genetic diversity. Even the term race is not completely universal as some scientists have defined only three races whereas others have defined more than ten (Taylor, 2001; Rodriguez, 2018). For the field of forensics, the concept of race and ethnicity are commonly referred to as ancestry. The idea of ancestry is a controversial topic that is currently being discussed and debated, especially within the field of forensic anthropology.[2]

It is not only (artificial?) to put these people in groups but problematic. Every face is different and a large variety exists even within these categories. However, the grouping of these populations can help to better understand traits as they exist genetically and geographically. Some faces only vary slightly and others, significantly. Most are somewhere in between. No one ethnic group, as a whole, is necessarily a closer match in general appearance of the face than any other (Marquardt Aesthetic Imaging Inc, 2014).

[2] My personal feelings on this topic are complicated. I do not believe that ancestry should be included in a biological profile, as the specific traits that define one population can be found in many others as well. However, I see the need and importance of evaluating ancestry for the sake of forensic facial reconstruction, especially when trying to identify unknown and even badly damaged remains.

1. **Caucasoid -** This group is generally referred to as "white," though that description is not only problematic but not all light skinned people are Caucasiod, nor are all Caucasiod people light skinned (Taylor, 2001). The major characteristics of this group are: In profile, the face looks relatively flat with zygomatic bones that slant backwards. Frontally, the nasal openings tend to be long and narrow (especially when compared to those of the Mongoloids or Negroids). They generally have thinner upper and lower lips. They also have flatter eyebrows, with very little arch to them. They may also have Narrow eyes, a longer vertical chin, and a longer nose (Marquardt Aesthetic Imaging Inc, 2014). The group has been broken down further into three groups based on geographic location as well as two groups based in Africa:
    a. Mediterranean - This group can be exemplified by the typical Sicilian - someone who is short in stature with a somewhat stocky build and olive skin. They also have dark hair and eyes, a long head and a narrow, ovular face and a small mouth. The group generally refers to people from the Iberian Peninsula. Western Mediterranean Islands, Southern France, Italy, and the Western parts of Wales and Ireland.
    b. Alpine - This group typically refers to the rounder headed people generally found in Europe. They can possess darker complexions with thick, heavy, brown, usually wavy hair and thick eyebrows. They often have a broad face, brown (or dark) eyes and a thicker neck as well as a medium to heavy postcranial build. The geographic locations of this group tnd to extend from the central plateau of France, Switzerland, and

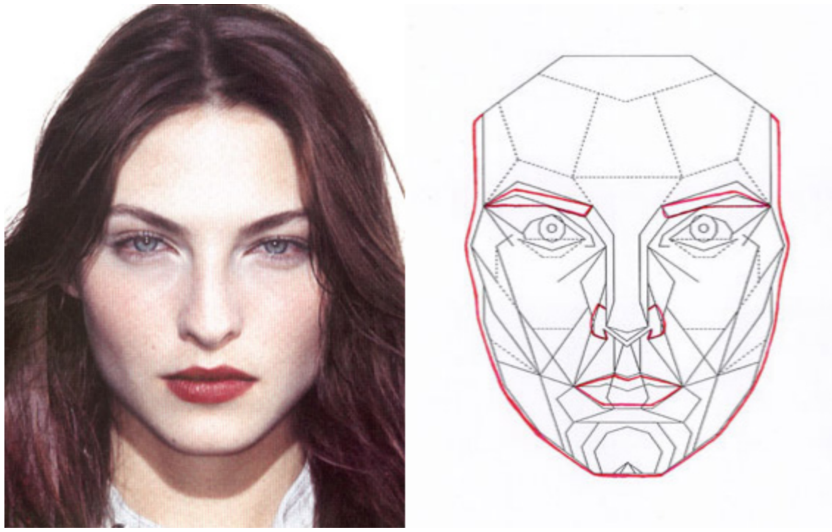
Czecholosovakia southward into the Balkans and eastward into the Soviet Union.

c. Nordic - This group is associated with the typical Scandinavian look of a taller individual with light skin and hair, blue eyes, a long head and a prominent nose and chin. These people inhabit Scandinavia, northern Germany, and parts of Holland and Belgium.

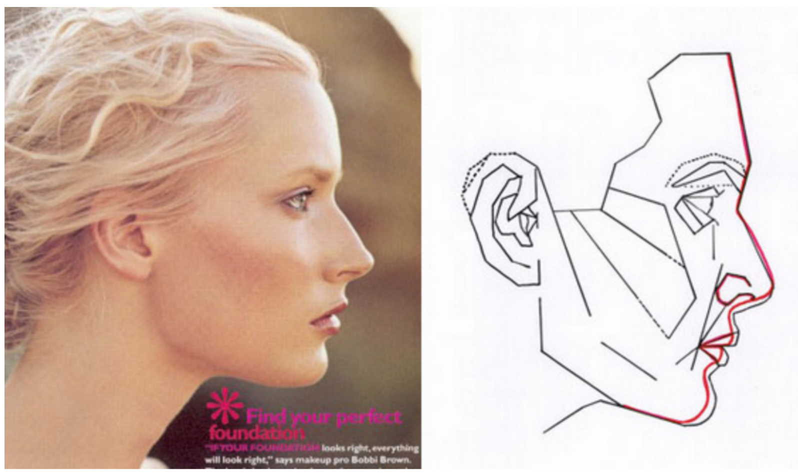
The major scientists of the early 20th century, such as Dr. Henry Feild, also described his early observations on race in a 1946 book called *The Races of Mankind*. He also described the Caucasoid people from Africa in two groups:

d. Hamites - Typically this group includes individuals who come from northeast Africa. They often have hair that ranges from dark brown to black that is usually curly or wavy. They have skin that varies in color, from reddish brown to dark brown. Average stature of these people also varies, from very tall to medium with a more slender build. They may also have a long, ovular head, and elongated face with no forward protrusion, thin lips, pointed chins, and (well shaped) noses.

e. Semites - This group resembles the last. However, they typically live in the extreme north of Africa, as well as Arabia, as they migrated. They usually are medium in stature and are dark haired with oval faces (that can either be long or broad) and long narrow, straight noses.



2.0 Frontal Features of a Caucasoid woman



2.1 Lateral display showcasing the features of a Caucasoid woman

Unfortunately, this "white" face has been the ideal of beauty, especially in the Victorian era.

2. **Negroid -** This group is generally referred to as "black" despite the fact that the group's skin tone can range on a continuum from light to darker brown. The group's characteristics are defined by alveolar prognathism, which is the projection of the lower face. This is especially true when looking at a profile view. The group also possess wider, and often shorter nasal openings, especially when compared with caucasoid or mongoloid faces. The nasal bridge tends to be brader

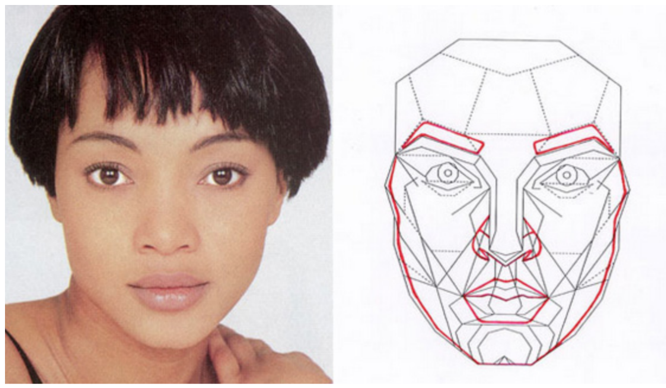
and flatter, as well. Their mouths can be broad with full lips. They may also have wider set eyes. This group has also been broken down into further divisions including:

a. West African - Generally refers to people of coastal Africa. Long headed individuals, of medium stature with well developed, heavy torsos and "massive" limbs. Generally, their arms are long and short in comparison with the length of the trunk. The face tends to be very large and broad in addition to a wide nose and thick, sometimes everted lips. They may also have thick, wool-like hair and darker eyes.

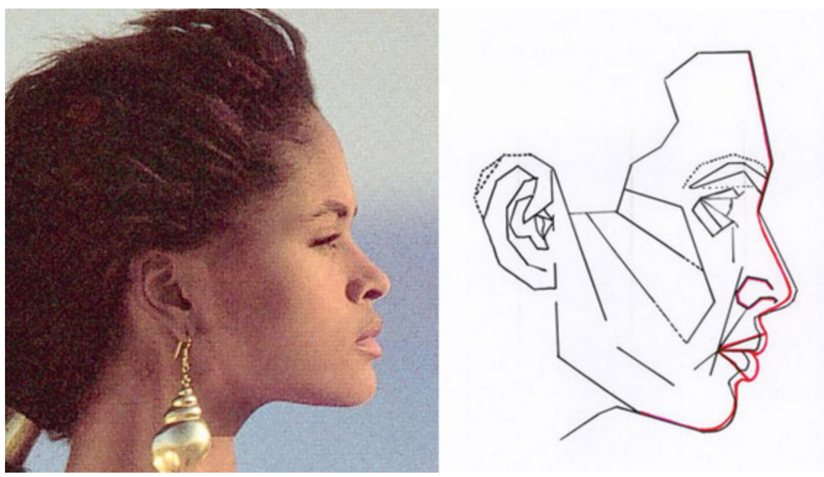
b. Nilotic - Refers to people of the upper nile. In comparison to the other groups, they are greater in stature with a more slender build and faces that are much longer than they are wide.

c. Pygmies - The term refers to the Wambuti of the Ituri Forest in the northern part of the Congo. They have dark brown hair, often short. Their complexion ranges in color from a light brown, yellowish to a deep brown, chocolate color. They are very small in stature, with an average male reaching approximately 4 feet and 6 inches. They also have small limbs. They often have rounder heads with more prognathism and full lips. Additionally they have flat, broad noses.

d. Bushmen - Are often short, with frizzy hair. However, they seem to have very little hair on their faces or bodies. They can have a range of complexions from yellow to olive. The skin tends to wrinkle at a very young age. The head is usually small and is in the middle of long and round. The forehead protrudes slightly and is extremely broad and flat. They have dark eyes that tend to be much more narrow and are quite small in stature.



2.2 Frontal Features of a Negroid woman



2.3 Lateral display showcasing the features of a Negroid woman

3. **Mongoloid -** Unfortunately, this group has often been referred to as “red” or “yellow.” In actuality it includes Native Americans, American Eskimos, and the many different, diverse groups of Asians - who, of course, have many different skin tones and facial features. The face, in profile, is described as flat with a short cranial vault (distance from front of the head to the back of the head). From the front, this face has a wide, projecting cheek area and a nose that is in between the

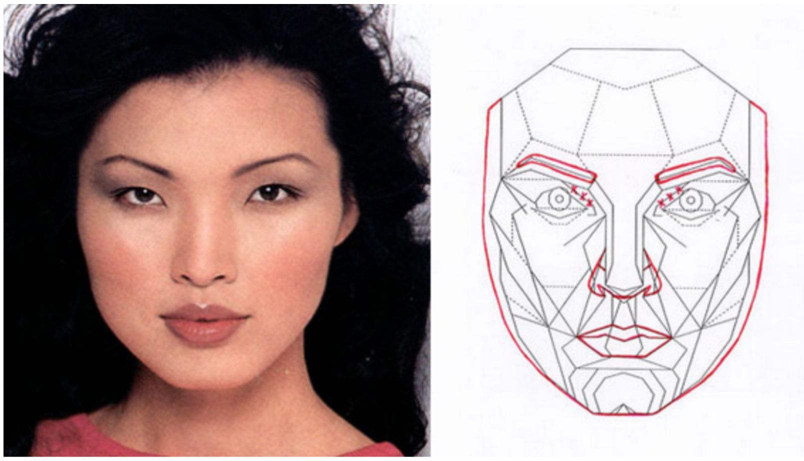
caucasoid and negroid groups in terms of shape and size. The mouth size and shape also tends to be intermediate. The Mongoloids are broken into:

a. Chinese - A single racial unit that typically are medium in stature. They also contain skulls that are intermediate between long and round. They tend to have a more yellow-brown skin tone with straight black hair. They also often have oblique shaped eyes with a prominent fold - nicknamed the mongolian fold. Today, this feature is known as the epicanthic fold and can have many different variations. The most common is that of the upper eyelid, which covers the inner corner.

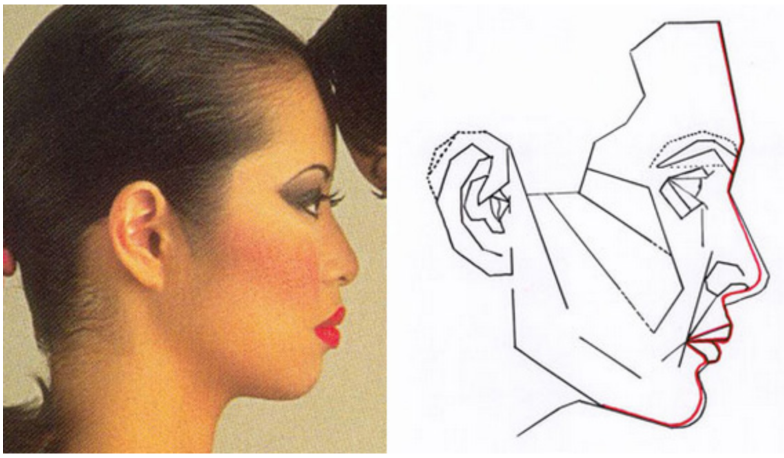
b. Japanese - There are two distinct types of Japanese facial features. One is more fine and gracial, while the other is more coarse. The first is associated with aristocracy and tends to be taller as well as more slender. They often have elongated faces and prominent, narrow, arched noses. Their eyes tend to be straight or oblique. This group also contains the mongolian/epicanthal fold. The other, more rough group tends to have a shorter, more stocky build as well as, broader faces and short, concave noses with rounded nostrils. They may also have oblique eyes, an epicanthic fold and a darker complexion.

c. Native Americans (often referred to as American Indians) - This group typically has a brown complexion that is red or yellowish in tinge, dark eyes, straight, coarse black hair and a broad face with higher and more prominent cheekbones than other mongoloid groups. They usually have more round heads and noses than range from flat to aquiline (hooked shape, due to a prominent nasal bridge).

d. Eskimos - This is a definitive group that often has a short, stocky build and very long heads as well as long faces. They also have very large jaws and narrow noses. They may also have a ridge on the dome part of their skulls. Lastly, the eyes tend to have the mongolian/epicanthic fold.



2.4 Frontal Features of a Mongoloid woman



2.5 Lateral display showcasing the features of a Mongoloid woman

4. **Australian Aboriginals -** Some anthropological texts differentiate this group as an entirely separate and distinct race (others do not, however they are almost always seen as a distinct group based on geography and social patterns). They

> have been described as having "jet black, wavy or curly hair, which is often heavy on the face; dark chocolate brown skin; medium staturee with slim limbs; and a long head with a flat retreating forehead, prominent brow rides, projecting face, and a deeply set, broad nose" (Benedict et al, 1943, p5, Taylor, 2001).

SEX: MALE VERSUS FEMALE + DIFFERENCE IN APPERANCE

While seemingly synonymous, the terms "sex" and "gender" do not mean the same thing and should not be used interchangibly. Sex refers to biological idenity, anatomical or chromosomial differences that designate male, female, and sometimes intersex (Walker and Cook, 1998; White 2000). Gender, similar to the idea of race, is socially constructed (Walker and Cook, 1998; White 2000). In the archaeological context skeletal analysis can provide insight into sex and other elements such as grave goods and other kinds of material culutre may offer insight into gender. For forensic anthropologists and forensic artists the estimation of sex is extrimiley important as is helps create a biological profile and therefore identify the individual. This is done through examining the skeleton. However, sexual identification is most accurate after the individual reaches maturity and therefore is generally only performed on adults (White, 2000).

Humans tend to have a lower amount of sexual dimorphism than our other living promates, however size can help determine sex. Generally, when looking at an assemblage of bones the larger, more robust bones with rugosity can be identified as male. In fact, males can average 20% larger than females in skeletal dimensions (White, 2000). The smaller, more gracile bones tend to be female. As a result of human variation, it is in fact possible to find more robust females and more gracile males. Because of this osteologists usually estimate sex through analysis of the pelvis and skull. Although the pelvis is the most accurate method for etimating sex, only the methods for sexing the skull will be discussed since this is focused on facial resconstruction and the elements of the face and skull.

The male skull is characterized as more robust than that of a female. Additionally, it may also contain more prominent features, such as very large supraorbital ridges, a larger glabella region, as well as heavier temporal line and nuchal lines (White, 2000). The frontal bone and parietal bones also tend to be less bossed (less curved) than the female counterpart (White, 2000). They also have larger, more broad palates, squarer orbits, larger mastoid processes, larger sinuses, and larger occipital condyles (White, 2000). There are always new methods being studied and tested, but the current practice for sexing is to use 5 different points on the skull and score them on a level of 1 through 5 - with 1 being more gracile and therefore feminine and 5 being more robust and therefore male (White, 2000). These 5 points include; the nuchal crest, mastoid process, supraorbital margin, supraorbital ridge/glabella, and the mental eminence (White, 2000).

For artists the differences between male and female tend to differ as well and are important to note when recreating the face. Male faces are often larger and more angular. The lower half tends to be more prominent and the angle of the jaw is square. The forehead is more sloping and has a more defined brow ridge. Teeth can also be larger. The male face also tends to have less facial fat which allows for more of the underlying musculature to be seen. The female face, in contrast, is generally smaller and much softer in appearance. The jaw angle is more obtuse (wider) and less well defined, with a more pointed chin. The forehead is more upright and tends to be smaller and smoother as well. The female face may appear more curvilinear and will lack facial hair on the cheeks and chin. While this essay focuses on reconstruction, it is also important to note that when drawing the female face, such as the case for a composite artist, makeup and more complicated hairstyles should be considered (Taylor, 2001).

AGE

The skull can be very helpful in estimating age as well. Again, this is most easily and accurately done using the pelvis. Despite this fact, age can also be analyzed through dentition (eruption, reabsorption and wear) and through cranial suture closure. There is an important distinction between the age since one was born, known as chronological age and the actual physical age of the body according to biological damage to cells, known as biological age. Age estimations using tooth development are usually more associated with chronological age as other methods are more closely linked to biological age as they respond to factors such as genetics. Because teeth are extremely resilient and are often found in archeological as well as forensic cases dental development is the most common and widely used method for age estimation.

Teeth begin to form during development. At just 14 - 16 week in utero teeth begin to form (White, 2000). There are four distinct periods in which these teeth form and later erupt (after birth). First the deciduous, or non permanent baby teeth appear during the second year of life - this stage in early development is commonly known as teething, as babies will be much more irritable due to pain, swelling, and rubbing that results from the process of the teeth pushing through the surface of the gums. In the next stage, the two permanent incisors and first permanent molars will emerge around the ages of 6-8 (White, 2000) Most permanent canines, premolars, and second molars emerge around 10-12 years of age (White, 2000). Lastly, the third molars emerge around 18 years (White, 2000). These teeth are the most variable in terms of formation and eruption and are typically called wisdom teeth due to the fact that they come through at a more mature age. As humans have evolved and adapted our mouths have also shrunk. Of course, there is individual variation with these growth patterns (White, 2000). The third molar, which has been helpful for chewing, no longer fits into the smaller Homo sapien jaw and therefore is removed in order to provide room for the other teeth. This can be a painful process as the teeth often get stuck in the jaw, under the gums, a term dental professionals call impacted teeth. There are a few methods for estimating age through dental analysis, the first includes comparing tooth formation through individual teeth whereas another analyzes the individual in references to a chart of the eruption of all the teeth. Through these methods all aspects of development should be considered, including the completeness of the crowns and the roots (White, 2000). It is especially important to keep this in mind when estimating the age of a juvenile (subadult). Dental wear can also provide insights into age, especially when the wear is homogenous across the population. The basics of the method are that a first molar accumulates about 6 years worth of wear before the second molar of the same individual erupts. Therefore, finding a similar amount of wear on 3rd molars of different individuals (assuming these are erupting around 18) the age can be estimated through the equation 18 + 6 = 24 years of age (White, 2000). There are other methods for estimating age through wear as well, but this is the most known (White, 2000).

Age can also be estimated through the closure of cranial sutures. The skull is made up of a number of different bones that fuse together at different ages throughout development. The technique isn't as widely used today, as the development of the pubic symphysis is much more accurate. However, it can be useful when one only has a skull. The sutures are evaluated on a scale of 0-3 with 0 being completely unfused or open and 3 being completely fused, closed, or obliterated. The spheno occipital synchondrosis (located on the base of the cranium) is extremely useful in age estimation as it is typically fused between 20-25 years in 95% of the population (White, 2000).

Normally, the biological details of an individual would be assessed by a forensic anthropologist and given to the forensic artist for reconstruction. However, this thesis aims to understand and analyze all aspects of this process. It additionally, serves as a practicum, allowing (me) to practice skeletal analysis and experiment with reconstruction methods.

CRANIAL LANDMARKS (OSTEOMETRIC POINTS)

These points have been developed to allow physical anthropologists, and in this case craniofacial artists to take specific and comparable bone measurements. These points are generally separated into two groups: those that fall along the midline of the face or the midsagittal plane as well as those that are paired and appear on either side of the face (White, 2000).

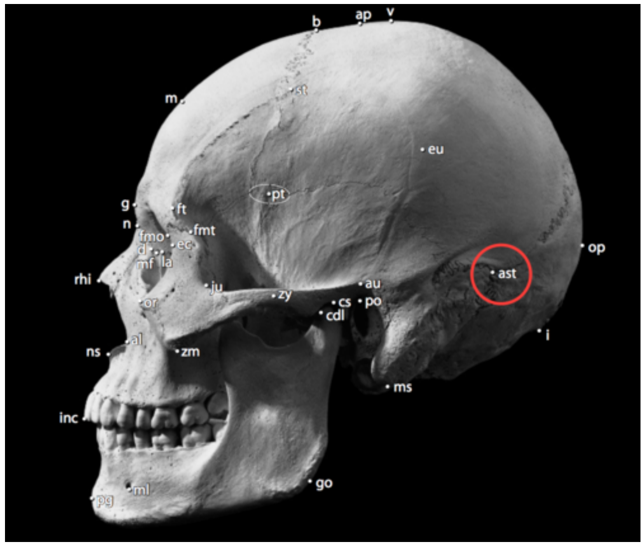
Unpaired:

- **inc. Incision**
- **ids. Alveolare (infradentale superius)**
- **pr. Prosthion**
- **ns. Nasospinale**
- **rhi. Rhinion**
- **n. Nasion**
- **g. Glabella**
- **m. Metopion**
- **b. Bregma**
- **v. Vertex**
- **ap. Apex**
- **ob. Obelion**
- **l. Lambda**
- **op. Opisthocranion**
- **i. Inion**
- **o. Opisthion**
- **ba. Basion**
- **spha. Sphenobasian**

- **ho. Hormion**
- **alv. Alveolon**
- **sta. Staphylion**
- **ol. Orale**
- **gn. Gnathion**
- **pg. Progonion**
- **id. Infradentale**

Paired:

- **zm. Zygomaxillare**
- **al. Alare**
- **or. Orbitale**
- **zy. Zygion**
- **ju. Jugale**
- **ek. Ectoconchion**
- **mf. Maxillofrontale**
- **la. Lacrimale**
- **d. Dacryon**
- **zyo. Zygoorbitale**
- **fmo. Frontomalare orbitale**
- **fmt. Frontomalare temporale**
- **st. Stephanion**
- **pt. Pterion**
- **co. Coronale**
- **eu. Euryon**
- **po. Porion**
- **au. Auriculare**
- **ast. Asterion**
- **ms. Mastiodale**
- **ekm. Ectomolare**
- **enm. Endomolare**
- **cdl. Condylion laterale**
- **cr. Coronion**
- **go. Gonion**
- **ml. Mentale**

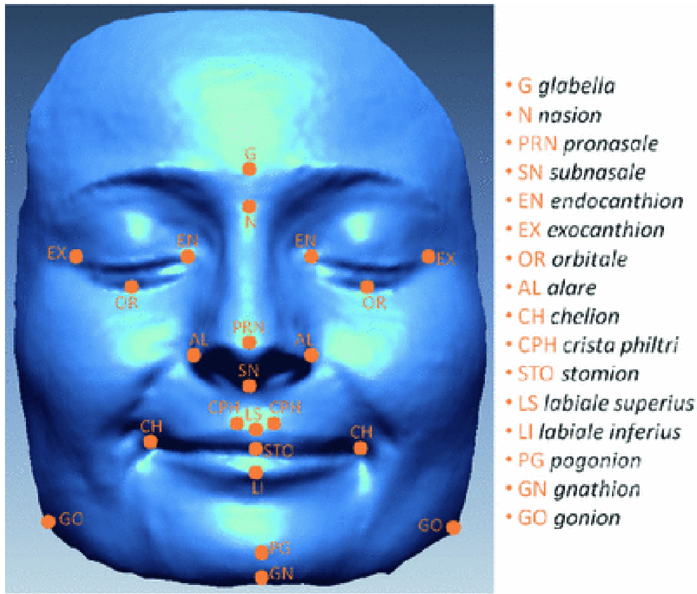


2.6 Diagram of the cranial landmark points typically used in osteology

Not all of these landmarks are entirely relevant for the field of craniofacial reconstruction, however. Those that are important are used for the marking tissue depth and they include (in this case the numbers matter as they are often written of the FSTT markers):

1. **Supraglabella**
2. **Glabella**
3. **Nasion**
4. **End of Nasals**
5. **Mid-Philtrum**
6. **Upper Lip Margin**
7. **Lower Lip Margin**
8. **Chin-Lip Fold**
9. **Mental Eminence**
10. **Beneath Chin**
11. **Frontal Eminence**
12. **Supraorbital**
13. **Suborbital**
14. **Inferior Malar**
15. **Lateral Orbit**
16. **Zygomatic Arch, Midway**
17. **Supraglenoid**
18. **Gonion**
19. **Supra M(2)**
20. **Occlusal Line**

21. Sub M(2)



2.7 ***Diagram of the cranial landmark points used in Facial Reconstruction***

FSTTS & TISSUE DEPTH

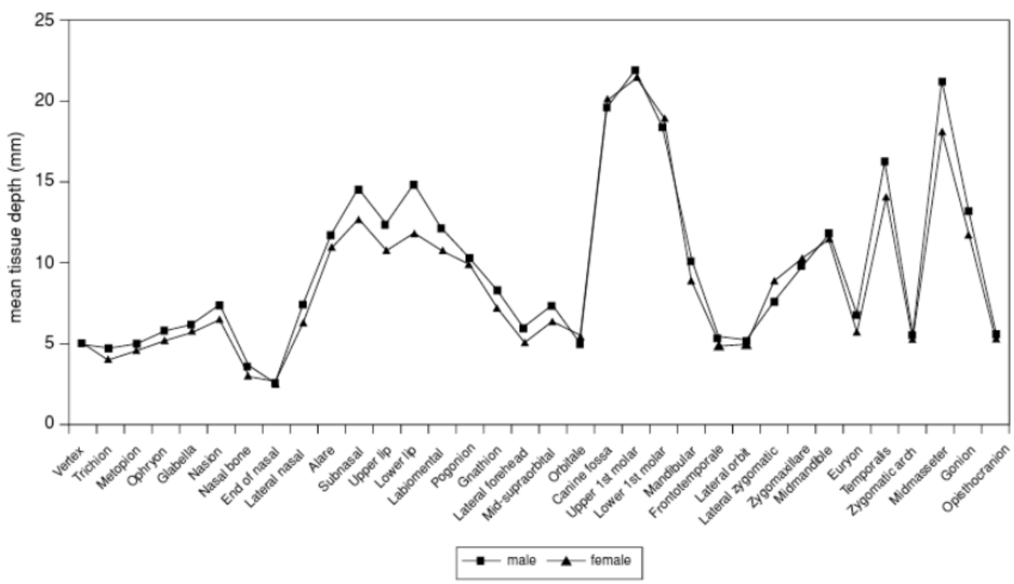
The variation in soft tissue depth between sexes, ages, ethnic groups and different nutritional states has been studied for the last 120 years (Wilkinson, 2004). The points used for depth markers range from 15-34 points and are based on craniometric points. As discussed before, Welcker was the first to study these tissue depths, however more recent study has focused on the same ideas. Many of these studies use cadavers, which can create problems as the post mortem face changes in depth due to loss of muscle tone and shrinkage (Wilkinson, 2004). “Soft tissue distortion occurs from drying and embalming even in the first few hours after death. Putrefaction, with bloating of the face, may occur rapidly even in temperate climates. The movement, skin elasticity and muscle tone in life all add bulk to a face, and the horizontal position of the cadaver when the measurements are taken create false tissue depth measurements due to the action of gravity. The results of these studies are not considered to be an accurate representation of the amount of tissue on the face in life” (Wilkinson, 2004). Interestingly, the process of embalming can affect the tissue depths at facial landmark sites - typically the measurements are actually thickened by approximately 35% which decreased to 20% after dehydration (Wilkinson, 2004). Other methods involving imaging techniques are currently being explored through utilization of X rays, MRI and CT scans (Wilkinson, 2004). So far, these methods seem to be even more accurate than the needle depths, originally explored by Welcker. Unfortunately these methods suffer from the fact that the individual must lie in a supine position which allows gravity to act on the face and therefore makes the tissue estimates inaccurate (Wilkinson, 2004). The most accurate technique has been through ultrasonic imaging. Results have shown that this method is the most similar and may even be more accurate to Welcker's original methodology. The main problem with this method is keeping the ultrasound wand or pen on the correct facial point. Studies have shown that these landmarks are often missed by approximately 3mm as a result of complex surfaces and complicated underlying structures. It has also been theorized that the angle in which the wand is held may affect the results (Wilkinson, 2004). Every skull presents its own unique challenges and therefore the attachment of tissue depth markers should be treated differently for every skull (Taylor, 2001). It is also important to note that many of these depths were originally studied using cadavers (Evison et al, 2003). The facial tissue of an individual will not be the same in life as it is in death and the age of the individual also plays a part as the face loses volume with age (Evison et al, 2003).Additionally, they come from very small samples, therefore they are somewhat biased.

DIFFERENCES IN FACIAL TISSUES RELATED TO NUTRITIONAL CONDITION

Swiss anatomist, His also studied the difference in facial depths of well nourished and emaciated people. He found that on average, the less nourished people had much thinner measurements except around the nasal bridge (nasion area) where measurements were about the same. The main differences were found in the jaw: mental eminence, mandible and under the chin. As well as in the cheek regions (Wilkinson, 2004). This is likely due to the fact that eating less calories causes the body to go into survival mode, where the metabolism slows down and begins to break down muscle and eventually fat. Other, later studies have confirmed this hypothesis - showing that emaciated individuals can have up to ⅓ less tissue than their counterparts (Wilkinson, 2004). They have also shown that even with less nutrition the tissue around the eye area did not decrease, likely due to the lack of extra musculature or fat. The most affected areas are those with well-developed muscles and hypodermic fat (fat located directly below the dermis).

DIFFERENCES IN FACIAL TISSUES RELATED TO SEX

Studies have shown that males typically have thicker tissue depths, especially in the brow, mouth and jaw regions. It can differ slightly by population, but women tend to have thinner measurements except in the cheek regions where they tend to have more tissue than males (Wilkinson, 2004).



2.8 Graph of the differences in facial depths according to sex

DIFFERENCES IN FACIAL TISSUES RELATED TO AGE

Differences in facial tissue as a result of age have been shown to be very variable. They have been studied by a number of different specialists, including His who analyzed white European males. Jan Czekanowski also studied the same and later Keiko Suzuki studied the faces of Japanese men and women. Overall, these studies have shown that tissues at the mouth and lower cheek tend to decrease with age, and tissues at the chin and brow may increase with age (Wilkinson, 2004).

DIFFERENCES IN FACIAL TISSUES RELATED TO ETHINIC ORIGIN

According to studies by anthropologists (such as Birkner, Fischer and Von Eggeling) tissue depths have differed by ethnographic region. These studies have shown that Chinese faces have thicker tissue than Europeans and Papuans, especially at the brow, upper lip, chin and zygomatic attachments. Papuan faces have thinner tissue than both Europeans and Chinese faces, especially at the nasion and zygomatic attachment, and thicker tissue at the mid mandible and gonial points. Black African faces have had significantly more tissue than all of these groups, especially at the upper lip and supraglenoid point. White European individuals tend to have much thinner tissue, especially in the masseter region.

Birkner (1907) concluded that the soft parts of the face vary more than the skulls between racial groups. When the Japanese population was compared with these groups, Suzuki (1948) found that Japanese faces had less of a difference between the nasion and mid nasal tissues (0.2mm) than European (2.24mm), Chinese (1.17mm) and Hereron (1mm) faces, but similar results to Papuans (see Tables 5.2 and 5.3). He also found that Japanese faces had thinner tissues at the chin, around the eyes and at the masseter areas than all the other groups, and thinner tissue at the zygomatic attachment than European, Chinese and Hereron faces. Japanese faces also showed thicker tissue at the supraglenoid point than all the other groups.Rhine and Campbell (1980) found that Black subjects showed thicker tissue depths than European faces at all facial areas apart from the frontal eminence (see Table 5.3). The greatest differences appeared at the lips, beneath and lateral to the eyes, and at the mandible. This may have been due to the use of fresh, undistorted cadavers by Rhine and Campbell, or it may be due to an increase in stature and weight between the early part of the twentieth century and the 1980s. It may also be due to racial group differences between White Europeans and Black Americans. Rhine and his colleagues then compared the Black American results with White American results (Rhine et al. , 1982). They found that the White American measurements fell between the White European and Black American measurements at the majority of points (see Table 5.3). The Black Americans had thicker tissues than White Americans at all points, except the forehead, nasion, rhinion, and lower first molar, where the tissues were similar, and the supraorbital point, where the tissues were thinner. Japanese faces showed smaller measurements at all points compared to Black American faces, and smaller measurements than both White Americans and Europeans at the majority of points. The exceptions were at the chin--lip fold, where the Japanese tissue was thicker than Whites, and at the zygomatic arch, where the Japanese tissues were similar to Whites. Rhine (1983) found that South-western Indians showed thicker tissue at all areas than the Japanese. Southwestern Indians showed tissue depths somewhere between Blacks and Whites, except below the lower molar region, where the tissue was thicker in South-western Indian men than both Black and White men (see Table 5.3). Phillips and Smuts (1996) suggested that. Black faces have thicker tissue than Mixed Race faces at the upper and lower parts of the face, notably at the lower lip, frontal eminence and cheeks (see Table 5.6). They also found that Mixed Race faces had thicker tissue at the philtrum, upper lip and gonial areas than White faces, but thinner tissue at the nasion, mental, supraorbital, lateral orbit and cheek points. Phillips and Smuts suggested that Mixed Race faces are not midway between Black and White faces, but should be considered a unique spectrum. Lebedinskaya and her colleagues (1993) found wide intergroup variation and minor differences between the nine different Russian ethnic groups that she studied (see Table 5.9). There was some overlap between Mongoloid (Koreans, Abkhazians and Buryats) and Europoid (Russians, Lithuanians, Armenians and Uzbeks) groups, and one group of mixed origin -- Kazakhs -- approached the Mongoloids, whilst another -- Bashkirs -- approached the Europoids. A tendency for thicker soft tissues in the nasal region was noted in both sexes of Europoids as compared to Mongoloids. When the White European (Helmer, 1984), White American (Manhein et al. , 2000) and White Australian (Simpson & Henneberg, 2002) ultrasonic measurements are compared, they appear very similar (see Tables 5.4, 5.7 and 5.8). The exceptions are that the male European faces had more tissue at the mouth and less at the gonion than the other groups, and the male Australians had more tissue at the glabella and nasal bones than the other groups. The female Europeans had more tissue at the mouth and beneath the chin, and less at the gonion than the other groups, the female Australians had more tissue at the nasal bones than the other groups, and the female Americans had less tissue at the glabella and alare than the other groups. Indian faces (Sahni, 2002) showed thinner tissues at the majority of points than White European, Black American, White American and Mixed Race South African faces (see Tables 5.3, 5.5 and 5.6). The Japanese faces showed thinner tissues at all points than the Indian faces. The exceptions are that Indian, White European and White American men had more tissue at the supraorbital point than Black American and Mixed Race men. Indian men had thicker tissues at the nasion, lower lip and upper molar regions than the Mixed Race men, and Indian women had thicker tissues at the lower lip and upper molar regions than the Mixed Race women. Japanese faces had similar tissue to Indian faces at the rhinion and chin--lip fold. In conclusion, there appear to be great differences in facial tissue depths between different ethnic groups. This may be a reflection of racial origin group variation, ethnic group variation, stature and weight, or just a reflection of the enormous variation between individuals in a world population. The most consistent variations are apparently that African faces have thicker tissue in general than other groups, especially at the mouth, beneath and lateral to the eyes, and at the mandible. Japanese faces have thinner tissues than most other groups, except at the chin--lip fold and side of the head. Whites and Indians have thicker tissues at the supraorbital region than Africans and Mixed Race individuals. Mixed Race faces have thinner tissue than African faces at all points, and thinner tissue than White faces at most points, except the upper lip, which has thicker tissue for Mixed Race than White faces. South-western Indians have tissue depths somewhere between Whites and Blacks, except at the lower cheek, where they have more tissue.

THE FACIAL FEATURES

The appearance of the face is determined through the underlying bone structure and musculature determines the shape of the soft tissue and how it overlaps to form the surface of the face. The facial features also play a large role in determining an individual's appearance. The development of the eyes, nose, lips, and ears is known as the artistic phase (Taylor, 2001). The features, in addition to the modeling of musculature and the corresponding depth measurements create a recognizable face. In order to correctly model the facial features, a careful study of the muscle attachments as well as any individual characteristics such as asymmetry should be noted as well as the measurements that correspond to each feature.

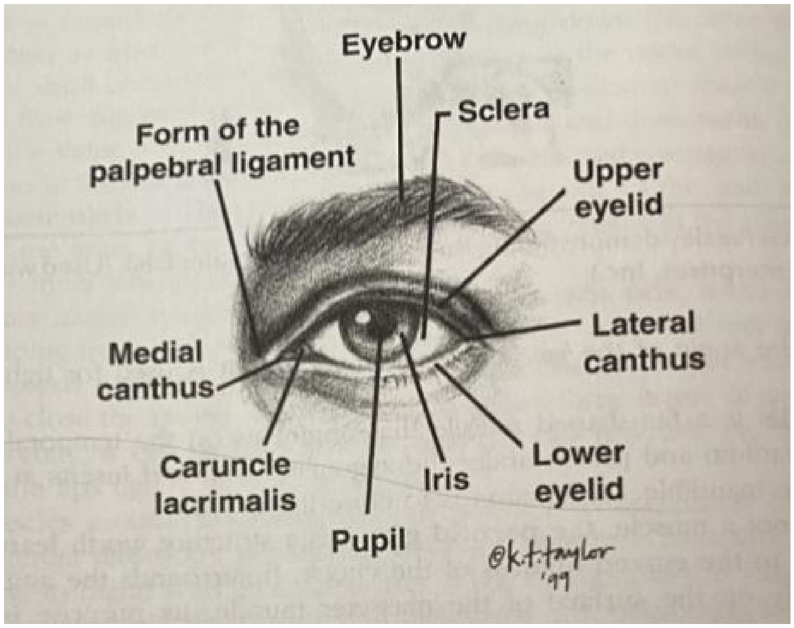
The eyes:

There is currently much disagreement among professionals when it comes to the eyes. Some artists and scholars claim that it is impossible to fully render an accurate eyeball in the correct anatomical placement. Others argue that the eyes are more predictable and can be rendered accurately. Regardless, it is impossible to know the color of the eyes when they are not present. Therefore the color of the eyes is more of a choice based on educated guesswork. There may be indicators found with the body that can help this process. For example light or dark hair can indicate whether the eyes should be light or dark in appearance. There can also be a level of what Karen Taylor calls "built in ambiguity" through the use of shading or grayscale modeling.

Parts of the eye:

The eye is made of ten individual features, including the Form of the Palpebral Ligament, Medial Canthus, Caruncle Lacrimalis, Pupil, Iris, Lower Eyelid, Lateral Canthus, Upper Eyelid, Sclera and finally the eyebrow. The opening of the eye is also called the eye fissure. It is important to understand that because the eye is round, the upper and lower portions of the face have volume and should be developed with a fullness in order to achieve a more realistic look. The upper and lower eyelids are not symmetrical with the lower having a less prominent curve than the upper. The form of the medial palpebral ligament gently rises up and often catches light which makes it visible just above the medial canthus. The outer lateral canthus should also be distinct, but much less round in appearance. It is also possible to have a vertical fold of skin, called the epicanthus or epicanthic fold, which may cover the medial canthus.[3]

[3] This feature is often associated with Asian descent, but can happen in people of any ancestry.



2.9 Labeled parts of the eyes taken from Taylor, 2001

Placement of the eyes:

Fontally - The eyeball should basically be centered in the orbit, when in a frontal view. According to most ophthalmology texts, the average human eyeball is the same size as a U.S quarter - 25mm (1 inch) in diameter (Taylor, 2001). The inner canthus of the eyeball is placed 2mm lateral to the lacrimal crest and the outer canthus is placed 4mm medial to the malar tubercle (Gupta et al, 2015). When the malar tubercles are absent, the outer canthus is placed 10mm below the line of frontozygomatic suture and 5-7mm from the orbital margin (Gupta et al, 2015).

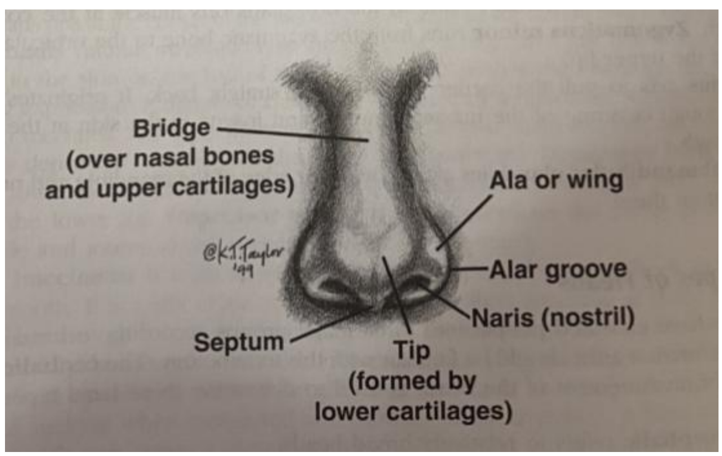
Lateral View - The projection of the eyeball in profile can be determined by drawing a light line from the center of the top of the orbit to the center of the bottom of the orbit. This line will overlap the FSTT landmarks (#12 and #13) that have already been placed. Although only a portion of the eyeball is seen when the lids are added, the correct shape and placement of the eye is very important.

The Nose

The nose is different for each individual. It is specifically determined by the skull. Many of the predictions for the placement and projection of the nose are based off of the nasal spine. Without the nasal spine, the prediction of the nose will be much more difficult and speculative.

Parts of the nose:

The nose is composed of six individual parts including the Bridge (form over the nasal bones and upper cartilage), septum, tip (formed by lower cartilage), Naris (nostril), Alar groove, and the Ala or wing. The reason that the nose is so difficult to estimate is because it is mostly composed of soft tissue and cartilage rather than bone. Additionally, the tissue can be very difficult to predict since the alar cartilage (cartilage below the wing of the nose) can be big or small and there is no way to tell.



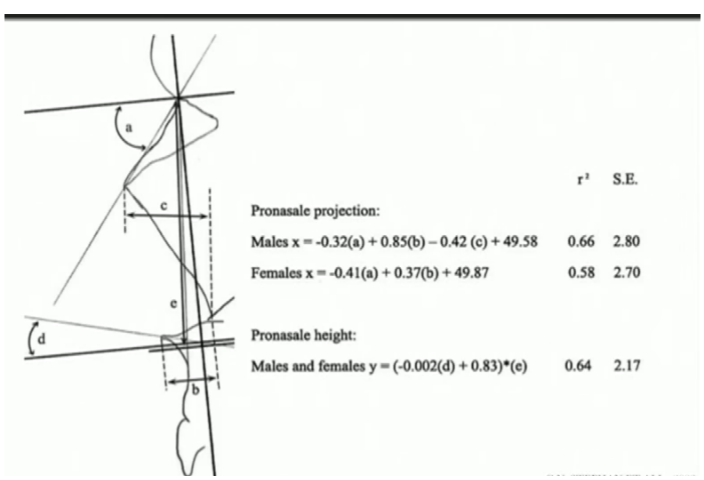
3.0 Labeled parts of the nose taken from Taylor, 2001

Placement of the Nose:

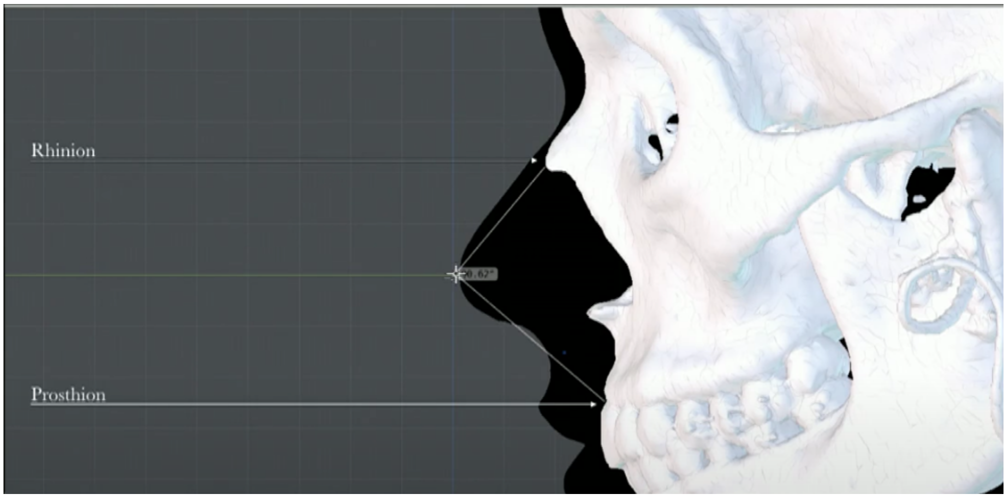
Fontally - The maximum width of the nose is determined by the bony nasal aperture at its widest point as three-fifths of the overall width of the soft nose (Gupta et al, 2015). Krogman developed a simple formula to predict the soft tissue nasal width based on the bony piriform aperture. For caucasoids, the nasal aperture is measured at its widest point and 5 mm is added to each side. For Negroids, the nasal aperture is measured again and 8mm is added to each side.

However, there was no formula provided for mongoloids and therefore it should be determined by the artist, based on an educated guess (Taylor, 2001). In order for the person to have been able to breathe in life, the location of the ala wing must have attached below the nasal aperture on either side (Taylor, 2001).

Lateral View - The profile of the nose is more complicated to estimate. Typically the shape and the size of the alae are determined by the nasal aperture (Gupta et al, 2015). However, the projection can be measured through another formula. Krogman determined that the measurement of the nasal spine multiplied by 3 and added to the depth of FSTT #5 should determine the projection starting at the subnasale and ending at the pronasale. More recent developments by a Brazilian team at the University of Sao Paulo have shown that a line can be drawn from the top (rhinion) to the bottom (prosthion) of the nose (making sure to stay in line with the projection of the nasal spine) and extended exactly 90 degrees to predict the projection of the nose (https://www.youtube.com/watch?v=mmJOgUHUa7QP) Karen Taylor also explains that the lateral view of the alar wing produces a C like form. She explains that this groove does not rest directly on top of the side of the nasal aperture. Instead, it sits more downward and forward (Taylor, 2001).



3.1 Typical equations used to find the projection of the nose

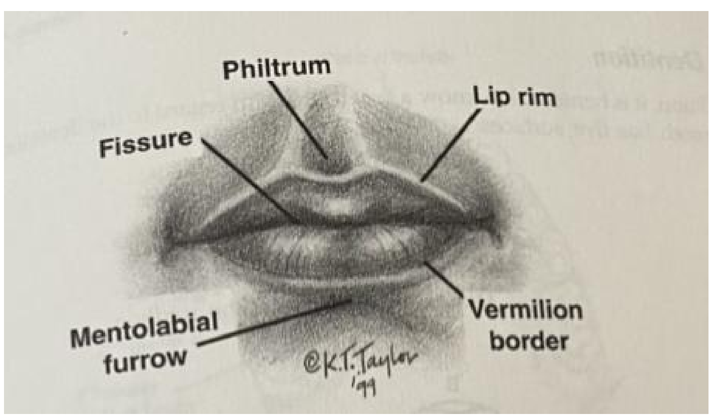


3.2 New technique used to find the projection of the nose found by the Brazilian team at the University of Sao Paulo

<u>The Mouth (lips)</u>

Parts of the mouth:

The mouth is made up of five main parts, including the Philtrum, Lip rim, Vermilion border, Mentolabial furrow and the Fissure. While it seems simple in shape and structure the mouth is extremely important for conveying emotion. There are at least seven different muscles in the area of the mouth.



3.3 Labeled parts of the mouth taken from Taylor, 2001

Placement of the mouth:

Fontally - According to Krogman, the width of the mouth is determined by measuring the front six teeth. The vertical thickness of the mouth is derived by measuring the combined height of the enamel of the upper and lower teeth. This can be effectively measured through the texture change of the tooth enamel and the cementum (root area) which often leaves a small, tangible ridge. The corners of the mouth are placed near the maxillary canine and first premolar (Gupta et al, 2015). The thickness of lips is determined by upper and lower anterior teeth. While it is important to follow these guidlenss it is also important to understand that every face is different and age, sex, and “race,” may change the apperance of the mouth (or any other feature for that matter). The parting line of the lips (fissure) can also be variable. However, a good estimation technique is using the teeth, with average placement slightly above the edges of the central incisors. While the mouth can differ, it is necessary that the teeth be drawn/modeled to exact correctness (Taylor, 2001).

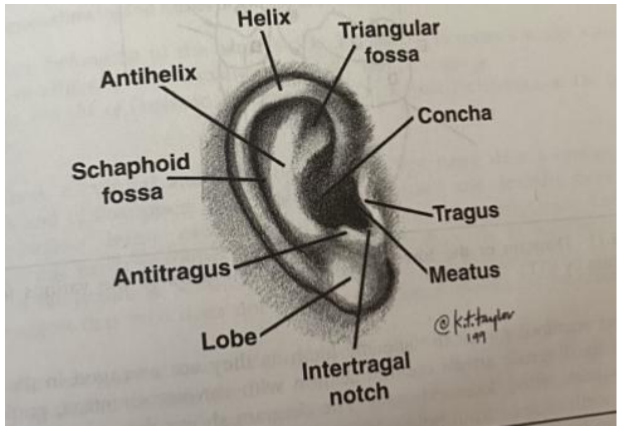
Lateral View - The lateral corner of the mouth is generally dropped. The FSTT markers numbers 5, 6, and 7 should help determine the depth of the lip area.

The Ears

Because the ears are composed primarily of cartilage, very little is known about how to predict what they may look like. The best way to estimate this is through creating an anatomically correct ear and placing it where it should go. The ear must reside behind the angle of the jaw and rests on an angle, about 15 degrees back. They should not be placed right next to the head, in fact there is about “one finger” of space between the back of the ear and the head (Taylor, 2001).

Parts of the ears:

The ears are composed of approximately ten different parts. These include the Helix, Antihelix, Scaphoid fossa, Antitragus, Lobe, Intertragal notch, Meatus, Tragus, and the Concha.



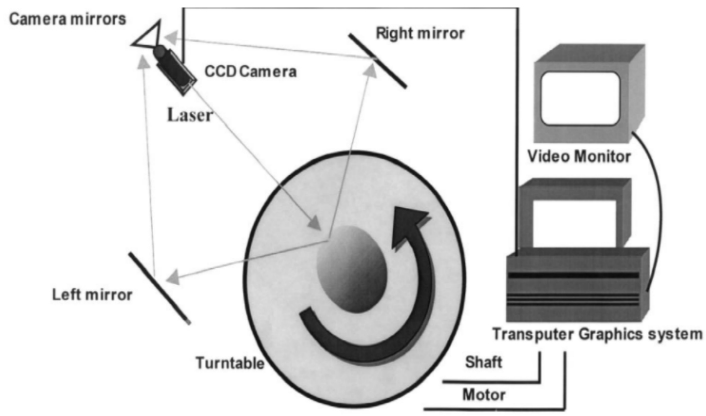
3.4 Labeled parts of the ears taken from Taylor, 2001

Placement of the ears:

Karen Taylor has observed that although it is untested, there may be some correspondence between the mastoid process and the projection of the ears (Taylor, 2001).

THE RISE OF COMPUTER GRAPHIC RECONSTRUCTION

The field of forensic facial reconstruction is time consuming and expensive. One way of combating these problems is to use computer graphic techniques in the reconstruction of the skull and face. 3D reconstruction methods are now being routinely used in forensic cases as well as archeological ones (Vanezis et al, 200). The methods for this process are relatively new, with few people working in the field (Rodriguez, 2018). However the methods are still being used and developed today and there is a large amount of literature on the subject (Turner et al, 2004; Shui et al, 2017; Tu et al, 2007; Romeiro et al, 2014). While this can be a great alternative to manual methodologies as it can save time and money, it is not without its challenges. In order to do this kind of work, it is vital to understand human anatomy (both bone morphology and musculature) as well as different modeling softwares and may even require an understanding of different coding languages such as C++. The first steps of this process usually begins with creating a digital representation of a physical skull. There are a few ways to do this. The most common method involves the use of Computerized Tomography (CT) scans. After a skull is scanned, it is uploaded onto the computer and analyzed. A wide variety of different techniques such as needle probing, caliper or radiographic measurements, or ultrasonographic assessments are used to determine the FSTT, which lead to different results in the FSTT statistics. In addition, 3D imaging techniques such as CT or Magnetic Resonance Imaging (MRI) are employed for this purpose (Giezten et al, 2019). Other institutes use scanning technology. For example, the Department of Forensic Medicine and Science at the University of Glasgow, uses a Facia Optical Surface Scanner which was developed by the Medical Physics Department of University College London. “With the room in darkness, a thin beam of light is emitted from the laser and strikes a small cylindrical prism filter in front which fans it out to produce a vertical line on the skull which is 0.7 mm wide (Fig. 2). The laser used 2 is low power (1 mW) and the intensity does not exceed 5 W/cm. When a live subject’s face is scanned, despite the fact that there is no hazard to the person, it is recommended that the beam is not observed directly any closer than 30 cm from the laser source” (Vanezis et al, 1989). Other institutions, such as The University of Sheffield in England use a Cyberware 3030 RGB CN color laser scanner and Silicon Graphics Indy™ computer to capture 3D images of a skull (Evison, 1996). As the platform rotates a 'wireframe' matrix is generated. However, CT scanning permits more accurate measurement of tissue depths. The benefits of this scanner are that it allows large samples of tissue depth measurements to be collected, with associated attributes of age, sex, build and, where appropriate, ethnic group (Evison, 1996). “A pilot study on the collection of tissue depth measurements from CT scans has been carried out by one of the University's staff members (Nelson, 1996). Digitized images of facial features not predicted by the skull contours (nose, eyes and mouth) must be added by separate means to generate a wireframe face, onto which color and texture can subsequently be rendered. If necessary, a skull can be reconstructed 'virtually' from the separately scanned parts" (Evison, 1996; Nelson, 1996).



3.5 Facia Optical Surface Scanner (left), Cyberware 3030 RGB CN color laser scanner and Silicon Graphics Indy™ computer (right)

Similar to manual reconstruction techniques there are a number of different techniques that currently exist for digital reconstructions. Many of these have developed in the 1980s[4] and continue to be developed even today (Evison et al, 2003). One approach involves placing the tissue depth landmark positions on a 3D laser scanned image of a skull manually, using a mouse 'click and drag' operation (Evison et al, 2003). Next, "A computer program is then executed that automatically attaches the selected set of tissue depths at the appropriate landmarks and renders a smoothed composite facial image over the newly generated surface. Although some subjectivity can remain in the 'pegging' of a composite facial image onto the digitized skull matrix, the results are far more rapid and reproducible than sculpted reconstructions" (Evison et al, 2003). A related approach by Kähler et al. in 2003, involves manual location of landmark sites and tissue depth markers. This unfortunately loses some of the advantage of automation. However, combined with a partial recreation of the craniofacial musculature the method allows for the musculature properties of motion and even permits the reconstruction to exhibit some facial expression

[4] To learn more see: Vanezis et al. 1989, Ubelaker and O'Donnell 1992, Miyasaka et al. 1995; Tu et al. 2000, Nelson and Michael 1998; Kähler et al. 2003

(Evison et al, 2003). Another method involves warping or deforming a volume tissue depth data set derived from medical imaging of a living person's head - typically using CT scans (Evison et al, 2003). While this method offers quantitative advantages as it offers a comprehensive tissue depth coverage of the skull, it relies on scans, which have not always been an accurate representation of tissue depths in a healthy population (Evison et al, 2003).

There are some limitations to this type of approach. Some of these include misalignment between palpated landmarks on the face of cadavers and the actual landmarks on the skull; deformation of soft tissue occurring during the procedure; and the poor relationship between the soft tissue of the cadaver and tissue depths in vivo (Vanezis, 2000; Suk, 1935). Another issue related to the topic deals with the distortion due to the during or embalming of the face due to decomposition of the body. There is also a lack of research relating to pediatric soft tissue data.

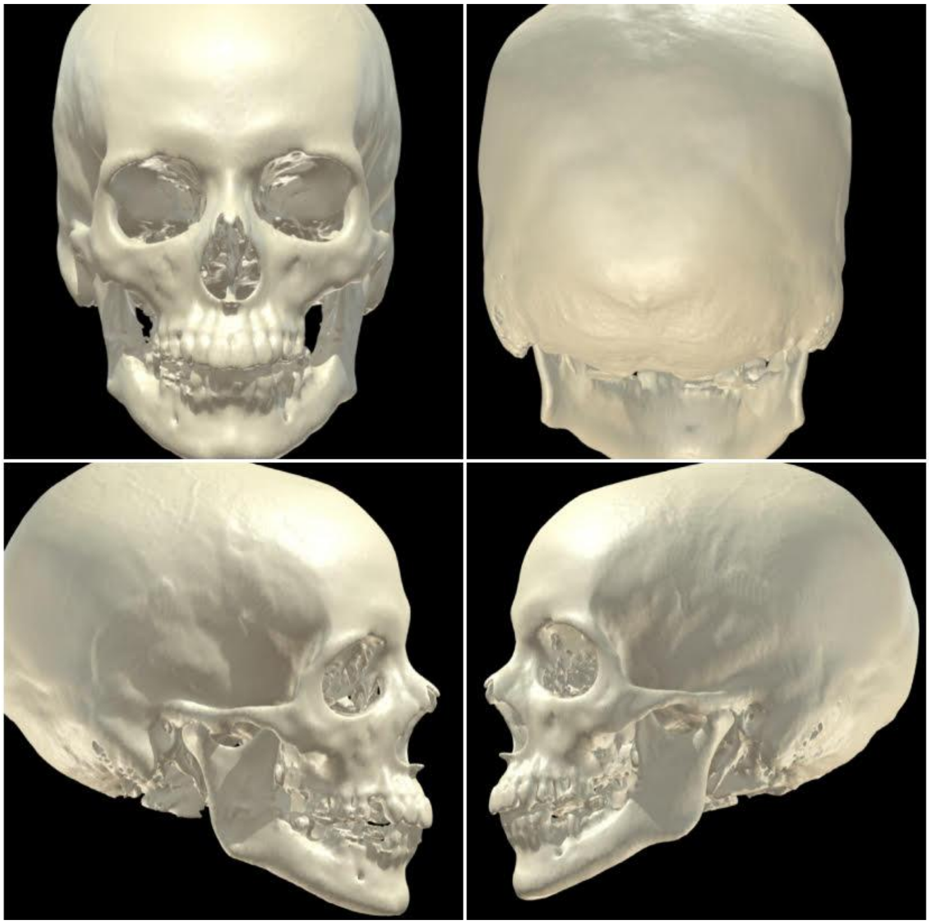
Despite these limitations and the lack of research in the field, these computerized techniques do have advantages. The advantages of such a method over traditional, plastic reconstruction are a lack of subjectivity, thus improving the chances of producing a closer resemblance to the deceased, and speed. Furthermore, a number of alternative faces may be produced at the same time and images can also be stored and reconstructions repeated at any time if required. Other advantages are that the original skull may be used rather than a cast or model, since it is not being built on directly.

PICKING THE SKULL: SKETCHFAB AND THE SKULLS

The skull(s) used in this process will come from 3D models on sketchfab. Sketchfab is an online database used for storing and accessing models. The platform is highly accessible, as it is available and compatible across every browser, operating system, desktop and mobile device.

The platform also supports VR and AR for devices with compatible hardware (https://sketchfab.com/about).

While there are numerous skull models on the platform, in order for it to be usable for this project the skull must not only be complete but it must be downloadable. It should also be high enough quality that the details of the skull are discernable. There are skull models that cost money to download, however this project is also looking at the most accessible methodologies for forensic facial reconstruction - therefore free (or low cost) models are ideal. With these parameters it becomes a little bit harder to find a working skull, however The University of Dundee in Scotland had a few potential skulls. Another option is a collection of models created based on CT scans from the Cancer Image Archive (TCIA) (https://www.cancerimagingarchive.net/) These skulls are not quite as high quality as those from the other institutions, however, they are free, downloadable, and contain information about the age and sex of the individual. They are also able to be 3D printed, which is useful for a manual reconstruction. The difficulty in using these skulls will come from the older age of most of the individuals present within the collection. This will not affect the underlying structure of the face such as the placement of the musculature, but it may affect the final look of the face as the loss of muscle tone and skin as well as the shrinkage of the underlying fat will cause the face and skin to become more drooping and less smooth and less elastic in appearance. (https://copdo.com/wp-content/uploads/Facial-Aging-Flipchart.pdf)

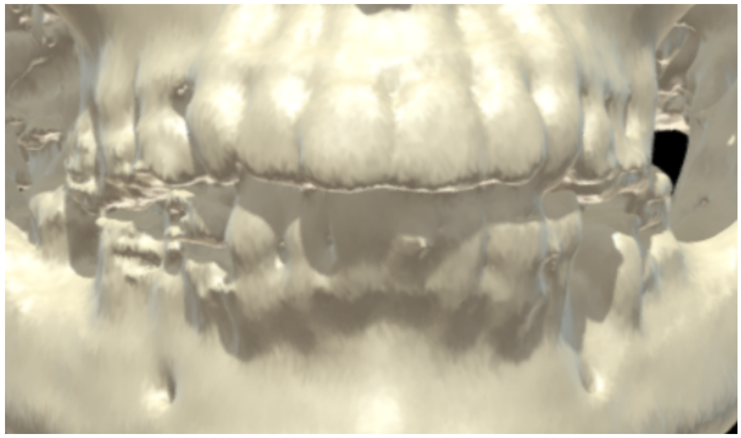


3.6 Sketchfab skull (anterior, posterior, right lateral, and left lateral)

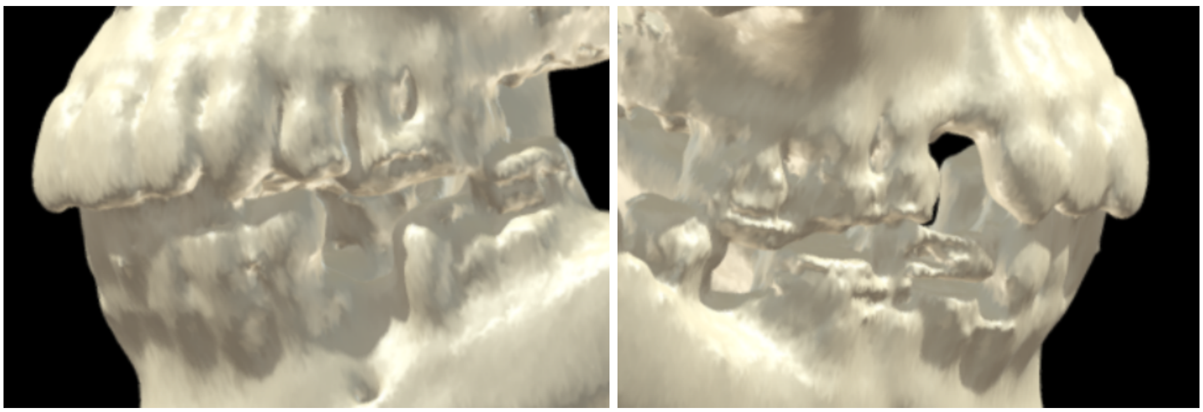
ANALYSIS OF THE SKULL

1. **Age** - the skull does not seem to have any sutures. I doubt this is a result of age, as there are no signs of sutures and not many other signs of advanced age. My guess is that the scan didn't show the sutures well and therefore the model was created without them. As a result of this, the best method for estimating the age of this individual will come from the teeth. Unfortunately, however it is impossible to examine the wear on the teeth for a more accurate analysis. The upper and lower molars on the left side seem to contain a decent amount of wear, however I cannot be certain that this is front he modeling process or due to some kind of pathology. Looking at a frontal view of the skull it seems as if most teeth are present; 8

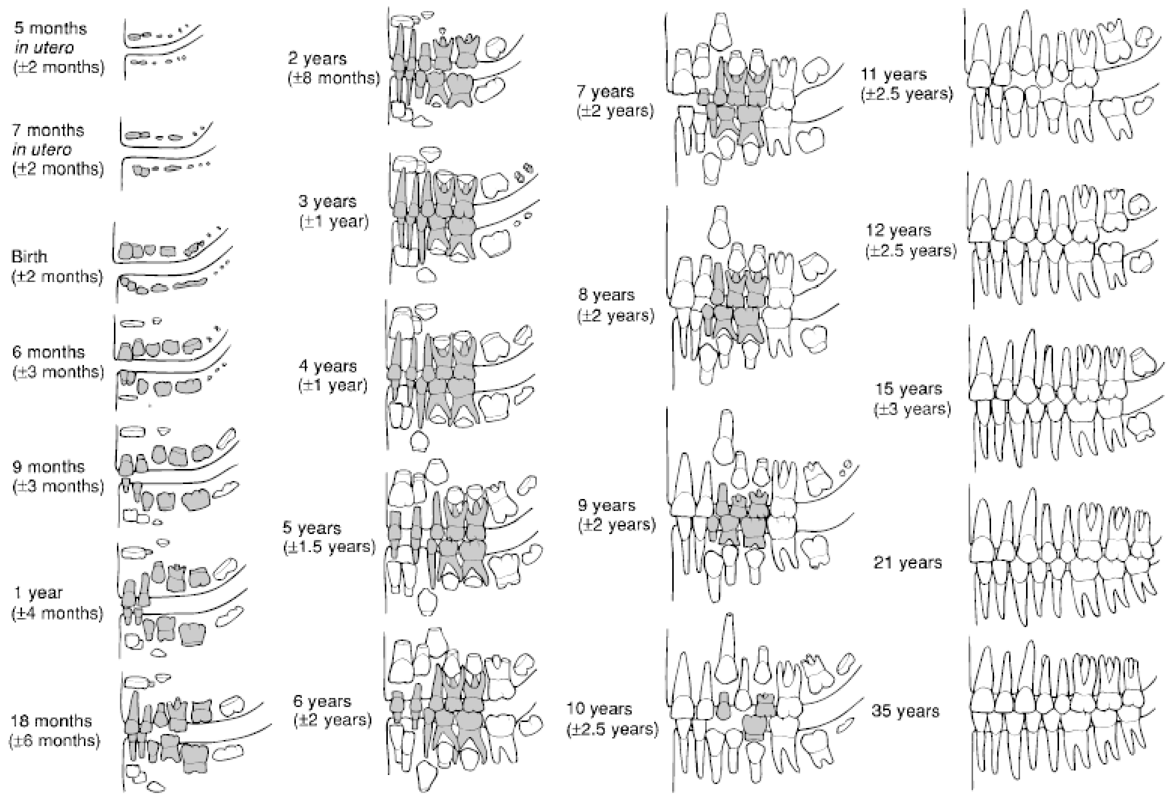
incisors (4upper+4lower) 4 canines (2upper+2lower) and 8 premolars and 12 molars or a lateral pattern of 2.1.2.3. There are no upper 3rd molars, though it looks like there is a space for them on both the left and right sides. There also seem to be a few anomalies. The right upper first molar contains a space and no tooth, however I cannot be sure what this is attributable to. It may be mandibular alveolar resorption which tends to start happening around or after menopause (ages 40-50 ish, though the average in the U.S is 51 years old) in women (Mays, 2014; Jonasson, 2018) but it could also be due to pathology (which is likely as the scans come the cancer imaging center) or even both. The lower right back half of the jaw is very messy and I cannot make out what is happening, though it looks as if there was once a spot for all permanent teeth, regardless of whether they are actually present or not. There is also a space on the left mandible where the second premolar should be and on the maxilla where the first permanent molar is. I, again, am not certain what this is caused by. It would be much easier to tell on an actual skull. Based on this analysis I would say the individual is at least 35 years old. If I were to analyze wear using this model, I would say that all three molars are present (or at least once were) Based on the fact that the 1st molar usually accumulates 6 years worth of wear before the next molar erupts (White, 2000) an addition 6 years can be added 35 + 6 = 41 years of age. Based on the fact that the second and third molars are (or at least were present) allows for another 12 years, 6 for each tooth. Therefore 35 + 18 = 53 years old. This would also line up with the ages corresponding to alveolar resorption.



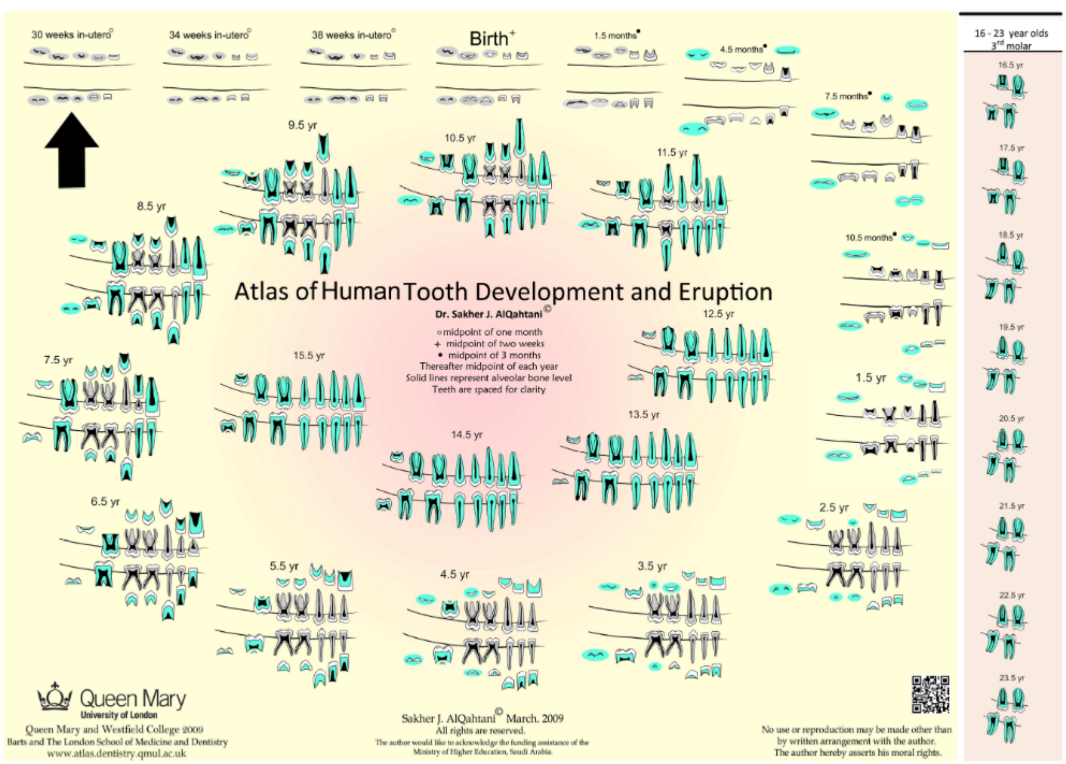
3.7 Frontal view of the maxillary and mandibular teeth from the Sketchfab skull



3.8 Right and left maxillary and mandibular incisors, canine, premolars and molars from the Sketchfab skull



3.9 Chart depicting the eruption of teeth by individual age, taken from White, 2000.

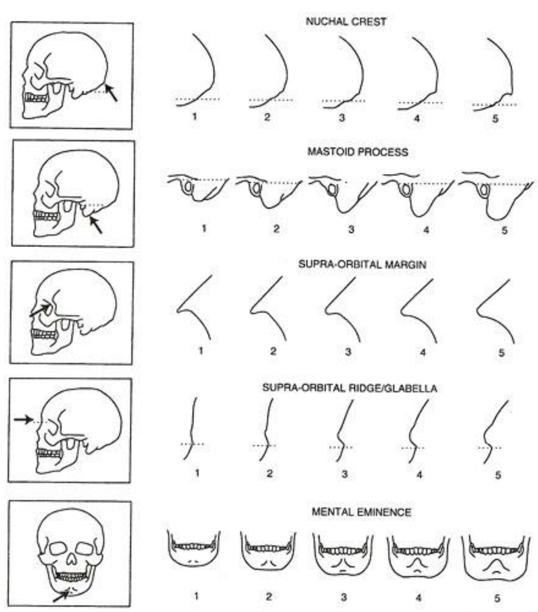


4.0 Chart showing tooth development based on age, taken from the University of London's school of dentistry

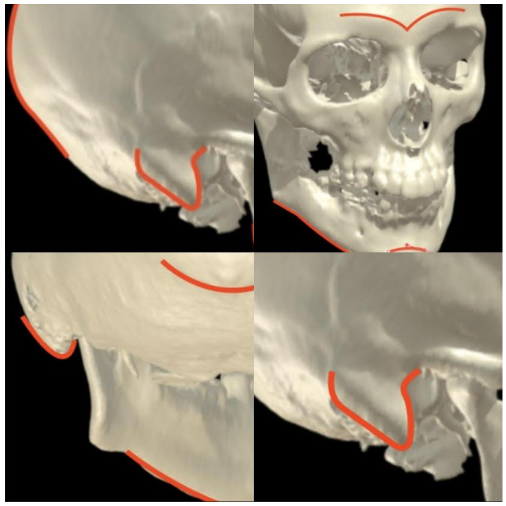
2. **Sex** - The skull is quite gracile, promting me to beleive it is probably a female. Additionally, both the mental eminence and the brow ridge are not prominent. However, this is not enough to make an estimate as these characteristics may also be found on a male skull and more robust skulls can also be female, therefore other morphological elements must be analyzed. Using the scoring system, I would say the following:

Feature:	**Score:**
Nuchal crest	1
Mastoid process	2
Supra-orbital margin	1 (maybe 3)
Supra-orbital ridge/glabella	1
Mental eminence	2 (maybe 3)

Based on the low scores even when averaged together (1.4-2) this skull belongs to a female individual.



4.1 Comparable evaluation chart of different morphological traits and how they relate to sex estimation



4.2 Sex estimation landmarks on the skull from Sketchfab starting with the supraorbital margin, mastiod process and occipital bone, supra-orbital ridge/glabella gonial angle, and mental eminence, nuchal crest and finally the mastiod process

3. **Ancestry -** There are a few morphological landmarks on the skull that can be used to help determine ancestry. The dentition can often offer insights as well, with shovel shaped incisors often indicating a person of Native American descent.[5]

In order to estimate ancestry with any level of accuracy, statistical analysis should be performed. There are tools and databases that already exist for osteologists and forensic anthropologists. One of these is Osteomics's herneR database, which allows for morphoscopic estimation of specific cranial landmarks. These include the Anterior Nasal Spine (ANS), Inferior Nasal Aperture (INA), Interorbital Breadth (IOB), Malar Tubercle (MT), Nasal Aperture Width (NAW), Nasal Bone Contour (NBC), Nasal Overgrowth (NO), Post Bregmatic Depression (PBD), Supranasal Suture (SPS), Transverse Palatine Suture (TPS), and finally the Zygomaticomaxillary suture (ZS). These are analyzed on the individual skull and evaluated on different scales, typically from 1-3 or 0-1. Based on the information, the database analyzes the result and gives the probability of

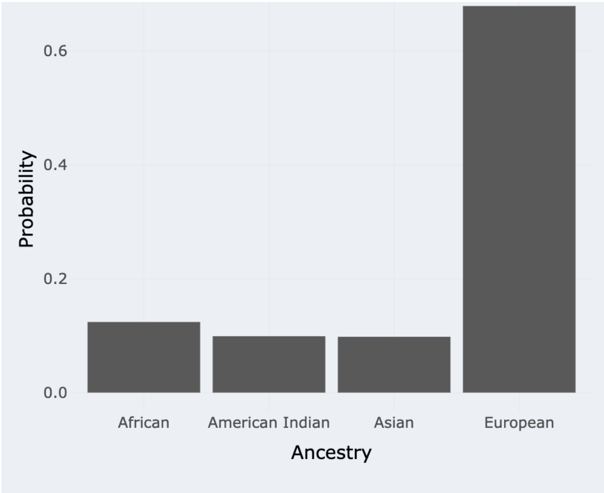
[5] This has been understood in biological anthropology for years, however this indicator and many others are starting to be questioned as these traits can be found in individuals that come from a very different place. For example these curved teeth have been found at a dig site I have worked on in Transylvania, Romania. We have also found skulls with nasal guttering, which can be associated with African Americans, however the dig site was located in Eastern Europe.

African, American Indian, Asain and European ancestry. Because of the overlap in traits it is hard to estimate just one ancestry. As a result of this I performed multiple analyses the results show that the individual is likely of European descent:

- First analysis: Included the following data:

Feature:	Score:
Anterior Nasal Spine (ANS)	2
Inferior Nasal Aperture (INA)	3
Interorbital Breadth (IOB)	2
Malar Tubercle (MT)	1
Nasal Aperture Width (NAW)	1
Nasal Bone Contour (NBC)	0
Nasal Overgrowth (NO)	1
Post Bregmatic Depression (PBD)	0
Supranasal Suture (SPS)	NA
Transverse Palatine Suture (TPS)	NA
Zygomaticomaxillary suture (ZS)	NA

The result of the data gave a probability of 67.87% that this skull belongs to someone of European descent.



African	American Indian	Asian	European
0.1240	0.0990	0.0980	0.6789

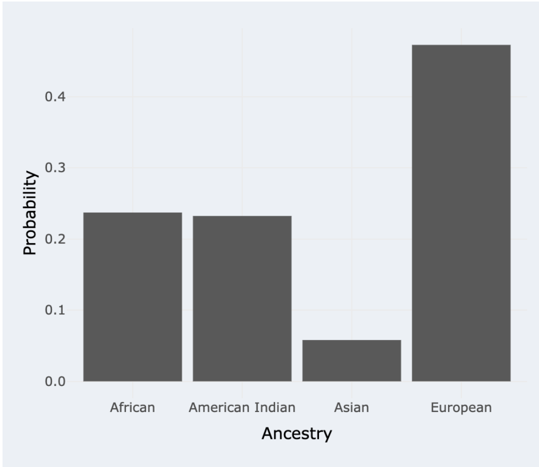
4.3 Graph and statistical likelihood of European ancestry versus other possible descendant groups

- Second analysis:

Because these features can seemingly lie in the middle of two numbers I ran the tests for both possibilities, where in the second I changed the score of the Inferior Nasal Aperture from 3 to 2, the Malar Tubercle from 1 to 2, and the Nasal Bone Contour from 0 to 1

Feature:	Score:
Anterior Nasal Spine (ANS)	2
Inferior Nasal Aperture (INA)	2
Interorbital Breadth (IOB)	2
Malar Tubercle (MT)	2
Nasal Aperture Width (NAW)	1
Nasal Bone Contour (NBC)	1
Nasal Overgrowth (NO)	1
Post Bregmatic Depression (PBD)	0
Supranasal Suture (SPS)	NA
Transverse Palatine Suture (TPS)	NA
Zygomaticomaxillary suture (ZS)	NA

These data inputs also gave a higher probability of European Ancestry with a result of 47.26%



African	American Indian	Asian	European
0.2371	0.2323	0.0580	0.4726

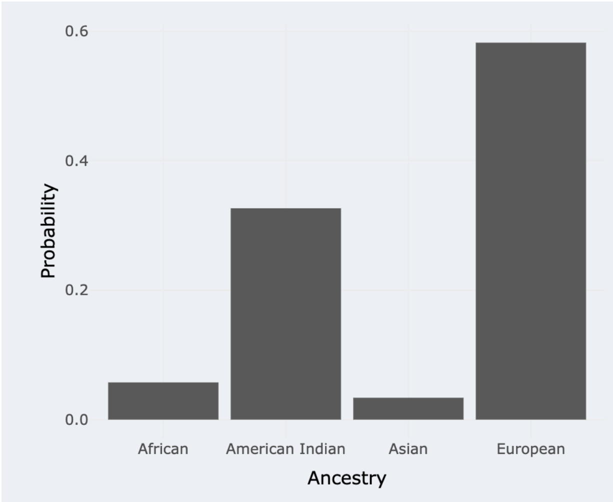
4.4 Graph and statistical likelihood of European ancestry versus other possible descendant groups, with a higher likelihood of a different ancestral background based on the different evaluation of morphological traits. Specifically, a higher score for the Anterior Nasal Spine (ANS) and the Interorbital Breadth (IOB).

- Third (and final) analysis:

In this analysis I changes the value of the Anterior Nasal Spine to 3 and the Interorbital Breadth to 1

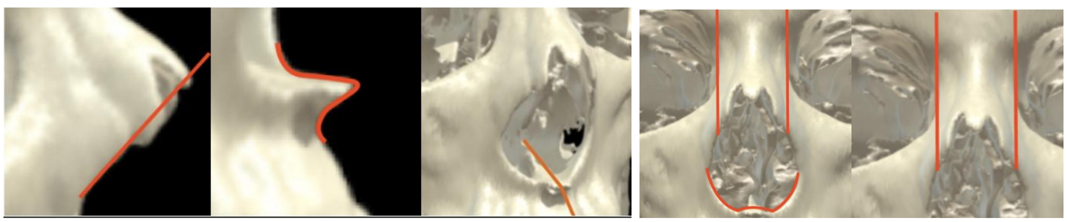
Feature:	Score:
Anterior Nasal Spine (ANS)	3
Inferior Nasal Aperture (INA)	2
Interorbital Breadth (IOB)	1
Malar Tubercle (MT)	2
Nasal Aperture Width (NAW)	1
Nasal Bone Contour (NBC)	1
Nasal Overgrowth (NO)	1
Post Bregmatic Depression (PBD)	0
Supranasal Suture (SPS)	NA
Transverse Palatine Suture (TPS)	NA
Zygomaticomaxillary suture (ZS)	NA

These inputs gave the probability of 58.22% European.

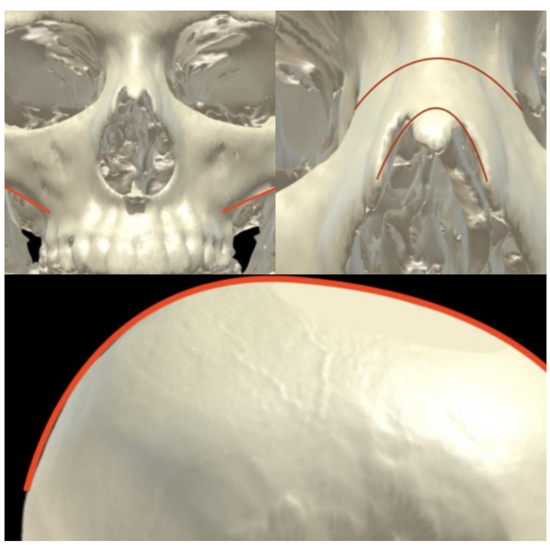


African	American Indian	Asian	European
0.0575	0.3264	0.0338	0.5822

4.5 Graph and statistical likelihood of European ancestry versus other possible descendant groups, with a higher likelihood of an American Indian ancestry based on the different evaluation of morphological traits. Specifically a higher score for the Interorbital Breadth (IOB) and the Malar Tubercle (MT).



4.6 Morphological landmarks used in the evaluation of ancestry. Starting on the left from the Nasal Overgrowth (NO), Anterior Nasal Spine (ANS), Inferior Nasal Aperture (INA), Interorbital Breadth (IOB) and the Nasal Aperture Width (NAW).



4.7 Morphological landmarks used in the evaluation of ancestry starting from the left with the Malar Tubercule (MT), Nasal Bone Contour (NBC) and the Post Bregmatic Depression (PBD).

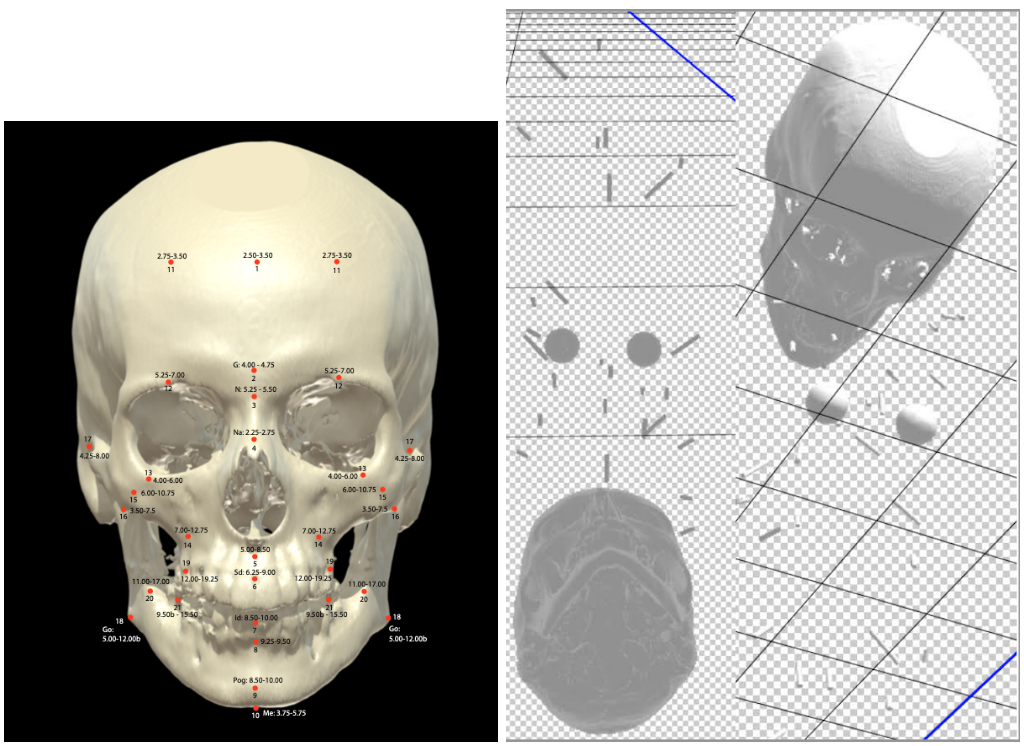
To model and build the face I used a software program designed for 3D artists. The program, called Zbrush, combines 3D/2.5D modeling, texturing and painting. It uses a proprietary "pixol" technology which stores lighting, color, material, orientation, and depth information for the points making up all objects on the screen (https://pixologic.com/; http://docs.pixologic.com/getting-started/basic-concepts/the-pixol/). The main difference between ZBrush and more traditional modeling packages is that it is more similar to traditional sculpting. ZBrush was developed by the company *Pixologic Inc*, founded by Ofer Alon (also known by the alias "Pixolator") and Jack Rimokh (https://pixologic.com/; http://docs.pixologic.com/getting-started/basic-concepts/the-pixol/). One of the issues with this kind of software is that it is expensive to buy and maintain. However, I have used the free trial period to do this experiment with. Unfortunately, the trail is quite short and only lasts for 30 days so the sculpting had to be done rather quickly. I mainly used this program to model the muscles and glands for the face. I did these separately from the actual reconstruction as it allowed me to import them and use other tools to mold them to the face. In order to do this, I used a free 3D animation software called BLENDER. While it took a while to learn, and I would still say I am not an expert, this system worked much better because there were no time constraints and it has a downloadable user guide.

APPLICATION: OVERVIEW

In this thesis, I have undertaken a process in which I have attempted to rebuild the face of a person using free three dimensional softwares. I first began by researching, so as to understand the methods present within the field and learn how to actually attempt this process. I then found and analyzed an individual skull through morphological traits and assessing sex, age (or age catagory) and acenstry. Once the analysis was done I learned how to use Blender and Zbrush as well as learned how to understand 3D software files and the differences between them. Because of this I was able to import the skull and place 21 facial depth markers on the correct landmarks according to the depth charts provided by Karen T Taylor. Next I sculpted muscles in zbrush and imported them onto the face in Blender. Once the depth markers and facial muscles were present I was able to add the features of the face including the eyes and the nose according to the parameters provided by the individual face. I then placed the corresponding facial fat in order to build up the surface of the skin. Unfortunately this whole process took much longer than I had expected. I began the research in early September and finally began building the face in October. It is now late December and I still have to finish modeling the surface of the skin, add the eyebrow, lips and ears as well as hair. However, I began the process with no training in these softwares or even in facial reconstruction and have gotten very far - in fact, I have gotten farther than I expected. With all the challenges I faced I did not think I would be able to rebuild the face, but I am close to a fully rendered person. Unfortunately, there is no way to test the accuracy of this skull because the face is not only incomplete but it does not belong to a missing person and therefore will not be recorded in a database. However, it is possible to use google parameters to run an image search and turn up a matching person (assuming that they have any sort of social media). I cannot be sure if this is something that would work or not, but it would be worth a shot.

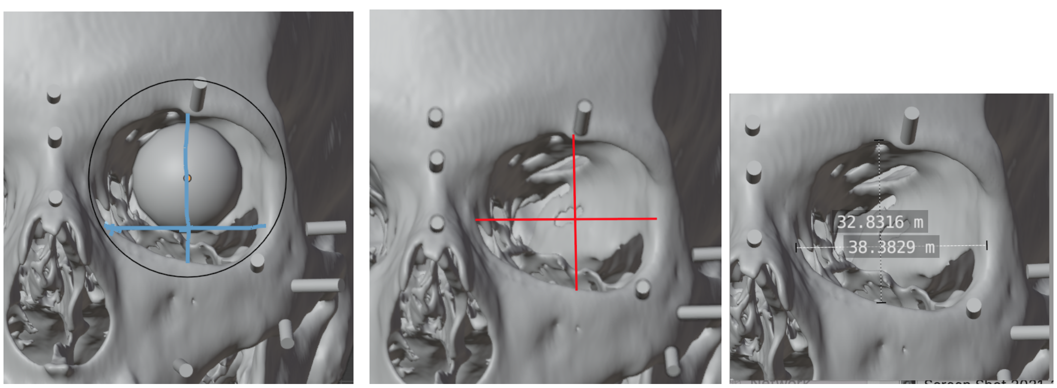
PROCESS

The first step in the process was importing the skull into the right platform. I downloaded the skull as a zip file. Next I opened that file, found the meshlab file and opened it. I then converted this file into a wavefront or .OBJ 3D file and imported it into BLENDER. Once the file was open I was able to start placing FSTT landmarks, beginning with the glabella and ending with the lower occlusal line. In order to accurately place these landmarks I first placed them on the skull using a non 3D platform. I uploaded an image of the skull and placed red dots where each marker should go. Once this was done I started placing them three dimensionally. I started the process in zbrush by creating a cylinder. However I was struggling to manipulate the cylinder in a way that would allow for the correct size, placement and depth. Because of this I decided to try another application. This new program, BLENDER, was easier to use and I was able to create a mesh cylinder that I could manipulate using the toolbar on the left side of the application. What I did not account for, however, was the way that objects appear in space in a three dimensional world. Because of this I had difficulty placing the markers exactly where they belonged and instead wound up with an unusable skull that did have depth markers, but were not actually anchored to the skull.

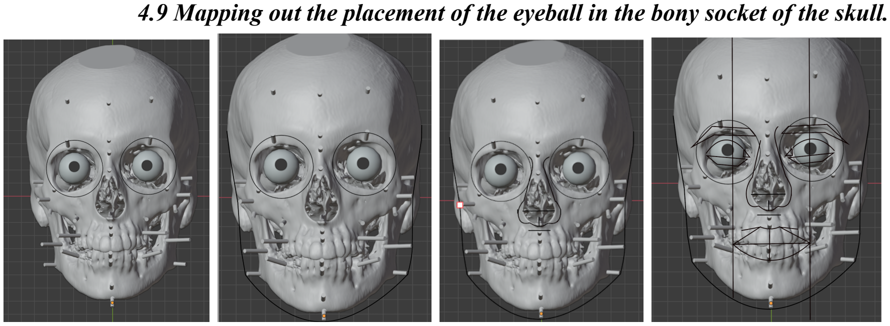


4.8 21 labeled osteometric points on the Sketchfab skull (left). First attempt at adding FSTT markers and eyes to the skull (right).

After two days of trial and error, I eventually figured it out. It then took another few days to add all 21 markers. Next I could start adding the musculature. In order to do this I used zbrush to sculpt the muscles and then imported them into the BlENDER. Before moving on to the musculature of the face, I decided to edit the skull in Adobe Illustrator. I used the superimposition methodology to get a feel for what the face would look like based off of the parameters I learned about. In order to do this, I added eyeballs in BLENDER before importing the document into Illustrator. I followed the parameters given by Karen Taylor in her book Forensic Art and Illustration. I used a "meatball" to create the eyeball and then a cylinder to create the pupil. Afterwards a drew a contour of the face and used the boney guidelines to dictate the proportions of soft tissue and the features of the face.

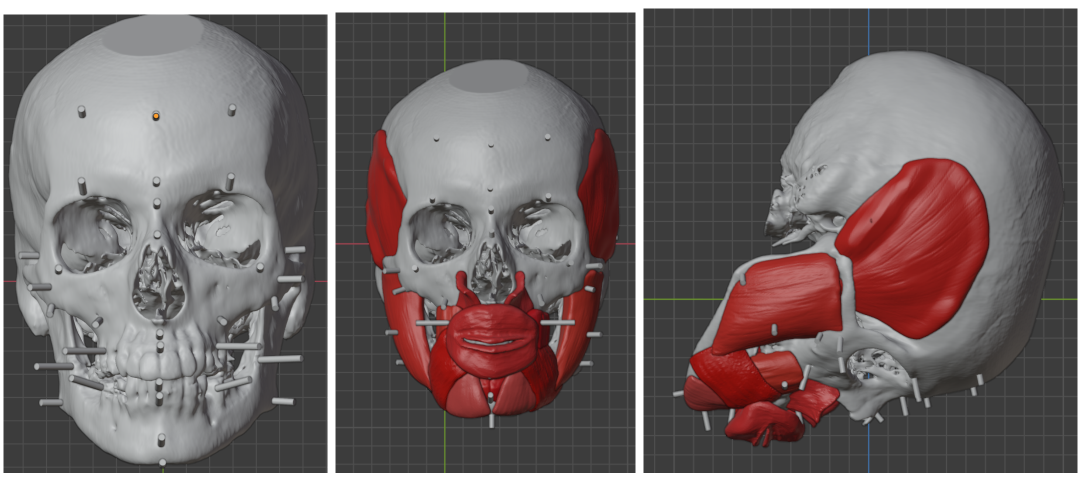


4.9 Mapping out the placement of the eyeball in the bony socket of the skull.



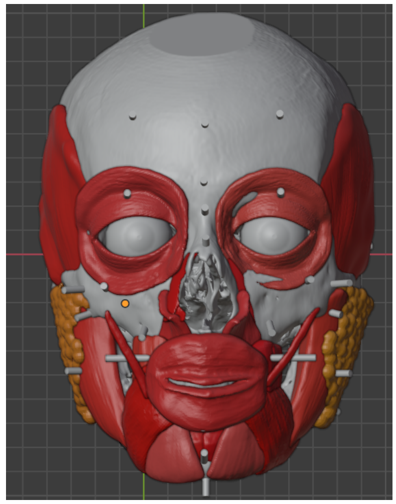
5.0 The overlay of facial features in Adobe Illustrator, used to generate a first image.

I was then able to use the edit mode to sculpt the individual muscles to the correct contours of the bone. This took most of the process, as I had to make sure each aspect of the muscle was correctly placed, from every angle. I started with the two large temporalis muscles and built on them through layers. I added most of the facial muscles and then had to add the eyes, in order to correctly place the next muscles. I started having difficulties with the eyes, as the "meatballs" started acting strange. I am still unsure why this happened but one would stop being visible while the other was fine. Additionally it became difficult to manipulate one at a time. Even though I only selected one, the second would move anyway. As a result, I deleted them and redid the eyes. I decided it would be best to use already modeled eyes and so I downloaded a blue eye from sketchfab and imported it into BLENDER. This worked much better, though I could not get the color to appear. The eye did, however, have an indication for the pupil as it was slightly raised.



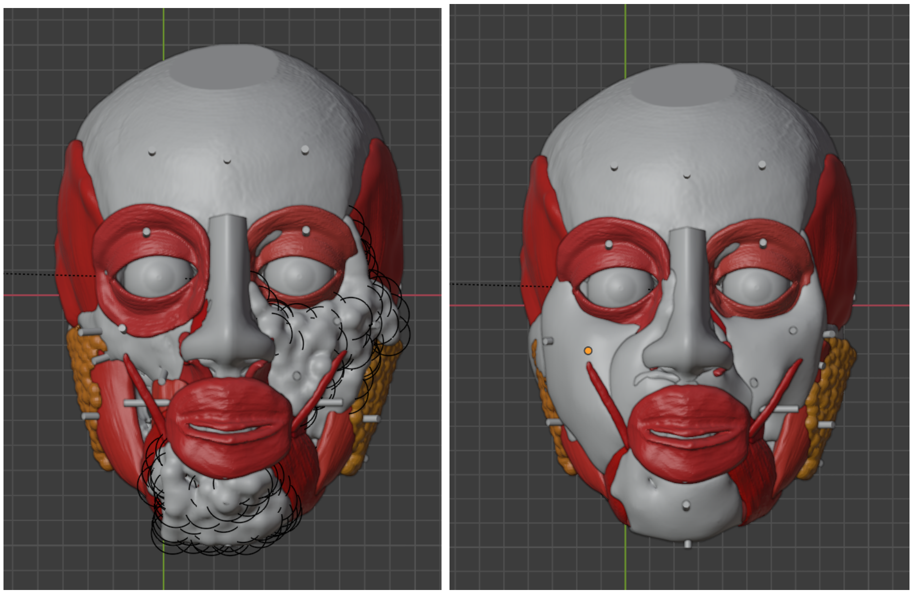
***5.1* Skull with all FSTT markers added (left), frontal view of the skull with the majority of the facial muscles attached (middle), lateral view of the face with most of the muscles attached.**

Once this was all done, I added the rest of the facial muscles and the parotid gland.



5.2 Skull with depth markers, all facial muscles, eyeballs and the parotid glands.

The next step was to add the features. I started with the nose, as it is the most important feature to get correctly placed. I first tried to build the nose with the tools in BLENDER, however each time I wound up with a globular mess that did not, in any way, resemble a nose. Therefore I decided to use sketchfab. I decided that I would try to find a downloadable nose with typical european characteristics (relatively small and narrow with a longer bridge) and modify it in the application. Then it was time to model the skin and build up the face to the correct thickness. I tried a few different methods for doing this. I tried moving the whole skull into edit mode, where I pushed and pulled the contours of the face into the correct position. This left the face distorted and unrecognizable so I instead used more “meatballs.” Essentially I used these “meatballs” as a little ball of clay that I later morphed to fit the correct placement. I had trouble with this initially aas I could not edit the “meatballs.” I later learned that I had to group them, convert them into an object and then create a mesh object, in order to be able to edit them. Once I did this, however, I was able to smooth them out and achieve a flat, skin-like surface.



5.3 Skull with correct nose placement and "meatballs" added to build up the surface of the face (left), skull with mesh "meatballs" smoothed to simulate skin (right).

The next steps would be to finish the layer of skin, and add the missing features (eyebrows, lips, ears). Afterwards the final steps would be to add details such as hair and hair color, eye color and maybe even a neck.

DIFFICULTIES

Some of the main difficulties I face have stemmed from the lack of understanding the 3D programs. For example, I did not understand how a three dimensional platform worked. I did not realize how importing an object can be any part of the plane. Even when dragging the object close to the skull (such as an FSTT peg) it may only appear to be close. Because it's a three dimensional world the object has to be adjusted from every angle, not just frontaly. Additionally I had to understand the different types of 3D files including *TL, OBJ, FBX, COLLADA, 3DS, IGES; STEP, and VRML/X3D.* These files are mainly used for storing information about any kind of model, with the parameter that it exists in a 3-dimensional space. They store the object's *geometry*, *appearance*, *scene*, and *animations* and are commonly used in 3D printing, video games, movies, architecture, academia, medicine, engineering, and earth sciences. The problem with these file types is that there are hundreds of them. In addition, each computer aided design

(CAD) software such as AutoDesk, Blender, or Zbrush uses its own file and only accepts certain ones to be imported. If you use AutoCAD, you get a DWG file whereas if you use Blender you get a BLEND file. The first problem I faced involved these file formats. I had to download the skull file and import it into the BLENDER application. After a long period of trial and error I learned that using a wavefront file (.OBJ) was the best option. The OBJ file format is a simple data-format that represents 3D geometry alone — namely, the position of each vertex, the UV position of each texture coordinate vertex, vertex normals, and the faces that make each polygon defined as a list of vertices, and texture vertices. Vertices are stored in a counter-clockwise order by default, making explicit declaration of face normals unnecessary. OBJ coordinates have no units, but OBJ files can contain scale information in a human readable comment line (http://fegemo.github.io/cefet-cg/attachments/obj-spec.pdf). Another issue I faced came down to time. While I knew it would take a while to do the reconstruction, I did not expect it to take as long as it did. I started this process in early October and am just getting to the process of forming the skin of the face now, in late December. Much of this stemmed from the fact that I do not have training in these software programs and had to take time learning them as well as being a full time student. I also ran into problems with a lack of research or public documentation on methods. A lot of what I was doing throughout this process was made up by me. While the basic method exists in a list of steps: FSTT, muscles, glands, skin and features, nowhere could I find any kind of procedure for using these tools to create features such as the eyes and nose. Nor could I find anything on how to create skin. Of course BlENDER has a user guide that offered solutions, however they were more sculpture based and were not applicable to this use. I only found one other example of someone using BLENDER to do facial reconstruction and they only used it for the features.

CONCLUSION/GOING FORWARD

SOFTWARE

While I only used two different software packages in this experiment it is important to note that there are other possibilities with millions of other programs ranging from 3D graphics programs, animation software and rendering programs. However, I will evaluate the two I used (Zbrush and BLENDER) based on the categories of usability and accessibility, as well as the benefits and drawbacks of both. I began this experiment with Zbrush. While it is the only program I know of that has been used for this kind of work by reconstructive professionals, I found it to be difficult to use. Unlike the second program, BLENDER, Zbrush is designed for those who already understand 3D graphics programming. I say this because the interface can be confusing without knowledge of the program already. Additionally there are no user guides or opportunities to reach out for support. BLENDER, on the other hand, has a beginner friendly user guide that I used numerous times throughout the process of this project. Additionally, the two programs differ vastly in accessibility. Zbrush has an associated monthly cost, whereas BLENDER is free to download and use. While pixologic, the development company behind Zbrush offers a 30 day free trial, this - at least for me - was not long enough to fully learn and understand the program. Additionally, the monthly fee is not cheap starting around $360 with other packages costing around $900. This higher fee may allow for more detailed work and features that BLENDER does not have, however, I did not experience much of this. This may also be due to my lack of understanding the program, but ultimately the ease of BLENDER combined with the lack of cost made it a better option. The monthly cost associated with Zbrus definitely limits the access to the program as most people, including myself, would not be able to spend this kind of money for a monthly subscription to this program.

OVERVIEW

After doing the work myself and testing the methods behind facial reconstruction, especially those designed for computer graphic reconstruction, I believe that it is possible to recreate a face using free 3D softwares. However, I believe an accurate representation of the face can only be built if the artist has a background in human anatomy and understands how to use the software.

I believe that using these techniques in combination with free and accessible programs will solve a number of problems within the field, specifically the lack of access. One other issue present within the field is the cost associated with the equipment. Scanners that digitize skulls can cost thousands and are delicate and cannot be portable. A solution to this problem may be photogrammetry, the art and science of extracting 3D information from photographs. The process involves taking overlapping photographs of an object, structure, or space, and converting them into 2D or 3D digital models. Once the photos are taken, they are uploaded into a program which then builds the model. Again, some of these programs can cost a monthly fee, which is not always cheap. However there are also free options such as Meshlab, which is very commonly used. This process is something that can be done by anyone and may solve some of the problems associated with costly equipment. I would have liked to include a photogrammetry study in this thesis as well, however I ran out of time.

While I was not able to complete everything that I had hoped to in this project, I believe that this thesis serves as an informative research project that has allowed me to explore the field of forensic facial reconstruction in great depth. I also believe that this project can serve other purposes, possibly as a starting point for a masters thesis and other research projects in the future. Lastly, through this project, I have learned that there is still the need for more research in this field. The field of facial reconstruction has been used for many different cases and purposes and offers an insight into a person's life when there may not be other options. This is extremely valuable and should be utilized more, especially if the issues of cost can be fixed.

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