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Teaching Pedagogy of Online vs In-Person Learning: Relative to Osteology

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TEACHING PEDAGOGY OF ONLINE VS IN-PERSON LEARNING: RELATIVE TO OSTEOLOGY

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With the Covid-19 global pandemic and the increasing need for a better way to teach on a global scale, this study focuses on a possible alternative to standard teaching that would address these issues. This research study examines the effectiveness of using 3D-scanned images vs cast bones in teaching human osteology. There are two main teaching concepts examined: the first examines the pedagogy of teaching and assessing if a 3D or online virtual classroom assessment compares favorably to a more traditional method of teaching osteology and other similar courses in a hands-on setting. The second consideration is to assess the quality and effectiveness of the 3D scans compared to a bone or cast. The accuracy of the 3D images is not only important for education, but if the scans prove accurate, they could be used in other contexts such as peer-reviewed research and legal settings.

This paper will dive into the current education practices, 3D imagery, and the benefits and consequences of using 3D imagery in different settings such as education, research and legal settings. The main goal of this study is to look at how 3D imagery can be beneficial to education. So, throughout this paper, there will be techniques discussed about how to create 3D images, and how to use them in a class setting. The paper focuses on a human subject's study where participants took part in a mini class study to test the

effectiveness of 3D learning compared to cast learning. While this was the main study, another part of the study included testing the accuracy using experienced students and testing their knowledge using a 3D image. The study proved to be a success even though the study size was a smaller than anticipated. The students proved that they could learn the material using 3D images, and that the accuracy of the images is just as high quality as the original item.

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Table of Contents

Table of Figures

Table of Tables

Chapter I: Introduction

The purpose of this-research is to look at the pedagogy of the use of 3D scans versus physical material to teach and learn osteology. With the onset of the COVID-19 pandemic in 2020, many schools had to shift abruptly to online/remote learning. This paper looks at the benefits and challenges of the online learning environment and the use of 3D images in an educational setting as well as in research, peer reviewed analysis and legal setting. The COVID-19 pandemic affected many things around the world, including education. Students from all around the world were sent home from their educational institutions as schools shut down in-person learning, However, this situation did not stop students from wanting to continue their education nor education institutions to fulfilling their mission.

For some students and faculty, online classes were not a concern as the only difference for their classes was lectures were given using an online media platform, such as Microsoft Teams, Zoom, or WebEx. For others, this meant that they had to purchase additional class materials in order to get a hands-on approach, and for some this meant that their learning and education was in jeopardy since there was no appropriate learning alternative. This problem in and of itself is one of the foci of this research. There are two main research questions for this thesis, the first being, can students effectively learn osteology using 3D images instead of the traditional method of using casts or bones? The second question is, are the 3D scans accurate enough to use for teaching, testing, peer review work and legal settings? The purpose of this research was to test the idea of using 3D images to teach in comparison to a traditional style of teaching osteology. Without a

3D model, students taking osteology had two options, they could buy their own skeletons to have the traditional hands-on approach or they were forced to learn using books and other forms of text. This research proposes a third option. Instead of being saddled with additional cost, or having to learn solely from a book, students could instead use 3D imagery that would allow for a better understanding of the bones and material without the additional cost to students.

There has been some research on 3D imagery for teaching, but it is still in very early stages for academia. While the pandemic pushed distance learning and non-traditional methods farther than ever before, not all faculty and students were happy about this change. The hope is that if this study shows promise in the use of 3D imagery to teach osteology, then this could lead to more advancements in this area of academia. If the results find that students can and do learn just as well with a 3D scan as they do with the physical bones, then educational institutes will be able to offer online classes in osteology and other related courses knowing that the learning outcomes will be similar to that of students taking the course in a more traditional way.

Furthermore, another benefit of using 3D images for osteology would be that it would allow more variety in the skeletal material and would also allow for more students to learn additional human and other animal variability. Skeletal casts can be expensive, but if a school does not have to purchase multiple casts and can have students access the material on an electronic device, this would give students a chance to learn osteology in any location and at a hopefully lower cost for everyone. This thesis reviews the literature on pedagogy, osteological teaching methods and articles, scientific review process and the advantages and disadvantages to 3D learning.

Chapter II: Literature Review

This chapter is broken up into a few different parts. The first section goes over education and is broken down into a few subsections. The first subsection is a problem orientation section, it reviews why this research matters and what the real-life impacts of the study could be. The other subsections in the education section discuss: types of teaching, types of students and specific osteology teaching and training information. The other parts to this section include research on the use of 3D imagery in court rooms, and the use of 3D imagery in a peer-reviewer setting.

Education

The value of this research can be seen in a number of different educational areas. During the COVID-19 pandemic, many places physically shut down, including schools. This was a temporary phase for many educational facilities, so that they could transition into online learning (UNESCO, 2021). The information below shows what happened at the University of Nebraska-Lincoln (UNL). At UNL, a decision was made to extend the 2020 spring break for an extra week in order to allow instructors to transition to an online learning platform (Green, 2020). While this was a solution to allow for the continuation of education, it was not an easy transition for all classes, students, and instructors.

UNL had 25,390 students enrolled in the 2019-2020 school year (Gutierrez, 2021) (University of Lincoln Registrar Office, 2021). In the last five years, 2016-2020, enrollment numbers have stayed consistently between the 25,000 - 26,000 range (Gutierrez, 2021) (University of Lincoln Registrar Office, 2021). For the 2020-2021 school year there was a total of 25,108 students (Gutierrez, 2021) (University of Lincoln

Registrar Office, 2021). These numbers fell within the normal enrollment range. This shows that even with the pandemic the number of students wanting to learn and continue their education did not decline at the University of Nebraska-Lincoln.

The total number of course sessions in the 2019-2020 school year was 9,038 (University of Lincoln Registrar Office, 2021). These numbers do not show the transition from classes taught in-person at the beginning of 2020 to those that had to transition to on-line learning after the start of the semester. The breakdown of the 9,038 sessions was 8,471 in person and 567 online. In the 2020-2021 school year the total number of class sections was 9,460. This was broken down in to 8,185 in-person sessions and 1,275 online sessions (Gutierrez, 2021). The number of in-person sessions was higher due to physical distancing as classes were not able to have the normal number of students in classrooms (Fedderson, 2020). The 8,185 also does not reflect the number of classes that stayed in-person throughout the semester. Some classes chose to meet in person the first-class period and then went online, and some split their classes to online and in-person sessions (Gutierrez, 2021). If a class started the semester in-person then the class was still listed as in-person for the registry department.

The total number of class sections for the 2018-2019 school year was 8,829 consisting of 8,291 in-person sections and 538 online sections (Gutierrez, 2021). The number of in-person sessions within the last five years has fluctuated around the mid eight thousand, in 2019-2020 there were 8,471 in person sessions and that number declined to 8,185, a loss of 286 in-person sessions for 2020-2021. For on-line sessions, the numbers were 462, 494, 538, 567, and 1,275 for 2016-2020 accordingly (Gutierrez,

2021). This shows that within the last few years the number of online classes increased with a significant increase at the start of the pandemic.

COVID affected some classes more than others, and had a major impact on the students. Many educational institutions had to go to remote learning, send students home and cancel classes. This was a hardship for the institution as well as the students. UNL offers one-credit recreational activity classes. When the university shut down due to COVID-19 in March 2020, this impacted 44 academic recreational activity classes (Wagner, 2021). Out of all of these classes only one was canceled, and the others were able to continue with some form of on-line portion or finished the course early giving the students their current grade as the grade for the end of the semester (Wagner, 2021). The option to award the students their current grade instead of just canceling the class was due to the fact that over 200 students were signed up in the 44 classes (Wagner, 2021). Without the decision to give the final grade for the partially completed course, this could have delayed graduation for those that needed just one additional credit to graduate (Wagner, 2021). For the 2020-2021 school year, the university would normally offer around 80 recreational activity classes (Wagner, 2021). Out of these 80 classes, seven were not able to run in the 2020-2021 year because of the impossibility of offering the classes as an online or hybrid method. These classes consisted of swimming and martial arts/self-defense classes (Wagner, 2021).

The jump from only a couple hundred online courses to over a thousand online courses meant that many classes had to adopt an on-line learning platform that traditionally had not been taught on-line. There was no university-wide information available on classes that were not able to run due to not being able to have an online

option. This is because the university registrar's office is not able to obtain this data (Gutierrez, 2021) (University of Lincoln Registrar Office, 2021). However, the recreation department was not able to run seven classes due to not having an online option (Wagner, 2021). This would stand to say that at least a few other departments chose to not offer a course due to lack of online options. This jump in on-line classes meant laboratory and other hands-on classes had to adapt to not being able to have students physically in the classroom. For osteology and other similar classes, this meant that students had to buy their own skeleton casts in order to be able to look at a physical specimen instead of just at pictures and professors' lectures. This is one specific reason why this research is important. It would allow for students to have a free resource for accessing the material, instead of having to buy their own or having to try and borrow a skeleton from their education system.

Money and space are something that need to be taken into consideration when planning a class. With osteology, having enough specimens and a large enough area to both store them and have class can be challenging, especially for a smaller school. Having students learn using 3D images opens up the possibility for a larger number of students to take the course at a time, and it also allows for less money to be spent on casts or actual human specimens[1]. This could also be beneficial for schools that may not have the ability to run their own osteology course as they could partner with larger institutions in order to have their students take an osteology course online through a partner school.

[1] Current high-quality casts of complete skeletons can run between $1500 and $2000 per set while an actual human skeleton can cost between $5000 and $15,000. Actual human specimens also require materials to be ethically sourced from donor agreements.

Lastly, the idea of having students have access to the 3D imagery would give students the ability to look at casts in a classroom setting but also be able to look at them at home or anywhere. Most classes have students look at the casts while they are in class, but they cannot take them home to study. This means that they do not have a large amount of time to study the physical bones. With the ability to have a 3D scan at the student's disposal, this would allow students to have access to study and learn the material 24/7. A 3D image is an upgrade to a traditional 2D image in a book or hand drawing. The use of a 3D rotating image vs a 2D picture is a great advantage as it allows the students to manipulate the 3D scan in several positions. Whereas the 2D image only allows one angle that may or may not show a specific feature.

The use of 3D imagery in the classroom is becoming more popular. There is a free app by Catfish Animation Studio called Skeleton 3D Anatomy, that allows a user to look at 3D bones and see how they relate to one another. A downside to this app is that some of the features are not visible, and there is no way to edit or manipulate the scans for teaching purposes. An example of this would be if an instructor wanted to mark specific features on the bone that students would need to identify, this app does not allow this manipulation of the scan. There is a push to create 3D models that can show how the bones work in the human body that are user friendly and adjustable for different users and purposes (Van Sint Jan et al., 2003). Dr. Van Sint Jan, expresses the concern with free or low-cost educational options for students in underdeveloped countries as books and other resources are not always available or cost efficient (Van Sint Jan et al., 2003). This is where computer-assisted learning (CAL) is becoming a great alternative or addition to traditional teaching methods. Computer-assisted learning is using a digital or

multimedia platform to learn material without a human teacher (Van Sint Jan et al., 2003). The human subjects' study, conducted for this research thesis, uses a combination of CAL, peer assisted learning, and some didactic style teaching.

Another benefit of the 3D images is it can allow for remote learning and testing. If a professor is using a 3D image for quizzes, exams, research projects or anything else, students could be able to access these remotely. This would be helpful in terms of online classes or if someone has to miss a class they could still make up the graded assignment or work. There are a few ways this could be done such as the students downloading a lock down browser which helps eliminate cheating, but would allow them to take the exam on their own computer from any location (Respondus, 2022). Students could take the exams at a testing center, which would also eliminate cheating, or any other way students can take a test using an electronic device. During the study one student participated completely remotely as they were in another state, and two other students had to take one or more of the quizzes in a remote setting due to personal conflicts.

With the emergence of 3D technology and the possibility of using it to teach, there are some concerns with it. Some of the main concerns have to do with how well the students will learn the material, their ability to implement it, and access to it (Van Sint Jan et al., 2003). In order to put some of these concerns to ease, more testing needs to be done to determine how well students learn the material. The best way to implement or teach it and how to create an open environment that will allow anyone to access and learn the material.

Types of Students

Osteology and anatomy are common course requirements for anthropology and medical/dental students. However, these are not the only students that would benefit from taking these classes. Other majors such as law enforcement, criminal justice and forensic science may have great use for an osteology course or a shortened course on identification of bone, human/non-human and key features on remains. This may be of use to these students due to their potential line of work as they may have to work with human or non-human remains in the future. With current teaching standards, it may be difficult for these departments to offer a course on osteology because they may not have the resources. Having an online course could change this because it could allow a qualified individual to teach the material virtually without the added cost and storage of casts and other materials. This could also help to inform a larger population of future police officers and detectives. “Various studies on higher education within police departments have shown that on average, only 50% of individuals have some college experience while only 30% have a bachelor’s degree” (Berlier, 2018, p. 4). With only 30% of this population graduating with a post-secondary degree, even if schools started requiring training similar to those listed above, there is not a guarantee that new officers and detectives would have such training or educational experience. In order to adapt for this, police units and other organizations, that may have similar needs for a training in osteology or a sub section of it, could use these 3D casts to teach the information in order to properly train these individuals (Berlier, 2018).

Group vs Individual work

Osteology can be taught in many different ways; the two common ways of teaching are Didactic and Peer-assisted learning. Didactic teaching is the standard of having a teacher lecture the students, while peer assisted learning has some lecture but is more of a students teaching students approach (Anantharaman et al., 2019). A study was done to test the effectiveness of using peer-assisted learning and didactic teaching (Anantharaman, et al., 2019). Their conclusion found that peer-assisted teaching is at least as effective as didactic teaching (Anantharaman et al., 2019). The purpose of this study was to understand the effectiveness of two different pedagogies. One outcome was that students were more likely to review the course material beforehand in the peer-assisted learning, so that they could better help with understanding the material as a group rather than with didactic learning where students may or may not have looked over the material (Anantharamanet al., 2019). Using 3D images, students would be able to familiarize themselves with the material in not just an image form but with a rotating and interactive form, creating a better understanding of the material. Another benefit this has for students is it allows them to work or study as a group. With students having the ability to look at 3D images at any time, this would allow for greater flexibility of being able to study the material in a group since there would be less restraints on time. Studying in a group may be able to be accomplished with casts if the students set up a time with professors, have access to the classroom with the specimens or if they can check out the material somewhere else on campus. Though these are possible options, professors' schedules and the availability of the room may not always be an option to students with a busy schedule. Materials located in a library, or elsewhere on campus, may not have the

quality of casts or other materials needed to learn certain features. Having a 3D image would allow for these students to always have access to high quality specimens. This would also allow for a group of students to get together and review the material in person or even virtually using a video chatting source such as Zoom (Zoom, 1995).

Some items are too fragile to be handled, but with a digital model of the item they could be handled and examined with less concern (Carew and Errickson, 2020). This would allow students to interact and study the material without causing risk of damage to the material or themselves (ibid.). This can also be the case for items that the school does not physically own, but may have access to as a digital version such as a specimen with a specific pathology. There are common practices at libraries where an individual can access material from a partnering library if their own institution's library does not have it. These 3D image collections could work in this same way as it would give partnering institutions the ability to access the 3D images. Partnerships are common in universities and colleges allowing for sharing of ideas, material, resources, and other forms of collaboration. The use of 3D imagery could become a more prominent part of these partnerships.

Allowing the students to have access to the scans at all times is important for learning. With any class, a majority of the learning takes place outside of class through readings, assignments, study and other means of learning. According to Lumen Learning (Lumen Learning, 2022), the recommended ratio for learning is 1:2 or 1:3. What this ratio means is that for every hour of in person class, you should study two or three hours outside of class. This is the general rule of thumb, although difficulty of the class, course length, schedule of class and other factors may increase this ratio (Lumen Learning,

2022). For most osteology courses or other similar courses, students generally do not have permission to be with the specimens alone, so they have to fit study time around the professors' schedule if they want access to the material. For those with a busy schedule this is not always an option, or sometimes students just want more time with the material then what is available to study. Looking at pictures and diagrams has been a standard way to learn osteology and other material. With access to a wider range of buying platforms, casts are becoming a little cheaper and they can be bought on Amazon and other sites for just over $100 such as the hBARSCI skeleton, (Amazon, 2022). However, there are some flaws with 2D images and cheaper casts. Many students like to be able to manipulate and move objects in order to learn the material instead of just looking at an image. This can be especially helpful when learning how to determine the side of origin of specific bones. Buying the casts online is a great option for those that have the ability and that are able to purchase them ahead of the class's start date in order to have them in time for the course. Although $100 is not a large amount of money for some, adding that to the price of the books for the class and all of the other class fees adds up. Some universities may allow individuals to check out skeletons through the department or the library, but from personal experience with this, the skeletons are generally not very good quality, and are really only good for learning the names of the bones. Having access to a 3D library of images all of the time would eliminate the problem of students having to learn solely from pictures or having to buy their own.

Osteology Training and Education

In a traditional class on osteology, there are several areas of study, including: bone structure, ethics, human/non -human, pathologies, taphonomy, sex, ancestry, height, and age. These are just a few of the common subsections taught in an osteology class. Although the study completed for this thesis was brief and did not cover all of the above options, the methods below are just a few of the common areas of study and are not intended to be the only methods used in osteology or that could be used in a 3D classroom.

Bone Structure

One of the first topics covered in an osteology class is normally bone structure. This can be taught in many ways but is most commonly taught using images in a book or slide lecture. In anthropology, bone structure has a few main purposes. One purpose is to look at age estimation using bone fusion (White, Black and Folkens, 2012). An example of bone growth can be seen in Figure 1, in which the tibia is shown in different stages of age (White, Black and Folkens, 2012 p. 38).

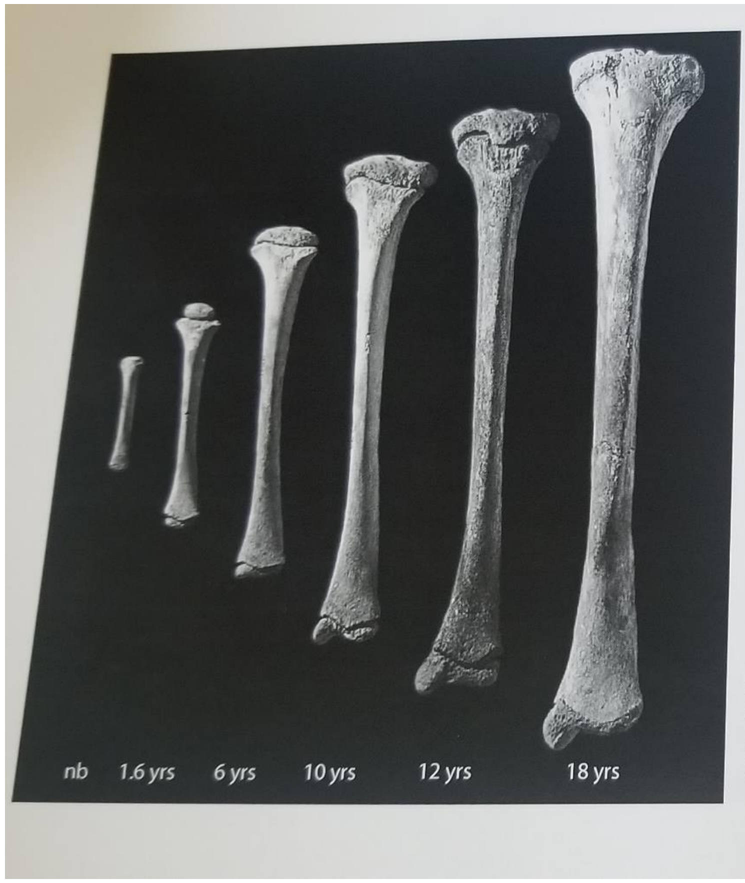

Figure 1 Bone Growth - The image shows a human tibia at different stages of growth starting from left to right in years: newborn,, 1.6, 6, 10, 12 and 18 years of age (White, Black and Folkens, 2012, p. 38).

Another important factor when learning about osteology is how the bones move in the body or biomechanics of the bone. Understanding the different joint types in the body can be helpful when understanding how the bones connect to one another (White, Black and Folkens, 2012). The biomechanics can also be useful when looking at trauma that may be present on an individual. Being able to understand the movement and connection of two or more bones can allow for a better understanding of what may have happened to the individual if trauma is present. Although trauma is specific per situation, it is great for students to have a basic understanding of trauma as it relates to osteology. As mentioned later in this paper, there has been success in court rooms using 3D imagery to showcase

evidence. This should be able to transfer over to students being able to learn about trauma from 3D imagery in order to get real-life experiences.

Lastly, it is helpful to have a general knowledge of bone structure and bone health. Having this understanding is useful when looking at the health of an individual. It may give clues to who the individual is or what happened to them. Knowing how bones develop, and what they are made of is important for a number of reasons (Figure 2) (White, Black and Folkens, 2012). A few of those reasons may include trauma and bone modification. If trauma or bone modifications are present, having an understanding of the bone morphology will help to understand how these occurred and potentially when they occurred.

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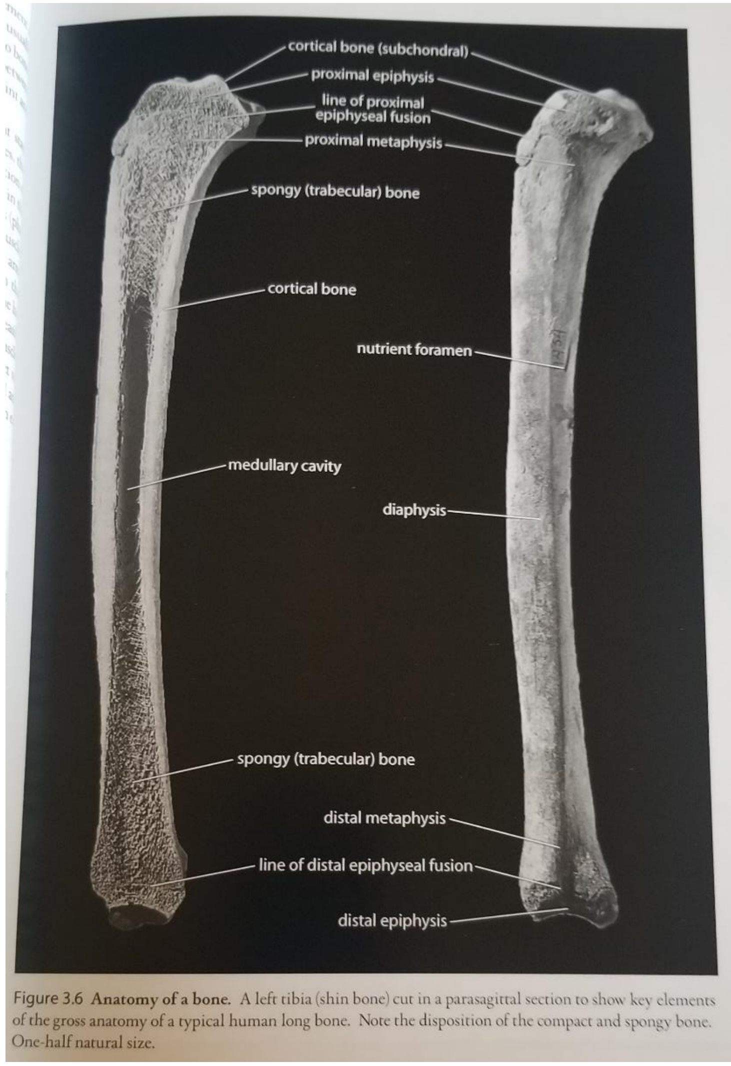


Figure 2. Bone Makeup Diagram in White, Black and Folkens (2012, p. 33). The bone can be seen from the inside giving an image of how the bone looks internally as well as externally.

Ethics

When dealing with human remains, it is important to always remember these skeletal remains are a person and that there are certain ethics that should be followed (Dupras et al., 2011). These ethics include proper handling/use of the remains, making sure to have the proper permission to use the remains, and making sure that everyone that

has access to bones is doing so for the correct reason/purpose. Anthropologists/Archeologists in the past have had a negative reputation for the misuse of human remains. Márquez-Grant and Errickson (2017) talk about the history of analyzing human remains, and the curation and repatriation of remains that were not brought to an institution in the correct manner (Márquez-Grant and Errickson, 2017).

Another case of ethics violation is in regard to the misuse and stealing of remains by the University of Pennsylvania and Princeton (ABA, SBA, BiBA, 2021). In this particular case, the two universities used the remains from one or two children that were victims of the police bombing of the MOVE organization in 1985 (ABA, SBA, BiBA, 2021). The parents of the child/children were not notified of the remains, because they did not know the remains were found. So, they were unable to give consent for their children's remains to be used in that manner (ABA, SBA, BiBA, 2021). This is a major concern on many levels. One is that the professors at the university thought of the remains as their own personal equipment and did not think of them as human remains. No attempt was used to return the remains or notify the families even though there was a good idea of who the remains belonged too. The use of 3D images could potentially lower these ethics violations, as professors and universities could have access to quality material that has been properly obtained and limit the stealing of remains.

While casts are less of a concern then actual human bone, the ethics need to be the same for any material representing or related to human remains. A 3D image is not fragile, so there is no risk in damaging it unlike the ability to damage a real bone or cast. This allows for training and educational purposes to be conducted with less concern of damage to the original specimen. Students and professors need to teach that although no

matter what form the remains are in, they should be treated in an appropriate manner. The same manner of respect and ethics should be followed with the 3D images as well (Berlier, 2018). One advantage to the 3D images is that a large database could be created that could represent different ages, ancestry, sex, trauma, and much more in a more ethical manner as long as approval is given to create the 3D image. Once the image is completed, the remains could be given back to the family for burial or taken out of the teaching cycle in order to protect the remains. This would also mean that any institution or individuals that would have access to this database would have access to several specimens and be able to explore more variation instead of a limited collection at their institution.

Human/Non-Human

In osteology, it is important to be able to determine whether a fragment of bone is Human or non-human. The methods used to determine the type of material is normally taught by looking at the item/material to determine if the fragment is bone and then trying to figure out what type of bone it is. The last step is trying to determine what specific bone it is. There are a few different techniques that can be used to see if something is human bone or non-human bone. Some of these techniques include histology, x-ray and other lab tests. Since this study is looking at how well students can identify the different morphologies and features of bone, all of the different methods mentioned in this section will focus on identification of human bone based on morphology.

First, it is important to understand that there are many variations within humans. These variations can make it more difficult to identify human bone, as there are differences in size and length. Second, there can be challenges depending on the age of

the individuals remains. Adult bones are commonly used for osteology; however, juvenile bones can be a challenge as they may be smaller and they may have a different look to them. An example of these differences between a set of adult and juvenile remains is that the bone will not be completely fused. Another challenge is that there are other materials that can mimic bone, and some animal bones can be very similar to human bones.

Variation of size and length

Human variation means that there are differences in each human's bones from another human. "For a random living sample of fifty male and fifty female individuals from various human populations, it would be easy to establish physical characteristics that would allow each person to be recognized individually (White and Folkens, 2005, Pg. 31-32). When looking at variation amongst humans, it is important to understand the context of the bone, for instance depending on the age of the remains, there can be differences as humans have changed over the years. This is only one example of variation. There are variations amongst all humans because of ancestry, height, age, sex and other biological makeups.

Juvenile

When looking at juvenile bones, there are a few things that are different. For one, fusion of epiphyseal plate will not be complete, this can lead to long bones looking different as the proximal and distal ends may appear missing or look different then how they would on an adult skeleton (Figure 1) (White, Black and Folkens, 2012 p. 38). Understanding how bones grow and fuse is important in osteology as this can help give an estimate of the age of the individual as well as help with identification of the bone and

features of the bone. It is possible with 3D images to have variety in the types of scans to show some of the bones at different stages in age, as well as to get a view of how fusion and bones change over time.

Mimic material

There are a few different types of materials that can mimic bone. A few items that may resemble bone include shell, some types of wood, minerals and other biological materials. It can also be difficult to identify bone depending on the environment the bone is found in. Bones can soak up surrounding material which can cause the bone to change color (Figure 3) (France, 2009, p. 9). In the figure, the top shows how similar wood can look to bone, while the bottom picture shows how bone can change color depending on its surroundings.

Figure 1.5 Human femur (top), wood (middle), very weathered bone (bottom).

Figure 1.6 Bleached white vertebra that has been in the elements (left), vertebra that was discovered in dark soil (middle), vertebra that has been cleaned and preserved (right).

Figure 3.The top image has three items, the top is a human femur, the middle is wood and the bottom is weathered bone (France, 2009, p. 9). This shows the challenges when it comes to identification of bone. The bottom image has three vertebrae displayed. All of these are human vertebrae, but are different colors depending on how they have been preserved or exposed to the elements (France, 2009, p. 9).

Animals

Once it is determined that the material is bone, the next step would be to figure out if it is human or animal. There are a few animals that can have similar skeletal remains to humans. One well known example of this is with bears. There are other animals though that can look very similar (Dupras et al. 2011, p. 290) (Figure 4). As seen in the images, depending on the animal and on the bone, they can look very similar to

human remains. An example of a bear paw vs human hand can be seen in Figure 5 (Bone Clones 2019 and 2021), this is more of a challenge if the bear’s paw is completely stripped of the soft tissue, as human hands are not covered in fur. Depending on context and location of the remains, some animals may be able to be ruled out. When teaching osteology, it is important for student to learn about these similarities. Using 3D images, students could learn about these differences by having a 3D image of different animals and human bones. This would allow students to be able to compare and contrast the animal and human bones, and to also be able to identify their differences.

290 Forensic Recovery of Human Remains: Archaeological Approaches

Figure 10.6 Morphological comparison of ulnae (anterior view) in large mammals: (a) adult human; (b) bear; (c) mountain lion; (d) wolf; (e) cow, fused with radius; and (f) domestic pig, fused with radius. (Not to scale.)

Figure 10.7 Morphological comparison of femora (posterior view) in large mammals: (a) adult human, (b) bear, (c) mountain lion, (d) wolf, (e) cow, and (f) domestic pig. (Not to scale.)

Figure 4. In this figure, from Dupras et al. 2011 (Page 290), the top image shows similarities of a human ulna to other animals. The bottom picture shows similarities with a human femur and other animals. The images both use the same animals from left to right: hu man (a), bear (b), mountain lion (c), wolf (d), cow (e) and a domestic pig (f).

Figure 5. Bear vs Human Hand from Bone Clones Website (2019 and 2021) Images. In this figure from Bone Clones, the image on the left represents a skeletal bear paw, while the image on the right is a human hand.

Pathologies

Pathologies can be very difficult to teach as acquiring a cast or bone that has a pathology can cost more with most being several hundred US dollars (Bone Clones, 2022). This means that even if an educational institution wanted to purchase the casts with pathology, they would have to purchase several of them to show some of the differences between different pathologies. Another way to teach about pathologies is using books and online resources. One book that has great examples of pathologies is *Orner's Identification of Pathological Conditions In Human Skeletal Remains* by Jane E. Buikstra (2019). This is a great way to learn as students can learn about several types of pathologies and see pictures of what they look like. One downside to books is that they are a 2D image. For some pathologies, a 2D image may be enough to show the change caused by the pathology, but having a 3D image that allows a student to see the texture may be more educational.

With a 3D image, students are able to rotate, manipulate and examine all aspects of the bone pathology. The use of the 3D image with online resources and books would allow students to learn about many different types of pathologies at a free or low cost to them. Another benefit to the 3D images would be the variety of pathologies. Instead of an institution having only enough money and storage for a few types of pathology casts, they could have access to a digital set of potentially unlimited 3D pathology bones.

Taphonomy

Taphonomy is the study of how something changes as it moves between the different layers of earth until it is recovered. While this may be a smaller section for a basic osteology course, this may be heavily covered in other related courses such as forensics. There are two common ways to teach taphonomy. The first is using education material such as books, papers and lectures. This is a great way to learn about Taphonomy, but it does not allow for students to learn in a hands-on way. The second way is hands-on, and generally includes students looking at how an animal carcass decays. This is another great method to learn taphonomy as it allows students to get firsthand knowledge of the process and experience. One down-side to this method is having the space and resources to observe an animal's decomposition. For this type of learning, there has to be space as the animal will smell and may attract other animals or insects. It must also be able to be contained so that a larger scavenger does not take the carcass. Although a combination of the two methods above is an ideal way to learn about Taphonomy, the second option is not available for all students or institutions.

When looking at taphonomy, the bone is studied but other hard tissue may also be studied such as material found in the teeth or other calcified tissue. Having access to

these materials is not common, but may be available at some institutions. For those institutions that do not have this material, a 3D image along with traditional teaching material could help in the teaching process. Another importance when looking at taphonomy is to look at how the bone has changed not, just physically, but also how it has changed chemically. Looking at how the bone changed is important, as this may help with identifying if the item is in fact bone, and what happened to the bone.

The last section about taphonomy will be discuss bone modification. Depending on where the remains are found, there could be significant changes in the bone or time that it took for the remains to become skeletonized. When looking at weather, cold weather normally means it will take longer for the remains to become skeletonized compared to warmer weather (Komar, 1998). Animals can also play a role in taphonomy, as animals may help break down the remains which can lead to a faster rate of skeletonization (Komar, 1998). Climate is not the only factor that can change the rate of skeletonization or change the remains. In certain situations, such as cultures or if the individuals partook in war trophies, may play a part in the taphonomic process (Pokines, 2018). Remains may also be moved from one location to another. Example of this can include families moving remains, animals disturbing the remains, or in ritualistic practice where remains may be used (Pokines, 2018). The use of 3D imagery could help in the study of taphonomy, as it could allow students to see how bones are affected in different situations. This may also be a more ethical way to study the bones if the 3D images are created with consent.

Sex

Determining sex on human remains can be done in a number of ways. One method looks at the ventral arc, subpubic concavity and medial aspect of the ischio-pubic ramus (Phenice, 1969). Klales (2012) is a modification of the Phenice (1969) article and gives a more in-depth chart on how to characterize the three traits by changing the scale from one to three into a one to five scale (Klales, 2012). In the figures section below, Figure 6 depicts the original images from Phenice (1969) (Figure 6). Figure 7 depicts Klales (2012) modification which shows the difference between the three phases to five phases for the three traits. These resources are very popular in determining sex, and they do work on determining the sex on a 3D image of the os coxae; subpubic concavity (Figure 8), medial aspect (Figure 9) and ventral arc (Figure 10).

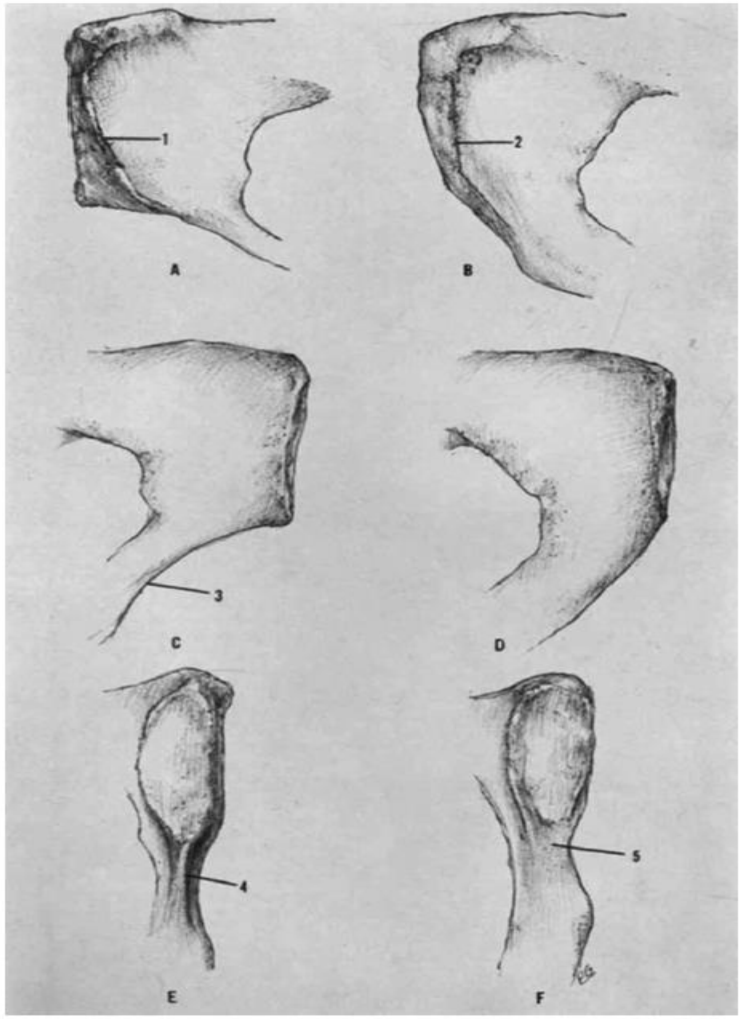


Figure 6. Sketch in Klales (2012) page 105.The image represents the morphological features used for sex determination.

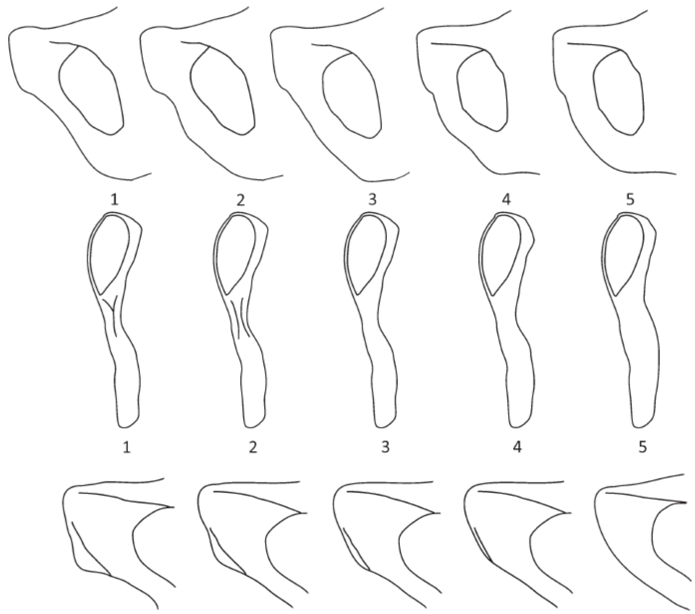


Fig. 2. Character states and ordinal scores for the SPC (top), the MA (middle), and the VA (bottom).

American Journal of Physical Anthropology

Figure 7. Sketch in Klales (2012) page 107. The image represents drawings of the morphological features used for sex determination.

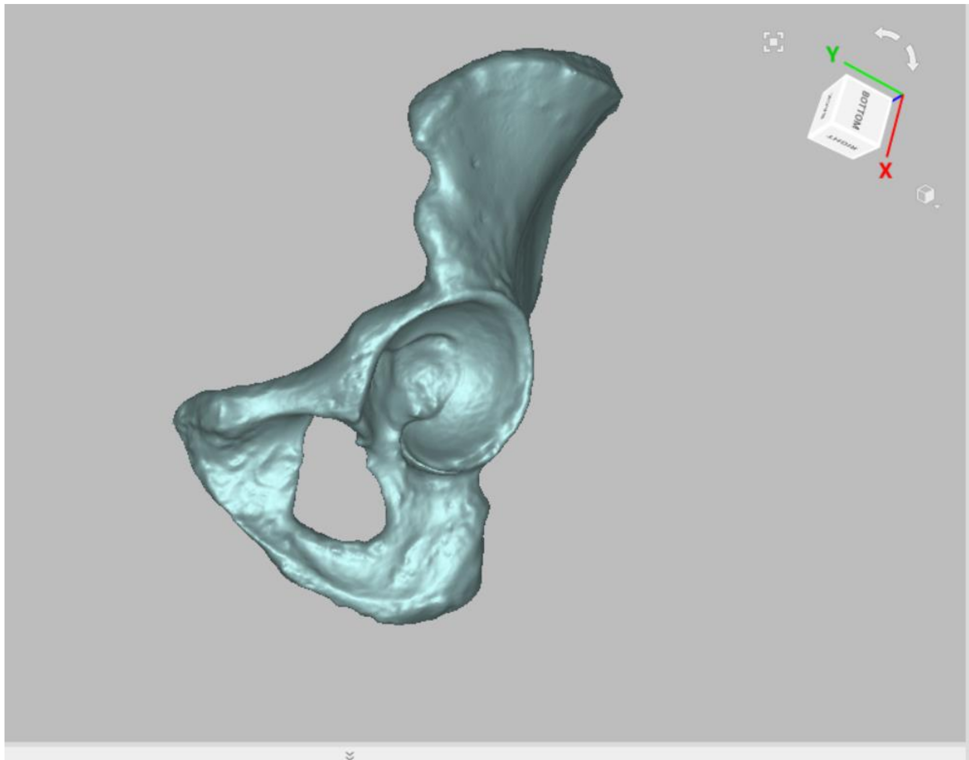


Figure 8. Sex Morphological Features (Subpubic Cavity View) 3D Image by Schulz (2022) The 3D os coxa image is displayed in a view that is supposed to be a similar viewpoint for looking at the subpubic cavity morphology as depicted in Klales (2012) Figure 2 Page 107.

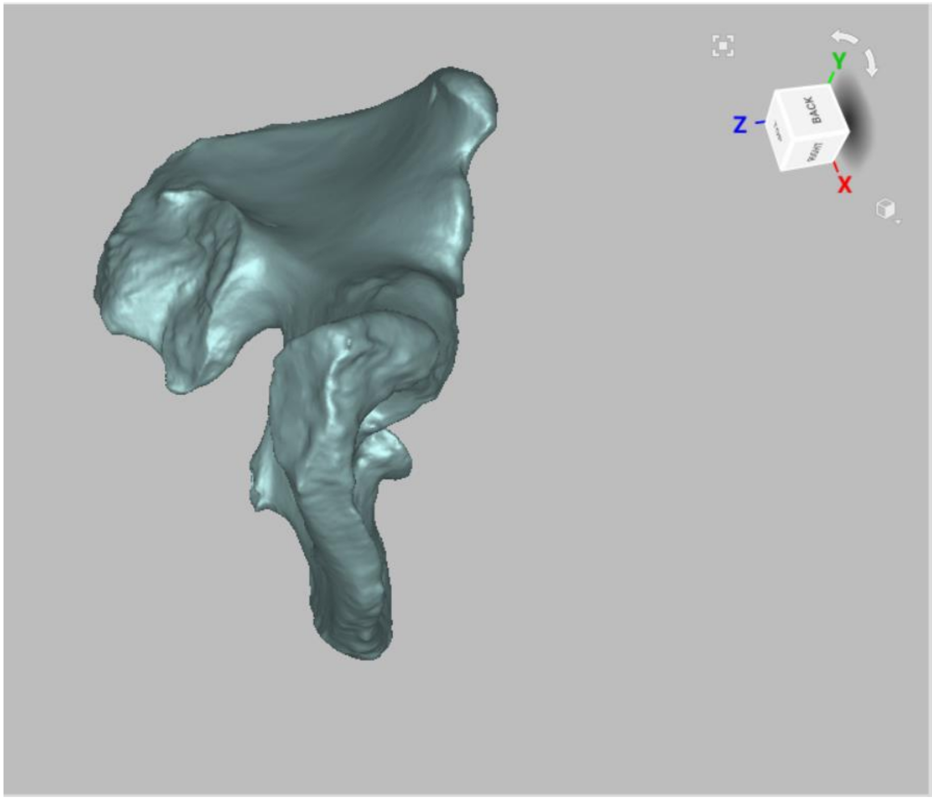


Figure 9. Sex Morphological Features (medial aspect) 3D Image by Schulz (2022) The 3D os coxa image is displayed in a view that is supposed to be a similar viewpoint for looking at the medial aspect morphology as depicted in Klales (2012) Figure 2 Page 107.

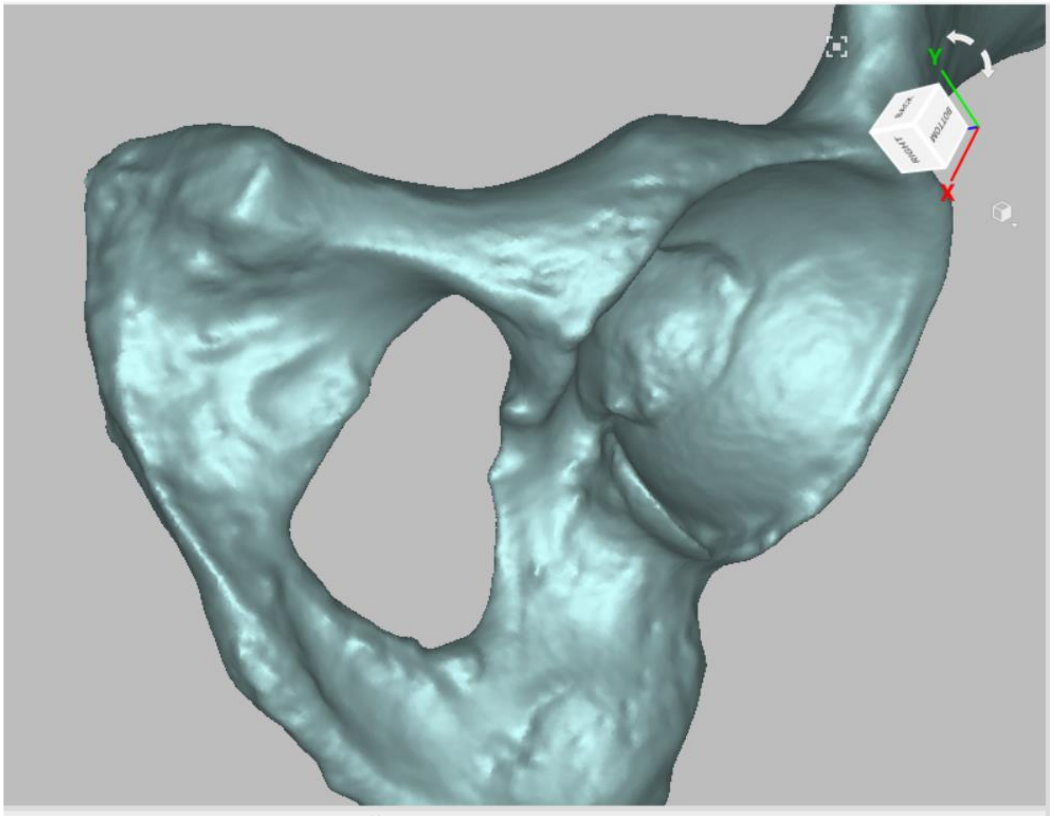


Figure 10. Sex Morphological Features (ventral arc) 3D Image by Schulz (2022) The 3D os coxa image is displayed in a view that is supposed to be a similar viewpoint for looking at the ventral arc morphology as depicted in Klales (2012) Figure 2 Page 107.

If the *os coxae* is not available to be used for determining sex, the cranium can be used. To use the cranium, there are five morphological traits that are looked at; mental eminence, orbital margin, glabellar area, nuchal area and mastoid process (Buikstra and Ubelaker, 1994). This method is done by giving each of the five traits a number between 1 and 5 based on morphological standards, if the number is lower than 3 it is likely a female, if it is more than 3 it is likely a male the method was originally created by Bukstra and Ubelaker (1994) and was added onto by Walker (2008). The five traits with the respective number are shown in Figure 11.

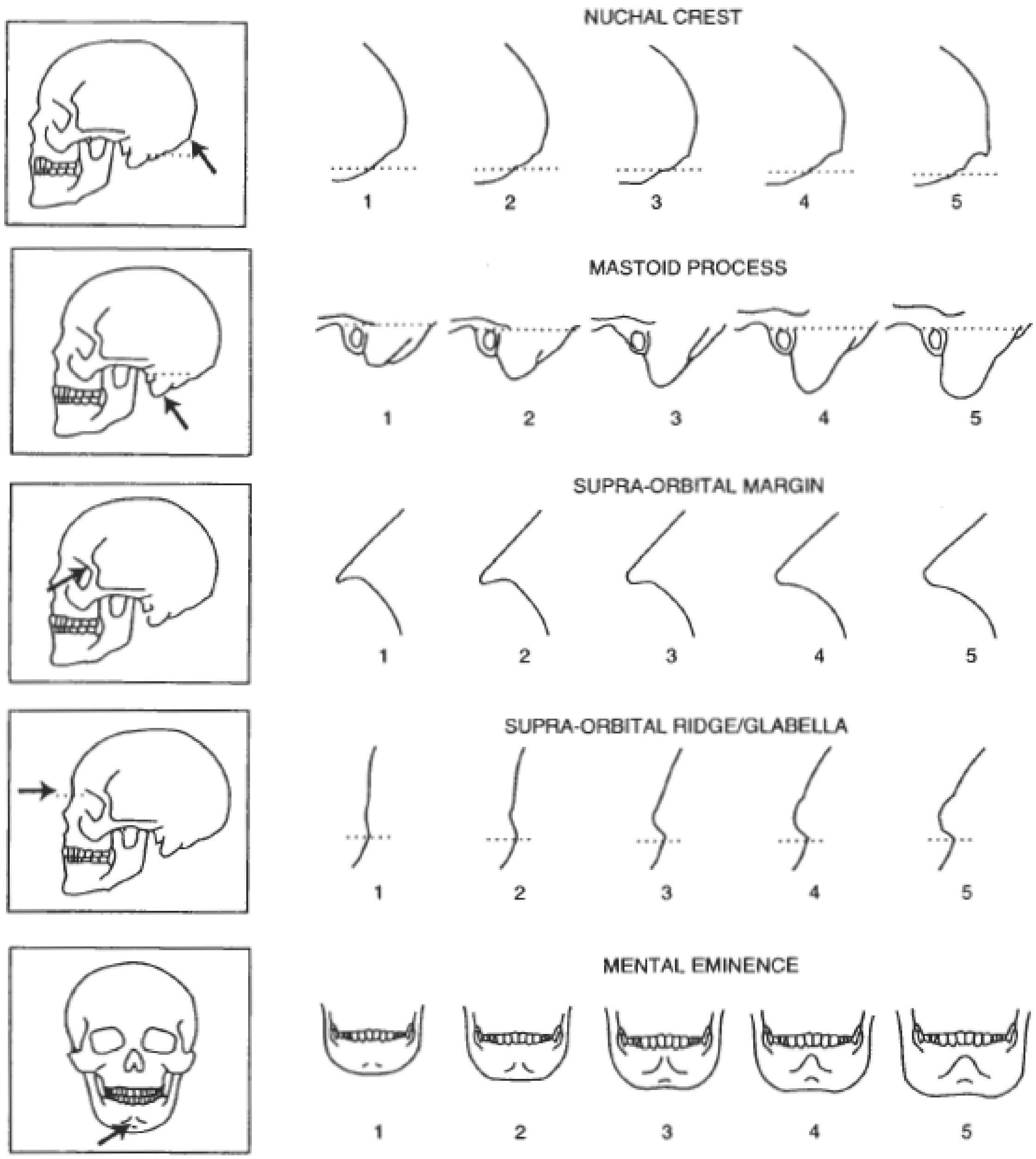


Figure 4. Scoring system for sexually dimorphic cranial features. Drawing by P. Walker.

Figure 11. The image represents drawings of the morphological features used for an estimation of sex. (Buikstra and Ubelaker 1994. Page 20).

These traits can also be visible within the 3D images, Figures 12 - 17 display a couple of different views of the cranium that could be used to determine the rank of each

trait. These 3D image screenshots do not show the full benefit of the 3D image as it is only a 2D image, however, it is still possible to see the detail to understand how sex determination could be used with 3D images.

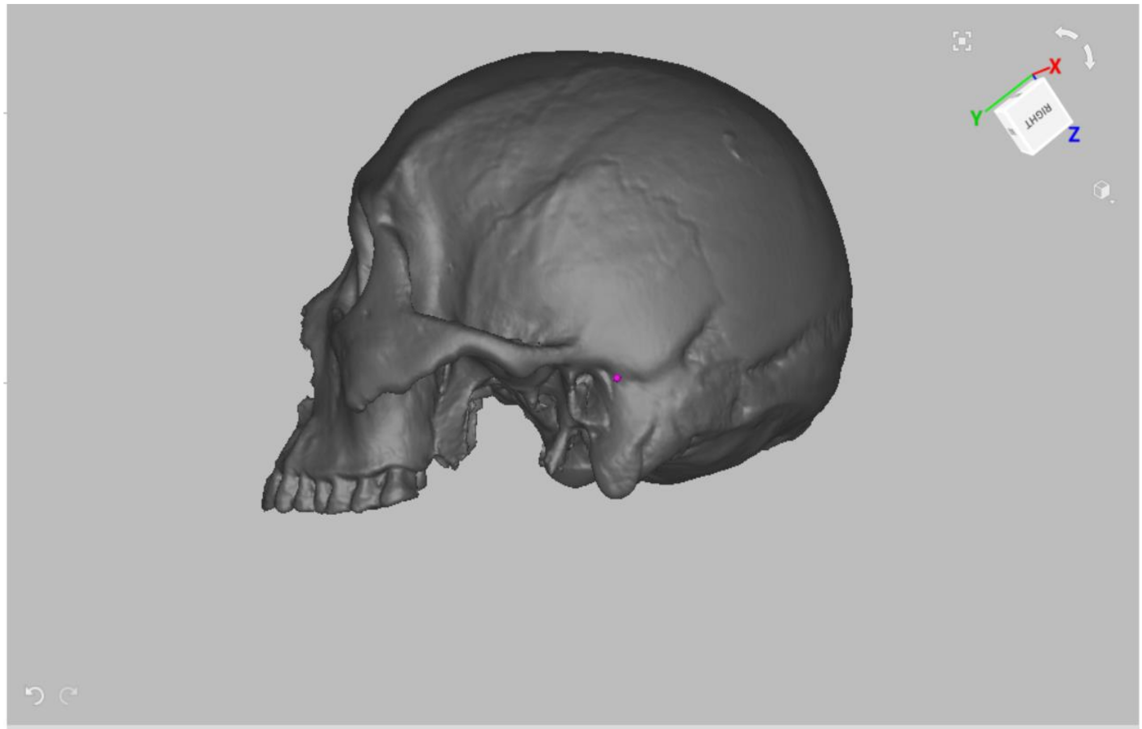


Figure 12. 3D view of the Nuchal Crest by Schulz (2022). Is a left lateral view of the cranium with an emphasis on the Nuchal Crest. This angle is supposed to be similar to Buikstra and Ubelaker (1994) page 20 image that represents sex estimation traits for the Nuchal Crest.

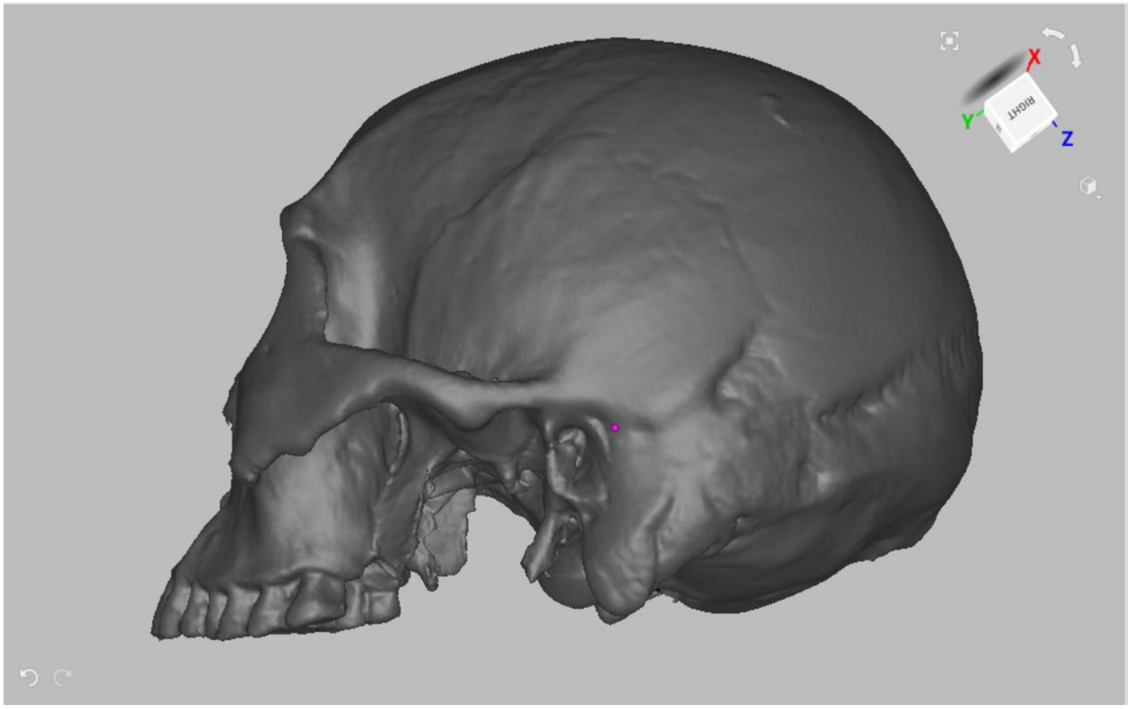


Figure 13. 3D view of the mastoid process by Schulz (2022). Is a left lateral/posterior view of the cranium with an emphasis on the Mastoid Process. This angle is supposed to be similar to Buikstra and Ubelaker (1994) page 20 image that represents sex estimation traits for the Mastoid Process.

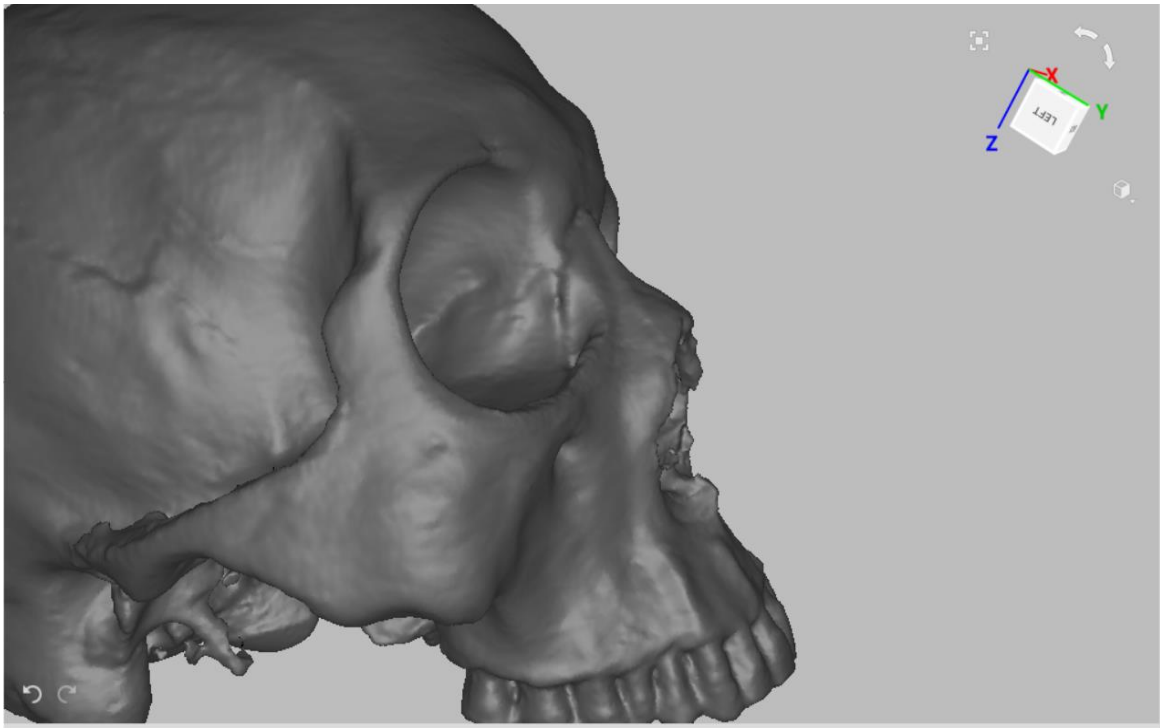


Figure 14. 3D view of the Supra-Orbital Margin by Schulz (2022). Is a right lateral/anterior view of the cranium with an emphasis on the Supra-Orbital Margin. This angle is supposed to be similar to Buikstra and Ubelaker (1994) page 20 image that represents sex estimation traits for the Supra-Orbital Margin.

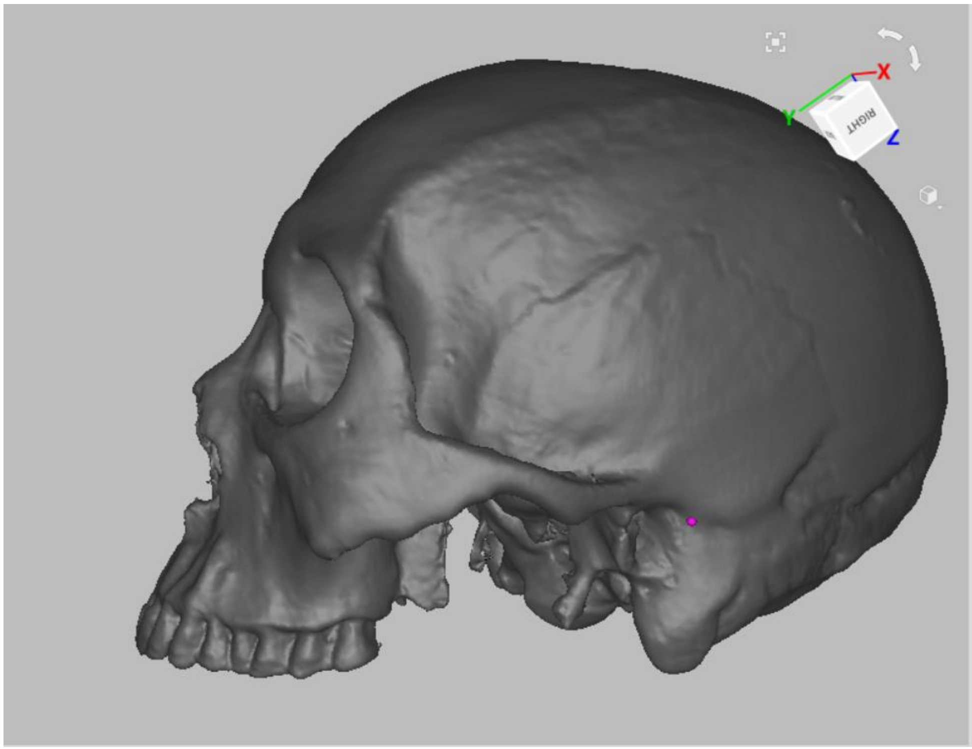


Figure 15. 3D view of the Supra-Orbital Ridge/Glabella by Schulz (2022). Is a left lateral view of the cranium with an emphasis on the Supra-Orbital Ridge/Glabella. This angle is supposed to be similar to Buikstra and Ubelaker (1994) page 20 image that represents sex estimation traits for the Supra-Orbital Ridge/Glabella.

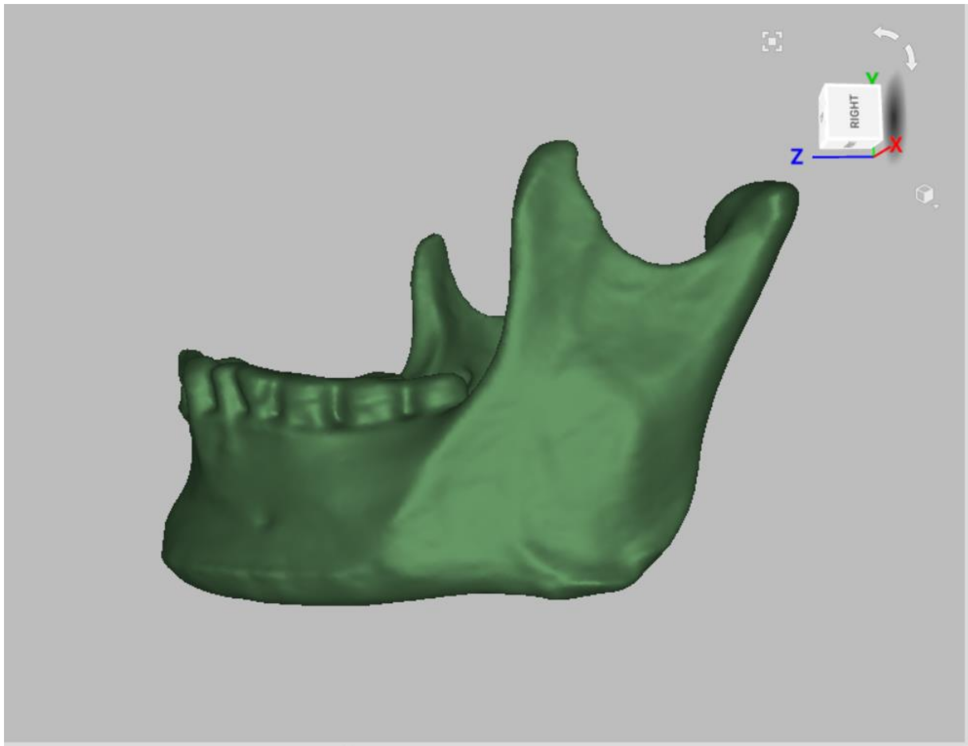


Figure 16. 3D view of the Mental Eminence by Schulz (2022). Is a left lateral view of the mandible with an emphasis on the Mental Eminence. This angle is supposed to be similar to Buikstra and Ubelaker (1994) page 20 image that represents sex estimation traits for the Mental Eminence.

Figure 17. 3D view of the Anterior Mental Eminence by Schulz (2022). Is a anterior view of the mandible with an emphasis on the Mental Eminence. This angle is supposed to be similar to Buikstra and Ubelaker (1994) page 20 image that represents sex estimation traits for the Mental Eminence.

Ancestry

When estimating ancestry, there are several different methods that use a variety of metric and nonmetric traits. There are also many things that can make estimating Ancestry difficult such as population factors, age, accuracy of population records, time period of population factors and more. For this paper, the goal is to determine if 3D images are a suitable alternative or addition to standard Osteology teachings. In support of this goal, the 3D images are valuable in being able to use them as a teaching resource for estimating ancestry. For non-metric traits, the cranium can be used to look at different traits (Hefner, 2009). Another example of estimating ancestry is through dental

characteristics (Edgar 2013). Edgar (2013) details a few different dental characteristics and how accurate they are for different populations.

There are different morphological methods for looking at ancestry. Another method is using metrics. Once measurements have been taken, FORDISC can be used. FORDISC is a database that allows a user to input metric data in order to obtain an estimation for Ancestry and Sex of the individual (Jantz and Ousley, 2005). In order to test the accuracy of the 3D scans for this research thesis, measurements were obtained from both the casts and the 3D images of the same casts. All measurements taken, of both the physical casts and 3D images, were within 2 mm, which is the standard margin of difference. Since accurate measurements of the 3D scans was deemed possible, all of the information needed for FORDISC in order to get an estimation of sex and ancestry can be accomplished. This is important as FORDISC is a great resource, and has a large database that the results can be compared to in order for FORDISC to calculate an estimate of the specimen's ancestry and sex.

Height

Height is determined by taking different measurements of the bones. In one method from Wod (2008), measurements are taken from the femur to estimate height. There are several other methods that can be used to look at stature. Each method has its own limitations depending on the amount of skeletal remains and sample population (Blau and Ubelaker, 2016). Some of these methods include looking at long bones, cranial measurements and vertebra.

The measurements can be taken using the Artec 3D software (Artec, 2022). One benefit to using a 3D image is that there is not a need for expensive measuring

equipment. Sliding and spreading calipers can have a large range of quality and cost with some being less expensive and some being over a thousand dollars. Depending on an institution's financial situation the institution may be able to provide the equipment for its students, or the institution may require the students to purchase them as material for the class. There are more expensive items such as a mandibulometer which can be thousands of dollars or an osteometric board/table which can also be several hundreds to thousands of dollars (OsteoLab, 2022). OsteoLab supplies were used as an example of costs, and are not the only company where these supplies can be purchased from. Not only are these incredibly expensive, but in order to teach a medium to large size class that allows students to practice and become efficient with these tools, more than one would be needed for efficiency. There are some challenges with teaching metrics on a 3D image. One challenge would be that the students will need to learn how to take the measurements on a real bone or cast at some point in their career. The second challenge is that there are no standards created yet that document the process of how to take these measurements using a 3D image. However, to learn what the measurements are and to become proficient with how to measure and identify the landmarks, this could easily be done with the 3D images.

Age

One way to determine age is using the Suchey-Brooks (1990) method which is looking at the pubic bone and involves six phases. This method is a morphological method for age, and would be able to be completed using a 3D image. Another method that is great for a secondary age estimation is the Buckberry and Chamberlain (2002)

method. This method looks at the auricular surface and uses seven phases. With this also being a morphological method, this could be taught using the 3D images.

Age can also be estimated by using Iscan (1984) and Iscan (1985) methods. These methods involve using the fourth sternal rib to make an age estimation (Iscan, 1984) (Iscan, 1985). This again is a morphological trait so it could theoretically be done using a 3D scan. Theoretically is used here because depending on the quality of the scan and the original item, this could be more difficult to assess due to the ribs size. In ideal situations, this should be able to be taught with no concerns.

The last way that will be talked about is looking at teeth. There are several different methods used to look at teeth and age. Mincer et al. (1993) looks at the development of the third mandibular molar to give an estimation on age. Although similar concerns about the quality of the scanner and the 3D scan can be made as with Iscan (1984 and 1985). When dealing with teeth, the scanner could do individual teeth as well as attached teeth. This could allow for a model to be made showcasing teeth in situ in order to give a better understanding of how the teeth align, form and grow.

One challenge to keep in mind when estimating age is that juvenile bones are not fully fused together. Juvenile bones are smaller than adult bones and may look different as they may not be fully fused, or may be completely unfused which results in the bone looking non-human (Dupras et al. 2011). Therefore, it is important when looking at age that the correct method is used. However, if a method can be done using a cast or bone, this same method should work using the 3D image.

Bones and Features

The bones and features were tested in the 3D part of this study. Although only a few bones were used in the study. 3D images were created for most of the bones in the body. In all of the scanned bones, the image quality remained the same and features were still visible in the 3D model as on the cast. Only one cast was used to create the scans, there was no reason for this other than the convenient access of that cast. There is no evidence to suggest that scanning another cast or real bone would have any different result or quality. Although no human bones were used to create a 3D image, animal bones were successfully created using the 3D scanner. Giving evidence that cast vs actual bone made no difference in quality or ability to scan the original material.

Court Usage and Review

Advance technology in the courtroom is becoming more popular or at least more studied (Mcdonald, 2015). When creating 3D images, it is important to make them as close to the original item as possible. When done correctly, the 3D image and the original bone/cast should be identical in size, how they look and how it relates to its surroundings. 3D imagery is relatively new, but it has been used in the court system before (Carew and Errickson, 2020). Carew and Errickson (2020) focus on 3D printed material, but the same concept can apply for digital 3D images. Through the article there are several examples of how 3D printing can and has been used in court, but one example is using it for blunt force trauma illustration (Carew and Errickson, 2020). When dealing with blunt force trauma, the images can be gruesome (Bandes and Salerno, 2014). Using 3D imagery can be beneficial as it allows the trauma to be shown in detail without being so graphic. This

can also allow for a skull to be 3D scanned to show the trauma without showing tissue and other markers to enhance the visualization of the trauma area. It can also be used to show the location of certain material in retrospect to a larger area in order to give an overall view of the scene or trauma (Carew and Errickson, 2020).

An issue that can arise with human remains in a court setting is that after the trial the remains may be buried, cremated or any other means of burial practices. Depending on the type of burial, legal process and condition of the remains it may be difficult to use the remains at a later date such as for an appeal. If there is a 3D image for the individual's remains, this could allow for the individual to not be exhumed and for the evidence to still be used at a later date even if the individual is cremated (Carew and Errickson, 2020). There is some debate about who owns a 3D image (Carew and Errickson, 2020). In this case with it being human remains this becomes a difficult question, but if it was determined to be evidence, the 3D image could stay on a secured drive, in evidence storage.

Peer Review Process

The peer review process is important in many scientific fields, a peer review process allows for another professional to look at the same set of information and material as one researcher and come up with their own analysis. This can be done in many fields and for many reasons. One example is in forensic anthropology reports. The idea of the review is for two independent researchers to come to the same conclusion about the remains on their own. This is useful because it shows that the other individuals were able to come up with the same conclusion. When it comes to human remains, peer review can be a little more challenging due to the fact that this individual should be

treated as a human and not just as another object. In most cases, the peer review process is completed by the first specialist, and then a second specialist will come in and perform their assessment to see if their conclusions are the same. This however can be difficult if you would like to get the opinion of someone else that is not in your lab. If you ship the remains, you risk damaging them, releasing sensitive information, travel restrictions and other issues. Even when remains are in perfect condition they can still easily be broken during travel. Another option and a more reliable option is to use photographs of the remains and send those to the peer reviewer. This is great as it allows the reviewer to see what the initial reviewer was seeing. However, there are some limitations when using a 2D image that could be enhanced by the 3D image, such as an ability to get a different angle, rotate and manipulate the image and take accurate measurements.

To get an outside individual to conduct the peer review of the remains, it means either the material has to be shipped, photos and other information will have to be shared or the reviewer needs to travel to the remains. With a 3D image that is accurate on both measurements and morphological traits, a reviewer could have access to the remains in a virtual setting. This would be especially important for remains that may be in too fragile of a state to ship. 3D printing is becoming more popular as well, this could mean that a reviewer or a researcher could create a 3D image and use that to print a 3D product. Working with 3D images or Printed 3D objects could allow an educational institution, a legal institution or a criminal situation a great alternative to present information in a cost effective and a more stable alternative to biological remains.

Chapter III: Methods

In the following chapter, a few different methods will be discussed. The first components of the methods discusses the actual methods of creating the 3D imagery. The second method goes into how the study was conducted and how the students were taught and tested on the material. Lastly, the section discusses how the results were analyzed and reviews the different statistical methods used.

Creating 3D Images

For creating the 3D images, an Artec Eva Light 3D scanner was used (Artec, 2022). The cast material was from Bone Clones, and was skeleton SC-092-D, which is a Human Male Asian Disarticulated Skeleton (Bone Clones, 2022). The Artec Eva Light scanner can be used with most computers, laptops and tablets. The program and scanner are not free, but were funded through the School of Global Integrative Studies at the University of Nebraska-Lincoln.

Step 1 Scanning

For creating the scans, a turntable was used in order to turn the cast in a full 360-degree rotation. Some casts required the use of putty in order to stand them up on their own for a different view of the bone. The scanner was used in a rainbow/arch motion in order to capture each angle of the cast. This method is not required, but it is the recommended method to ensure a proper 3D image (Artec Representative, 2020). For most bones this meant taking scans at two to three different views/positions in order to capture the complete surface area of each bone. For the cranium, there were several

views/positions used. This was due to all the crevasses, foramen and just the high number of features in a small area.

This scanner has two main modes, standard and autopilot mode which creates an auto generated image (Artec Manual). The standard mode is the one that was recommended by the company to use in order to get the best detail in the 3D image (Artec Representative, 2020) (Figure 18). When you finish a scan in this mode you get a raw image that needs cleaning up. This method does create the most detail and is the fastest way to complete a scan. The second is the Auto generate mode (Figure 19), this mode allows a user to scan the object and have a 3D image generated automatically instead of having to clean up the raw images.

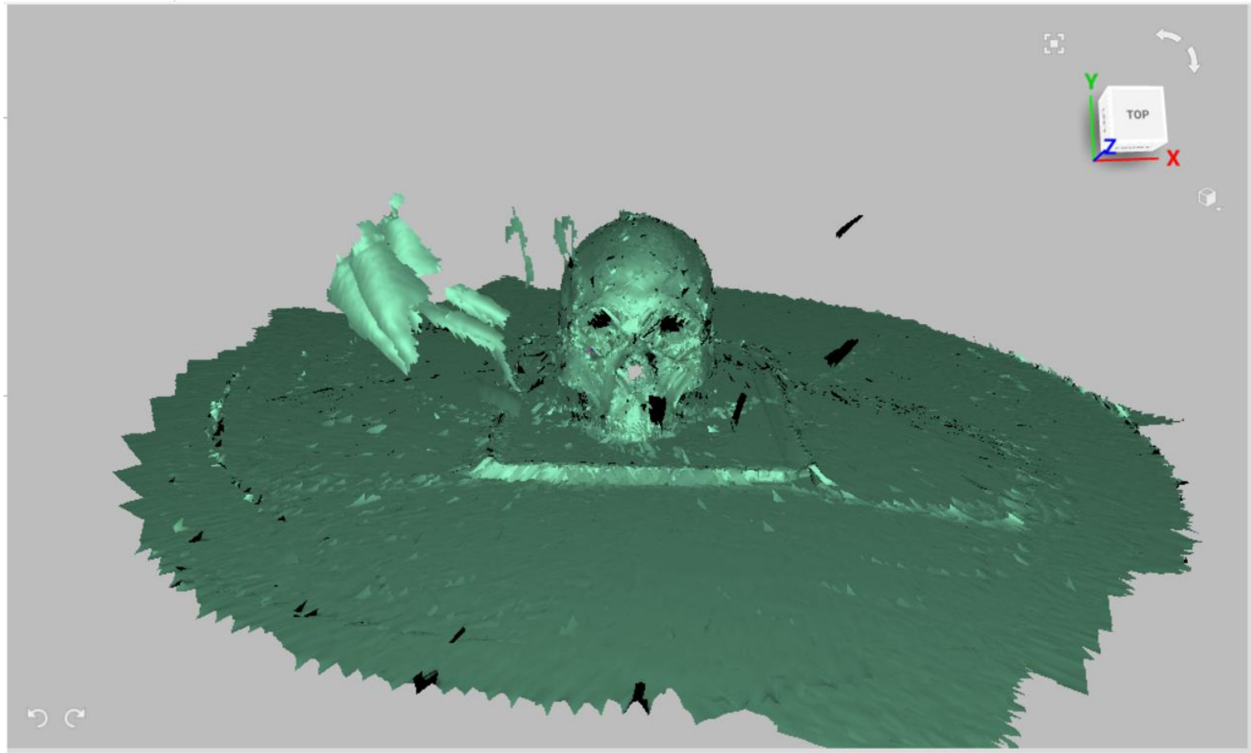


Figure 18. Standard Scanning Mode 3D Image by Schulz (2022), unedited image. This is the raw 3D image that is given after completing a full 360 scan of the original item.

Figure 19. Auto Generated Scanning Mode 3D Image by Schulz (2022), unedited image. This is the raw 3D image that is given after completing a full 360 scan of the original item using the Auto Generated feature.

This mode looks the most detailed at first, but does lack some of the small and more specific details. Because of this, this mode was used as a guide for how the final product may turn out, but was not used in the final product. This was a helpful guide because if the auto generated models had no holes, and the image was complete. It meant that this was a good representation that all of the angles and sides of the object were correctly captured in the scanning. The auto-generated images could sometimes be used in the final mesh if the standard mode scans did not pick up a certain view/angle. When using this mode, the scanner takes scans in both of the modes. Meaning that it completes the auto generated mode while scanning in the standard mode, so you get both image

types. Since it was helpful to have both types of images, this is the mode that was always used when scanning the bones. This does make the scanning process take a few minutes longer as the scanner has to do more.

While scanning, there are a few things to consider and monitor. First, I used a turntable because this allowed me to keep the bone in the same spot, but rotate the bone so that I could change the view. Using the turn table seemed to give a cleaner image than trying to rotate around the bone with the scanner. The scanner has two power options, one option requires it to be plugged into an outlet and the other requires an external battery. The scanner used for this research did not have an external battery, so the turntable made it easier to scan all sides of the object instead of physically moving the scanner around the object being scanned. The scanner is also connected to the computer through a cord, which means even with a battery there can be limitations to movement. Scanning in an arch/rainbow motion also allowed for the best data recording. The scanning motion meant that I would hold the scanner on the side of me and go in an arch/rainbow motion while twisting my wrist. This motion seemed to allow for the best image as it would capture different angles on the bones which allowed for the scanner to pick up holes/crevasses. When scanning, it is important that the individual scanning looks at the computer and not the scanner itself or the object.

When looking at the computer, you see a few different things. The first is the image itself. When using the auto generated mode, the image comes in as a rendering of the 3D image. Which means as you rotate the object, you start to see the areas that have already been scanned show up on the screen. Having this rendered image is helpful so that you can see if you missed anything while scanning. Although this method works well

to get a preview of how the image will look, rotating the object/turntable 20 to 30 degrees after each arch motion generally obtains all of the viewpoints needed (Artec Manual). It does not ruin the scan to rescan the same parts. While looking at the computer you will also see a distance meter/color change. When scanning you want to be in the green on the distance meter. This roughly seemed to be around 18 inches from the object itself. If you are too close or too far away the scanner will not pick up the image or it will be severely distorted. If the scans are not taken at the correct distance this can cause the scanner to have an error by not knowing where the object is. If the object is lost from the field of view, the scanner will need to be slowly moved until the image comes back. Speed is also important, if a user moves too fast, the scanner can produce an error, it is important to go at a steady slow pace for the best results. Fast movements can also distort the image which can cause the user to have to redo the scan. As stated earlier, the angle is very important when creating a scan. The arch/rainbow method seems to work the best, but you may need to use other motions in order to get a complete scan. Having the scanner perpendicular to the face of the item you are trying to scan has proven to be the most accurate. When the scanner is not held perpendicular, there can be issues with the smaller details. Having a well-lit environment was also important as it allowed for adequate light for the scanner to see into crevasses. The user can increase texture brightness for dark objects or decrease the brightness for lighter objects in the scanning settings. Some materials may need to have the sensitivity of the scanner increased in order to get a clear image which can also be changed in the settings. Lastly, the higher the frame rate the better, before starting the scan there is a setting to have the scanner "perform optimally" which increases the frame rate on the scanner (Artec, 2022).

For most bones, the scanning process took anywhere from 20-30 minutes. For the Cranium, this process took about 40-60 minutes. One bone was scanned at a time. When creating the scans, the software will show all of the separate scans you complete on the side of the screen. Once there are enough scans and angles in order to complete the 3D image, the steps below are used to create a finished 3D image. At this point there is no longer a need for the item/cast that was being scanned or the scanner. The next steps are all done in the Artec software (Artec, 2022).

Duplicate Scans

The Artec software allows users to duplicate the scans (Artec Manual). Duplicating the scans is not a required step, but is highly recommended. Duplicating the scans allows you to have saved copies of the original scans (raw scans) without having any alterations. Having these original scans is important because they may be needed later if the user needs to start over or go back to a previous version of the scan to try to get a better image. The Artec software also allows users to unload scans. Unloading the scans allows for them to be accessed, but it does not allow the user to edit the scans while they are in the unload phase. When a scan is unloaded it grays the scan out to distinguish the copies from the originals. At this stage there are no differences between the two sets of scans, so whichever set is not unloaded will be used for the next steps.

Global Registration

This step has to be done for each 3D scan, and its purpose is to start making the object look clearer (Artec Manual). The software takes the raw 3D image and starts to clean it up. “The global-registration algorithm converts all one-frame surfaces to a single coordinate system using information on the mutual position of each surface pair” (Artec, 2017). At this stage, when doing Global Registration of each scan, the key frame ratio should be set between 0.1 and 0.3 (Figure 20). If using the Auto Generate scanning technique, this step cannot be completed as it does this while the scan is being taken. What this frame ratio means is 1.0 is 100% of the image meaning that if you put 1.0 it will make everything into one frame. This can cause some issues with image quality if you put it this high. In a later step Global Registration happens again and at this time it is done at a higher frame ratio. Once this is done for all of the scans, it is time to move onto the next two steps.

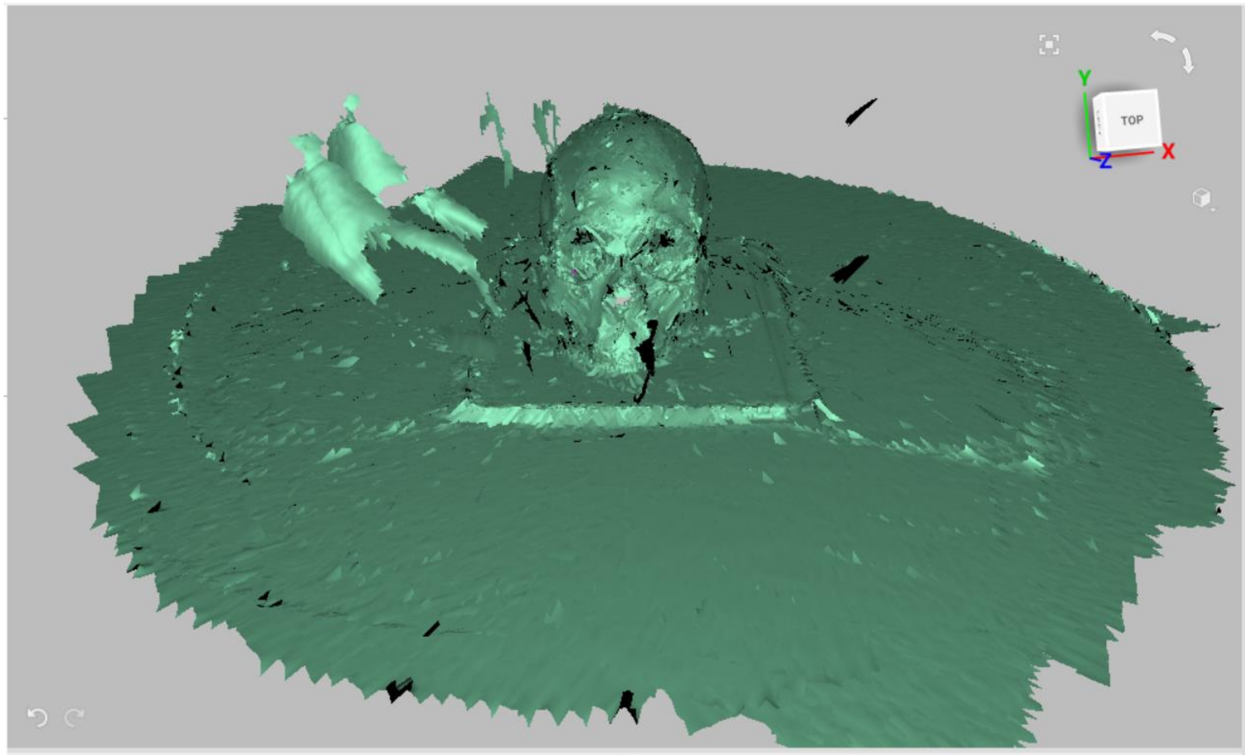


Figure 20. Global Registration 3D Image by Schulz (2022). This is after the scanning process and is the start of the editing process. This is the Global Registration at 0.3 Key Frame Ratio.

Align/Erase

The next steps can be done in either order depending on the scans. If a scan has a lot of outliers/things not part of the image it may be better to delete some of the outliers as this can affect aligning all of the scans into one 3D image. If there are no significant outliers, aligning the scans can be done first and then the user can erase the extra outliers after they are all combined (Artec Manual). When doing these steps, the advantages to erasing the outliers first is that it generally helps the software to align the images. Also, since a turntable was used for the scanning, the software would sometimes have problems aligning the scans due to the different positions of the turntable in the scans. The benefit

to aligning first is that instead of having to erase the outliers for every scan, the user would only have to erase the outliers for the combined scan. For most scans, the erasing was done first and then the scans would be aligned. Additional erasing was done as needed. Once the image has most of the outliers removed (Figure 21), the scan can be aligned with other scans to complete a finished 3D image (Figure 22). There are two ways to align the images. An auto alignment in which the software finds points that are a match and aligns all the images to those points to create a unified 3D image. The second way is manual alignment, this means the user picks points on a scan and correlates that point to a point on another scan. Once the user has enough points, the software matches the points and creates one 3D image. If the image is complex, and the points do not appear to be easily connected, it would be recommended to use manual alignment. Once these steps are completed another round of global registration will occur.

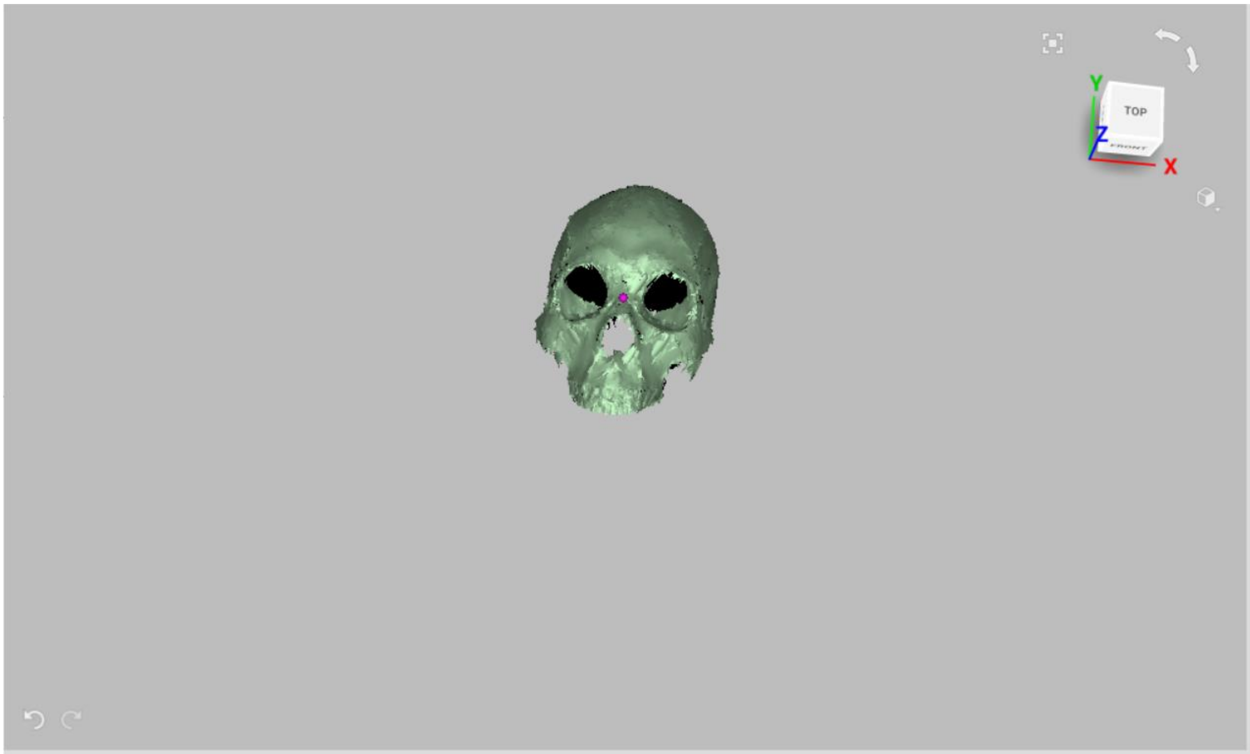


Figure 21. Erasing Step 3D Image by Schulz (2022). This is in the editing process. This image depicts the image (cranium) with everything erased besides the items features.

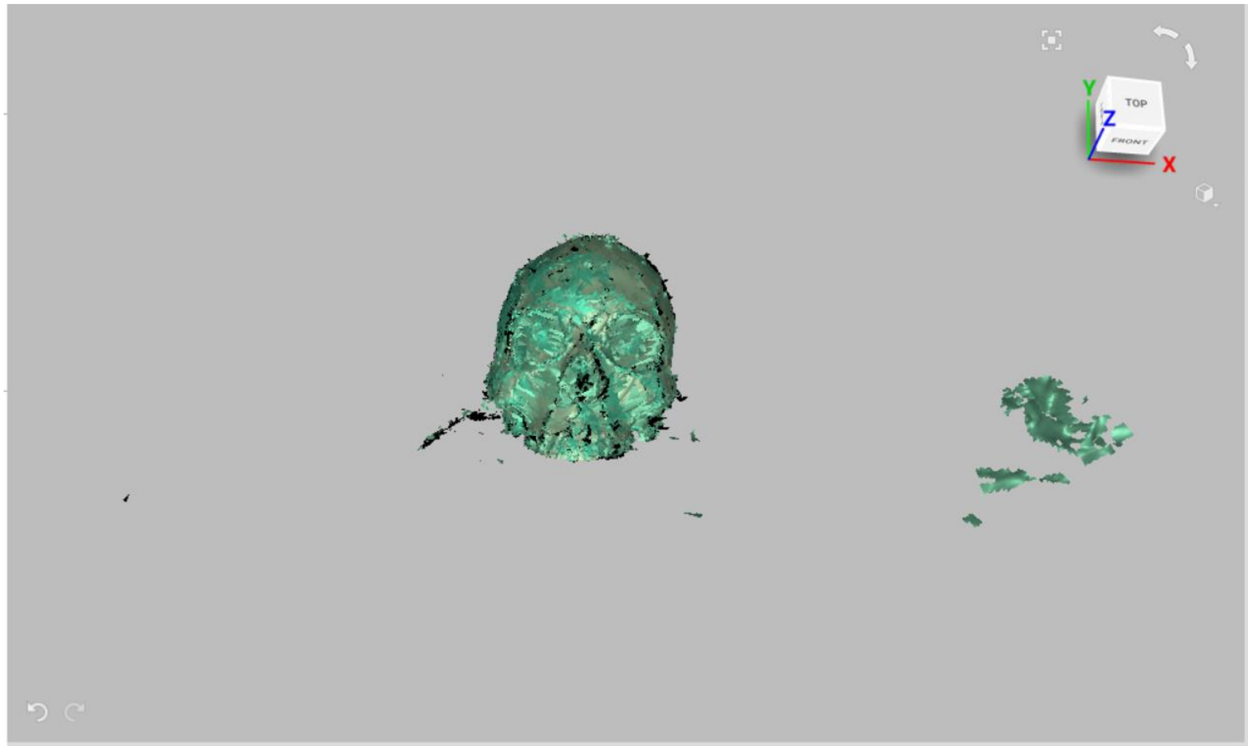


Figure 22. Aligning Scans Step 3D Image by Schulz (2022).This is in the editing process. This image depicts the image (cranium) with three different scans aligned to create one image.

Global Registration and Outlier Removal

At this point, there should be an almost complete 3D image. For the key frame ratio, it is recommended to have a range of 0.5 to 0.8. This should fix any small alignment issues. Once this is done, outlier removal is the next step. Removing the outliers involves taking out the points that the software does not believe are part of the image. When scanning, the scanner picks up some noise around the object. Noise refers to other images that might be in view of the scanner that are not related to the object being scanned. The object itself is the focus of the scan therefore it has more points. The outlier removal step starts to filter out the noise by taking away anything that does not

have as many points as the item that is being intentionally scanned. This makes the image clearer and should leave the user with an image of the item/cast only and not include anything else. Once these steps are completed, there are some other tools that may be useful depending on the 3D image, but if the image looks complete there is only one step left (Figure 23).

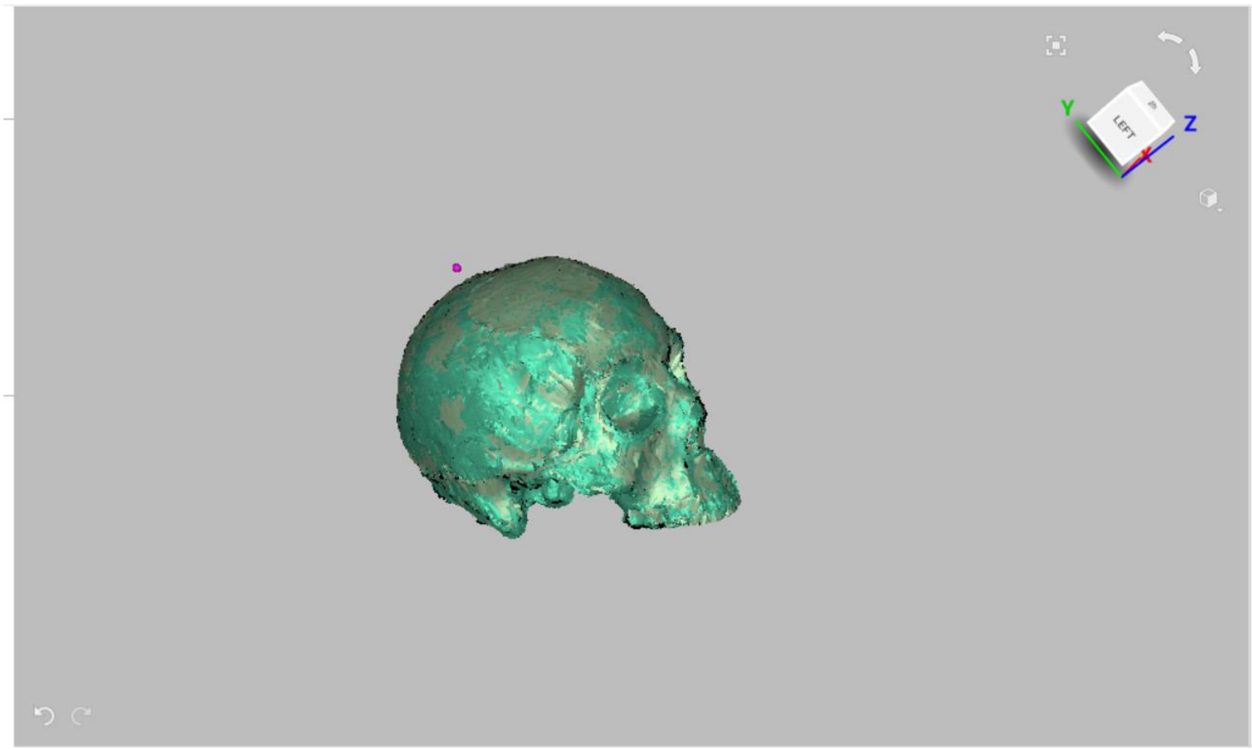


Figure 23. Outlier Removal Step 3D Image by Schulz (2022). This is in the editing process. This image depicts the image (cranium) after it has been processed through the Outlier Removal and the second round of Global Registration.

Fusion and Editing

This is the final step in completing the 3D image (Artec Manual). The fusion step takes the aligned 3D image and creates one solid image (Figure 24). Once the Fusion step is completed, it is time to fix any holes and features. The software has several tools that

can be used to do these tasks, but one of the best is the defeature tool as this can be used to fix holes and delete or smooth down an area. Once the 3D image is complete, a mesh can be saved for exporting. To finish all of the steps on the Artec software can take anywhere from 30 minutes for bones such as the Femur to several hours for bones such as the Cranium. The time it takes to complete a scan is all dependent on the complexity of the scans, the number of scans and the amount of editing that is required.

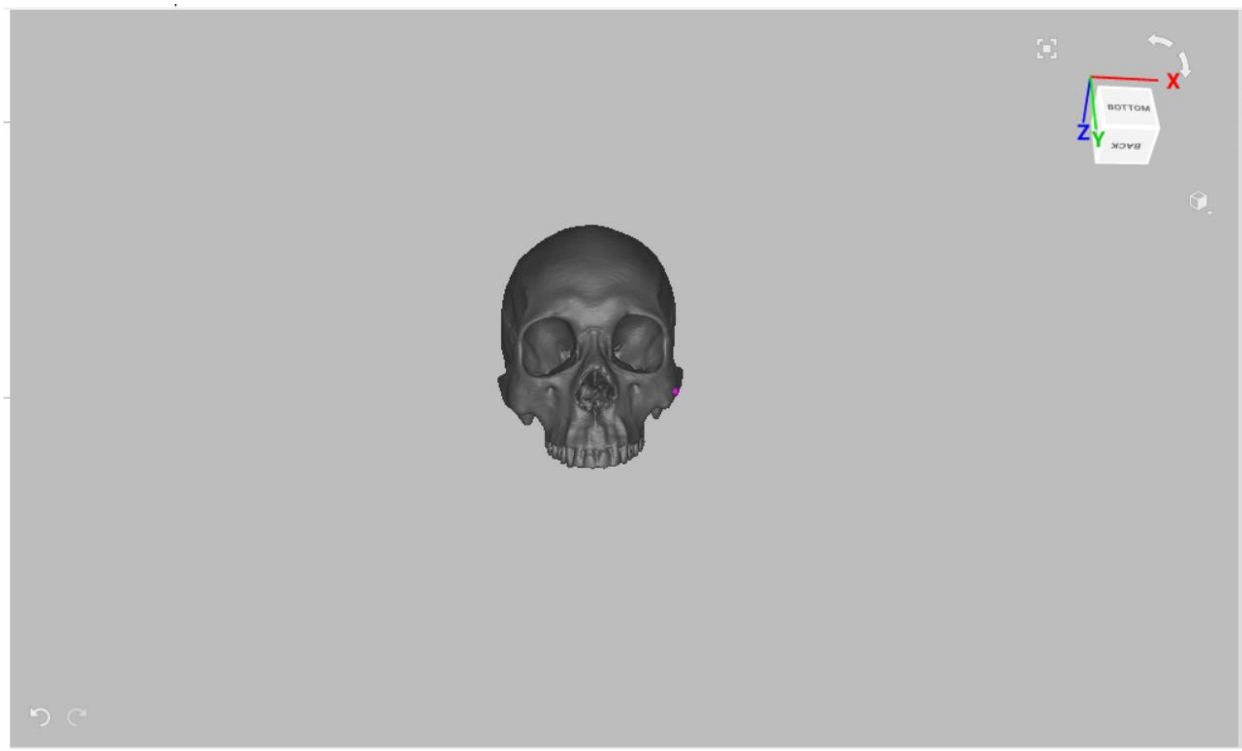


Figure 24. Final 3D Image by Schulz (2022). This is how the final 3D image turned out as a final product. More editing can be done later if needed.

Morphological Traits

Morphological traits transfer well onto a 3D image. Without future research, a specific percentage of accuracy for using different morphological methods cannot be obtained. However, based on the quality of the features and the success of this study, it

would suggest that a qualified individual could obtain the same estimates using the 3D scans as they could with the bones/casts.

Metric Traits

Most methods use morphological traits to make the estimation. However, there are many methods that use metric traits to determine an estimation or range. Based on the scans, it would appear that the ratio of scan to image is 1:1. Meaning that all measurements should be able to be obtained on both the original item and the 3D image without having to calculate a scale difference. There is a challenge with some of the measurements that deal with circumference as the Artec software does not allow for this measurement. A user could measure the diameter of the bone and multiply it by pi in order to get the circumference. This is an extra step, but it would still allow a user to get the same results.

Accuracy

Although testing the accuracy of the 3D images is normally done by making sure the morphology matches, another way to verify the accuracy includes taking measurements of the cast and comparing them to the 3D image. The Artec software has an ability to take measurements. It is important to have accurate measurements, not just for teaching purposes and accuracy of the scans, but also for inputting information into programs such as FORDISC (FORDISC). FORDISC is a program that allows a user to input metric information in order to get an estimation for a biological profile of an individual. Without FORDISC, measurements can also be used to help determine estimations for parts of the biological profile such as calculating stature of an individual.

For measurements, that have to deal with maximums and minimums such as maximum cranial breadth, the measurements can be a little more difficult as the user will have to find the maximum or minimum by taking several measurements. The Artec software allows for a user to place two or more points while taking measurements, but the user can also move the points in order to obtain the correct measurement and point of measurement. Having the ability to move the point of measurement is similar to using a caliper and moving it around the bone in order to obtain the maximum or minimum distance. Moving the points is the best process for taking the Maximum Cranial Breadth as the user can place a dot where they believe the euryon is by looking at the 3D image. Then the user can place a second dot on the opposite side and move the dots until they find the euryon on the other side. If need be, the first dot placed can be moved in order to make sure the Maximum Cranial Breadth is correct. With the orbital breadth measurement or other similar measurements that use one specific point on the bone to another specific point on the bone, the measurements can be easily done with the 3D images.

Taking the measurements using both the 3D software and the calipers was done for two reasons. The first reason was for testing the accuracy of the scans. The second was for the potential of having students at a later time conduct craniometrics in order to test how well individuals can take measurements using a 3D image. I took measurements of the 3D cranium using the *Data Collection Procedures for Forensic Skeletal Material* 2.0 (Langley et al., 2016). With the Data Collection Procedures for Forensic Skeletal Material 2.0, 27 measurements of the 3D cranium, and three measurements of the 3D mandible were taken. Once this was done, I did the same measurements with the cast

cranium that was used to create the 3D image. In the first trial, 21 out of the 30 measurements were within 2mm. This is a common acceptable standard margin of error. The nine measurements that were off by more than the 2mm were then remeasured on the 3D side. It was determined that the original 3D measurements were not accurate. Most of the measurements were smaller than the respective cast measurements. Six out of the nine measurements had a smaller measurement using the 3D scan compared to the cast. It was determined that one of the points was not in the correct spot for a maximum length such as with maximum cranial length and maximum cranial breadth (Table 1) (Figure 25).

Table 1: Measurement Testing on 3D Image and Cast

1							
2	**Skull:**	BC253					
3		Swiss		Artec Scan			
4	**Standard Craniu**	T1	T2	T1	T2		
5	GOL	174		169.99	173.7		Maximum Cranial Length
6	XCB	125		122.05	125		Nasio-occipital length
7	ZYB	125		124.83			
8	BBH	130		129.89			
9	BNL	94		96.41			
10	BPL	92		92.15			
11	MAB	65		62.08	64.91		Maximum-Alveolar Breadth
12	MAL	46		51.54		47.52?	Maximum - Alveolar length This one hard.
13	AUK	117		117.98			
14	WFB	86		85.43			
15	UFBR	98		96.49			
16	ASB	107		107.71			
17	ZMB	100		101.39			
18	NLH	53/54		52.03			
19	NLB	26		25.21			
20	OBB	36		35.42			
21	OBH	38		38.36			
22	EKB	85		89.11	85.85		Biorbital Breadth
23	DKB	24.5		24.11			
24	FRC	102.5		98.07	102.55		Frontal Chord
25	PAC	116		111.96	115.32		Parietal Chord
26	OCC	92		87.52	93.79		Occipital Chord
27	FOL	36		33.88			
28	FOB	31		31.53			
29	MDH	37		36.91/36.66			
30	MOW	62		70.62	62.57		
31	UFHT	78		70.32			
32	**Standard Mandible**						
33	GNI	33		30.54			
34	HML						
35	TML						
36	GOG	99		98.45			
37	CDB	113		113.77			
38	WRB						
39	XRB						
40	XRH						
41	MLT						
42	MAN						
43							
44	**Date**	3/1/2021		1-Mar			
45							

Skull:	**Skull:**	BC253			
		Swiss	Artec	Differences	
Standard Craniu	**Standard Craniu**	T1	T1	(-) is higher swiss reading (+) is higher Artec	
GOL	GOL	174	169.99	-4	
XCB	XCB	125	125	0	
ZYB	ZYB	125	124.83	0	
BBH	BBH	130	129.89	0	
BNL	BNL	94	96.41	2	
BPL	BPL	92	92.15	0	
MAB	MAB	65	62.08	-3	
MAL	MAL	46	51.54	6	
AUK	AUK	117	117.98	0	
WFB	WFB	86	85.43	-1	
UFBR	UFBR	98	96.49	-2	
ASB	ASB	107	107.71	1	
ZMB	ZMB	100	101.39	1	
NLH	NLH	53/54	52.03	-1	
NLB	NLB	26	25.21	-1	
OBB	OBB	36	35.42	-1	
OBH	OBH	38	38.36	0	
EKB	EKB	85	89.11	4	
DKB	DKB	24.5	24.11	0	
FRC	FRC	102.5	98.07	-4	
PAC	PAC	116	111.96	-5	
OCC	OCC	92	87.52	-4	
FOL	FOL	36	33.88	-2	
FOB	FOB	31	31.53	1	
MDH	MDH	37	36.91/36.66	0	
MOW	MOW	62	70.62	8	
UFHT	UFHT	78	70.32	-8	
Standard Mandible	**Standard Mandible**				
GNI	GNI	33	30.54	-2	
HML	HML				
TML	TML				
GOG	GOG	99	98.45	0	
CDB	CDB	113	113.77	0	
WRB	WRB				
XRB	XRB				
XRH	XRH				
MLT	MLT				
MAN	MAN				
Date	**Date**	3/1/2021	1-Mar		

Note: This table depicts the measurements taken by the author to test accuracy of the 3D scans. On the left side is a table that has the measurements from Langley et al. 2016. The table is split into 4 columns, the first column labeled Swiss T1 and T2 represents measurements taken with Swiss calipers on the cast cranium. Trial 2 was not done, as the results were similar to the 3D image that a comparison trial was not completed. The 2 columns on the right side are for the measurement trials taken with the 3D image. Two trials were completed for the 3D scans as there were significant differences in the measurements. The table on the right shows the difference in millimeters for the cast measurements compared to the 3D measurements. Green represents the same measurement, Yellow is within 2mm, and the red is more than 2mm difference. After a second measurement with the 3D measurements, all measurements were able to be within the 2mm range of the cast measurements.

Larger Image can be found in Appendix A.

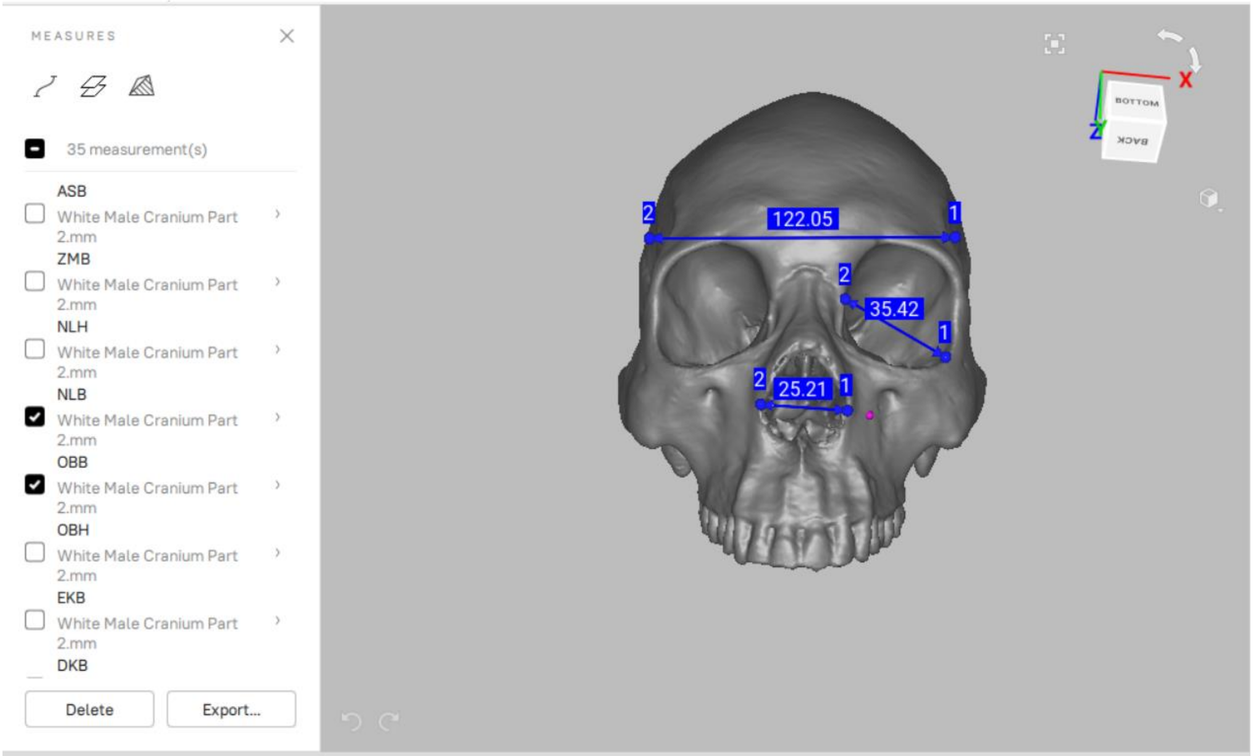


Figure 25. Measurements on 3D Image by Schulz (2022). This is how the software takes measurements of the 3D images. On the left is a list of the measurements with three of them checked. On the right is the cranium with those three measurements. The pink dot allows users to rotate the 3D image on that spot, this can be moved and is not part of the study or measurement process.

Pedagogical Study

The first goal of the study was to test how well participants could learn the information using 3D scans and compare that to the traditional groups results. The second part of the study was to see how well graduate students could identify features on a 2D image as well as a 3D image. The human subjects research study was conducted at the University of Nebraska-Lincoln. Since this study involved student subjects, the research proposal was sent to the IRB where it was approved (IRB Approval number: 20210320890EX). The study is made up of three main groups. Groups 1 and 2 were

made up of undergraduate students, and Group 3 was made up of graduate students. The purpose of this study was to see how well students could learn osteology using two different methods. Group 1 was the traditional group and they used physical bone casts, while Group 2 used 3D images of the bone casts. The study was conducted over five weeks, with different 5-week sessions that happened throughout Spring 2021 and Fall 2021. Week 1 consisted of students taking the pretest. The pretest was made up of 2D images that asked the student to identify the bone displayed and to identify certain landmarks/features. The order of the bones in the pretest followed the order of the quizzes: scapula, humerus, femur, cranium, mandible and *os coxae*. Once the students completed the pretest, they started studying for the first quiz (scapula). Each week the students would take a quiz that would cover the bone or bones studied in the previous week. Then they would start examining and studying the next bone or set of bones. The last week of the study participants took the quiz over the *os coxae.* When they finished the quiz, they immediately took the final test, which was the same as the pretest. The final test was issued to see how much material they were able to retain throughout the study and to see how much they improved over the five weeks.

The third group, which was made up of graduate students, was included in this study to be able to verify the accuracy of the scans. This group was asked to participate in two different segments. The first segment consisted of the graduate students taking the same pretest as the undergraduates in order to get a basis of their understanding. The second segment immediately preceded the pretest. The second segment had the graduate students take the same 3D quizzes as the undergraduates to see if they could correctly

identify the same features. Segment two tested the accuracy of the scans on a morphological scale.

Questionnaire and consent forms

The first step the students were asked to complete was to fill out a questionnaire and a consent form. The questionnaire's goal was to gain information about the participants as well as to set up a schedule of when they could participate in the study (Questionnaire Form see appendix B). The questionnaire gave a brief description of the study and asked a few questions. The consent form (Consent Form see appendix C), was a basic consent form that was approved by the UNL IRB. The main point of the consent form was to get permission from the students to use their information in the study, and to inform the participants about their rights.

Student Resource Library

Groups 1 and 2 were given a resource library, the purpose of the resource library was to replace a text book for the students (Student Resource Library Informational PowerPoint see appendix D). It contained helpful information and study material. The resource library was available to the students at all times through Box/SharePoint. Group 1 had a resource library consisting of a PowerPoint with 2D images that had both a blank and labeled picture of the bones as well as some pages out of the *Human Bone Manual* (White and Folkens, 2005) (Student Resource Library Labeled and Blank Images see appendix E). When in the classroom, they also had access to all the bone casts. Group 2 had access to the same resource library, but in addition they had access to 3D scans of the

bones that they were able to use to study. Group 2 did not have access to the casts at any time.

How The Students Were Divided Into The Groups

The undergraduate students were split into two different groups. The first group used casts of bones in order to learn the material. While the second group used 3D images of the casts in order to learn the material. Group 1 was tested on casts, while group two was tested on the 3D images. Students participating in the study turned in a schedule of when they would be available to meet for the study. The schedule is how the individuals were split up for each group, no other information was looked at to determine who would go into each group. The goal was to create as even numbers as possible. The first session of the study that took place in the Spring 2021 semester had 14 students who completed the entire study. There were eight students in the 3D group, and six in the cast group. They were split up by their schedule and this allowed for there to be no difference or bias among who was selected for each group. The third group, or graduate student group, was not split up considering they all were completing the same tasks.

Casts

The casts that were used are from Bone Clones. There were several adult skeleton casts Group one had access to that had different biological sex, ancestry and age. These casts were chosen as they are the same ones that are used for teaching purposes in the UNL Anthropology Department. Although these casts had differences in size, shape and the other differences associated with the variation of the human body, these were still a great option to use for this test.

3D

The 3D scans were created at UNL using an Artec Lite 3D scanner using the steps in the methods section above. A random Bone Clones Skeleton was selected for Group 2. The product number for the skeleton selected is SC-092-D Human Male Asian Disarticulated Skeleton (Bone Clones, 2022). The students had 3D images of all the bones that Group 1 had, and the bone pairs were included to help students with the practice of siding the bones.

Testing Distance

Although the point of this study was to see how the results compared for 3D imagery vs casts and did not involve a specific distance learning option, there was one student who did complete the study remotely, and two students that had to take a quiz remotely. The individual who completed the entire study remotely was put into the 3D group as they did not have access to the casts in the physical room. The study was conducted the same way as the others in the 3D group, with one alteration. The remote student took all quizzes and studied the material over Zoom, and used the share screen feature to show the students the quiz. This required more communication then with the other groups as I had the students tell me how to move the 3D image instead of them being able to do it themselves. This did not seem to alter how well they did on the quiz or change anything with the study. Two individuals are not really an adequate sample size, but these two individuals did show that this is a valid possibility for how to teach and test osteology.

Graduate Students

Graduate students were recruited through an email from myself and the department asking for their participation in the study. The purpose of the graduate student's participation was not to look at how well they could learn, as they have already taken the appropriate classes, but to test their identification of the bones and features using 3D imaging. There were two parts to the graduate piece of the study. The first was that they would take the same pretest as the undergraduates. This was done to create a baseline of information. The second part was completed immediately after the first part and that was that the graduate students would take quizzes one through four. This was done to test how accurate the 3D scans are. If the 3D image is a true comparison to the cast or real bone, then individuals should be able to answer questions about features and siding on both casts as well as the 3D bone.

Qualtrics

In order to conduct the pre and posttest as well as the quizzes, an online platform called Qualtrics was used. Qualtrics allows a user to create a questionnaire with an unlimited number of questions and several different formats. For the pre and posttest, a 2D image of a bone with label markings was uploaded to the site. Below the image were questions about what bone, side (if applicable), and features (Figure 26). With this being an online software there is a computer version as well as a phone version. This means that if students did not have a computer, they could still take the quizzes/tests using their smartphone.

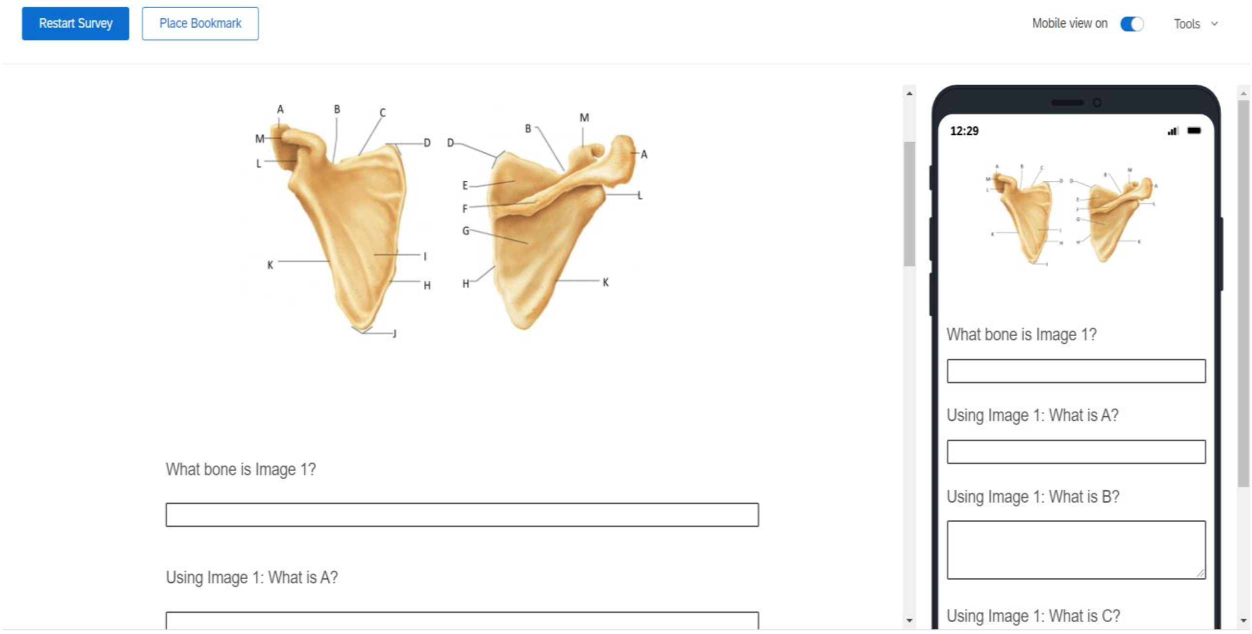


Figure 26. This is a screen shot of the of the pretest/posttest in a preview format, which is why the test is in two different spots. This test was taken by all students and was completed in Qualtrics. The image on the left is how the students would see the test if they are taking it on a computer, while the image on the right is how the test would appear if taken on a phone. Qualtrics allows for all quizzes and tests to be taken on a computer, tablet or phone. At the top of each test page was an image with labels, the students would then have to answer the questions. Each page was over a different bone as to not cause confusion on which bone the questions referred too.

Data Sharing Platforms

Box is a data sharing platform that I stored the resource libraries in. This allowed me to put the students from each group into the appropriate resource library. I chose this platform because the University of Nebraska-Lincoln had a partnership with Box, so it was free for students to use. Individuals could also access Box from anywhere and at any time they have internet. They could also download the material so that they could access it if they knew they would not have internet access. For the 3D image group, the students were able to access the 3D images in Box. This 3D image they could manipulate by

moving, changing the size, color, shading and other features. This allowed for more time to study the bones out of the classroom.

After the first semester of the study, UNL switched over to SharePoint. This data sharing platform is not as user friendly as Box is. One downside to the switch in software was that the 3D images, although they could preview them the same as they could in Box, constantly rotated unless you clicked on the object. If the image was paused, it would start rotating again after a few seconds. This feature made it harder for students to study a certain area as it was constantly moving. SharePoint also did not have an option for students to change the color, shade and a few other beneficial features that Box had. Despite some of the difficulties with SharePoint, it did not seem to have a significant impact on the study, but it was mentioned by the students that they did not like the 3D feature in SharePoint.

Classroom Management and Setup

Testing

The pretest and posttest are the same test, consisting of questions over the scapula, humerus, femur, cranium, mandible and os coxae. In total there are 92 questions. The format for the tests consists of six pages and on each page, there is an image of a bone that is labeled with numbers or letters (Figure 27). The numbers and letters identified a feature the student was to identify. The first question was "what bone is this," then the following questions asked for the participant to identify the different landmarks/features.

There were only two differences between the groups, the first is that Group 2 had access to the 3D images, and the second is how the quizzes were laid out and taken. For Group 1, casts were laid out on a table with one cast per table. The casts had colored sticker dots that were numbered or lettered. Each cast generally had two to three stickers (Figure 27). Participants were split up so it was one person per table. They would then start at one table and after a minute, or once everyone was done, I would have them move to the next table. The cast that had the first number or letter on was the cast that was used for siding if applicable.

Figure 27. Quiz 2 Example for Group 1 (Traditional Group). This is how the quizzes were set up for Group 1. There was one cast per table and the students rotated around to the different tables. This image above shows a pink, yellow and orange sticker that represent the specific features. Students were able to pick up and move the bones.

The participants in Group 2 used my computer which has the 3D software and access to the 3D images with a digital sticker on them (Figure 28). The numbering and questions were the same as Group one. However, only one person at a time could take the

quiz. Having the students take the quiz one at a time allowed the students free range to enlarge, move, and change the image in order to give themselves the best view. This concept is versatile because it could also be done with having an image projected onto a screen if a bigger view was needed.

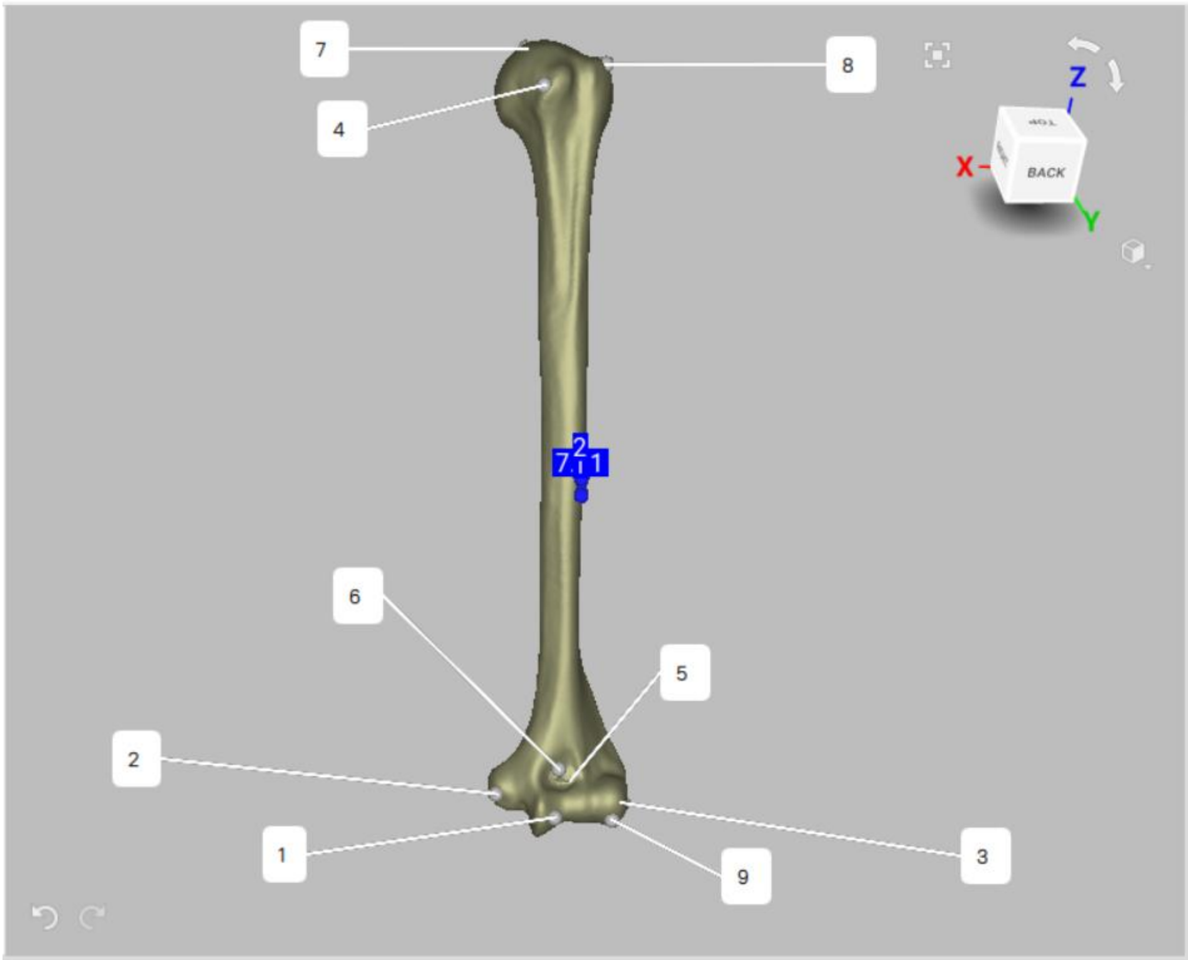


Figure 28. Quiz 2 Example for Group 2 (3D Group). This image shows how the quiz looked for students in Group 2 and the Graduate Group. The white boxes point to the feature. There is a little sphere to document this point as the image can be moved the sphere follows the correct point/face of the feature. This allows for a user to see the difference between 5 and 6 as they look like they are pointing at the same thing, but one is anterior and the other is posterior. The blue numbers are measurement numbers that the students were told to ignore. The white boxes in the software are used as comment boxes for measurements, which is why the measurement numbers have to be shown. There is no other way at this time to just make a comment on the 3D image without the blue numbers. Link to 3D models: https://sketchfab.com/erkschlz/models

Both groups were allowed to move the bones in their own respective way, both sets took the quiz using the same Qualtrics quiz questions, so that the only difference was viewing the 3D image or having a cast. Students were able to spend as much time on the

quiz as they needed or go back to previous questions. There was no time restraint unlike a normal class setting. Quiz 1 was over the scapula and had 15 questions, Quiz 2 over the humerus and femur had 11 questions each for a total of 22 questions. Quiz 3 was over the cranium and mandible and had 14 questions over the cranium and three over the mandible for a total of 17 questions. Quiz 4 over the os coxae had 12 questions. For all of the quizzes there were a total of 66 questions. The quizzes were not meant to ask every question that was on the tests, this was to simulate a real class where there is information that you learn that is not on the test. The quizzes also asked the students to side all of the bones besides Quiz 3. Quiz 3 added four questions that were not asked on the tests. At the end of each quiz, the students were asked two additional questions; "Did you study outside of the study time? If so, how long and using what resources"? Any "comments or questions about this week's bone analysis or the project study"? These questions were not required and were just to gauge how the students were doing with the material, how seriously they were taking the study and to see if there were any problems that needed to be addressed. For the graduate students, they used my computer to complete the pretest and the quizzes. The pretest and quizzes were completed the same way as group two.

Teaching

This study was conducted over five weeks with an hour session each week. This meant that there was not a lot of time to teach the participants, so a peer teaching style was encouraged. After the pretest or quiz, a brief lecture was given to go over the bone or bones for the next week. The lecture included the student resource library PowerPoint. The features, siding and a few other helpful topics were reviewed. For group one and

group two the same information was included in their respective lectures, as this study's purpose is to test the difference between the learning media, not the information taught.

Students were told that they could work in groups or by themselves to study the material. It was explained during the first lecture that this study would have a small teaching introduction each week, but was mostly a self-taught study or peer reviewed learning style. Group work was encouraged, as working in a group seems to be more effective as students are more likely to talk to their peers about questions versus an instructor (Anantharaman et al., 2019). If participants asked questions, an answer would be provided to them. Even though this study was conducted largely as an independent learning course, questions were still encouraged.

Grouping for Analysis

For documenting the study and creating the analysis all of the student data had to be deidentified. The first, was to determine how to de-identify the individuals and how to keep track of their results and group number. To track them and keep track of their results, four groups were created. Group 1 (Cast) was now the A group, Group 2 (3D) was B, Group 3 (Graduate) was G and an X group was created for those who did not complete the study. The X group was not planned, however I thought it was important to create this group as there was some viable information that could still be gathered. With these groups, it was time to give the students a specific ID made up of the group letter and a number. The number relates to the order in which the students took the pretest per group. For example, the first person in the cast group to finish was given 1A as their de-identified ID.

This ID stayed the same for the individual for all of the quizzes and tests. The ID was created at the end of the study which is why there are no missing numbers or gaps in IDs for those that dropped out of the study. The students are not aware of their ID number as none of them have access to the date and time of when everyone or themselves finished the pretest. There is no way to track this information back to a specific student, anything that related to a specific name, professor or any other identifiable information has been removed from the analysis. For information in the questionnaire, the data will not be associated with a specific ID because that could be traced back to the individual. Lastly, the names of the individuals that participated in the study, their scores and any sensitive or specific information was not given to others or the participants.

Methods for analysis

For this study there were a few different methods used to document the study. The first involves using averages to convey the results. Averages were used because it related to how one group compared to another. Group 1 was a control group as the students used more traditional methods, but because of how the study was conducted there were still variables in Group 1. With the sample sizes being smaller than intended, averages also worked well to convey information about the groups. The grades and scores/averages can be found in Appendices 2 and 3. Averages tell a story, but it is also important to have the data in which the average came from. Tables were used to share the data in a numeric expression while graphs were created to show a visual representation of the data.

The second method used the Wilcoxon Signed-Rank test, this test was used because it is a nonparametric test that is commonly used for smaller samples. The Wilcoxon Signed-Rank test was used to look at how Group 1 and Group 2 improved

throughout the study. The study looks at the absolute value change between the pretest and posttest. For this study the pretest was used as the first value, while the posttest was used for the second value. The results were calculated using a significance level of .05 and a one-tailed hypothesis.

The third test was the Mann-Whitney U test, which compares the two groups based on the pre and posttest difference for each group. This was only done for Groups 1 and 2 as the third groups study outcomes were different than that of the other two groups. This is also a nonparametric test, but unlike the Wilcoxon Signed-Rank test this one is able to compare two independent samples. For this method, a significance level of .05 was used. The results were first run using a one-tailed method, and then were done with a two-tailed method to see if there was a significant difference between the two.

The last statistical method that was used was a Multiple Regession test. This test uses three variables in order to give a line that predicts how well someone will do based on the variables. This was a perfect test for looking at how study times compared to how well the individuals did on each quiz. For the variables, X1 was the pretest score for the individual, X2 was time studying in minutes and Y was the score the student received on the quiz. The results were calculated for Group 1 and Group 2 in order to compare the two groups.

A third Multiple Regression test was run to see if there was any correlation between those that studied more outside of the allotted time and those that studied less or not at all. The groups were still kept as Group 1 and Group 2. This was done to see how the groups differed with this statistical method. The test was also run again splitting the groups up, and creating two new groups. The two new groups were those that studied at

least 30 minutes on average and those that did not. This was to compare quiz scores with time spent studying but not looking at which group the participant came from.

Chapter IV: Analysis and Results

In this chapter, the first part talks about the demographics of the questionnaire. Although this is not an important part of the paper, it is good to understand the background of those in the study. Later in this chapter the results from the students' quizzes and test scores are discussed. The last part of the chapter describes some of the students' reactions to the study, wraps up the discussion on how the study was completed and the results of the study.

Demographics

For the questionnaire, there were a few main parts that could be analyzed for this study. All undergraduate students filled out the questionnaire. Since the questionnaire information has less to do with how the study turned out and more to do with demographics, those that quit the study will be included in the questionnaire results.

Year

This study was predominantly taken by freshmen (Graph 1), this could be because many students take Introduction to Anthropology to fulfill a general requirement at the UNL. Since this study was sent out amongst the Introduction to Anthropology classes, this could explain this relation. Most of the students were out of the Introduction to Anthropology course, but there were some from other Anthropology courses. Out of the 20 total students, 14 of them were Freshman, two Sophomores, two Juniors and two Seniors. The ages for the students are primarily younger, with 18 and 19 being the most common age. The average age of the students was 21.7, but the mean was 19 (Graph 2).

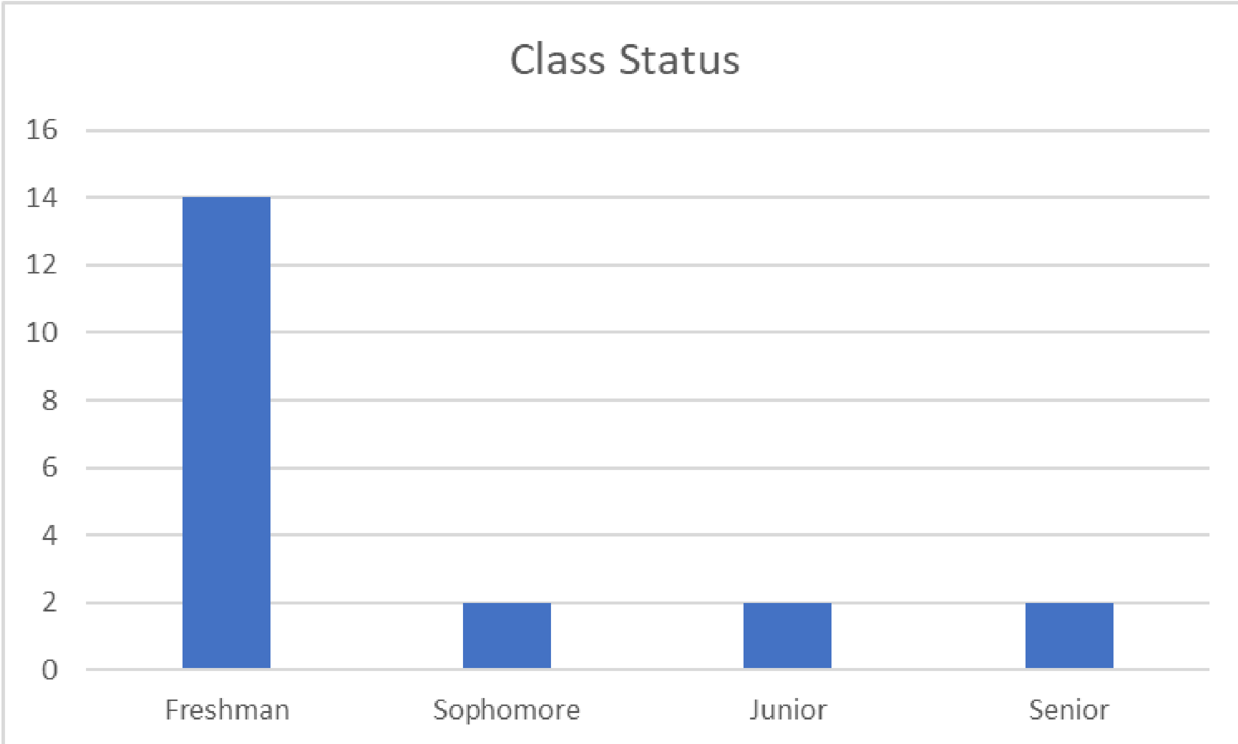


Figure 29. (Graph 1). Class Status of Participants. Represents the class status for the individuals in the study. This does not include the three graduate students.

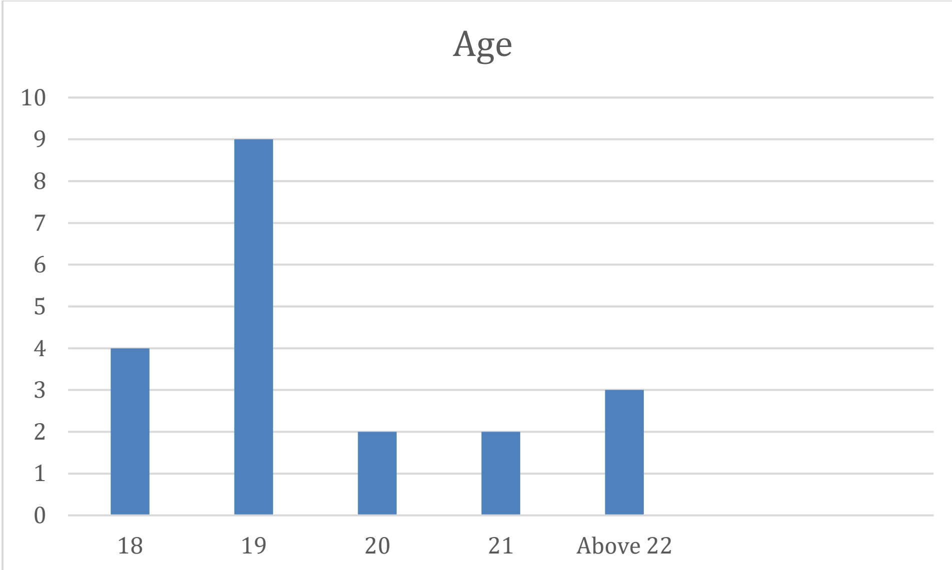


Figure 30. (Graph 2) Age of Participants. Represents the age of the individuals in the study.

Major and Minors

The majority of the students that participated in the study were studying to obtain some sort of business degree (Graph 3). There were two students working towards an Anthropology degree (Graph 3). The term business degree is used in a broad sense here. In the graph the specific degrees are listed. There is not much of a trend in one specific degree for this study with three people in Accounting, two students in Anthropology and two students in Business Administration. The other degrees all had one person. With minors most individuals did not report a minor, there was no significant trend for this information (Graph 4).

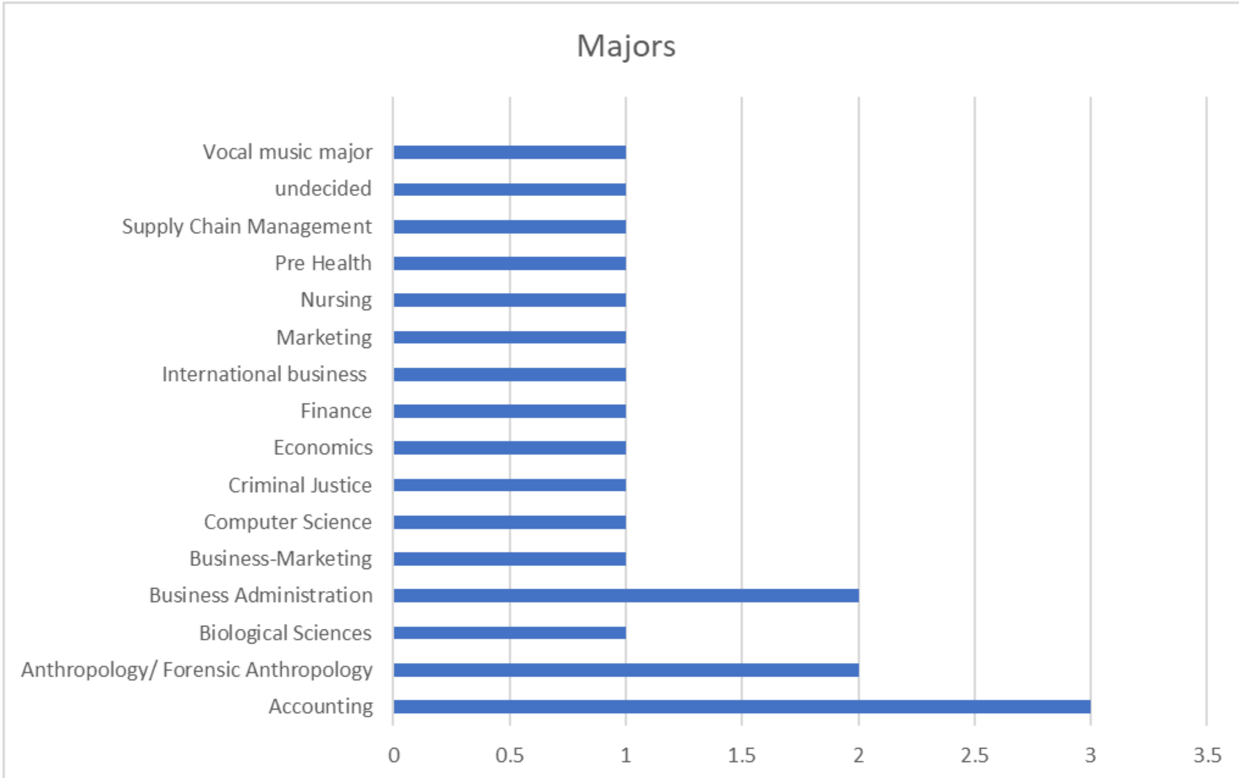


Figure 31. (Graph 3) Majors of Participants. Shows the Majors for everyone in the study.

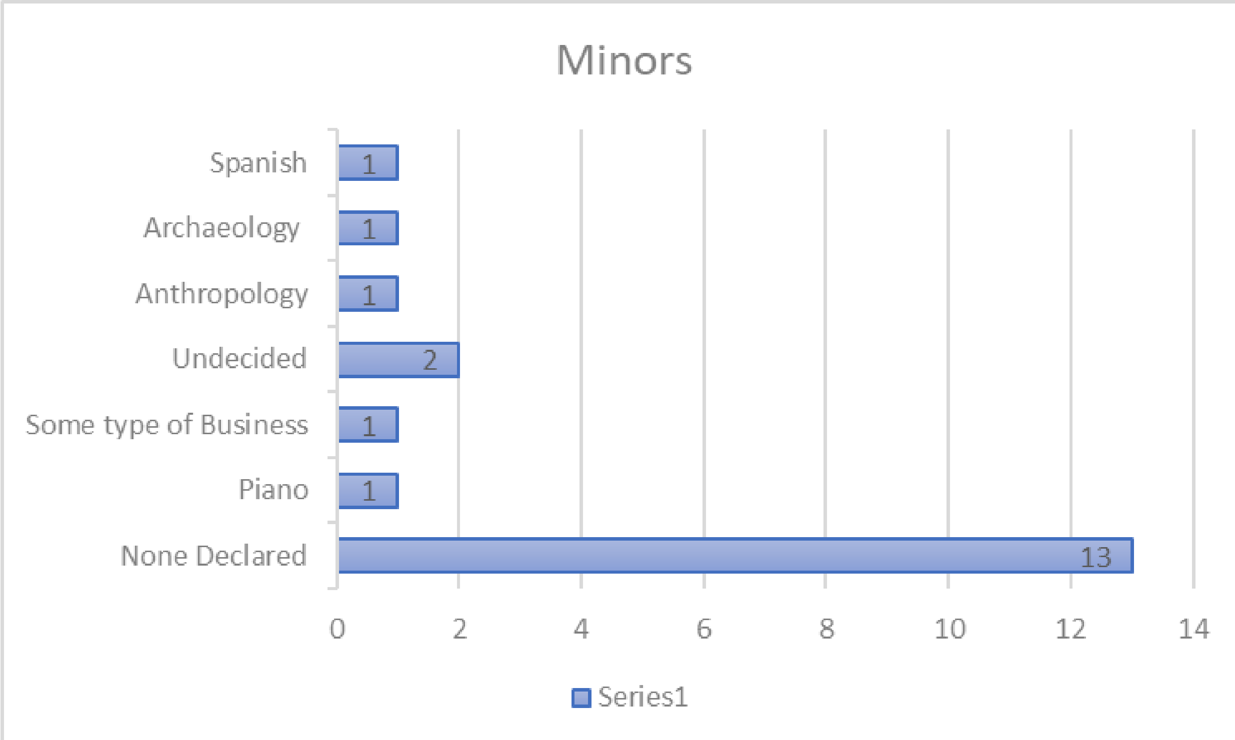


Figure 32. (Graph 4) Minors of Participants. Shows the Minors for those in the study.

Experience

The purpose of this study was to have students that had not taken an osteology course. This means no one that participated in the study had ever taken Osteology. There was one student who had taken some other Anthropology courses, but never Osteology. There were two students that took a form of anatomy in high school. For the other 17 students, they reported that they had never taken Osteology or a similar class. For most this was their first Anthropology class.

Pretest

Every individual started off with the pretest. Out of the 20 students that began the study the average for the pretest was 13.275% (Table 2). Out of the 16 students who completed the study, the average pretest score was 13.9375% (Table 2). With the lowest score of 1% and the highest score of 60.9%. For Group 1 (Cast), the average for the six students that fully completed the study was 5.733% (Table 2). For Group 2 (3D), the average for the ten that completed the study was 18.86% (Table 2). This group started off with a higher percentage as three of the individuals in the group scored high on the pretest. If you take these three individuals out, the average drops to 6.429% (Table 3). With these three individuals taken out, the average starting point for each individual is relatively similar. (Tables 2-3). There were five total students that did not take the post test, but did take the pretest. Out of these five, only one of them completed all of the quizzes. The student that completed all the quizzes will be counted in the analysis. The other four will be mentioned, but will not be counted as their scores cannot be analyzed with the others.

Table 2: Pre- and Post-Test Scores

Group 1	Pre-Test	Post Test	Percentage Increase
1A	7	67	60
2A	8	88	80
3A	4.6	81	76.4
4A	5.7	18.9	13.2
5A	5.7	77.8	72.1
6A	3.4	84	80.6
Average	5.73333	69.45	63.71666667
Group 2	Pre-Test	Post Test	
1B	7	54.4	47.4
2B	3.4	43.3	39.9
3B	10	64.4	54.4
4B	9	64	55
5B	43.7	94.4	50.7
6B	10	23	13
7B	4.6	21.1	16.5
8B	1	98.9	97.9
9B	39	94.4	55.4
10B	60.9		NA
Average	18.86	61.9889	47.8
Group X	Pre-Test	Post Test	
1X	8		NA
2X	19.5		NA
3X	9		NA
4X	6		
Average	10.625		

Note: This table shows the pre and posttest average scores for Group 1, Group 2 and Group X. The far-right column shows the amount of change for each student. The color represents each group. The yellow color signifies Group 1 (Cast) and the blue represents Group 2.

Table 3: Pre- and Post-Test Group 2 Adjusted

Group 2	Pre-Test	Post Test	Increase
1B	7	54.4	47.4
2B	3.4	43.3	39.9
3B	10	64.4	54.4
4B	9	64	55
5B			
6B	10	23	13
7B	4.6	21.1	16.5
8B	1	98.9	97.9
9B			
10B			
Average	6.4285714	52.7285714	46.3

Note: This table represents the pre and post test scores for Group 2. Students 5B, 9B, and 10B all scored higher on the pretest than anyone else in the study. This table depicts scores closer to that of Group 1 for a pretest.

Quiz 1

For Quiz 1, Group 1 had one student (5A) that was unable to take the first quiz. So, these results are for the five other students that completed this study in Group 1. The average score was 65.2%, with an average outside study time of 19 minutes (Table 4). To see how the students' scores changed throughout the study, pre and post test scores were broken down by quiz section (Table 5). The pretest average for the scapula or Quiz 1 section was 5.833%, while the post-test average was 72.84% for the five students and

73.8% for all of Group 1. This shows that the cast group did have a positive learning outcome.

Table 4: Time spent on Studying VS Quiz 1 Grade

Group 1	Quiz 1 %	Time Studying (Minutes)
1A	100	60
2A	73	5
3A	93	30
4A	27	0
5A		
6A	33	0
Average	65.2	19
Group 2	Quiz 1 %	Time Studying (Minutes)
1B	80	20
2B	47	30
3B	60	0
4B	87	30
5B	73	15
6B	27	40
7B	33	10
8B	100	5
9B	66.67	60
10B	66.67	20
Average	64.034	23

Note: This table displays the score each student had on Quiz 1 and how much time each of them spent outside of class studying in minutes.

Table 5: Average Score based on Scapula Section (Quiz 1)

Individual	Pre-test %	Quiz 1 %	Post-test %
1A	7	100	92.9
2A	7	73	92.9
3A	7	93	85.7
4A	7	27	7
5A	0		78.6
6A	7	33	85.7
Average	5.833333	65.2	73.8
	Pre-test %	Quiz 1 %	Post-test %
Group 2			
1B	7	80	50
2B	7	47	64.3
3B	7	60	78.6
4B	7	87	64.3
5B	64	73	100
6B	7	27	28.6
7B	7	33	50
8B	7	100	100
9B	29	66.67	100
10B	86	66.67	
Average	22.8	64.034	70.6444444

Note: This table displays the score each student had on Quiz 1 (Scapula) and how it compared to the Scapula section of the pre and posttest. 10B did not take the post test.

For Group 2, all of the students completed Quiz 1. The average score was 64.034% with an average study time of 23 minutes (Table 4). The same breakdown of pre and posttests was completed for this group. For the pre-test, the students average score

was 22.8%. This number again is higher as the three students who did well on the pretest had higher scores in this section as well. If these three students are taken away, the average in this section drops down to 7%. One student did not take the post test, so the average for the nine that did take the post test was 70.644% (Table 5).

Quiz 2

Group 1 had an average of 61.33% on Quiz 2 which covered the humerus and femur. The average study time was 22.5 minutes (Table 6). The pre-test average was 2.5% and the post-test average was 68.57% over this set of bones (Table 7). This shows a significant increase in what the students learned about the long bones. This quiz also had the biggest difference between the two groups with Group 1 outscoring Group 2 by about 4.5%.

The digital group had an average of 56.77% and studied for an average of 30.5 minutes, this average is a little distorted as one of the participants reported studying for 60-120 minutes (Table 6). The average of this time, 90 minutes, was used to calculate the average for all of the students in Group two (Table 6). For the pre-test scores the average was 12.75% and post-test scores minus the individual who did not take the post-test was 58.52% (Table 7). Similar to the average on the quiz, this section had the largest difference in percentage with group two scoring about 10% less than Group one on the post-test.

Table 6: Time spent on Studying VS Quiz 2 Grade

Group 1	Quiz 2 %	Time Studying (Minutes)
1A	68.2	20
2A	95.5	10
3A	68.2	30
4A	13.6	0
5A	45.5	15
6A	77	60
Average	61.33333	22.5
Group 2	Quiz 2 %	Time Studying (Minutes)
1B	45.5	60
2B	32	5
3B	36.4	0
4B	54.5	0
5B	91	0
6B	36.4	60
7B	41	20
8B*	77	90
9B	72.7	60
10B	81.2	10
Average	56.77	30.5
		* This individual put 60-120 minutes of studying.

Note: This table displays the score each student had on Quiz 2 and how much time each of them spent outside of class studying in minutes.

Table 7: Average Score on Humerus and Femur Section (Quiz 1)

Individual	Pre-test %	Quiz 2 %	Post-test %
1A	6	68.2	64.5
2A	3	95.5	87.5
3A	3	68.2	73.4
4A	0	13.6	12.5
5A	3	45.5	96.9
6A	0	77	76.6
Average	2.5	61.3333333	68.5666667
Group 2	Pre-test %	Quiz 2 %	Post-test %
1B	0	45.5	39.1
2B	0	32	46.9
3B	6	36.4	59.4
4B	0	54.5	71.9
5B	25	91	87.5
6B	9	36.4	15.6
7B	0	41	12.5
8B	0	77	100
9B	25	72.7	93.8
10B	62.5	81.2	
Average	12.75	56.77	58.5222222

Note: This table displays the score each student had on Quiz 2 (Humerus and Femur) and how it compared to the Humerus and Femur section of the pre and posttest. 10B did not take the posttest.

Quiz 3

For Quiz 3, which was over the cranium and mandible, Group 1 had an average score of 74.38% with an average study time of 23.33 minutes (Table 8). For the breakdown, Group 1 had an average pretest score of 9.6% with a post-test score of 74.38% for these bones (Table 9). This means that Group 1 did improve throughout the

study when it came to the cranium and mandible and they were able to maintain their knowledge for the next week.

Group 2 scored about 1% lower than Group 1 with a score of 73.44% with an average study time of 45 minutes (Table 8). There was one student who gave a timeline of 60-120 minutes, so this was converted to 90 minutes for an average. For the pretest, Group 2 had an average score of 27.36% and a post-test score of 67.29% with one student not having a post-test score (Table 9).

Table 8: Time spent on Studying VS Quiz 3 Grade

Group 1	Quiz 3 %	Time Studying (Minutes)
1A	82	20
2A	88	5
3A	88	30
4A	53	10
5A	76.5	15
6A	58.8	60
Average	74.38333	23.33333333
Group 2	Quiz 3 %	Time Studying (Minutes)
1B	70.6	30
2B	47	30
3B	58.8	60
4B	82	30
5B	94	0
6B	64.7	60
7B	64.7	60
8B	88	60-120
9B	94	60
10B	70.6	30
Average	73.44	45

Note: This table displays the score each student had on Quiz 3 and how much time each of them spent outside of class studying in minutes.

Table 9: Average Score based on Cranium and Mandible Section (Quiz 3)

Individual	Pre-test %	Quiz 3 %	Post-test %
1A	7	82	66.7
2A	18.5	88	92.6
3A	7	88	88.9
4A	11.1	53	37
5A	7	76.5	66.7
6A	7	58.8	94.4
Average	9.6	74.38333333	74.38333333
Group 2	Pre-test %	Quiz 3 %	Post-test %
1B	14.8	70.6	55.6
2B	7	47	55.6
3B	18.5	58.8	66.7
4B	22.2	82	83.3
5B	48.1	94	98.1
6B	14.8	64.7	35.2
7B	11.1	64.7	22.2
8B	0	88	92.6
9B	66.7	94	96.3
10B	70.4	70.6	
Average	27.36	73.44	67.28888889

Note: This table displays the score each student had on Quiz 3 (Cranium and Mandible) and how it compared to the Cranium and Mandible section of the pre and posttest. 10B did not take the posttest

Quiz 4

This is the last quiz for the undergraduate participants. For Group 1, the average was 62.52% and the average time studying was around 32 minutes (Table 10). The average time studying is not exact because one of the students, 6A, put that they studied

“some” time instead of a numerical value. The average for Group 1 on the pretest was 3% and the average for the post-test was 68.98% (Table 11).

For Group 2 the average was 59.99% with a study time around 26.25 minutes (Table 10). This again is an estimated average as two students, 1B and 2B, put “some” for the amount of time studying instead of a numerical value. The average for Group 2’s pretest was 10.64% and their post-test average was 59.89% minus participant 10B (Table 11).

Table 10: Time spent on Studying VS Quiz 4 Grade

Group 1	Quiz 4 %	Time Studying (Minutes)
1A	41.7	10
2A	100	10
3A	75	60
4A	16.7	10
5A	75	70
6A	66.7	Some
Average	62.51667	32
Group 2	Quiz 4 %	Time Studying (Minutes)
1B	41.7	Some
2B	50	Some
3B	58.3	15
4B	50	30
5B	83.3	0
6B	50	0
7B	33.3	15
8B	83.3	60
9B	91.67	90
10B	58.33	0
Average	59.99	26.25

Note: This table displays the score each student had on Quiz 4 and how much time each of them spent outside of class studying in minutes.

Table 11: Average Score based on os coxa Section (Quiz 4)

Individual	Pre-test %	Quiz 4 %	Post-test %
1A	6	41.7	50
2A	0	100	88.9
3A	0	75	88.9
4A	6	16.7	13.9
5A	6	75	83.3
6A	0	66.7	88.9
Average	3	62.51667	68.98333333
Group 2	Pre-test %	Quiz 4 %	Post-test %
1B	6	41.7	38.9
2B	0	50	55.6
3B	6	58.3	55.6
4B	6	50	66.7
5B	47.1	83.3	100
6B	6	50	27.8
7B	0	33.3	11.1
8B	0	83.3	100
9B	23.5	91.67	83.3
10B	11.8	58.33	
Average	10.64	59.99	59.88888889

Note: This table displays the score each student had on Quiz 4 (Os coxa) and how it compared to the Os coxa section of the pre and posttest. 10B did not take the posttest.

Post-Test

With the post-test scores, there are a few different things that need to be looked at. Table 2 shows the pre and post test scores and the average for each test. On the right of the table, it shows the percentage increase from pre to post test and the total average. Based on this information, it shows that the post-test scores for both Group 1 and Group 2 have a difference of approximately 7.5% with Group 1 scoring higher (Table 2). With the posttest averages being close, the amount that each group improved was worse for Group 2. This is because Group 2 had a higher starting pretest score. The average increase from pretest to post test for Group 1 was 63.7%, and Group 2 was 47.8% (Table 2). There are two things to consider with this score, first is that Group 2 had a higher pre-test average, so the overall increase in score was going to be less than that of Group 1. The second consideration is that Group 2 has almost double the number of participants as Group 1.

Another table looking at post-test scores has the same information as Table 2, but it has all of the individuals that did not improve by at least 25% removed (Table 12). This means it removed one individual from Group 1, 4A, and two individuals from Group 2, 6B and 7B. From this data, Group 1 has a post-test average score of 79.56% and a total average increase of 73.82% (Table 12). Which means taking out (4A) improved the average by 10% for both the post-test and total average. For Group 2, this also improved the results. By removing 6B and 7B the post-test scores went up from 61.98% to 73.4% and the overall average change went up to 57.24% (Table 12). This increased the post-test results by about 11% and the overall average score by almost 10%.

Table 12. *Table 12: Students that Improved by at least 25% or more*

1A	7	67	60
2A	8	88	80
3A	4.6	81	76.4
4A			
5A	5.7	77.8	72.1
6A	3.4	84	80.6
Average	5.74	79.56	73.82
1B	7	54.4	47.4
2B	3.4	43.3	39.9
3B	10	64.4	54.4
4B	9	64	55
5B	43.7	94.4	50.7
6B			
7B			
8B	1	98.9	97.9
9B	39	94.4	55.4
10B			NA
Average	16.1571	73.4	57.2429

Note: This table shows the scores for everyone that improved by at least 25% from their pre to post test score. 10B did not take the posttest.

The last table depicts the same data as the tables above but includes taking out the information for the three that scored higher on the pretest (Table 13). This information shows that the cast group scored better on the posttest than the 3D group by about 14.9%. The biggest difference for the quizzes and the post test results was testing the femur and humerus. Group 1 did marginally better with the long bones scoring about 10% better than Group 2 (Table 14). The second section that Group 2 did poorer on was on the os coxae section, again scoring about 9% lower than Group 1 (Table 14). It is unsure why these differences were so drastic given that the other two quizzes were so close.

Table 13. *Table 13: Pre and Post test scores with Difference with Modified Participants*

1A	7	67	60
2A	8	88	80
3A	4.6	81	76.4
[redacted]			
5A	5.7	77.8	72.1
6A	3.4	84	80.6
Average	5.74	79.56	73.82
1B	7	54.4	47.4
2B	3.4	43.3	39.9
3B	10	64.4	54.4
4B	9	64	55
5B			
[redacted]			
[redacted]			
8B	1	98.9	97.9
9B			
10B			
Average	6.08	65	58.92

Note: This table combines Table 3 and Table 12. In order to represent those that were taking taken out that did not improve by at least 25% and taking those out that did significantly better on the pretest then the other participants.

Table 14: All Scores by Percentage

Group 1	Pre-Test	Quiz 1	Quiz 2	Quiz 3	Quiz 4	Post Test
1A	7	100	68.2	82	41.7	67
2A	8	73	95.5	88	100	88
3A	4.6	93	68.2	88	75	81
4A	5.7	27	13.6	53	16.7	18.9
5A	5.7		45.5	76.5	75	77.8
6A	3.4	33	77	58.8	66.7	84
Group 2	Pre-Test	Quiz 1	Quiz 2	Quiz 3	Quiz 4	Post Test
1B	7	80	45.5	70.6	41.7	54.4
2B	3.4	47	32	47	50	43.3
3B	10	60	36.4	58.8	58.3	64.4
4B	9	87	54.5	82	50	64
5B	43.7	73	91	94	83.3	94.4
6B	10	27	36.4	64.7	50	23
7B	4.6	33	41	64.7	33.3	21.1
8B	1	100	77	88	83.3	98.9
9B	39	73	72.7	94	91.67	94.4
10B	60.9	73	81.2	70.6	58.33	

Note: This is table shows the grade for all of the quizzes and tests broken down by group and participant number. 5A did not take Quiz 1, and 10B did not take the posttest. Those in Group X were not included in the table above.

Siding and Bones

Being able to identify and side a bone are the most basic objectives in an osteology class, but they are very important. In this study the students had to identify six different bones: the scapula, humerus, femur, cranium, mandible and os coxae. Both groups were able to successfully identify the cranium and mandible, which is why this

result is not in Table 15. Group 2 correctly identified each bone during the quizzes. Group 1 however had an average of 79.15% for identifying the other four bones (Table 15). Siding was tested for all of the bones besides the cranium and mandible. Group one correctly sided the bone 62.5% of the time while Group 2 only correctly sided the bone 50% of the time (Table 15). Both groups struggled the most with the scapula siding with Group one having an average score of 33.3% and Group 2 having an average of 40% (Table 15). Group 2 scored better for the overall average for siding and identifying the correct bone with 75% correct with Group 1 at 70.83% (Table 15).

Table 15: Siding and Bone Identification

	Quiz 1		Quiz 2.1		Quiz 2.2		Quiz 4			
	Bone	Side	Bone	Side	Bone	Side	Bone	Side	Average	
1A	1	1	1	1	1	1	1	0	87.5	
2A	1	0	1	1	1	1	1	1	87.5	
3A	1	0	1	0	1	1	0	1	62.5	
4A	1	1	0	0	1	0	1	1	62.5	
5A	0	0	0	1	0	0	1	1	37.5	
6A	1	0	1	1	1	1	1	1	87.5	
Average	83.3	33.3	66.7	66.7	83.3	66.7	83.3	83.3		70.825
	Quiz 1		Quiz 2.1		Quiz 2.2		Quiz 4			
	Bone	Side	Bone	Side	Bone	Side	Bone	Side	Average	
1B	1	1	1	0	1	1	1	0	75	
2B	1	0	1	1	1	1	1	1	87.5	
3B	1	0	1	0	1	0	1	0	50	
4B	1	0	1	1	1	0	1	0	62.5	
5B	1	1	1	0	1	1	1	0	75	
6B	1	0	1	0	1	0	1	1	62.5	
7B	1	1	1	1	1	0	1	1	87.5	
8B	1	1	1	1	1	1	1	0	87.5	
9B	1	0	1	1	1	0	1	1	75	
10B	1	0	1	1	1	1	1	1	87.5	
Average	100	40	100	60	100	50	100	50		75

Note: This table shows how well each participant correctly identified the bone, and correctly sided the bone when applicable. Green box (1) shows students that answered the question correctly, while the white box (0) represents a wrong answer. Averages were calculated for each participant as well as how well they did per bone and side.

*Quiz 3 is not shown, because this was over the Cranium and Mandible. All participants correctly identified the cranium and Mandible and siding was not applicable for these bones. *

X Group

Group X was an unplanned group as this consisted of four students who stopped participating in the study. It is unclear why the students stopped participating as they stopped responding to any and all attempts to communicate with them. Three students were part of the 3D group and one student was part of the cast group (Table 16). The students were showing signs of improvement before they stopped coming. Especially

student 2X who had an average score of 83.33% on the siding and identification of bones. Their quiz scores also improved to a passing grade for quiz two and quiz three (Table 16). Overall, everyone in this group seemed to improve, but because of the limited data, these results were not included in the analysis.

Table 16: Group X Grades

Group X	Pre-Test	Quiz 1	Quiz 2	Quiz 3	Quiz 4	Post Test
1X	8			35.3		
2X	19.5	20	81.8	70.6		
3X	9	73				
4X	6	80				

	Quiz 1		Quiz 2.1		Quiz 2.2		Quiz 4	
	Bone	Side	Bone	Side	Bone	Side	Bone	Side
1X	0	0	1	0				
2X	1	0	1	1	1	1		
3X	1	0						
4X	1	0						
Average	75	0	100	50	100	100		

Note: Represents the results for Group X. The top table shows all of the scores for the quizzes and tests that each participant completed. Grey box indicates that they did not complete that quiz or test. The bottom table shows how well each participant identified the bone and correctly sided it.
*Quiz 3 is not shown, because this was over the Cranium and Mandible. All participants that completed Quiz 3 correctly identified the cranium and Mandible and siding was not applicable for these bones. *

Wilcoxon Signed-Rank

For Group 1, all six participants scores were calculated using the Wilcoxon Signed-Rank test. The sum of the negative ranks was 21, with a mean difference of -82.27. Since the (N) value was under 10, a W value was used instead of the normal Z value. The results showed to be significant at $p < .05$ for W at 2. This shows that the

students in Group 1 did successfully learn the material (Wilcoxon Signed Rank Test see appendix F).

For Group 2, nine participants were calculated instead of the ten as one individual did not take the posttest. The sum of negative ranks was 45, with a mean difference of -29.11. The mean for this group is smaller than the mean in Group 1 in part because of the three individuals who scored higher on the pretest were in Group 2. A W value was used for this group as well due to the small sample size. The test gave an output that the result was significant at $p < .05$ for W at 8. This shows that the group displayed a significant increase in knowledge from the pre to posttest.

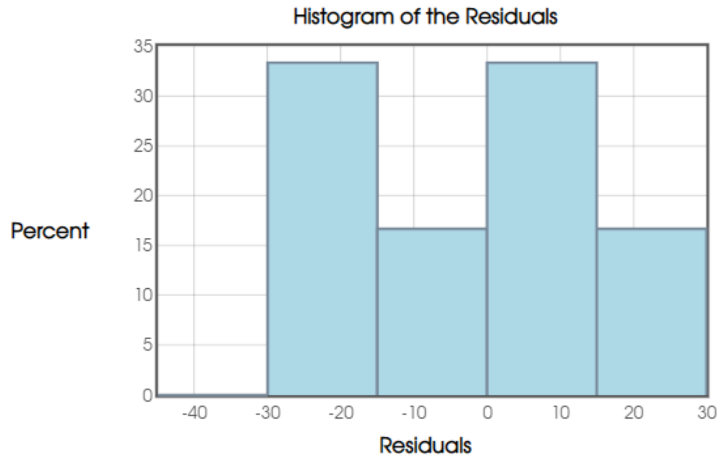
Mann-Whitney U Test

The results from the Mann-Whitney U test looked at the differences in both Group 1 and Group 2. It specifically looked at the amount of improvement from the pre and posttest. The test was run as both a two tailed and one tailed test to see if there was any difference in the results. For the one tailed test, the U-value was 13. The critical value for U at $p < .05$ is 12. This showed that there was no significance. However, the U value is close to being significant which could mean that there was almost a significance of Group 1 improving more than Group 2. For the two-tailed test the results still were not significant as the U value was still 13, but the critical value of U at $p < .05$ changed to 10 (Mann-Whitney U Test see appendix G). Although not significant is normally a bad result, this test shows that it is capable for students to learn the material using 3D images just as well as students learning with casts. This is an important find, as any alternative method for teaching has to be as good or better than the method its being compared to.

The result of not significant for the amount of improvement between Group 1 and Group 2 proves that these two pedagogies are significantly equal.

Multiple Regression

This test was run to see if there was a formula that could be created to estimate how well a student would do on a quiz in relation to the amount of time they spent studying. For all of the formulas, the same three variables were entered. X1 was the student's pre-test score, X2 was how much time they spent studying outside of the allotted class time and the Y variable was the average of all of their quizzes. For Group 1, the formula of the line was (Total quiz average = - 5.3405 + 8.8335 * pre-test + 0.7157 * Study (min)) (Graph 5). For Group 2 (Total quiz average = 45.9304 + 0.4231 * pre-test + 0.2921 * Study (min)) (Graph 6) (Multiple Regression Test see appendix H). Based on this information, it appears that the slope for Group 1 is a little steeper than Group 2.



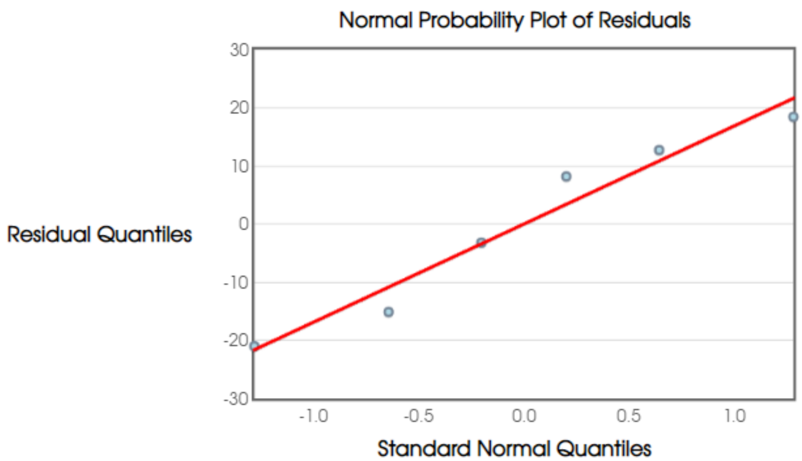
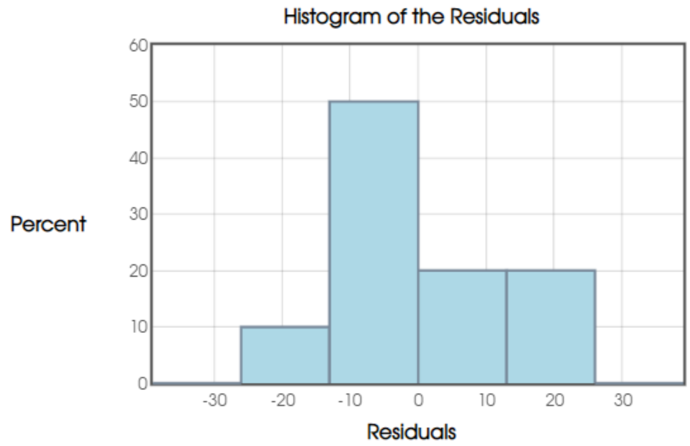


Figure 33. (Graph 5) Multiple Regression Graphs for Group 1. This graph is from the website Stats.Blue (Stats.Blue, 2018) and shows the results for Group 1.



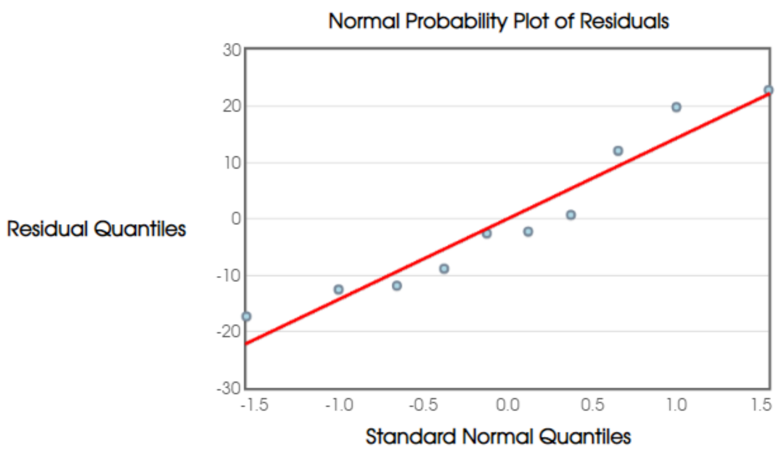


Figure 34. (Graph 6) Multiple Regression Graphs for Group 2. Note: This graph is from the website Stats.Blue (Stats.Blue, 2018) and shows the results for Group 2.

When looking at the difference between those that studied 30 minutes or more verses those that studied for under 30 minutes, there was a small change between the two groups. For the group that studied on average at least 30 minutes the participants did better on the quizzes. The slope for this group is (Total quiz average = 25.2493 + 0.1152 * pre-test +0.8681 * Study (min)) (Graph 7). The group that studied less than 30 minutes on average did have a more gradual slope. The formula for this group was (Total quiz

average = 42.5397 + 1.0267 * pre-test + 0.3817 * Study (min)) (Graph 8). This concludes that the students that studied on average 30 minutes or more performed better on the quizzes.

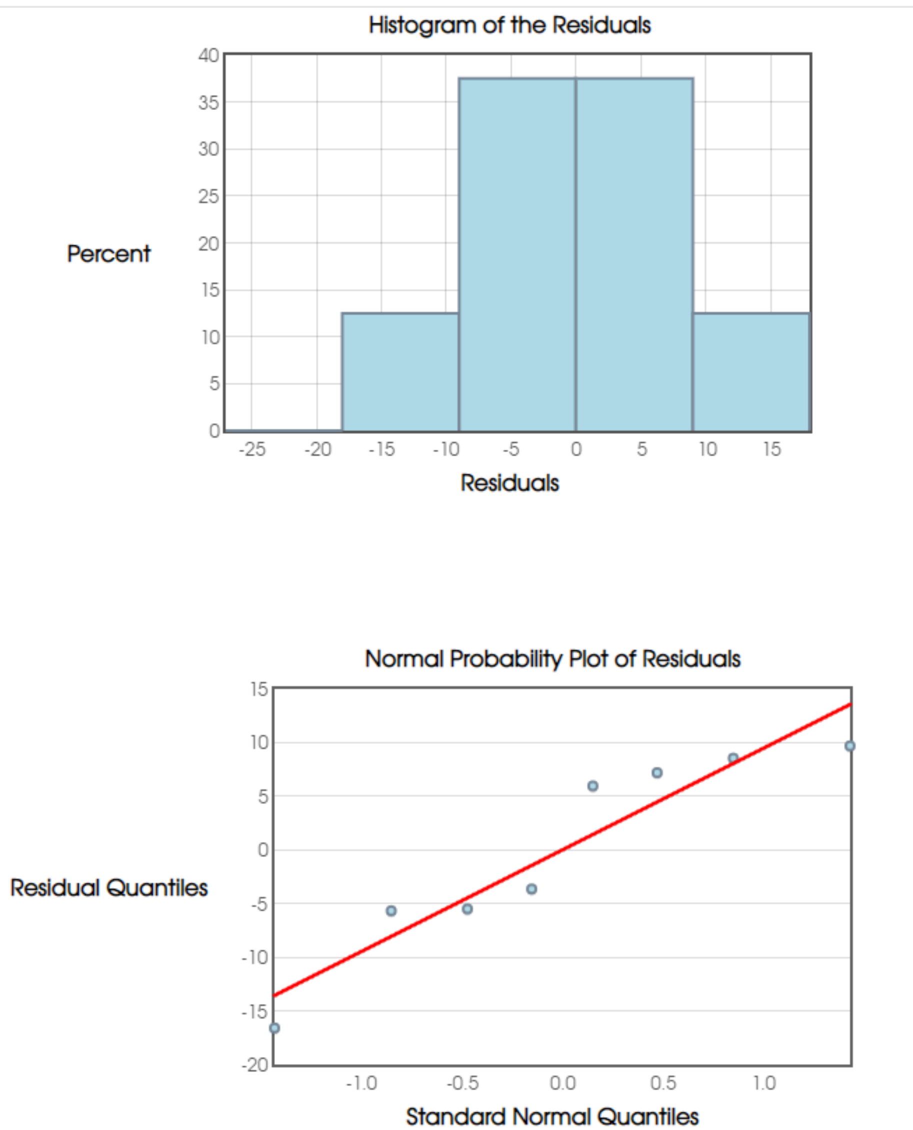
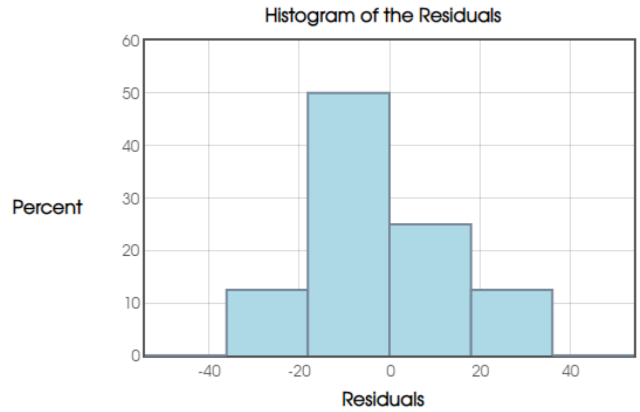


Figure 35. (Graph 7) Multiple Regression Graphs for Those that Studied at Least 30 Minutes per Week on Average. This graph is from the website Stats.Blue (Stats.Blue, 2018) and shows the results for the group that studied on average at least 30 minutes a week.



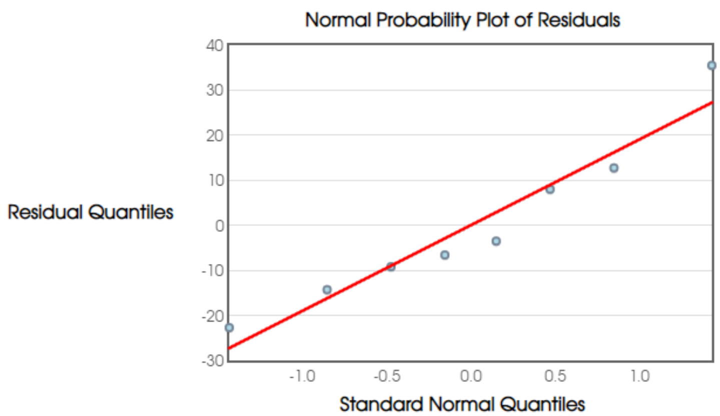


Figure 36. (Graph 8) Multiple Regression Graphs for Those that Studied Less than 30 Minutes per Week on Average. This graph is from the website Stats.Blue (Stats.Blue, 2018) and shows the results for the group that studied less than 30 minutes a week.

Student Reflections on Quizzes/Test

After each quiz and the pretest, students had an option to put any comments or questions about the study or specifics about that week's material. For Group 1, only one person used this section and they only used it for the first two quizzes. For the first quiz student 1A said “I definitely did better and learned more than what I knew before.” On this quiz they scored 100%. For Quiz 2 they scored 68.2% and this was their comment,

“Definitely did not do as good as last time. I should probably study more next time.” This student performed adequately throughout the other two quizzes and the post test, but they did not study as much as they had for the first quiz, and their scores reflected that.

For Group 2, a few people made comments. Student 1B made a comment on every quiz besides the first one. On the second quiz their response was “I thought going into this quiz that I knew more than the performance of this quiz, but I got mixed up with what parts of bones belong on what bones.” This student studied for an hour for this quiz, and scored a 45.5%. For Quiz 3, they scored 70.6% and commented “I thought that this week's bone analysis was a lot easier to recall, due to the two bones being fairly different from one another.” For Quiz 4, they had two comments, the first was on the amount of time they studied. “Unfortunately, I have had a really busy week, so I did the majority of my studying this morning. I used the blank and labeled documents to help review this information as well as the 3D scan to try and learn where the 3 main parts were on the coxae.” The second comment stated, “I found this week to be very difficult on time, so I did not get to review as much as I wanted. I would try to start the project study a week earlier so that the final test and last quiz are not the same week as finals week.”

Based on student 1B’s responses, a few observations can be made. The first observation was that, this student did study, and they improved significantly on the first and third quizzes. Quiz 2 showed to be the most challenging as students had much lower scores, this could be for many reasons. One reason that can be speculated is that they had to learn information about two bones that had a similar morphological shape. This speculation was supported by 1B who mentioned in their comment that they confused features on the two bones due to them being similar. The second observation made was

that having the student complete Quiz 4 and the post-test on the same day was a lot of information for them to review. This could have resulted in a lower score for both Quiz 4 and the post test. The last observation is that unfortunately the timing of the study made the last week of the study the same week as finals for all individuals besides 9B and 10B as they participated in the study in a different semester.

Student 2B made the same comment on Quiz 4 that they did not study as much due to finals week. Student 3B made a comment on Quiz 3, “Once it got to the bottom of the skull it was hard to learn/know what went where.” Identifying features at the base of the cranium can be challenging for students to learn in general. Student 3B similarly on Quiz 3 as they did on the other quizzes. Student 4B made a similar comment to student 1B about Quiz 2, “I think I got confused learning two bones at once.” On Quiz 3, student 1B also made a comment about the way the quiz was administered, “On zoom so a little more challenging but my own fault.” This student had to take the quiz over Zoom as they were not able to attend their session that week. This quiz was their second highest score, so taking the quiz on Zoom did not seem to affect their ability to take the quiz.

Student 6B made a comment on Quiz 4 that they were not able to study as much due to finals week. The last comment is from 9B and that was for Quiz 2 “I really liked using the 3D models for the humerus and the femur. I thought they were very useful when it came to studying.” This student did fairly well on Quiz 2 compared to some of the other students in the study. From all of the participants' comments, the biggest issues were on Quiz 2 because both of the long bones appear similar, Quiz 4 and the post-test being at the same time and the last week of the studying falling during finals week. These

are all valid comments about the study. If this study was to continue, one change may be to the timeline of the study to address these comments.

Final Thoughts

There was an optional survey that the students could take at the end of the study. This survey was anonymous and was created for a few reasons. One reason was that I wanted to give students the ability to say what they really thought about the study. This survey was anonymous and all of the other information they turned in had a name on it. There were also a few questions that were not addressed in the other Qualtrics forms that are important to the study. The first question asked if they were part of the cast or 3D group, out of the six individuals that completed this survey, two of them were from the 3D group and the other four were part of the cast group.

The second question was, “What did you like?” The responses for the cast group were; “Learning about the different bones,” “Seeing and feeling the bones,” “I liked how this study was basically on your own time,” “Being able to actually feel the bone and look at it up close.” The two 3D students wrote that “It was easy” and “Being able to learn the individual parts of bones in our body through a different way.”

The third question asked, “what did you not like?” The responses from the cast group were; “the 3D scans can be bit difficult to look at,” “Forgetting all the names,” “I didn’t like how I had to stay for an hour after I took my test, 30 minutes would have been plenty!” and “n/a.” The first response about the 3D scans I am unsure about because they said they were in the cast group, and since it is anonymous, I was not able to reach out for clarification. The 3D groups responses were; “Nothing” and “The 3D images were not as clear where it was pointed on the different bones.” While I am not 100% sure what the

student meant by this comment, I can only assume that they made this comment in regards to the points for the quizzes. Students were told that if they had questions about what something was pointing to, they could ask for clarification.

The next question was to gauge how serious they took this study compared to a registered class. The question read, “How much effort did you put into this "class/research?” Try and compare it to other classes you have taken, how hard did you try and or engage in the class compared to a normal class?” The cast group's responses were; “I put as much effort as I put in my other classes,” “I spent about 10 minutes a week.” “I put a good amount of effort into this. I thought it was very interesting to learn.” “I engaged in this class less than if it were one of my other classes. This is not necessarily due to anything, but I still put in a fair amount of effort.” The 3D group responses were; “Little to none in comparison,” “I didn’t try as hard as I would’ve in any classes but I still spent a little bit of time each week.” These responses were typical for what was expected. This study was a volunteer study that the students did not receive any class credit or monetary benefit. Some of the students did receive extra credit for their participation. This could mean that if this study was taught as a registered class, the data may be different as the amount of effort a student would put into it could change the results.

The next question was, “how well do you feel you learned the material, on a scale of 1 to 10 with 10 being the highest? Feel free to elaborate.” The responses from the cast group were; “8,” “Probably a 2. I didn’t spend enough time studying it,” “8”, “I would say that I memorized the material more than I actually learned it. This is user error though.” For the 3D group, the answers were; “9 as most of it was a refresher from my anatomy class,” “7 I learned many different parts on the different bones.” These answers

were a little surprising as most of them said they did not put in a lot of effort into the course compared to a regular class.

The last question was, “any other questions, comments or concerns?” Only one person answered this question and they were from the cast group. Their response was, “I would have preferred a list of names to work with. I found it very difficult to remember things without a prompt.” The decision to not have a word bank was made by my advisors and myself as a normal osteology course is generally taught without a word bank. The students were provided with all the names and terminologies in the handouts.

Graduate Results

Pretest

For the graduate student portion of the study, only three individuals volunteered. This is a very small sample size, but there does appear to be a pattern with useful results. For the pretest, the graduate students took the same pretest as the undergraduates in Groups 1 and 2 with one question removed due to it being a repeat question. For the entire study both undergraduate and graduate students were told that spelling did not count. The pretest was made up of 91 points, with a breakdown of 14 questions for the Quiz 1, 32 questions for Quiz 2, 27 questions for Quiz 3 and 18 questions for Quiz 4. The pre-test scores for student 1G was 68.7%, student 2G 87.4% and student 3G was 89.56% (Table 17).

Table 17: Group 3 (Graduate Students) Scores

2 D test	Section 1	Section 2	Section 3	Section 4		Pretest Score
1G	64.3	54.7	83.3	75		68.7
2G	85.7	85.9	87.1	91.7		87.4
3G	96.4	81.3	92.6	94.4		89.56
Average	82.13333	73.966667	87.6666667	87.0333333		
Name	Quiz 1 %	Quiz 2 %	Quiz 3 %	Quiz 4 %	Total Quiz %	2 D test %
1G	53.3	68.2	70.6	75	67	68.7
2G	53.3	100	100	100	88	87.4
3G	100	86.4	100	91.7	95	89.56
Average	68.86667	84.866667	90.2	88.9	83.33333333	81.88666667
Points per quiz	15 points	22 points	17 points	12 points		

Note: This table shows the scores for the graduate students that participated in the study. The top table shows the pretest (2D test) that the participants took. The pretest scores were broken into four sections, Section 1 (Scapula), Section 2 (Humerus and Femur), Section 3 (Cranium and Mandible), Section 4, (Os coxa). The overall score is for the pretest is on the right. The bottom table shows the quiz scores for each participant, and compares the total quiz scores to the pretest scores.

Quiz scores

The quizzes were the same as the ones used for Group 2. The quizzes had a total of 66 points with 15 coming from Quiz 1, 22 from Quiz 2, 17 from Quiz 3 and 12 from Quiz 4. Quiz 1 had all of the questions from the pretest with an additional question asking the participant to side the bone. The other quizzes had fewer questions than their counterpart on the pretest. Graduate student 1G had a score of 53.3% on Quiz 1, 68.2% on Quiz 2, 70.6 on Quiz 3 and 75% for Quiz 4 for a total average of 67% for all of the quizzes (Table 17). When comparing 1G’s quiz results to the pretest section results, there is some variation in scores with some being higher on the quizzes and some being higher

on the pretest (Table 17). Overall, the total percentage from the quizzes and the pretest was 1.7% different, with the pretest being higher.

For graduate student 2G, they scored 53.3% on Quiz 1 and then 100% on the other three quizzes for a total quiz average of 88% (Table 17). For their pretest, the graduate student scored better on the scapula (Quiz 1 section), with a score of 85.7% (Table 17). The other pretest sections scores were 85.9% for section 2, 87.1% for section 3 and 91.7% for section 4. Their total average score on the pretest was 87.4% (Table 17). Their average score is in line with their overall score on the quizzes. For the last graduate student 3G, they scored the best on the pretests and on the quizzes. Their overall quiz score was 95%, with Quiz 1 being 100%, Quiz 2 being 84.87%, Quiz 3 being 90.2% and Quiz 4 being 88.9% (Table 17). On the pre-test, they scored 89.56% with the following scores per section; 96.4%, 81.3%, 92.6% and 94.4% (Table 17).

Results

The first noticeable analysis for the graduate student scores is that they scored about the same using either the 2D material or 3D material. The biggest difference was with 3G, who scored 5.44% higher on the quizzes then the pretest. It seems that with this small sample size that having students who know the material can correctly identify markings on a 3D image the same as they can using a diagram. Another similarity is that the three individuals seemed to score higher using the 2D image when it came to the scapula vs using the 3D scapula (Table 17). The pretest scores for the scapula had an average of 82.13%, while the 3D quiz only had an average score of 68.87% (Table 17). This was reversed for Quiz 2 which went over the humerus and femur. The students had an average score of 84.87% using the 3D images and an average of 73.97% for the 2D

images. In both of these cases, 3G scored the most consistently between the 3D and 2D images while 1G and 2G scored 10% - 32% different in these two sections (Table 17 Columns 2 and 3). For the last two quizzes/sections, the average score was within 3%.

Chapter V: Summary and Conclusions

In this final chapter, some of the possible challenges of 3D images or concerns with teaching using only 3D imagery will be discussed. This is followed by the complications that I had with my research and future research that may be able to be conducted to enhance this study. In the conclusion the research questions are answered using the research and literature that was reviewed for this paper.

Challenges with 3D Teaching and Possible Solutions

While using 3D images has a lot of advantages there are still some challenges. One challenge for the 3D scans is that they do not allow physical touch of real bone. However, this is a limited concern for a few reasons. First, in most cases when students are learning osteology, casts are used for the majority of the learning as these are more accessible than real bone. The casts are more durable than bone. Casts do not feel like real bone but they are still used to teach. Second, an individual can learn the material using a 3D image to become familiar with the skeleton and then in a later more advanced class they could get a feel of real bone. Third, cast and bones are expensive, and can be a challenge to store and may not be feasible or assessable at in institution. The use of 3D images would allow for these institutions to teach students the material with a hands-on approach even though they do not have access to casts or bones. The ability to distinguish bone from other material does take some training, however, if an individual already knows the rest of the material, such as the names and how to distinguish human and non-human bone, then the training of how to identify bone is more easily taught in a higher class or through experience.

If a professor is hesitant about using 3D images in their in-person class instead of real bone, a professor could always supplement the 3D material with real bone from animals or ethically obtained human bone. The 3D images are a better alternative when studying then using a 2D image. If an individual has successfully learned osteology, and can identify the bone and tell it apart from animal bones, the transition to real bones would not be difficult.

Complications and Future Work

This study was smaller than originally hoped for, the goal size was a sample size of at least fifty individuals with 25 in each Group. For the graduate group an ideal size was around 10. There are a few potential reasons as to why this study was smaller then intended. The first potential reason was that this was a volunteer study. To go along with that, there was no funding for the study, which meant that the students were not given any monetary compensation for their time. An NSF grant was applied for but was not awarded. These two reasons mean there was very little monetary or educational benefit for participants other than them wanting to further their education or donate their time. This study also required the students to meet for an hour to an hour and a half every week for five straight weeks. This is a significant time commitment for most individuals. As mentioned above, the timing in which the first session of the study took place was close to the end of the semester with the last week being the same week as finals. For the graduate student group, most of the above reasons can relate, except that there was no

extra credit for them to complete the study. This meant that there were even fewer benefits to encourage the graduate students to participate.

The work done in this study is a great stepping stone for more research. With more time, and by making a few minor adjustments that were mentioned above, this study could potentially have more participants which would create a better sample population. The study has an approval status from the IRB for four more years. One addition that can be made to the study would be to add an additional quiz for the graduate student section. This would include having the graduate students take cranial measurements using the 3D software and comparing those measurements to the measurements taken by an individual that is a member of the Board of Forensic Anthropology or similarly accredited organization. It is a great resource to be able to use 3D images to learn, test features and side bones, but in order for this to truly be an alternative to the traditional learning methods, it must be accurate in both looks as well as metrics.

Conclusion

Although this study had a much smaller sample size then the intended, this does not mean that the information is less significant. There was proof that the 3D scans were a great resource for the students. Having access to the 3D material at any time allows for students to study the bones from anywhere and on a variety of electronic devices. Giving students as many resources as possible is a great way to improve their understanding of the material. As seen in the multiple regression test, students that studied tended to do better. The 3D scans can be used similarly as a textbook for a class if a professor would like to enhance a class without getting rid of the casts or bones. This means that the 3D

scans would be great even as a secondary form of learning if a professor would like to teach using casts, but give 3D access to their students so they can study on their own. The 3D scans showed to be more versatile in the way that they could be used by both the instructor as well as the students.

In the literature review section, there are some common subsections of osteology mentioned. In this section it talks about how a biological profile is created/estimated, and talks about the different methods used in analysis or teaching. Based on the results from the study as well as other articles in the literature review, there is strong evidence that all of the methods could be done using the 3D images. This means that even an advanced course in osteology or forensics anthropology could be taught using the 3D images.

Although these 3D scans could be used as a secondary tool for teaching, this study also proved that students can learn the material strictly using 3D images while not having access to casts or bones. Having a study show that individuals can learn the material using only 3D images and not requiring the use of casts or bones would have helped many educational facilities during the Covid-19 pandemic as the classes could have seamlessly switched to a remote setting instead of scrambling to have students have access to casts. It also could have helped professors from having difficulty accessing just how well the students learned the material due to a potential change in the testing process of the students. The ability to test the students using the 3D images was proven in a few different ways. The first is that all of the participants improved with most improving from their original pretest score by at least 40%. This was done mainly with self-taught and peer-reviewed teaching as a small lecture was given at the start of the week to help clarify a few key points on the bones. This is a great improvement as this was only a five-week

study that only required an hour of work each week. Based on the Wilcoxon Signed Rank test results, it was proven that all of the students had a significant increase in their scores from the pre to post test.

In the Mann-Whitney U test, the data showed that there was no significant difference in learning between the two groups, meaning that neither Group 1 or Group 2 had any significant difference in how much they learned over the other group. This proved that the 3D scans are equal to casts in the ability for students to be able to learn and be tested on the material. Being able to learn the material using 3D images is important, but being able to test using the 3D images is extremely important. Being able to test allows for students to take an osteology course fully remote, or for a smaller school that may not have casts or bones to be able to teach an osteology course with a lab component that ensures the students learn the material just as well as a student taking osteology somewhere else. Remote learning was not originally part of the study, but there was one student that completed the study completely remote and two other students that completed at least one quiz remotely.

Siding and identification of the bones was able to be done with both Groups 1 and 2. Group 2 was able to correctly identify the bone 100% of the time, which was better than that of Group 1. However, Group 1 did better at siding the bones correctly. There was not a significant change from Group 1 to Group 2 when it came to siding. A way to enhance siding for teaching using 3D imagery would be to have 3D images of the joints of bones which would give students a better ability to understand how to tell which side is what, and how all the bones fit and work together.

While the study looked solely at how well the students could identify the bone, side and correctly identify features on the bone, the quality of the 3D scans does allow for much more than that. The graduate student participants confirmed that someone that knows the material can correctly identify features and bones using the 3D images even though they have never worked with 3D imagery. This shows the accuracy of the 3D images. As mentioned earlier in the paper, the ability to use a 3D image in a legal or peer-reviewed setting is important. If the scans are not accurate, they should not be used for teaching or any other setting.

The graduate portion of the study proved that the morphology of the 3D scans is accurate, and I was able to verify that the metrics of the 3D images were also accurate. The measurements taken were of the cranium as well as a few other bones such as the scapula and long bones. This also proved that with training, an individual can correctly measure almost all of the standard bone measurements. This is important because osteology and other subfields rely on the morphology and measurements of bones to give more information such as health of the individual, a biological profile and identify any abnormalities or other unique characteristics of the bone or individuals. In proving that the 3D scans are accurate means that they can be used in any means that a cast or bone could be, and may be more ethical to use depending on the situation.

Appendices

Appendix A

Table 1. Enlarged

#	Skull:	BC253 Swiss T1	Swiss T2	Artec Scan T1	Artec Scan T2		
1							
2	**Skull:**	BC253					
3		Swiss		Artec Scan			
4	**Standard Craniu**	T1	T2	T1	T2		
5	GOL	174		169.99	173.7		Maximum Cranial Length
6	XCB	125		122.05	125		Nasio-occipital length
7	ZYB	125		124.83			
8	BBH	130		129.89			
9	BNL	94		96.41			
10	BPL	92		92.15			
11	MAB	65		62.08	64.91		Maximum-Alveolar Breadth
12	MAL	46		51.54		47.52?	Maximum - Alveolar length This one hard.
13	AUK	117		117.98			
14	WFB	86		85.43			
15	UFBR	98		96.49			
16	ASB	107		107.71			
17	ZMB	100		101.39			
18	NLH	53/54		52.03			
19	NLB	26		25.21			
20	OBB	36		35.42			
21	OBH	38		38.36			
22	EKB	85		89.11	85.85		Biorbital Breadth
23	DKB	24.5		24.11			
24	FRC	102.5		98.07	102.55		Frontal Chord
25	PAC	116		111.96	115.32		Parietal Chord
26	OCC	92		87.52	93.79		Occipital Chord
27	FOL	36		33.88			
28	FOB	31		31.53			
29	MDH	37		36.91/36.66			
30	MOW	62		70.62	62.57		
31	UFHT	78		70.32			
32	**Standard Mandible**						
33	GNI	33		30.54			
34	HML						
35	TML						
36	GOG	99		98.45			
37	CDB	113		113.77			
38	WRB						
39	XRB						
40	XRH						
41	MLT						
42	MAN						
43							
44	**Date**	3/1/2021		1-Mar			
45							

#	Skull:	Skull:	BC253 Swiss T1	Artec T1	Differences (-) is higher swiss reading (+) is higher Artec
2	**Skull:**	**Skull:**	BC253		
3			Swiss	Artec	Differences
4	**Standard Craniu**	**Standard Craniu**	T1	T1	(-) is higher swiss reading (+) is higher Artec
5	GOL	GOL	174	169.99	-4
6	XCB	XCB	125	125	0
7	ZYB	ZYB	125	124.83	0
8	BBH	BBH	130	129.89	0
9	BNL	BNL	94	96.41	2
10	BPL	BPL	92	92.15	0
11	MAB	MAB	65	62.08	-3
12	MAL	MAL	46	51.54	6
13	AUK	AUK	117	117.98	0
14	WFB	WFB	86	85.43	-1
15	UFBR	UFBR	98	96.49	-2
16	ASB	ASB	107	107.71	1
17	ZMB	ZMB	100	101.39	1
18	NLH	NLH	53/54	52.03	-1
19	NLB	NLB	26	25.21	-1
20	OBB	OBB	36	35.42	-1
21	OBH	OBH	38	38.36	0
22	EKB	EKB	85	89.11	4
23	DKB	DKB	24.5	24.11	0
24	FRC	FRC	102.5	98.07	-4
25	PAC	PAC	116	111.96	-5
26	OCC	OCC	92	87.52	-4
27	FOL	FOL	36	33.88	-2
28	FOB	FOB	31	31.53	1
29	MDH	MDH	37	36.91/36.66	0
30	MOW	MOW	62	70.62	8
31	UFHT	UFHT	78	70.32	-8
32	**Standard Mandible**	**Standard Mandible**			
33	GNI	GNI	33	30.54	-2
34	HML	HML			
35	TML	TML			
36	GOG	GOG	99	98.45	0
37	CDB	CDB	113	113.77	0
38	WRB	WRB			
39	XRB	XRB			
40	XRH	XRH			
41	MLT	MLT			
42	MAN	MAN			
44	**Date**	**Date**	3/1/2021	1-Mar	

Note: Measurements for Accuracy Table. Table on the left shows the measurements, while the table on the right shows the difference in millimeters. Green is the same, yellow is within 2, red is more than 2mm off. After the second round of measuring all were within 2mm.

Appendix B

Questionnaire

This is a questionnaire to better understand the different educational and background of those of you that will be participating in this study. The study is looking at teaching strategies using 3D images and casts of human bones. This study will require an hour to an hour and a half each week and will start on *DATE* and will end *DATE*. There will be a pretest at the beginning of the study and a final test at the end of the session to determine the level of learning. There will also be weekly quizzes that will also be used to look at learning evaluation.

My information is Erik Schulz, and my email is eschulz3@unl.edu.

Name:

Year:

Major/Minor:

Age:

Pronoun Preference:

Best email to contact you:

Have you taken osteology before: high school, college, other please explain? If you have taken a class please list grade and when you completed the course.

List days and times that you might be available for the study?

Times	Monday	Tuesday	Wednesday	Thursday	Friday
9-10:30 am					
10:30 -noon					
12-1:30 pm					
1:30-3pm					
3-4:30 pm					
4:30-6 pm					
6-7:30 pm					

Any questions, concerns or comments that you would like addressed before the study?

Appendix C

Consent Form

IRB# 20210320890EX
Date Approved: 03/26/2021

Template Revised: 05/03/2020

University of Nebraska Lincoln

IRB
UNL STUDENT INFORMED CONSENT

IRB Project ID#: 20890

1. **Participant Study Title: Learning Outcomes of Using 3D Images vs Casts for Human Osteology.**

2. **Formal Study Title: Teaching Pedagogy of Online vs In-Person Learning: Relative to Osteology**

3. **Authorized Study Personnel**

Principal Investigator: Erik Schulz, MA Cell: (402) 326-4797 Email: erkschlz@yahoo.com
Secondary Investigator: William Belcher, Ph.D. Email: wbelcher2@unl.edu

4. **Key Information:**

   The study is looking at teaching strategies using 3D images and casts of human bones. This study will require an hour to an hour and a half each week and will start on March 15th 2021 and will end April 23rd 2021. There will be a pretest at the beginning of the study and a final test at the end of the session to determine the level of learning. There will also be weekly quizzes that will also be used to look at learning evaluation. Although the primary investigator is the teaching assistant for the course, participating in the research or not is in no way tied to a student participants grade in the course.

If you agree to participate in this research study, the project will involve:

- (Males/Females/Research Participants) between the ages of (18 and up)
- Procedures will include Two tests, and weekly quizzes.
- Six visits are required
- These visits will take under an hour for a total of up to six hours for the whole study.
- There are/are no risks associated with this study
- Your data collected from this study may be shared as described below
- You will receive 1 point of extra credit for each visit.
- You will be provided a copy of this consent form
- Your participation is voluntary and you can decide not to participate at any time

5. **Invitation**

You are invited to take part in this research study. The information in this form is meant to help you decide whether or not to participate. If you have any questions, please ask.

6. **Why are you being asked to be in this research study?**

IRB# 20210320890EX
Date Approved: 03/26/2021

You are being asked to be in this study because you are a UNL Student in this Anthropology 110 course. You must be 18 years of age or older to participate.

7. What is the reason for doing this research study?

This study is to look at different teaching strategies and their effectiveness. There will be three groups of students all will be tested on their osteology ability, and their ability to learn using either the 3D images or the Casts. The purpose for this study is to improve future teaching techniques and strategies in order to give students their best chance to learn as well as giving academic institutes the ability to teach students in the best way possible. With Covid-19, it has been difficult for students and academic institutions alike to teach material. This study will hopefully be able to improve this process and allow better learning outcomes.

8. What will be done during this research study?

You will be asked to complete two tests, and five quizzes. The first test is a pretest to test your knowledge on osteology, the second test will be similar to the pretest to test what you have learned throughout the study. For each test you will be given an hour to answer the questions. You will have one quiz per bone section, this will be a short quiz that will test you over the bone region for that week. For each quiz you will be given 20 minutes to take it. You will be assigned an hour and a half time slot that works for you that you will be required to show up to each week. During this time slot you will take a quiz or a test if it is scheduled for that week, and the rest of the time you can use to learn the bones for the next week. You will not be required to stay the full time, but it will be encouraged.

9. What are the possible risks of being in this research study?

There are no known risks to you from being in this research study.

10. What are the possible benefits to you?

You will be granted one point of extra credit per session you attend. You are not expected to get any other benefits from being in this study.

11. What are the possible benefits to other people?

This study has the potential to change how osteology and similar classes are taught throughout different academic institutions. This would allow for more individuals to take classes, lower the cost of the class to students and the school, and allow for a better learning outcome for the students.

12. What are the alternatives to being in this research study?

Instead of being in this research study you can choose not to participate.

13. What will being in this research study cost you?

IRB# 20210320890EX
Date Approved: 03/26/2021

There is no cost to you to be in this research study.

14. Will you be compensated for being in this research study?

We will not pay you to take part in this study or pay for any out-of-pocket expenses related to your participation, such as travel costs. Your participation in this study will result in extra credit towards your Anthropology course. One point of extra credit will be given for each session completed other than the first session for a total of five points.

15. What should you do if you have a problem during this research study?

Your welfare is the major concern of every member of the research team. If you have a problem as a direct result of being in this study, you should immediately contact one of the people listed at the beginning of this consent form.

16. How will information about you be protected?

Reasonable steps will be taken to protect your privacy and the confidentiality of your study data; however, in some circumstances we cannot guarantee absolute privacy and/or confidentality.

This study involves the collection of private information (name, dates, etc.). Even if identifiers (name, dates, etc.) are removed, information collected as part of research will not be used or distributed for future research studies.

The research records will be stored in a locked cabinet in the investigator's office and will only be seen by the research team and/or those authorized to view, access, or use the records during and after the study.

The research records will be securely stored electronically through University approved methods and will only be seen by the research team and/or those authorized to view, access, or use the records during and after the study

Those who will have access to your research records are the study personnel, the Institutional Review Board (IRB), and any other person, agency, or sponsor as required by law or contract or institutional responsibility. The information from this study may be published in scientific journals or presented at scientific meetings and may be reported individually or as group or

IRB# 20210320890EX
Date Approved: 03/26/2021

summarized data but your identity will be kept strictly confidential. De-identified information will be kept indefinitely.

17. What are your rights as a research subject?

You may ask any questions concerning this research and have those questions answered before agreeing to participate in or during the study.

For study related questions, please contact the investigator(s) listed at the beginning of this form.

For questions concerning your rights or complaints about the research contact the Institutional Review Board (IRB):

- Phone: 1(402)472-6965
- Email: irb@unl.edu

18. What will happen if you decide not to be in this research study or decide to stop participating once you start?

You can decide not to be in this research study, or you can stop being in this research study ("withdraw") at any time before, during, or after the research begins for any reason. Deciding not to be in this research study or deciding to withdraw will not affect your relationship with the investigator or with the University of Nebraska-Lincoln.

You will not lose any benefits to which you are entitled.

19. Documentation of informed consent

You are voluntarily making a decision whether or not to be in this research study. Signing this form means that (1) you have read and understood this consent form, (2) you have had the consent form explained to you, (3) you have had your questions answered and (4) you have decided to be in the research study.

You will be given a copy of this consent form to keep.

20. Participant Feedback Survey

The University of Nebraska-Lincoln wants to know about your research experience. This 14 question, multiple-choice survey is anonymous. This survey should be completed after your participation in this research. Please complete this optional online survey at: http://bit.ly/UNLresearchfeedback.

IRB# 20210320890EX
Date Approved: 03/26/2021

Participant Name:

____
(Name of Participant: Please print)

Participant Signature:

____________________________________ ______________
Signature of Research Participant Date

My signature certifies that all elements of informed consent described on this consent form have been explained fully to the subject. In my judgment, the participant possesses the capacity to give informed consent to participate in this research and is voluntarily and knowingly giving informed consent to participate.

____________________________________ ______________
Signature of Person Obtaining Consent Date

Appendix D

Student Resource Library Informational PowerPoint

The following images were all included in the osteology resource library. The purpose of the resource library was to act as a textbook for the students. The resource library had pages from *The Human Bone Manual* (White and Folkens, 2005). These pages included text and pictures to help the students learn the different bones. Some other images were taken from other cites to give students different views and also provided labeled and blank labeled images.

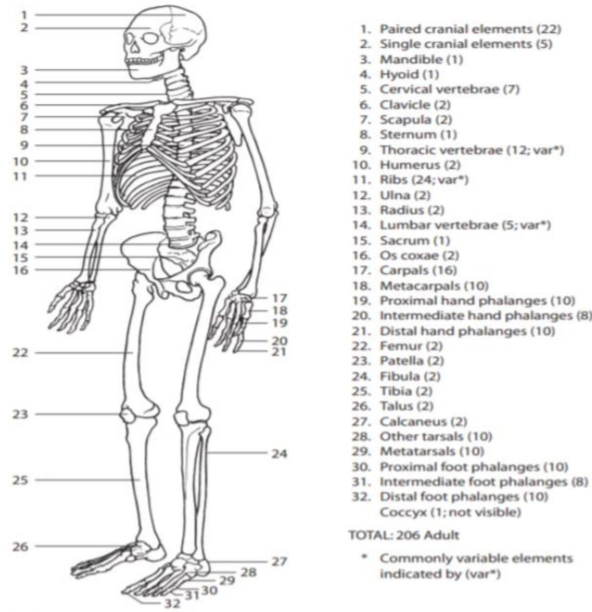
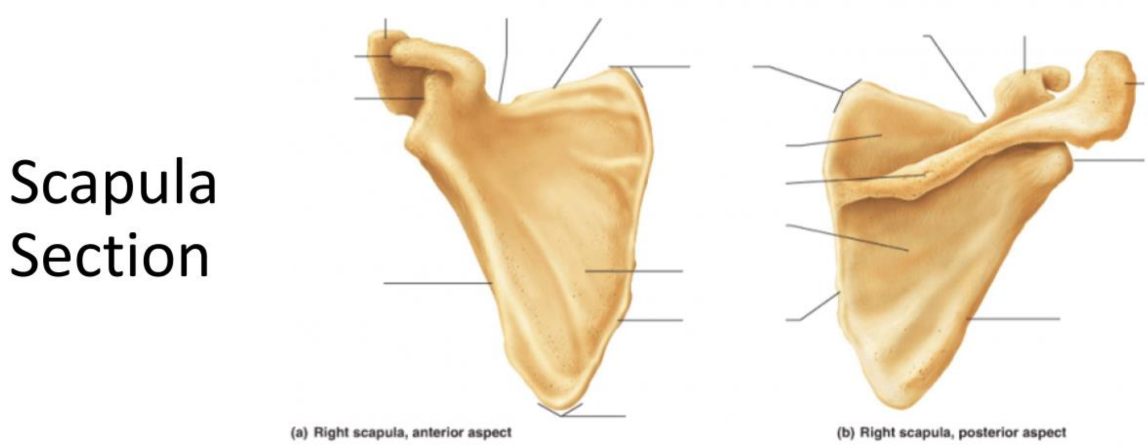


Figure 6.2 Skeletal elements.

This image depicts the bones in the human body, and was used to show students where the bones were located in the body (White and Folkens, 2005, p. 71).



This is a blank image of scapula that was used to help students learn the features (LilStride, 2022).

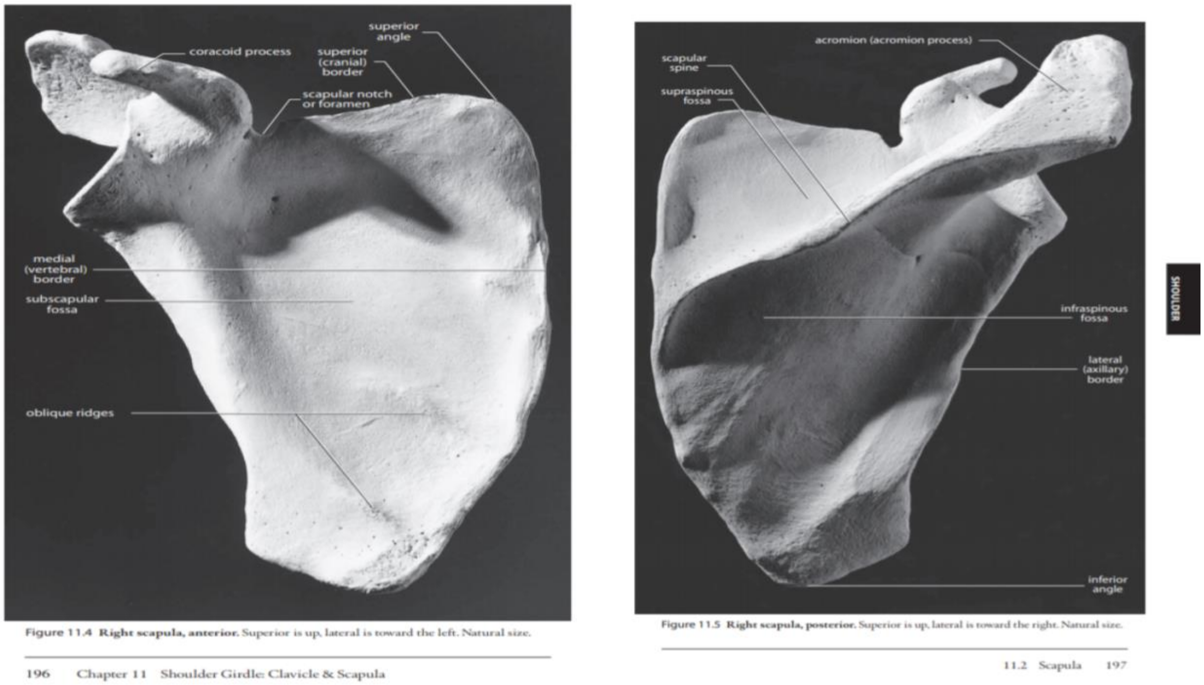


Figure 11.4 Right scapula, anterior. Superior is up, lateral is toward the left. Natural size.

196 Chapter 11 Shoulder Girdle: Clavicle & Scapula

Figure 11.5 Right scapula, posterior. Superior is up, lateral is toward the right. Natural size.

11.2 Scapula 197

The two pages above show different features of the scapula. (White and Folkens, 2005, p. 196 and 197).

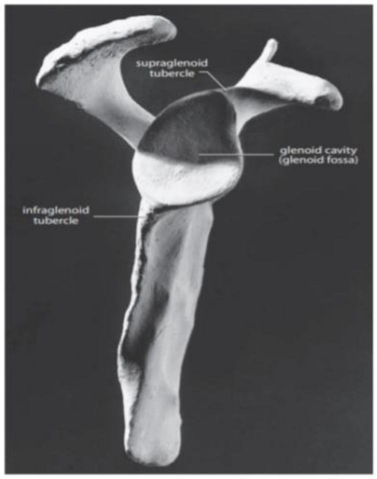


Figure 11.6 **Right scapula, lateral.** Superior is up, anterior is toward the right. Natural size.

a. The **superior** (**cranial**) **border** is the shortest and most irregular border.
b. The **scapular notch** (or **foramen**) is a variable feature on the superior border. This semicircular notch is formed partly by the base of the coracoid process. It transmits the *suprascapular nerve* and may become a foramen if the ligament across its cranial edge ossifies.
c. The **coracoid process** juts anteriorly and superolaterally from the superior border of the scapula. This finger-like, blunt, rugose projection anchors a variety of muscles, ligaments, and fascial sheets important in the function of the shoulder joint.

198 Chapter 11 Shoulder Girdle: Clavicle & Scapula

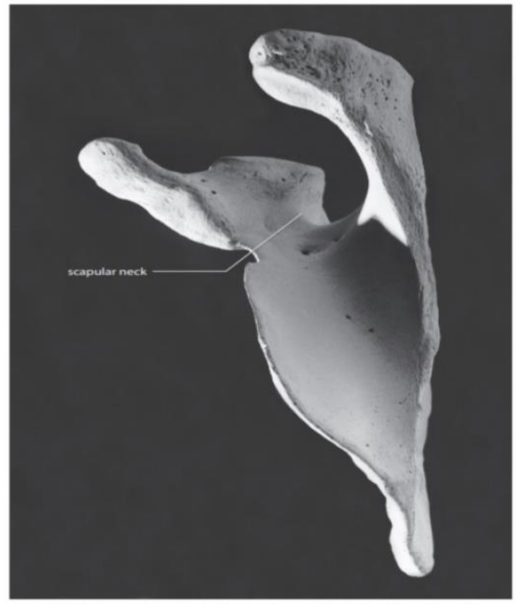


Figure 11.7 **Right scapula, superior.** Anterior is toward the left, lateral is up. Natural size.

11.2 Scapula 199

SHOULDER

The two pages above show different features of the scapula. (White and Folkens, 2005, p. 198 and 199).

d. The **subscapular fossa** is the shallow concavity that dominates the anterior (costal) surface of the scapula.

e. The **oblique ridges** that cross the subscapular fossa from superolateral to inferomedial are formed by *intramuscular tendons* of the *subscapularis muscle*, a major muscle that functions in medial rotation and adduction of the humerus and assists in other movements of the arm at the shoulder.

f. The **lateral (axillary) border** is the anteroposteriorly thickest border. It is usually slightly concave.

g. The **glenoid cavity (glenoid fossa)** is a shallow, vertically elongate concavity that receives the head of the humerus. The shallowness of this joint allows great mobility of the humerus (circumduction comes easily), but the shoulder joint is consequently more prone to dislocation than the hip joint.

h. The **supraglenoid tubercle** sits adjacent to the superior edge of the glenoid cavity, at the base of the coracoid. This anchors the *long head of the biceps brachii muscle*, a flexor of the arm and forearm.

i. The **infraglenoid tubercle** sits just adjacent to the inferior edge of the glenoid cavity. It gives origin to the long head of the *triceps brachii muscle*, an extensor of the forearm and an extensor and adductor of the arm at the shoulder.

j. The **scapular neck** is the slightly constricted region just medial to the glenoid fossa.

k. The **medial (vertebral) border** is the straightest, longest, and thinnest border.

l. The **scapular spine** dominates the posterior surface of the scapula. It passes mediolaterally across this surface, merging medially with the vertebral border and projecting laterally as the acromion process.

m. The **acromion (acromion process)** is the lateral projection of the scapular spine. Its cranial surface is very rough, providing attachment for a portion of the *deltoideus muscle*, a major arm abductor whose origins continue along the inferior edge of the scapular spine. The upper fibers of the *trapezius muscle*, which act as scapular rotators, also insert here. The anteromedial corner of the acromion bears a small articular facet for the distal end of the clavicle.

n. The **supraspinous fossa** is the large, mediolaterally elongate hollowing superior to the base of the spine. It is the site of origin of the *supraspinatus muscle*, a major abductor of the arm.

o. The **infraspinous fossa** is the hollowing inferior to the scapular spine. This extensive, weakly concave area is the site of origin of the *infraspinatus muscle*, a lateral rotator of the arm. The intramuscular tendons of this muscle attach to the ridges on the surface of the fossa.

p. The **superior angle** of the scapula is where the superior and medial (vertebral) borders intersect. The *levator scapulae muscle* attaches to the dorsal surface of the scapula in this region.

q. The **inferior angle** of the scapula is where the vertebral (medial) and axillary (lateral) borders intersect. Rugosities on the costal and dorsal surfaces in this area mark the insertions of the *serratus anterior muscles* and origin of the *teres major muscle* from the medial and lateral borders, respectively.

- A broken fragment of glenoid could be mistaken for the hip joint. The glenoid is much shallower and smaller than the acetabulum.
- The coracoid could be mistaken for the transverse process of a thoracic vertebra, but the coracoid is nonarticular.
- The lateral part of the acromion is sometimes mistaken for a fragment of lateral clavicle. However, because the acromion is continuous with the thin, plate-like spine, rather than a cylindrical shaft, this misattribution can be avoided. The inferior acromial surface is also smooth and concave; the distal clavicle is not.
- Tiny fragments of scapular blade or infant scapulas could be mistaken for wings of the sphenoid, but the thin bone of the scapula will be bounded by broken surfaces, whereas broken pieces of sphenoid pieces normally have free or sutural edges.

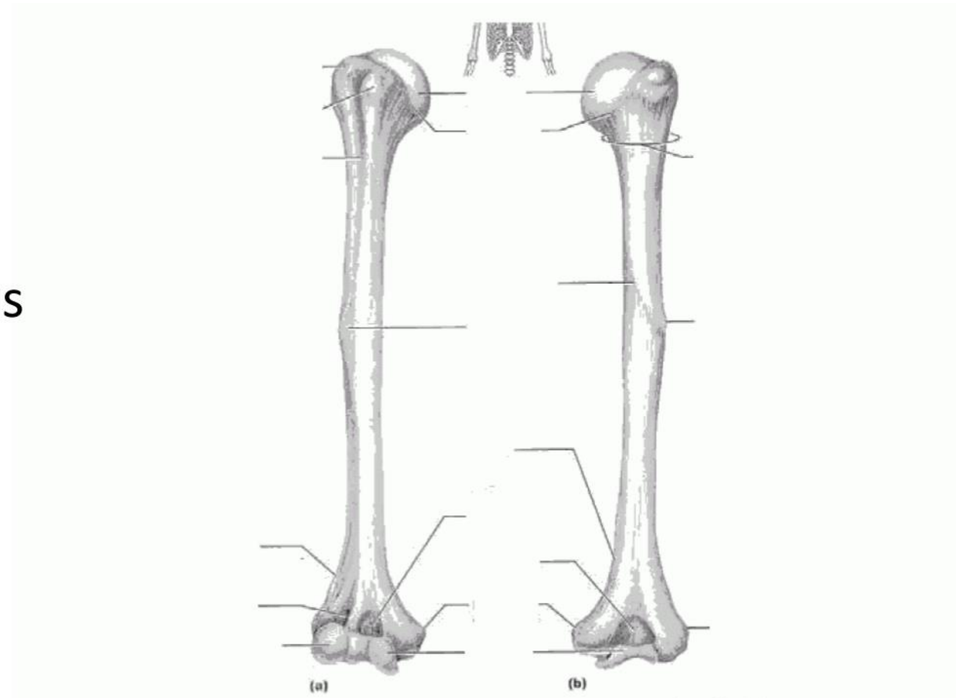
11.2.4 Siding

When intact, the glenoid is lateral and the spine is posterior. When fragmentary, use the following criteria:

- For an isolated glenoid, the fossa is teardrop-shaped, with its blunt end inferior. When looking directly into the correctly oriented glenoid fossa, note that the anterior edge of the fossa has a broad notch in it. The supraglenoid tubercle at the superior edge of the glenoid is displaced anteriorly. Posteriorly, the border of the glenoid is waisted, and the edge is raised and roughened. The anterior border is not as raised; it gently slopes into the rest of the scapula.
- For an isolated acromion, the inferior surface of the acromion is concave and is smoother than the superior. The clavicular facet is placed anteriormedially relative to the tip.
- For an isolated vertebral border, the anterior surface is concave and the posterior is convex. The oblique ridges run from superolateral to inferomedial (parallel to the scapular spine).
- For an isolated inferior angle, the anterior surface is concave, while the posterior is convex. The thickest border is lateral (axillary).
- For an isolated axillary border, the broad sulcus inferior to the glenoid parallels the border and is displaced anteriorly. The border itself thins inferiorly. The bony thickening is greatest (forming a "bar") on the anterior surface. Thickness of the cortex increases as the glenoid is approached along this border.
- For an isolated coracoid, the smooth surface is inferior, the rough superior. The anterior border is longer. The hollow on the inferior surface faces the glenoid area (posteroinferiorly).
- For an isolated spine, the spine thins medially (vertebrally) and thickens towards the acromion. The inferior border has a tubercle that points inferiorly. Adjacent to the spine, the infraspinous fossa is most deeply excavated medially. The supraspinous fossa is most deeply excavated laterally. A variably present foramen (or foramina) perforates the scapula at the superolateral base of the spine, at the depth of the supraspinous fossa.

The two pages above give definitions about different parts of the scapula and talks about how to side the bone (White and Folkens, 2005, p. 200 and 202).

Humerus
Section



This is a blank image of humerus that was used to help students learn the features (Sarahmcnamee, 2022).

Chapter 12

ARM: HUMERUS, RADIUS, & ULNA

THE FIRST VERTEBRATES lacked jaws. These animals, similar to modern lampreys and hagfish, also lacked paired fins. Jaws and fins evolved 400 million years ago, allowing fish to locomote and feed more effectively. Jawed fish have paired fins set on flat plates of bone that are attached to the muscles of their body walls. These paired fins, flexible fans of small bones, are used primarily as aids in stabilizing and steering. The limbs of terrestrial animals evolved from this structural arrangement as fins were transformed into rod-bearing segments. Although the limbs of land vertebrates seem very different from fish fins, the two homologous structures are actually highly comparable.

Each vertebrate limb has a base and three segments. The bases (the limb girdles) are the old basal fin plates of fish, which evolved to take on the function of transferring the weight of the body to the limbs of the terrestrial tetrapod. The proximal vertebrate limb segments constitute the upper arm and thigh. The intermediate limb segments, the forearm and foreleg, each bear two bones in humans, the radius and ulna in the arm, and their serial homologs, the tibia and fibula, in the leg. This chapter considers the three bones of the two uppermost segments of the forelimb: the humerus, radius, and ulna.

ARM

12.1 Humerus (Figures 12.1–12.6)

12.1.1 Anatomy

The upper arm bone, or humerus, is the largest bone in the upper limb (arm). It comprises a proximal end with a round articular head, a shaft, and an irregular distal end. The humerus articulates proximally with the glenoid fossa of the scapula and distally with both the radius and the ulna.

a. The **head** is a hemisphere on the proximal end of the humerus that faces medially and articulates with the glenoid fossa of the scapula.
b. The **anatomical neck** is the groove that encircles the articular surface of the head for the attachment of the *joint capsule*.

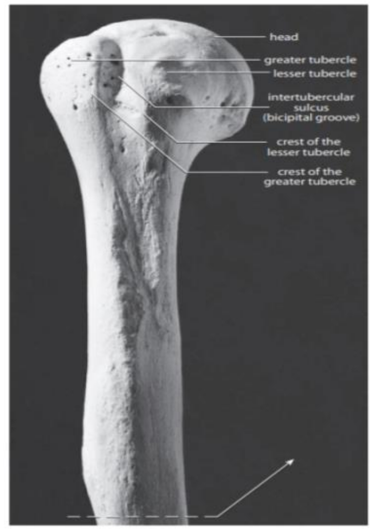


Figure 12.1a Right humerus, anterior. Proximal end. Natural size.

c. The **surgical neck** is the short segment inferior to the head. It links head and shaft.
d. The **lesser tubercle** is a small, blunt eminence anterolateral to the head on the proximal shaft. The lesser tubercle marks the insertion of the *subscapularis muscle*, which originates on the costal surface of the scapula and rotates the humerus medially.
e. The **greater tubercle** is larger, more posterior, and projects more laterally than the lesser tubercle. The greater tubercle bears rugosities for the insertion of the *su-*

The page on the left talks about different features while the image on the right shows placement of features (White and Folkens, 2005, p. 203 and 204).

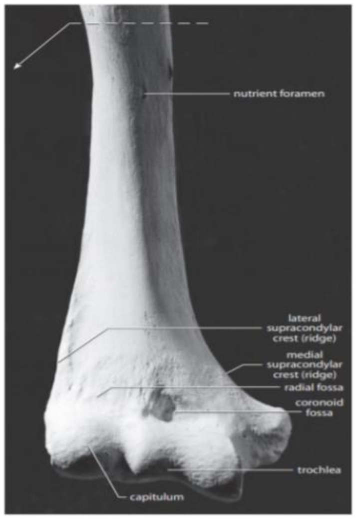


Figure 12.1b Right humerus, anterior. Distal end. Natural size.

praspinatus, *infraspinatus*, and *teres minor muscles*. These muscles, together with the *subscapularis muscle*, constitute the *rotator cuff muscles*. In addition to medial and lateral rotation, these muscles also aid in adduction and abduction of the arm.

f. The **intertubercular sulcus** (**bicipital groove**) extends longitudinally down the proximal shaft. It begins between the two tubercles and houses the *tendon of the long head of the biceps brachii muscle*. In life, the *transverse humeral ligament* connects the two tubercles to bridge the groove and form a canal.

12.1 Humerus 205

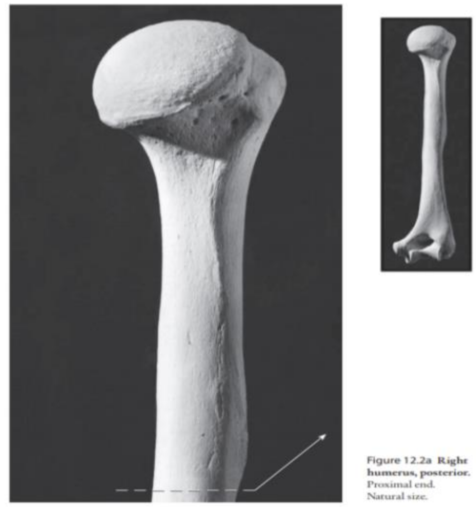


Figure 12.2a Right humerus, posterior. Proximal end. Natural size.

g. The **crest of the greater tubercle** forms the lateral lip of the intertubercular groove. It is the insertion site for the *pectoralis major muscle*, a muscle that originates on the anteromedial clavicle, the sternum, and the cartilage of the true ribs. This muscle acts to flex, adduct, and medially rotate the arm.

h. The **crest of the lesser tubercle** forms the medial lip of the intertubercular groove. It is the insertion site for the *teres major* and *latissimus dorsi muscles*, medial rotators and abductors of the arm.

206 Chapter 12 Arm: Humerus, Radius, & Ulna

The two pages above show different features of the humerus. (White and Folkens, 2005, p. 205 and 206).

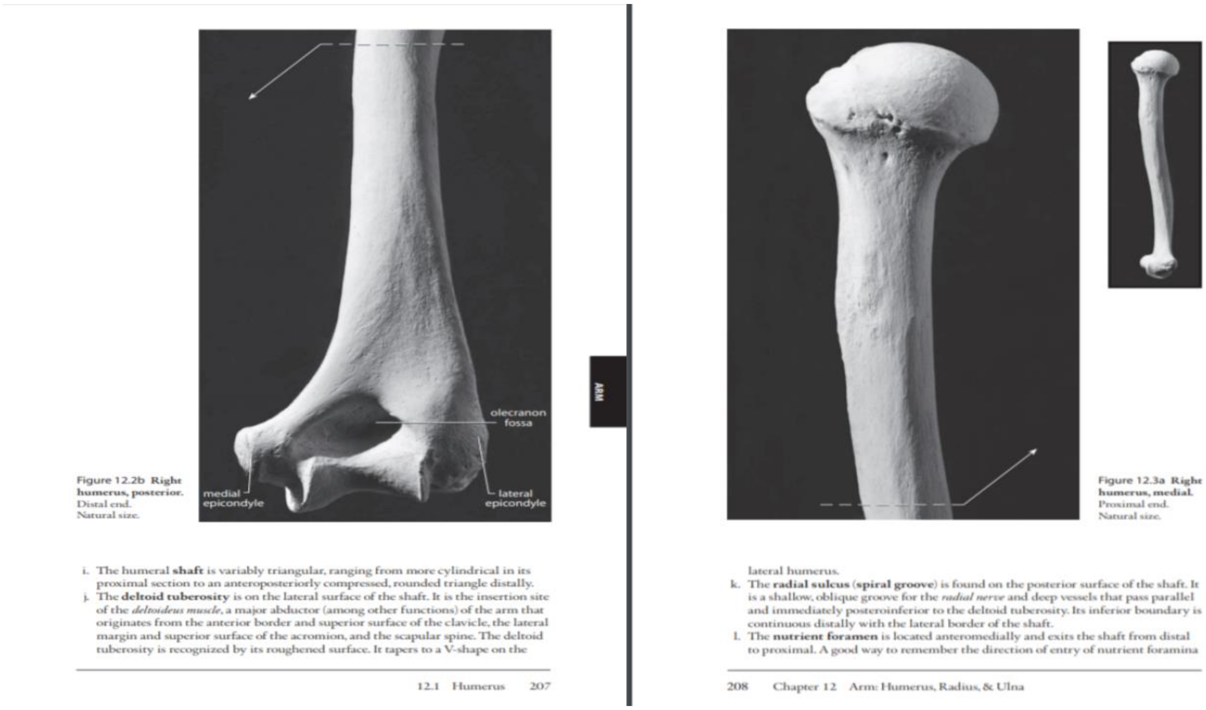


Figure 12.2b Right humerus, posterior. Distal end. Natural size.

i. The humeral **shaft** is variably triangular, ranging from more cylindrical in its proximal section to an anteroposteriorly compressed, rounded triangle distally.
j. The **deltoid tuberosity** is on the lateral surface of the shaft. It is the insertion site of the *deltoideus muscle*, a major abductor (among other functions) of the arm that originates from the anterior border and superior surface of the clavicle, the lateral margin and superior surface of the acromion, and the scapular spine. The deltoid tuberosity is recognized by its roughened surface. It tapers to a V-shape on the

12.1 Humerus 207

Figure 12.3a Right humerus, medial. Proximal end. Natural size.

lateral humerus.
k. The **radial sulcus** (**spiral groove**) is found on the posterior surface of the shaft. It is a shallow, oblique groove for the *radial nerve* and deep vessels that pass parallel and immediately posteroinferior to the deltoid tuberosity. Its inferior boundary is continuous distally with the lateral border of the shaft.
l. The **nutrient foramen** is located anteromedially and exits the shaft from distal to proximal. A good way to remember the direction of entry of nutrient foramina

208 Chapter 12 Arm: Humerus, Radius, & Ulna

The two pages above show different features of the humerus (White and Folkens, 2005, p. 207 and 208).

ARM

Figure 12.3b Right humerus, medial.
Distal end.
Natural size.

into all of the long bones is to imagine tightly flexing your own arms (at the elbows) and legs (at the knees) in front of you. In this position you can look into the bones via the foramina. In long bones, these foramina carry the *nutrient arteries*.

m. The **olecranon fossa** is the largest of three hollows on the distal humerus. It is posterior, accommodating the olecranon process of the ulna during forearm extension. The deepest area of this fossa may be perforated, forming a foramen, or **septal aperture**.

12.1 Humerus 209

Figure 12.4a Right humerus, lateral.
Proximal end.
Natural size.

n. The **coronoid fossa** is the larger, medially placed hollow on the anterior surface of the distal humerus. It receives the coronoid process of the ulna during maximum flexion of the forearm.
o. The **radial fossa** is the smaller, laterally placed hollow on the anterior surface of the distal humerus. It receives the head of the radius during maximum flexion of the forearm.
p. The **capitulum** is the rounded eminence that forms the lateral portion of the

210 Chapter 12 Arm: Humerus, Radius, & Ulna

The two pages above show different features of the humerus (White and Folkens, 2005, p. 209 and 210).

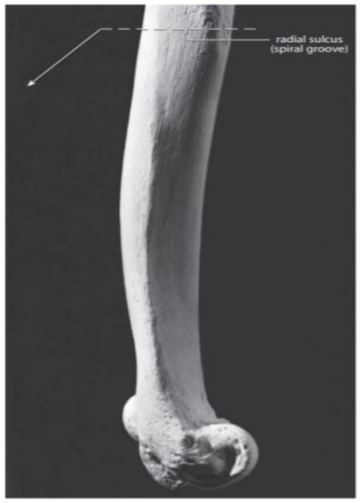


Figure 12.4b Right humerus, lateral. Distal end. Natural size.

distal humeral surface. It articulates with the head of the radius.

q. The **trochlea** is the notch- or spool-shaped medial portion of the distal humeral surface. It articulates with the ulna.

r. The **lateral epicondyle** is the small, nonarticular lateral bulge of bone superolateral to the capitulum. It serves as a site of attachment for the *radial collateral ligament* of the elbow and for the common tendon of origin of the *supinator* and the *extensor muscles* in the forearm.

12.1 Humerus 211

ARM

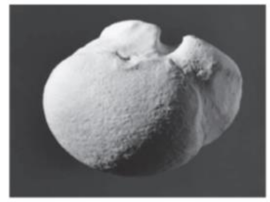


Figure 12.5 Right humerus, proximal. Anterior is up, lateral is toward the right. Natural size.

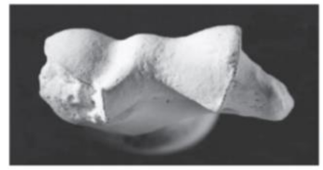


Figure 12.6 Right humerus, distal. Anterior is up, lateral is toward the left. Natural size.

s. The **medial epicondyle** is the nonarticular, medial projection of bone superomedial to the trochlea. It is more prominent than the lateral epicondyle. It provides a site of attachment to the *ulnar collateral ligament*, to many of the *flexor muscles* in the forearm, and to the *pronator teres muscle*.

t. The **medial supracondylar crest** (**ridge**) is superior to the medial epicondyle and forms the sharp medial border of the distal humerus.

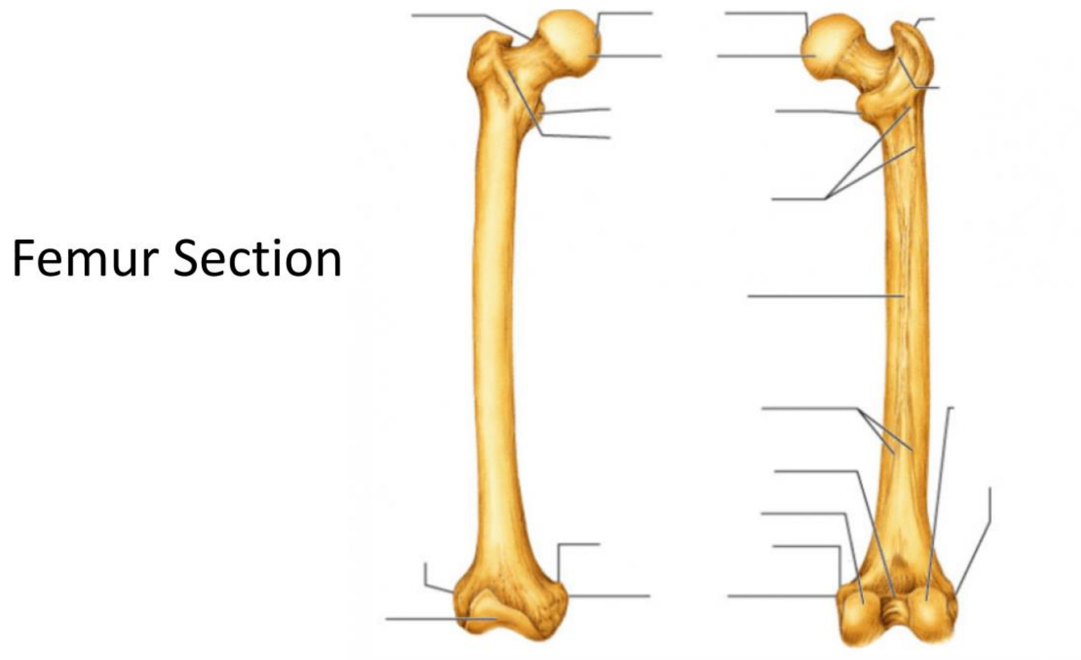
u. The **lateral supracondylar crest** (**ridge**) is superior to the lateral epicondyle and forms the sharp lateral border of the distal humerus.

12.1.2 Growth (Figure 12.7)

The humerus ossifies from eight centers: the shaft, the head, and both tubercles (a composite of several early centers including the head itself and each tubercle; a "conjoint"), the capitulum and trochlea (the capitulum fuses to the trochlea before either fuses to the shaft), and each epicondyle.

212 Chapter 12 Arm: Humerus, Radius, & Ulna

The two pages above show different features of the humerus (White and Folkens, 2005, p. 211 and 212).



This is a blank image of femur that was used to help students learn the features (Eric_Rice_@STJ, 2022).

Chapter 15

Leg: Femur, Patella, Tibia, & Fibula

The evolution of the leg mirrors that of the arm as described in Chapter 12. The single thigh bone, the **femur**, is the serial homolog of the upper arm bone, the humerus. Likewise, the lower bones of the leg, the **tibia** and **fibula**, are serial homologs of the radius and ulna. The largest sesamoid bone in the body, the **patella**, lies at the knee joint. The bipedal locomotor mode practiced by hominids has resulted in major specializations of the leg bones.

15.1 Femur (Figures 15.1–15.6)

15.1.1 Anatomy

The femur is the longest, heaviest, and strongest bone in the body. It supports all of the body's weight during standing, walking, and running. Because of its strength and density, it is frequently recovered in forensic, archeological, and paleontological contexts. The femur is a particularly valuable bone because of the information it can provide on the stature of an individual (see Chapter 19).

The femur articulates with the acetabulum of the os coxae. Distally, it articulates with the patella and the proximal tibia. The leg's actions at the hip include medial and lateral rotation, abduction, adduction, flexion, and extension. At the knee, motion is far more restricted, confined mostly to flexion and extension. Although the main knee action is that of a sliding hinge, this joint is one of the most complex in the body.

a. The **head** is the rounded proximal part of the bone that fits into the acetabulum. It constitutes more of a sphere than the hemispherical humeral head.
b. The **fovea capitis** is the small, nonarticular depression near the center of the head of the femur. It receives the *ligamentum teres* from the acetabular notch of the os coxae.
c. The **neck** of the femur connects the head with the shaft.
d. The **greater trochanter** is the large, blunt, nonarticular prominence on the lateral, proximal part of the femur. It is the insertion site for the *gluteus minimus* (an-

terior aspect of the trochanter) and *gluteus medius muscles* (posterior aspect), both major abductors of the thigh and stabilizers of the hip. Their origins are on the broad, flaring iliac blade of the os coxae. These muscles are crucial in stabilizing the trunk when one leg is lifted from the ground during bipedal locomotion.
e. The **intertrochanteric line** is a variable, fairly vertical, roughened line that passes between the lesser and greater trochanters on the anterior surface of the base of the neck of the femur. Superiorly, this line anchors the *iliofemoral ligament*, which is the largest ligament in the human frame. It acts to strengthen the *joint capsule* of the hip.
f. The **trochanteric fossa** is the pit excavated into the posteromedial wall of the greater trochanter. This pit is for insertion of the *tendon of obturator externus*, a muscle that originates around and across the membrane that stretches across the obturator foramen of the os coxae. This muscle acts to rotate the thigh laterally at the hip. Just above its insertion, the medial tip of the greater trochanter receives several hip muscles: the *superior* and *inferior gemelli*, the *obturator internus*, and the *piriformis*. The latter two are important abductors, and all of these muscles can rotate the femur laterally.
g. The **obturator externus groove** is a shallow depression aligned laterally and superiorly across the posterior surface of the femoral neck. In hominids, erect posture brings the *tendon of the obturator externus muscle* into contact with the posterior surface of the femoral neck, creating the groove.
h. The **lesser trochanter** is the blunt, prominent tubercle on the posterior femoral surface just inferior to the point where the neck joins the shaft. This is the point of insertion of the *iliopsoas tendon* (the common *tendon of the iliacus muscle*, originating in the iliac fossa, and the *psoas major muscle*, originating from the lumbar vertebrae and their disks). These muscles are major flexors of the thigh at the hip.
i. The **intertrochanteric crest** is the elevated line on the posterior surface of the proximal femur between the greater and lesser trochanters. It passes from superolateral to inferomedial. Just above its midpoint is a small tubercle (the **quadrate tubercle**), which is the site of insertion of the *quadratus femoris muscle*, a lateral rotator of the femur.
j. The **gluteal line**, or **tuberosity**, is a long, wide, roughened, posterolaterally placed feature that extends from the base of the greater trochanter to the lip of the linea aspera (see later). It can be a depression or it can assume the form of a true tuberosity. If the latter is present, it is often referred to as the **third trochanter**. It is the insertion for part of the *gluteus maximus muscle*, an extensor, abductor, and lateral rotator of the thigh at the hip that originates on the posterior half of the os coxae, the sacrum, and the coccyx.
k. The **spiral line**, spiraling inferior to the lesser trochanter, connects the inferior end of the intertrochanteric line with the medial lip of the linea aspera. It is the origin of the *vastus medialis muscle*, a part of the *quadriceps femoris muscle*, a knee extensor that inserts on the anterior tibia via the patella.
l. The **pectineal line** is a short, curved line that passes inferolaterally from the base of the lesser trochanter, between the spiral line and gluteal tuberosity. It is the insertion of the *pectineus muscle*, which originates from the pubic part of the os coxae and acts to adduct, laterally rotate, and flex the thigh at the hip.

The two pages above give definitions about different parts of the femur (White and Folkens, 2005, p. 255 and 256).

m. The **femoral shaft** is the long section between the expanded proximal and distal ends of the bone.
n. The **linea aspera** is the long, wide, roughened, and elevated ridge that runs along the posterior shaft surface. It collects the spiral, pectineal, and gluteal lines proximally and divides into the supracondyloid ridges distally. The linea aspera is a primary origin site for the *vastus muscles* and the primary insertion site of the adductors (*longis*, *brevis*, and *magnus*) of the hip.
o. The **nutrient foramen** is located about midshaft level on the posterior surface of the bone, adjacent to or on the linea aspera. This foramen exits the bone distally.
p. The **medial supracondylar line** (**ridge**) is the inferior, medial extension of the linea aspera, marking the distal, medial corner of the shaft. It is fainter than the lateral supracondylar ridge.
q. The **lateral supracondylar line** (**ridge**) is the inferior (distal), lateral extension of the linea aspera. It is more pronounced than the medial supracondylar ridge.
r. The **popliteal surface** is the wide, flat, triangular area of the posterior, distal femur. It is bounded by the condyles inferiorly and by the supracondylar lines medially and laterally.
s. The **lateral condyle** is the large, protruding, articular knob on the lateral side of the distal femur.
t. The **lateral epicondyle** is the convexity on the lateral side of the lateral condyle. It is an attachment point for the *lateral collateral ligament* of the knee. Its upper surface bears a facet that is an attachment point for one head of the *gastrocnemius muscle*, a flexor of the knee and plantarflexor of the foot at the ankle.
u. The **popliteal groove**, a smooth hollow on the posterolateral side of the lateral condyle, is a groove for the *tendon of the popliteus muscle*. This muscle inserts on the posterior tibial surface and is a medial rotator of the tibia at the knee.
v. The **medial condyle** is the large, articular knob on the medial side of the distal femur. Its medial surface bulges away from the axis of the shaft. The medial condyle extends more distally than the lateral condyle.
w. The **medial epicondyle** is the convexity on the medial side of the medial condyle. It is a point of attachment for the *medial collateral ligament* of the knee.
x. The **adductor tubercle** is a variable, raised tubercle on the medial supracondylar ridge just superior to the medial epicondyle. It is an attachment point for the *adductor magnus*, a muscle originating on the lower edge of the ischiopubic ramus and ischial tuberosity. This muscle adducts the thigh at the hip.
y. The **intercondylar fossa**, or **notch**, is the nonarticular, excavated surface between the distal and posterior articular surfaces of the condyles. Within the fossa are two facets that are the femoral attachment sites of the *anterior* and *posterior cruciate ligaments*, a pair of crossed ligaments linking the femur and tibia. These ligaments strengthen the knee joint.
z. The **patellar surface** is a notched, articular area on the anterior surface of the distal femur, over which the patella glides during flexion and extension of the knee. The lateral surface of this notch is elevated, projecting more anteriorly than the medial boundary of the notch. This helps prevent lateral dislocation of the patella during full extension of the knee.

LEG

15.1 Femur 257

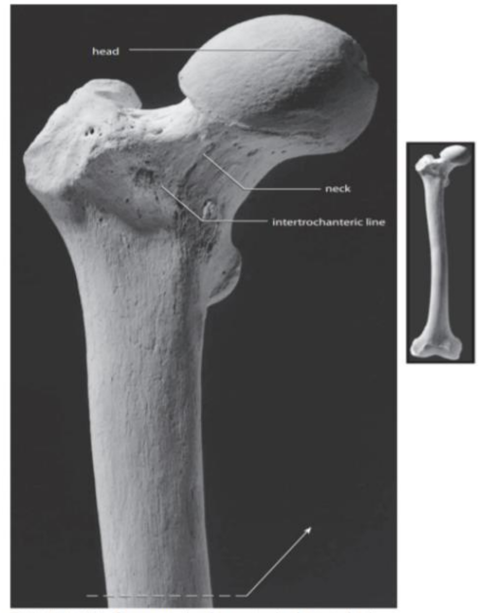
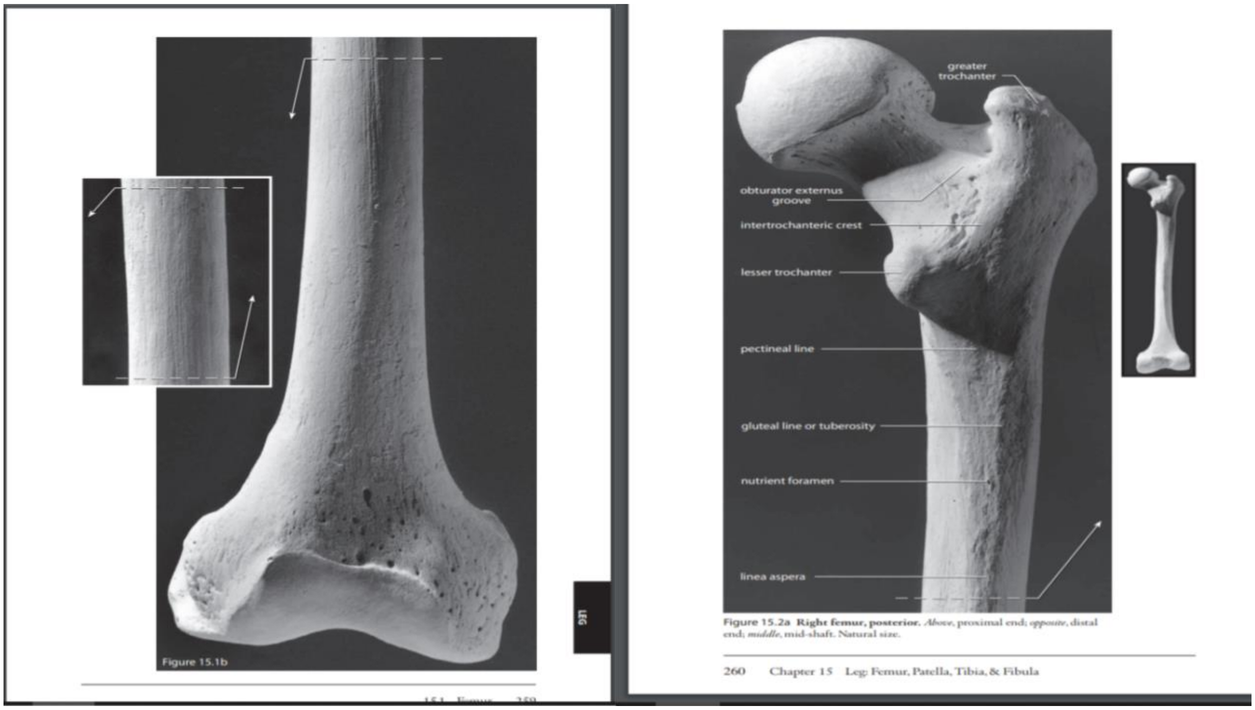


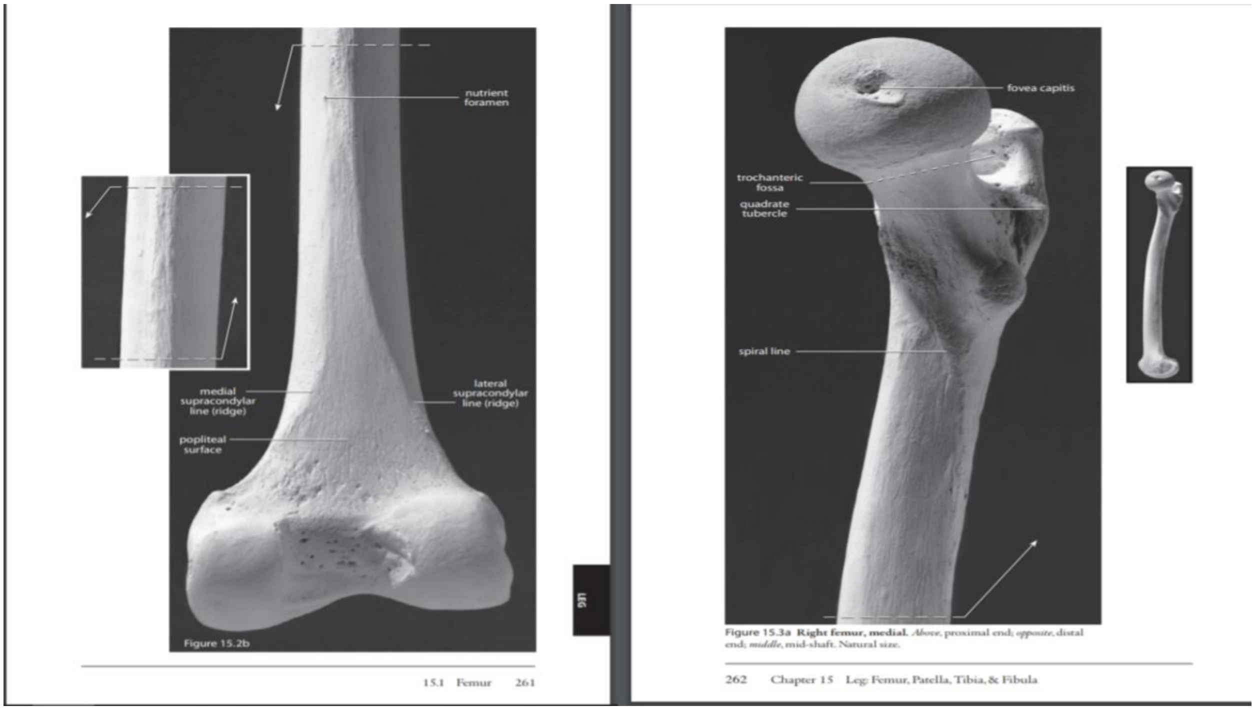
Figure 15.1a Right femur, anterior. *Above*, proximal end; *opposite*, distal end; *middle*, mid-shaft. Natural size.

258 Chapter 15 Leg: Femur, Patella, Tibia, & Fibula

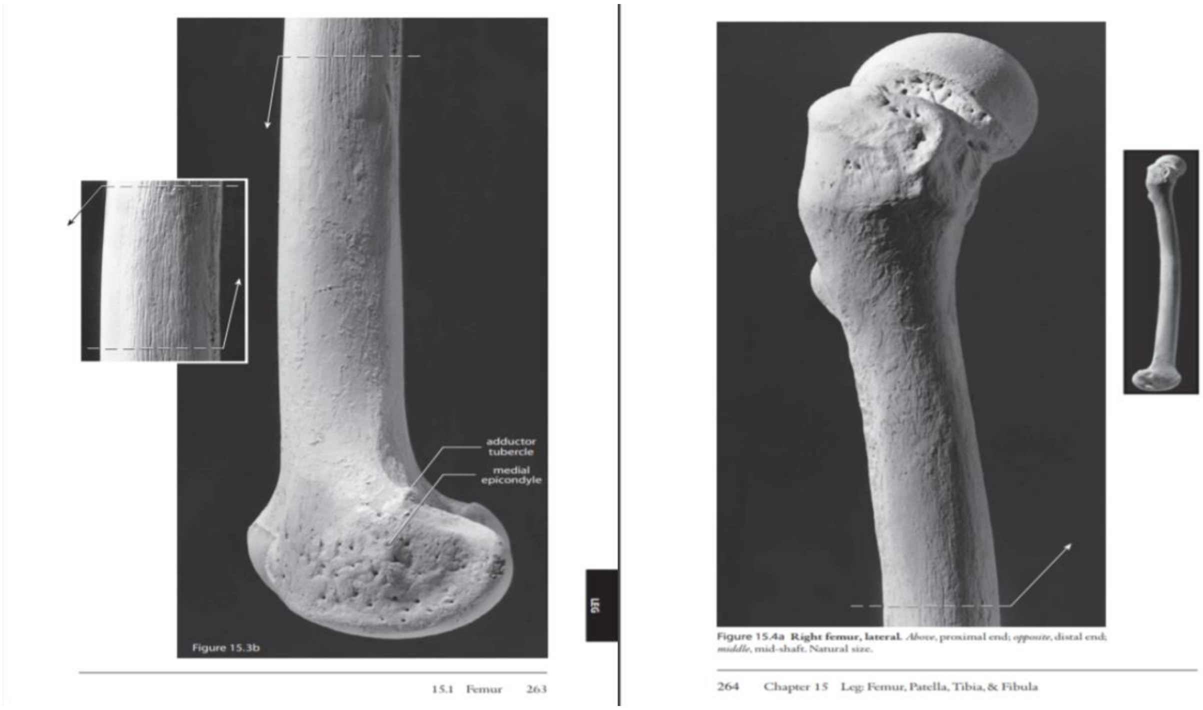
The page on the left talks about different features while the image on the right shows placement of features (White and Folkens, 2005, p. 257 and 258).



The two pages above show different features of the femur (White and Folkens, 2005, p. 259 and 260).



The two pages above show different features of the femur (White and Folkens, 2005, p. 261 and 262).



The two pages above show different features of the femur (White and Folkens, 2005, p. 263 and 264).

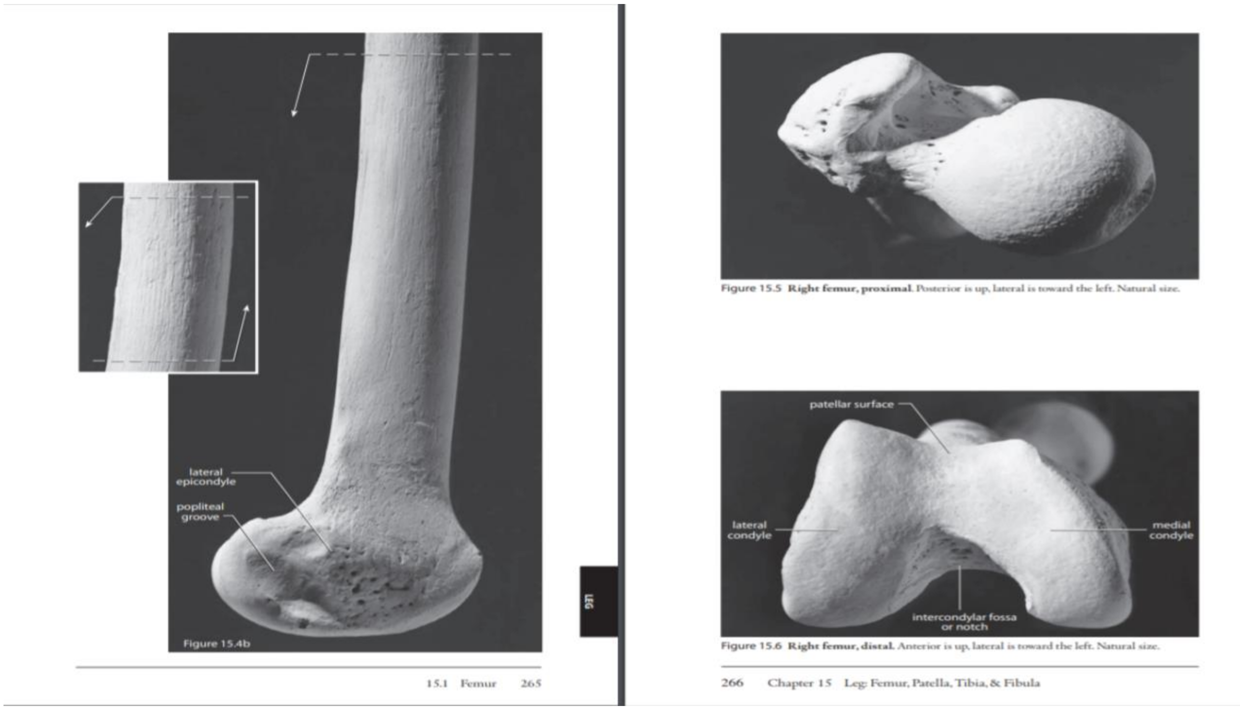


Figure 15.5 **Right femur, proximal.** Posterior is up, lateral is toward the left. Natural size.

Figure 15.6 **Right femur, distal.** Anterior is up, lateral is toward the left. Natural size.

The two pages above show different features of the femur (White and Folkens, 2005, p. 265 and 266).

15.1.2 Growth (Figure 15.7)

The femur ossifies from five centers: one for the shaft, one for the head, one for the distal end, and one for each trochanter.

15.1.3 Possible Confusion

Neither intact femora nor femoral fragments are easily confused with other bones.

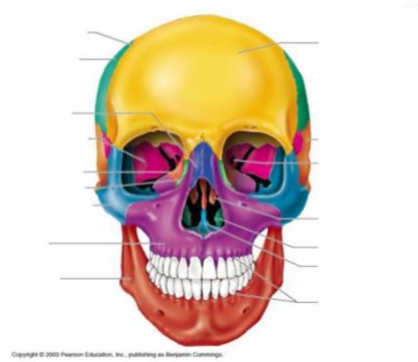
- The femoral head has a fovea and is a more complete sphere than the humeral head.
- The femoral shaft is larger, has a thicker cortex, and is rounder in cross section than any other shaft. It has only one sharp corner, the linea aspera.

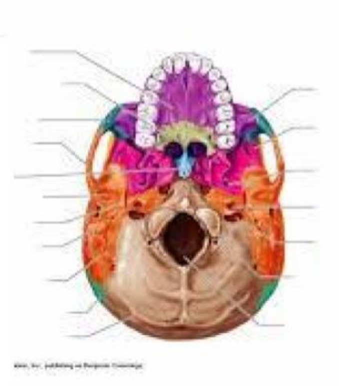
15.1.4 Siding

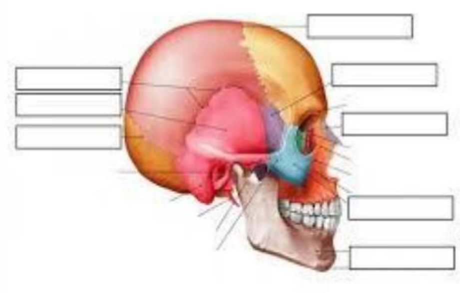
- For intact femora or proximal ends, the head is proximal and faces medially. The lesser trochanter and linea aspera are posterior.
- For isolated femoral heads, the fovea is medial and displaced posteriorly and inferiorly. The posteroinferior head–neck junction is more deeply excavated than the anterosuperior junction.
- For proximal femoral shafts, the nutrient foramen opens distally, and the linea aspera is posterior and thins inferiorly. The gluteal tuberosity is superior and faces posterolaterally.
- For femoral midshafts, the nutrient foramen opens distally, the bone widens distally, and the lateral posterior surface is usually more concave than the medial posterior surface.
- For distal femoral shafts, the shaft widens distally and the lateral supracondylar ridge is more prominent than the medial. The medial condyle extends more distally than the lateral.
- For femoral distal ends, the intercondylar notch is posterior and distal, and the lateral border of the patellar notch is more elevated. The lateral condyle bears the popliteal groove, and the medial condyle bulges away from the line of the shaft. Relative to the shaft axis, the lateral condyle extends more posteriorly than the medial. The medial condyle extends more distally than the lateral because in anatomical position the femur angles beneath the body.

The page above talks about siding and other information about the femur (White and Folkens, 2005, p. 267).

Cranium/Mandible Section

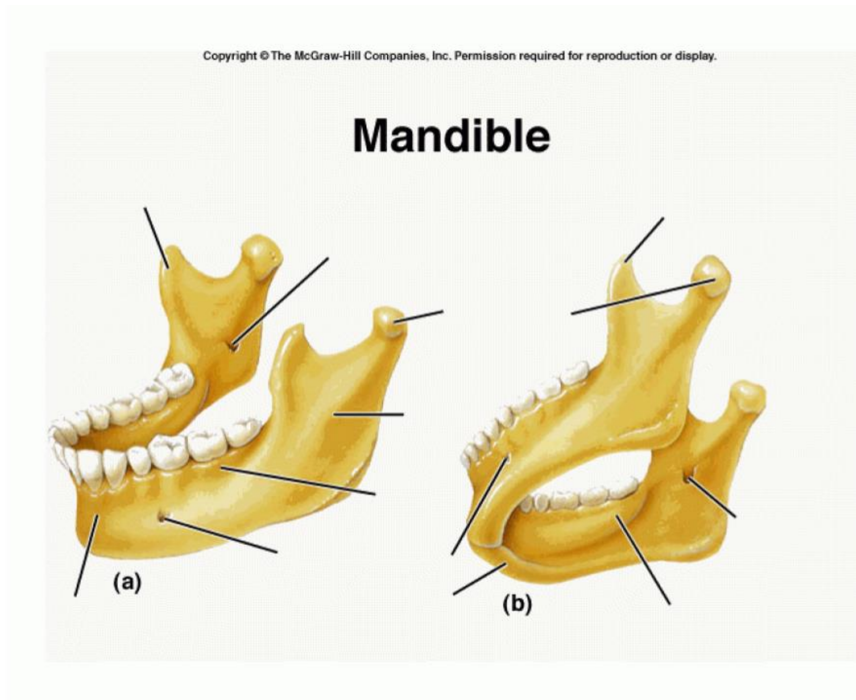






These are three different blank images of the cranium. Three different images were used in order to get a correct view of the different features. The left is an anterior view (Mcscole, 2022), the middle is a view from the base of the cranium (Ellsanatomy, 2022) and the image on the right is a lateral view (aarnold1216, 2022).

Mandible



This is a blank image of mandible that was used to help students learn the features (Srkessler, 2022).

7.20 Mandible (Figures 7.35–7.37)

7.20.1 Anatomy

The mandible, or lower jaw, articulates through its condyles (via an articular disk) with the temporal bones at the temporomandibular joint. The primary function of this bone is in **mastication** (chewing). The mandible holds the lower teeth and provides insertion surfaces for the muscles of mastication. These two functions are performed by the two basic parts of the mandible: the body (corpus) and the ascending ramus.

a. The **body** (**corpus**, or **horizontal ramus**) is the thick, bony part of the mandible that anchors the teeth. With its implanted teeth, the corpus of the mandible is very hard, dense, and resistant to destruction. For this reason, mandibular corpora outlast other body parts in bone assemblages that have been ravaged by carni-

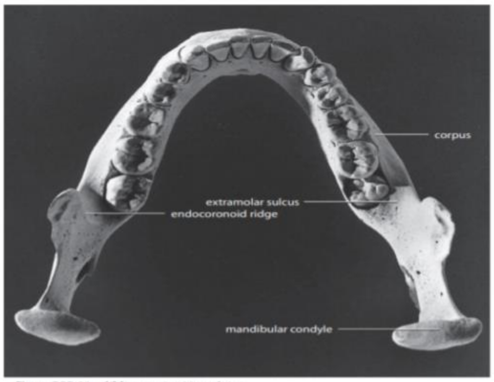


Figure 7.35 **Mandible, superior.** Natural size.

vores or subjected to physical degradation.

b. The **mental foramen** is the large, sometimes multiple foramen located on the lateral corpus surface, near midcorpus, below the premolar region. This foramen transmits the *mental vessels* and *nerve* (another division of cranial nerve 5).
c. The **oblique line** is a weak eminence that passes from the root of the ramus to the area at the rear of the mental foramen.
d. The **extramolar sulcus** is the gutter between the root of the anterior edge of the ramus and the lateral alveolar margin of the last molar. This area gives rise to the *buccinator muscle*, the muscle of the cheek.
e. The **mylohyoid line** obliquely crosses the medial surface of the corpus, beginning near the alveolar margin at the last molar position and diminishing as it runs anteroinferiorly. It marks an attachment site for the *mylohyoid muscle*, a muscle that forms the muscular floor of the oral cavity and acts to elevate the *tongue* and hyoid bone.
f. The **submandibular fossa** is the hollow beneath the alveolar portion that runs along the medial corpus, inferior to the mylohyoid line. In life, the *submandibular gland*, one of the salivary glands, rests in this fossa.
g. The **sublingual fossa** is the hollowing beneath the alveolar region, superior to the mylohyoid line in the premolar region. The *sublingual gland*, another salivary gland, rests in this fossa.
h. A **mandibular torus** is the variably developed thickening of the alveolar margin just lingual to the cheek teeth. This feature takes on a billowed appearance in its most extreme manifestations but is often imperceptible.
i. The **mandibular symphysis** technically refers only to the midline surfaces of unfused right and left mandibular halves in individuals less than 1 year of age. It is often used as a more general term referring to the anterior region of the mandible between the canines.
j. The **mental spines** lie near the inferior margin of the inner (posterior) surface of the anterior corpus. They are variable in prominence and anchor the *genioglossal* and *geniohyoid muscles*, muscles of the tongue.
k. The **digastric fossae** are the pair of roughened depressions on the posteroinferior aspect of the corpus adjacent to the midline. They face posteroinferiorly and are attachment sites for the *digastric muscles*, depressors of the mandible.
l. The **mental protuberance** (**mental eminence**) is the triangular eminence, or bony chin, at the base of the corpus in the anterior symphyseal region. It is separated from the alveolar margins of the incisors by a pronounced incurvation or "mental sulcus" (or the "labiomental sulcus" if flesh is still attached to the depression) in modern humans.
m. The **ramus** (or **ascending ramus**) is considerably thinner than the corpus. This vertical part of the mandible rises above the level of the teeth and articulates with the cranial base.
n. The **mandibular condyle** is the large, rounded, articular prominence on the posterosuperior corner of the ramus. It articulates at the temporomandibular joint.
o. The **condylar neck** is the area just anteroinferior to the condyle. A head of the *lateral pterygoid muscle* attaches to the anteromedial surface of the neck just below the articular surface of the condyle, in the **pterygoid fovea**. This muscle acts to depress and stabilize the mandibular condyle during chewing.

The page on the left shows the placement of the features while the right talks about different features (White and Folkens, 2005, p. 122 and 123).

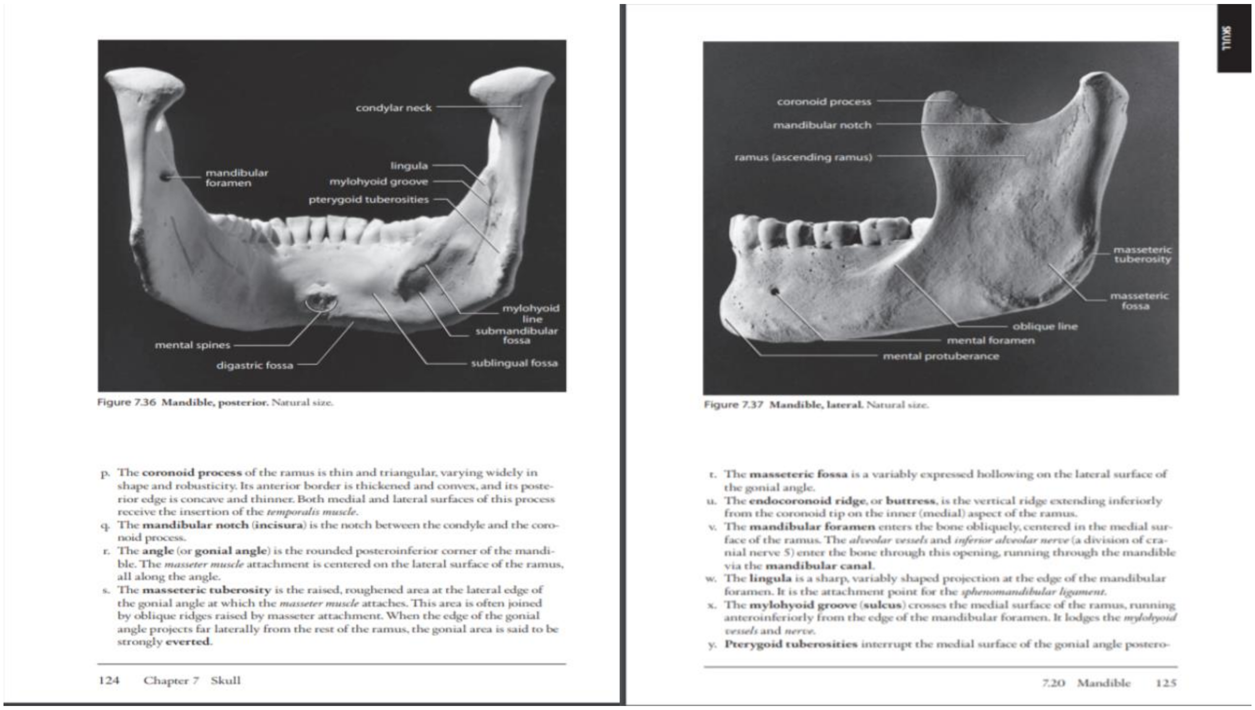


Figure 7.36 Mandible, posterior. Natural size.

p. The **coronoid process** of the ramus is thin and triangular, varying widely in shape and robusticity. Its anterior border is thickened and convex, and its posterior edge is concave and thinner. Both medial and lateral surfaces of this process receive the insertion of the *temporalis muscle*.
q. The **mandibular notch** (**incisura**) is the notch between the condyle and the coronoid process.
r. The **angle** (or **gonial angle**) is the rounded posteroinferior corner of the mandible. The *masseter muscle* attachment is centered on the lateral surface of the ramus, all along the angle.
s. The **masseteric tuberosity** is the raised, roughened area at the lateral edge of the gonial angle at which the *masseter muscle* attaches. This area is often joined by oblique ridges raised by masseter attachment. When the edge of the gonial angle projects far laterally from the rest of the ramus, the gonial area is said to be strongly **everted**.

124 Chapter 7 Skull

Figure 7.37 Mandible, lateral. Natural size.

t. The **masseteric fossa** is a variably expressed hollowing on the lateral surface of the gonial angle.
u. The **endocoronoid ridge**, or **buttress**, is the vertical ridge extending inferiorly from the coronoid tip on the inner (medial) aspect of the ramus.
v. The **mandibular foramen** enters the bone obliquely, centered in the medial surface of the ramus. The *alveolar vessels* and *inferior alveolar nerve* (a division of cranial nerve 5) enter the bone through this opening, running through the mandible via the **mandibular canal**.
w. The **lingula** is a sharp, variably shaped projection at the edge of the mandibular foramen. It is the attachment point for the *sphenomandibular ligament*.
x. The **mylohyoid groove** (**sulcus**) crosses the medial surface of the ramus, running anteroinferiorly from the edge of the mandibular foramen. It lodges the *mylohyoid vessels* and *nerve*.
y. **Pterygoid tuberosities** interrupt the medial surface of the gonial angle postero-

7.20 Mandible 125

The two pages above show different features of the mandible (White and Folkens, 2005, p. 124 and 125).

inferior to the mylohyoid groove. They mark the insertion of the *medial pterygoid muscle*, an elevator of the mandible.

7.20.2 Growth

The mandibular halves are separate at birth; they join during the first year at the symphysis. At birth the mandible holds unerupted deciduous teeth in crypts below the surface. The eruption of these teeth and their permanent counterparts effects dramatic changes on the mandible during ontogeny. Loss of permanent teeth results in resorption of the alveolar portion of the mandible.

7.20.3 Possible Confusion

Only small fragments of mandible can be confused with other bones. Where tooth sockets are present, the bone must be maxilla or mandible. The former has a sinus above the molar roots.

- The mandibular corpus has a much thicker cortex than the maxilla, as well as a basal contour.
- The coronoid process might be mistaken for thin cranial bones, such as the sphenoid or zygomatic. Note, however, that the coronoid does not articulate and its edges are therefore nonsutural.

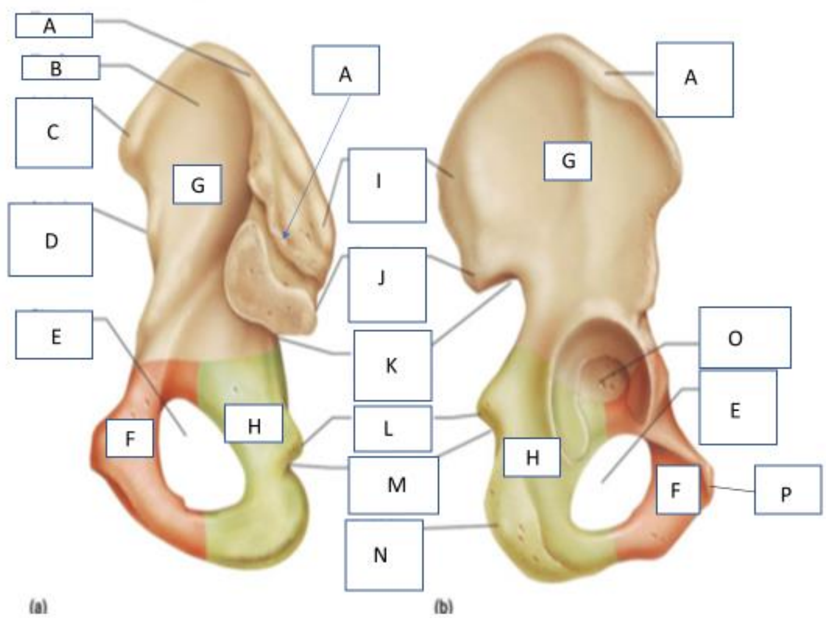
7.20.4 Siding

To side fragments of mandible, remember that the incisors are anterior and closer to the midline than the molars, and that the ramus is posterior, with greater relief on its medial surface.

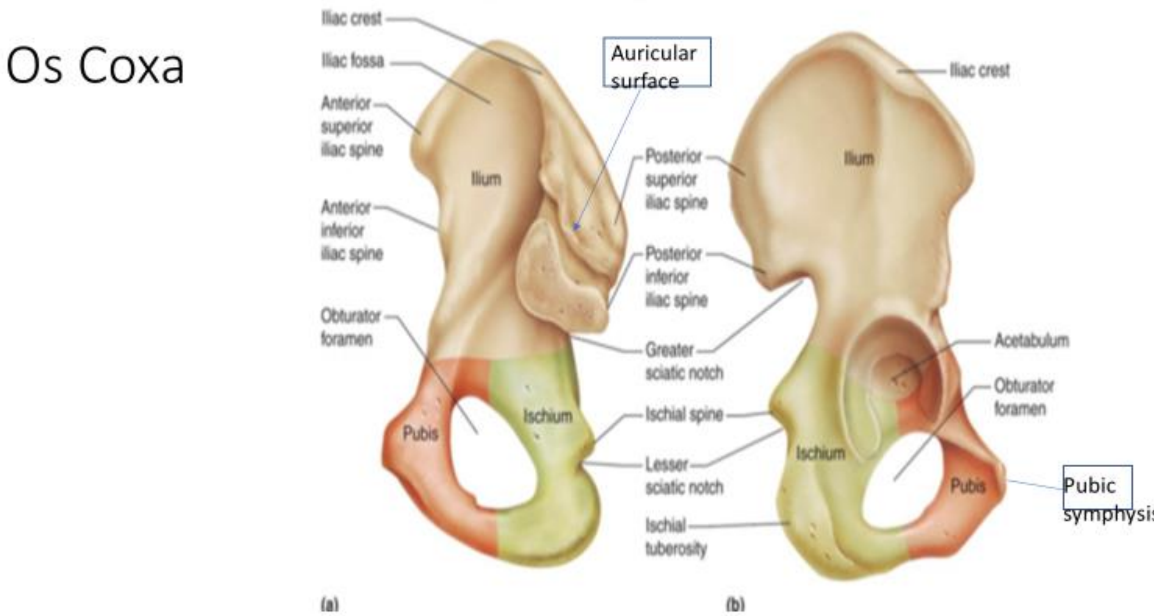
- For isolated condyles, the border of the mandibular notch is continuous with the lateral side of the condyle (most of the condyle itself lies medial to the plane of the ramus).
- For isolated coronoids, the notch is posterior, the tip superior, and the endocoronoid buttress medial.
- For isolated gonial angles, tuberosities for the medial pterygoid are medial and are anterosuperiorly directed.

The page above talks about siding and other information about the mandible (White and Folkens, 2005, p. 126).

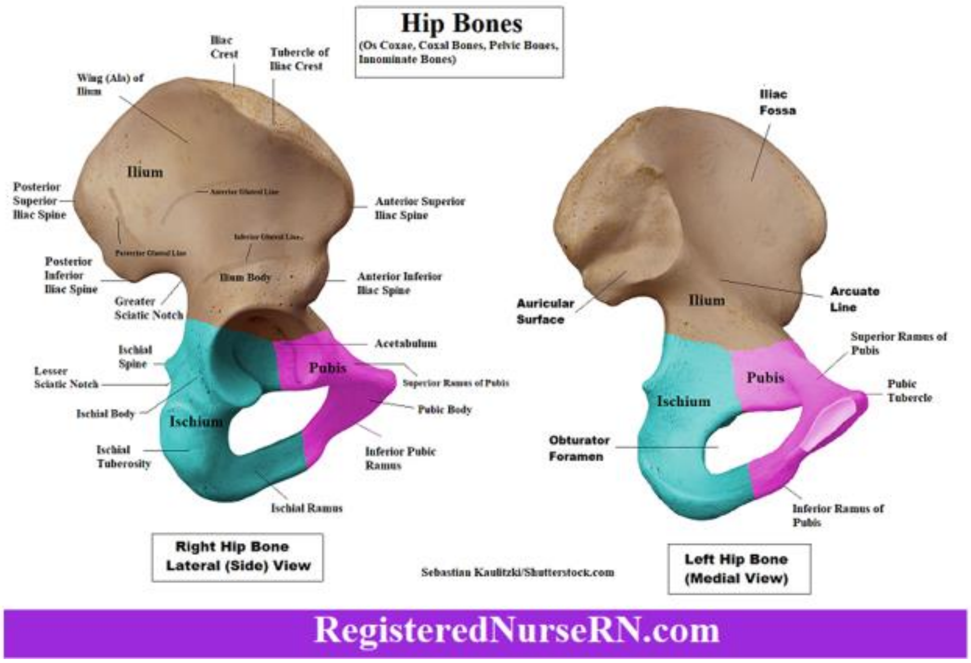
Os Coxa



This is a blank image of os coxa that was used to help students learn the features (Chandlerphysicaltherapy, 2014).

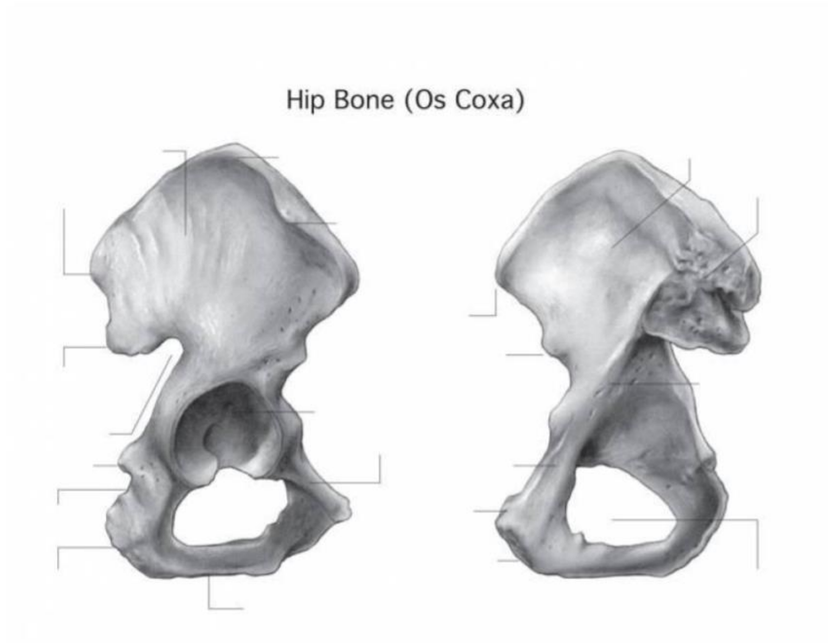


This is a labeled image of the os coxa that was used to help students learn the features (Chandlerphysicaltherapy, 2014).

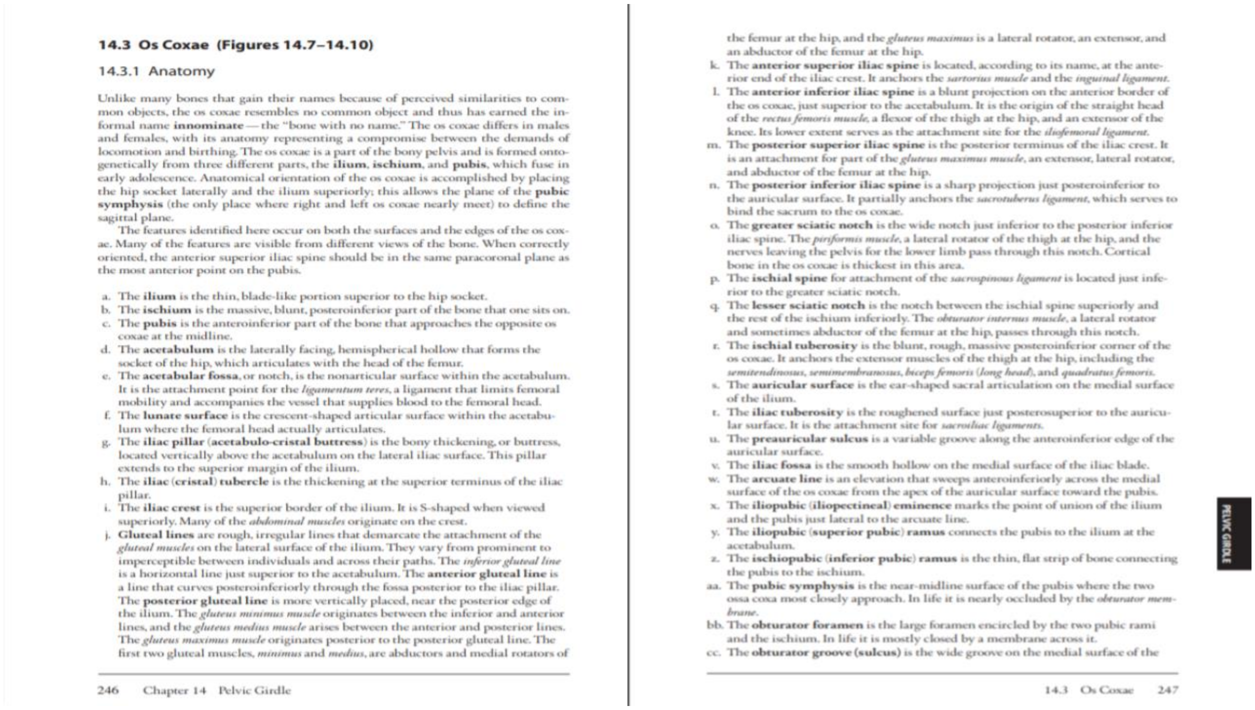


This is a labeled image of the os coxa that was used to help students learn the features (Registered Nurse RN, 2019).

Os Coxa



This is a blank image of os coxa that was used to help students learn the features (Soulpat, 2022).



14.3 Os Coxae (Figures 14.7–14.10)

14.3.1 Anatomy

Unlike many bones that gain their names because of perceived similarities to common objects, the os coxae resembles no common object and thus has earned the informal name **innominate**—the "bone with no name." The os coxae differs in males and females, with its anatomy representing a compromise between the demands of locomotion and birthing. The os coxae is a part of the bony pelvis and is formed ontogenetically from three different parts, the **ilium**, **ischium**, and **pubis**, which fuse in early adolescence. Anatomical orientation of the os coxae is accomplished by placing the hip socket laterally and the ilium superiorly; this allows the plane of the **pubic symphysis** (the only place where right and left os coxae nearly meet) to define the sagittal plane.

The features identified here occur on both the surfaces and the edges of the os coxae. Many of the features are visible from different views of the bone. When correctly oriented, the anterior superior iliac spine should be in the same paracoronal plane as the most anterior point on the pubis.

a. The **ilium** is the thin, blade-like portion superior to the hip socket.
b. The **ischium** is the massive, blunt, posteroinferior part of the bone that one sits on.
c. The **pubis** is the anteroinferior part of the bone that approaches the opposite os coxae at the midline.
d. The **acetabulum** is the laterally facing, hemispherical hollow that forms the socket of the hip, which articulates with the head of the femur.
e. The **acetabular fossa**, or notch, is the nonarticular surface within the acetabulum. It is the attachment point for the *ligamentum teres*, a ligament that limits femoral mobility and accompanies the vessel that supplies blood to the femoral head.
f. The **lunate surface** is the crescent-shaped articular surface within the acetabulum where the femoral head actually articulates.
g. The **iliac pillar** (**acetabulo-cristal buttress**) is the bony thickening, or buttress, located vertically above the acetabulum on the lateral iliac surface. This pillar extends to the superior margin of the ilium.
h. The **iliac** (**cristal**) **tubercle** is the thickening at the superior terminus of the iliac pillar.
i. The **iliac crest** is the superior border of the ilium. It is S-shaped when viewed superiorly. Many of the *abdominal muscles* originate on the crest.
j. **Gluteal lines** are rough, irregular lines that demarcate the attachment of the *gluteal muscles* on the lateral surface of the ilium. They vary from prominent to imperceptible between individuals and across their paths. The *inferior gluteal line* is a horizontal line just superior to the acetabulum. The **anterior gluteal line** is a line that curves posteroinferiorly through the fossa posterior to the iliac pillar. The **posterior gluteal line** is more vertically placed, near the posterior edge of the ilium. The *gluteus minimus muscle* originates between the inferior and anterior lines, and the *gluteus medius muscle* arises between the anterior and posterior lines. The *gluteus maximus muscle* originates posterior to the posterior gluteal line. The first two gluteal muscles, *minimus* and *medius*, are abductors and medial rotators of

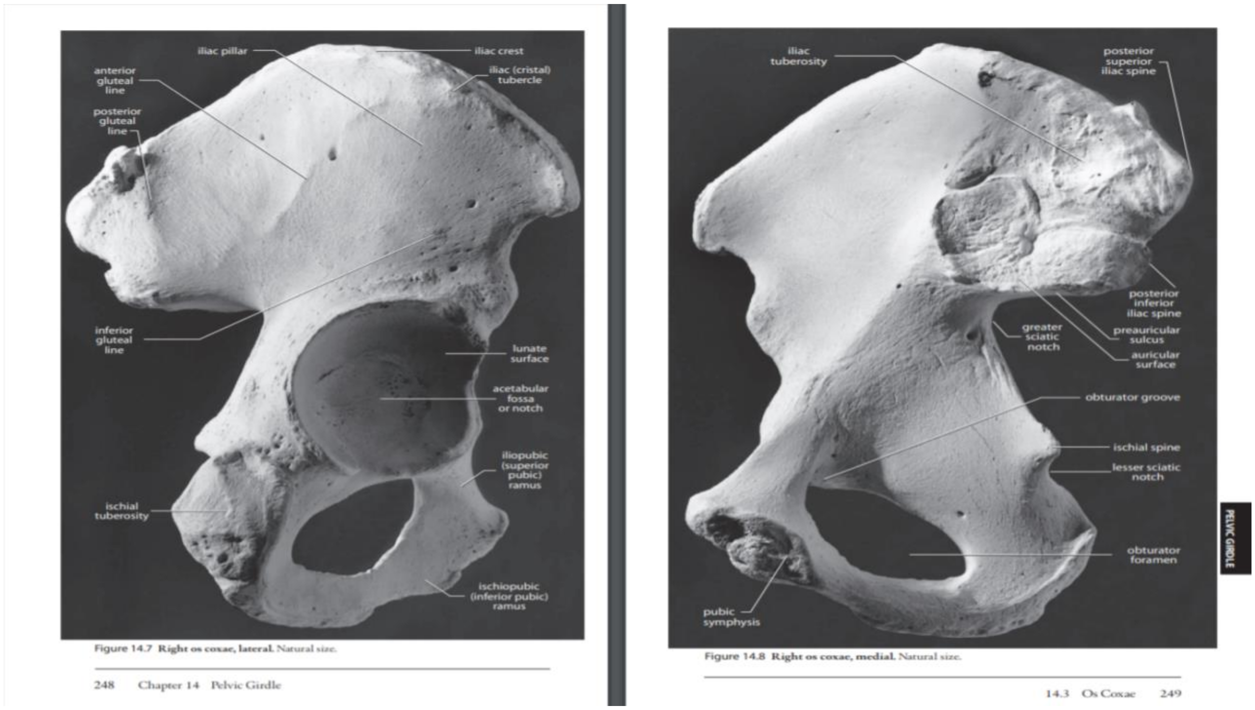
246 Chapter 14 Pelvic Girdle

the femur at the hip, and the *gluteus maximus* is a lateral rotator, an extensor, and an abductor of the femur at the hip.
k. The **anterior superior iliac spine** is located, according to its name, at the anterior end of the iliac crest. It anchors the *sartorius muscle* and the *inguinal ligament*.
l. The **anterior inferior iliac spine** is a blunt projection on the anterior border of the os coxae, just superior to the acetabulum. It is the origin of the straight head of the *rectus femoris muscle*, a flexor of the thigh at the hip, and an extensor of the knee. Its lower extent serves as the attachment site for the *iliofemoral ligament*.
m. The **posterior superior iliac spine** is the posterior terminus of the iliac crest. It is an attachment for part of the *gluteus maximus muscle*, an extensor, lateral rotator, and abductor of the femur at the hip.
n. The **posterior inferior iliac spine** is a sharp projection just posteroinferior to the auricular surface. It partially anchors the *sacrotuberus ligament*, which serves to bind the sacrum to the os coxae.
o. The **greater sciatic notch** is the wide notch just inferior to the posterior inferior iliac spine. The *piriformis muscle*, a lateral rotator of the thigh at the hip, and the nerves leaving the pelvis for the lower limb pass through this notch. Cortical bone in the os coxae is thickest in this area.
p. The **ischial spine** for attachment of the *sacrospinous ligament* is located just inferior to the greater sciatic notch.
q. The **lesser sciatic notch** is the notch between the ischial spine superiorly and the rest of the ischium inferiorly. The *obturator internus muscle*, a lateral rotator and sometimes abductor of the femur at the hip, passes through this notch.
r. The **ischial tuberosity** is the blunt, rough, massive posteroinferior corner of the os coxae. It anchors the extensor muscles of the thigh at the hip, including the *semitendinosus, semimembranosus, biceps femoris (long head)*, and *quadratus femoris*.
s. The **auricular surface** is the ear-shaped sacral articulation on the medial surface of the ilium.
t. The **iliac tuberosity** is the roughened surface just posterosuperior to the auricular surface. It is the attachment site for *sacroiliac ligaments*.
u. The **preauricular sulcus** is a variable groove along the anteroinferior edge of the auricular surface.
v. The **iliac fossa** is the smooth hollow on the medial surface of the iliac blade.
w. The **arcuate line** is an elevation that sweeps anteroinferiorly across the medial surface of the os coxae from the apex of the auricular surface toward the pubis.
x. The **iliopubic** (**iliopectineal**) **eminence** marks the point of union of the ilium and the pubis just lateral to the arcuate line.
y. The **iliopubic** (**superior pubic**) **ramus** connects the pubis to the ilium at the acetabulum.
z. The **ischiopubic** (**inferior pubic**) **ramus** is the thin, flat strip of bone connecting the pubis to the ischium.
aa. The **pubic symphysis** is the near-midline surface of the pubis where the two ossa coxa most closely approach. In life it is nearly occluded by the *obturator membrane*.
bb. The **obturator foramen** is the large foramen encircled by the two pubic rami and the ischium. In life it is mostly closed by a membrane across it.
cc. The **obturator groove (sulcus)** is the wide groove on the medial surface of the

PELVIC GIRDLE

14.3 Os Coxae 247

The two pages above give definitions about different parts of the os coxa (White and Folkens, 2005, p. 246 and 247).



The two pages above show different features of the os coxa (White and Folkens, 2005, p. 248 and 249).

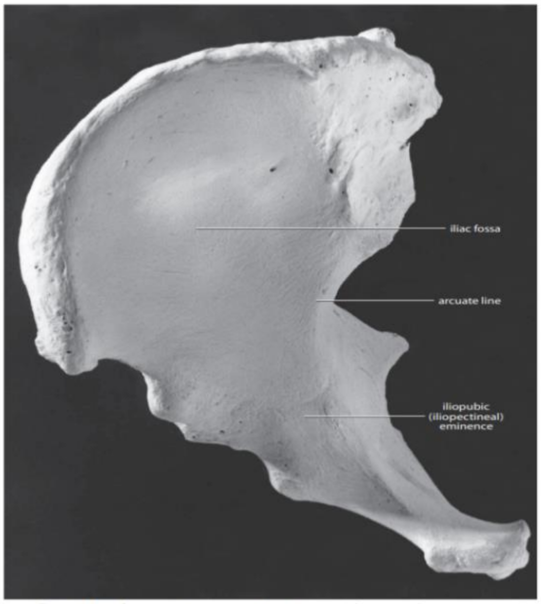
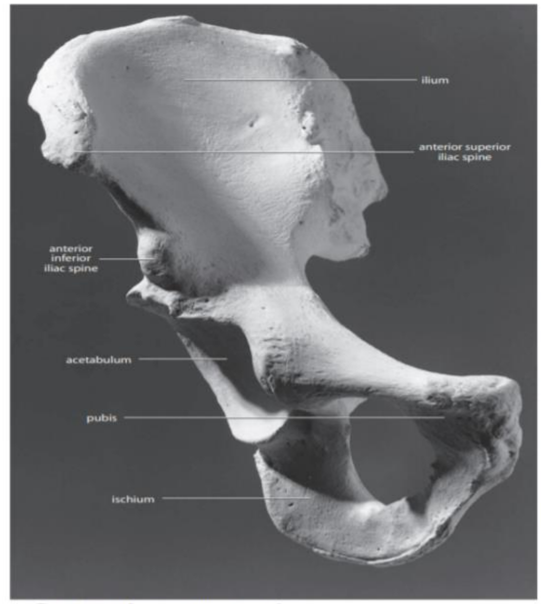


Figure 14.9 Right os coxae, anterosuperior view. Anterior is down. Natural size.

250 Chapter 14 Pelvic Girdle



PELVIC GIRDLE

Figure 14.10 Right os coxae, anterior. Natural size.

14.3 Os Coxae 251

The two pages above show different features of the os coxa (White and Folkens, 2005, p. 250 and 251).

iliopubic ramus, at the superolateral corner of the obturator foramen. The *obturator vessels* and *nerve* pass through this groove.

14.3.2 Growth (Figure 14.11)

There are three primary and five secondary centers of ossification in each os coxae. The ilium, ischium, and pubis form the primary centers, fusing around the acetabulum. The ilium has one secondary center at the anterior inferior spine and one across the iliac crest. The pubis has one center at the symphysis (the "ventral rampart"), and the ischium has one at the tuberosity that extends along the inferior pubic ramus. The eighth center ("os cotyledon") is located in the depth of the acetabulum.

14.3.3 Possible Confusion

- Fragmentary iliac blades might be mistaken for cranial or scapular fragments. The cranial bones are, however, of more uniform thickness. They have cortices of about equal thickness around the diploë.
- Scapular blades are thinner than iliac blades and display subscapular ridges.
- Fragmentary auricular areas could be mistaken for sacra, but in the latter bone there are attached alae, and the adjacent surfaces have no evidence of sacroiliac roughening or sciatic notches.

14.3.4 Siding

When intact, the os coxae is easily sided because the pubis is anterior, the iliac crest is superior, and the acetabulum is lateral. When fragmentary, various parts of the os coxae can be sided as follows:

- For isolated pubic regions, the ventral surface is rough, the dorsal surface is smooth and convex, the symphysis faces the midline, and the superior pubic ramus is more robust than the inferior pubic ramus.
- For isolated ischial regions, the thicker ramus faces the acetabulum. The thinner ramus is therefore anteroinferior. The surface of the ischial tuberosity faces posterolaterally.
- For isolated iliac blades, the iliac pillar is lateral and is anteriorly displaced. The auricular surface and related structures are posterior and medial.
- For isolated iliac crests, the iliac tubercle is anterior and lateral, and the lateral surface anterior to it is more concave than the surface posterior to it. The crest sweeps posteromedially from this point until it reaches the level of the anterior edge of the auricular surface and turns laterally.
- For isolated acetabula, the acetabular notch is inferior and faces slightly anteriorly. The inferior end of the "c" made by the lunate surface is broader and more blunt than the superior end. The ischial ramus is posterior, and the superior pubic ramus is anterior. The ilium is superior.

252 Chapter 14 Pelvic Girdle

Figure 14.11 Os coxae growth. The three elements of the os coxae, shown here in lateral view, are from a one-year-old (*left*) and a six-year-old (*right*). Natural size.

PELVIC GIRDLE

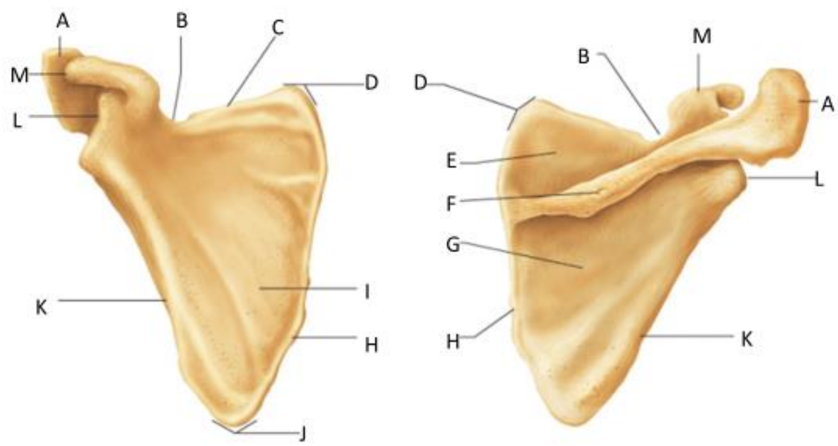
- For isolated auricular surfaces, the auricular surface is posterior on the ilium and faces medially. Its apex points anteriorly, and the roughened surface for the sacroiliac ligaments is posterosuperior. The greater and lesser sciatic notches are posteroinferior.

14.3 Os Coxae 253

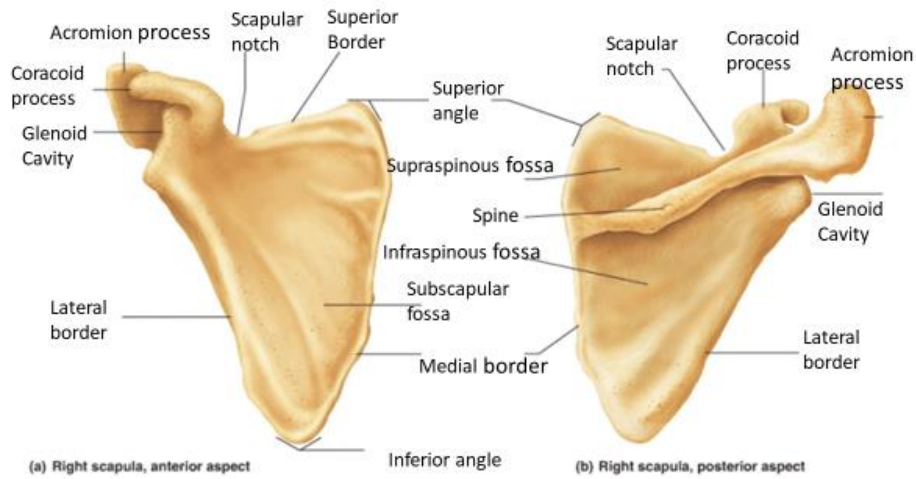
The page on the left talks about siding while the image on the right illustrates growth of the os coxa (White and Folkens, 2005, p. 252 and 253).

Appendix E

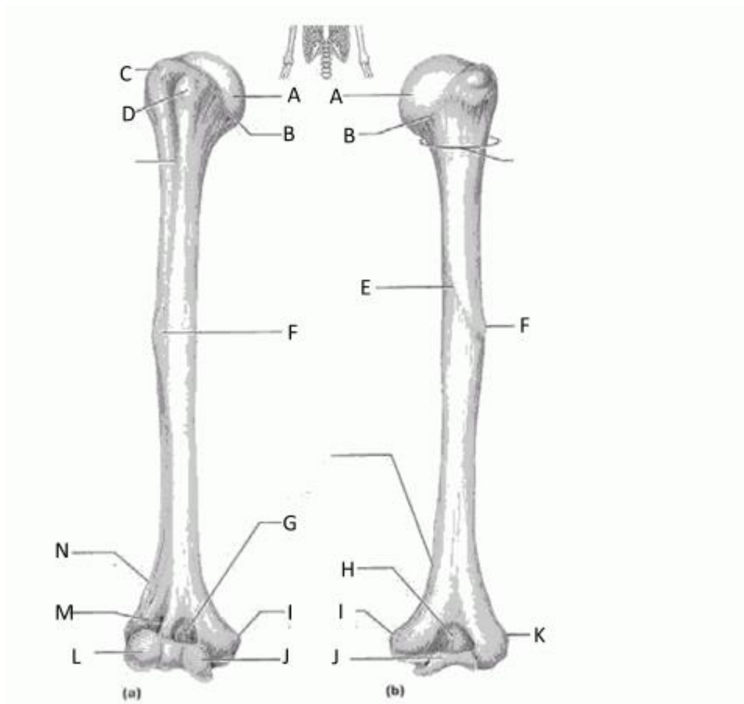
Student Resource Library Labeled and Blank Images



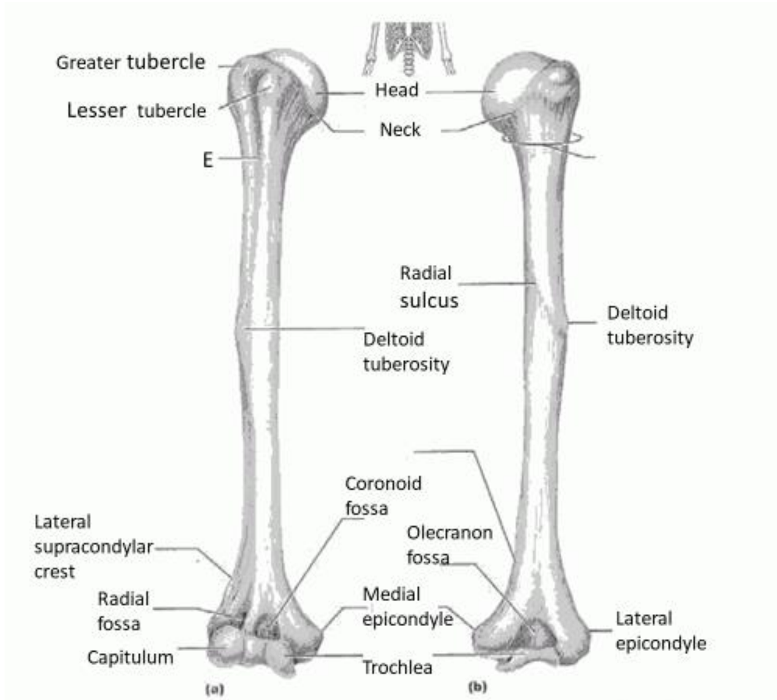
For this section of the resource library students had images that were blank/labeled with letter and numbers and images that had the correct name of the features listed. The Labeled images were used for the pre and posttests as well as being a resource for the participants in the resource library (LilStride, 2022).



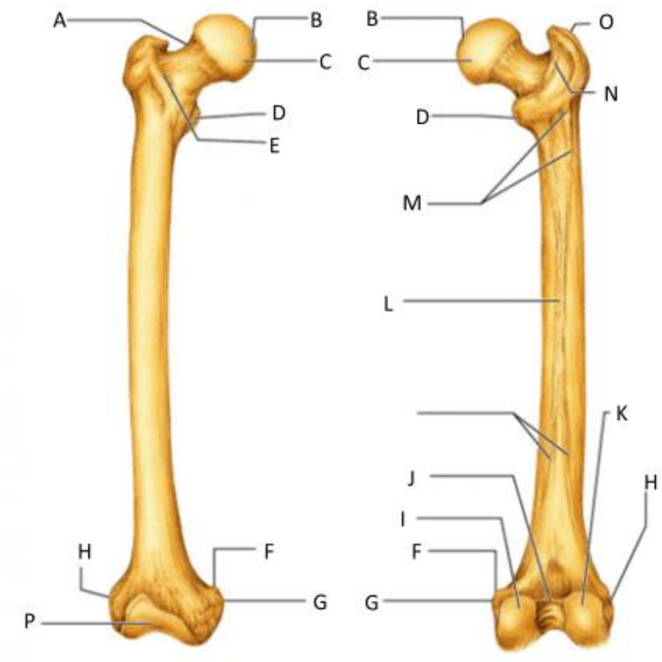
This image depicts the scapula with the features labeled (LilStride, 2022).



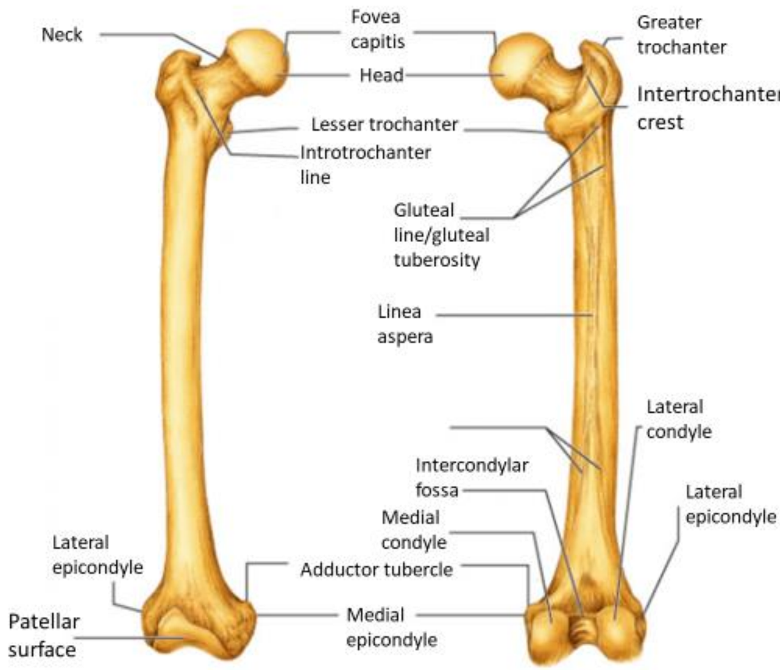
This image depicts the humerus with the features not listed (Sarahmcnamee, 2022).



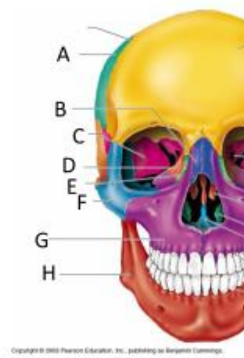
This image depicts the humerus with the features labeled (Sarahmcnamee, 2022).

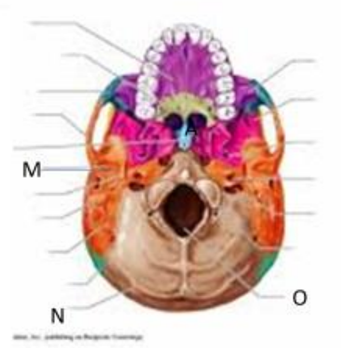


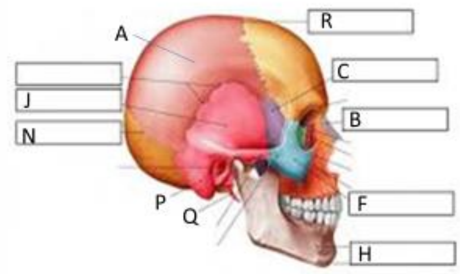
This image depicts the femur with the features not listed (Eric_Rice_@STJ, 2022).



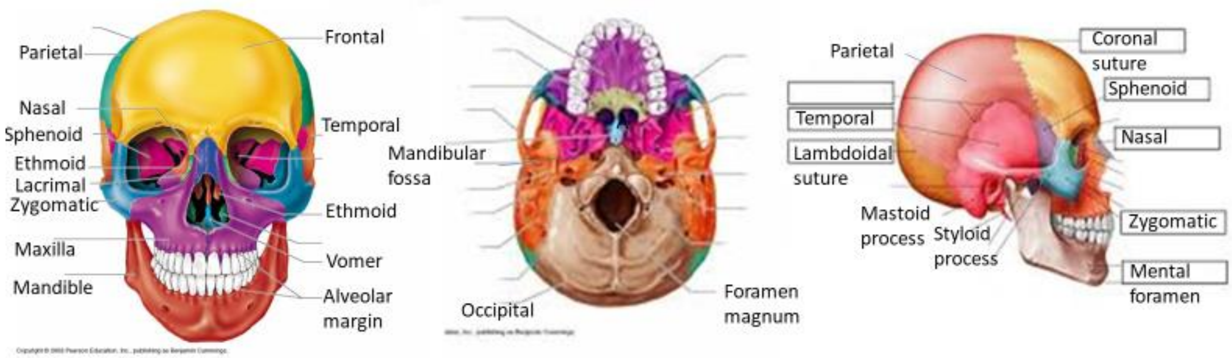
This image depicts the femur with the features labeled (Eric_Rice_@STJ, 2022).



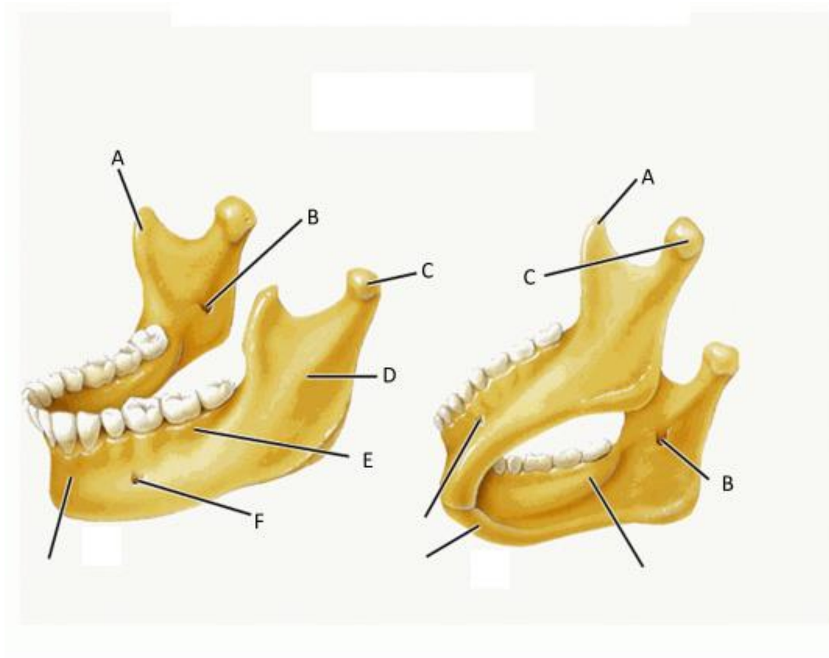




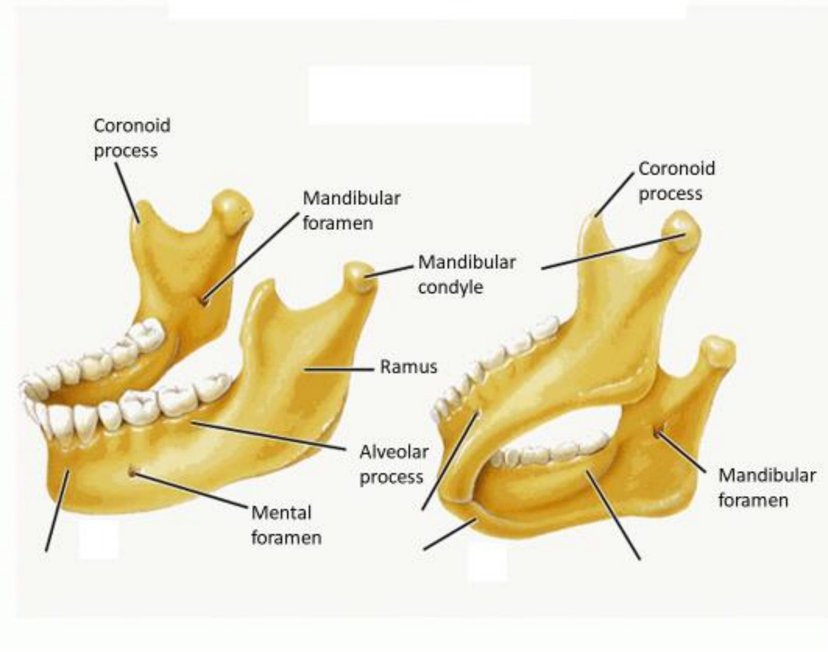
These are three different blank images of the cranium. Three different images were used in order to get a correct view of the different features. The left is an anterior view (Mcscole, 2022), the middle is a view from the base of the cranium (Ellsanatomy, 2022) and the image on the right is a lateral view (aarnold1216, 2022).



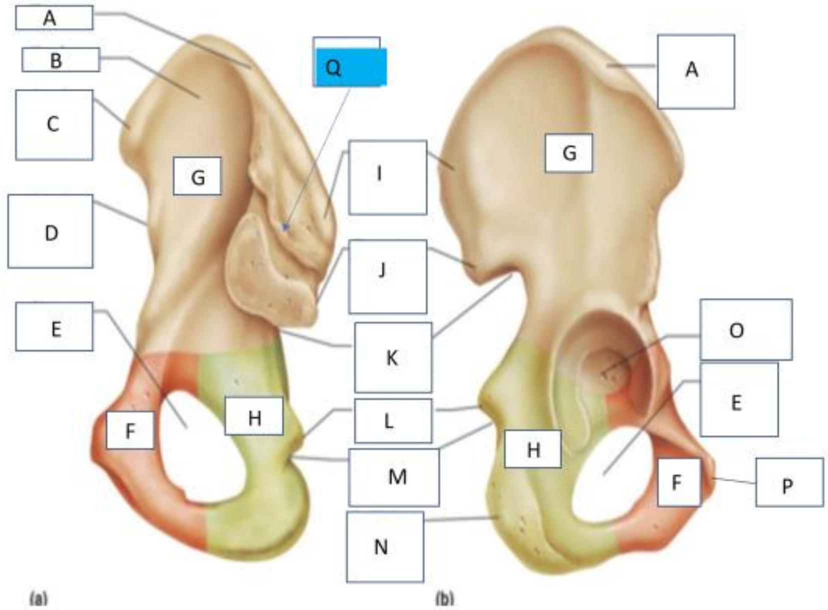
These are three different labeled images of the cranium. Three different images were used in order to get a correct view of the different features. The left is an anterior view (Mcscole, 2022), the middle is a view from the base of the cranium (Ellsanatomy, 2022) and the image on the right is a lateral view (aarnold1216, 2022).



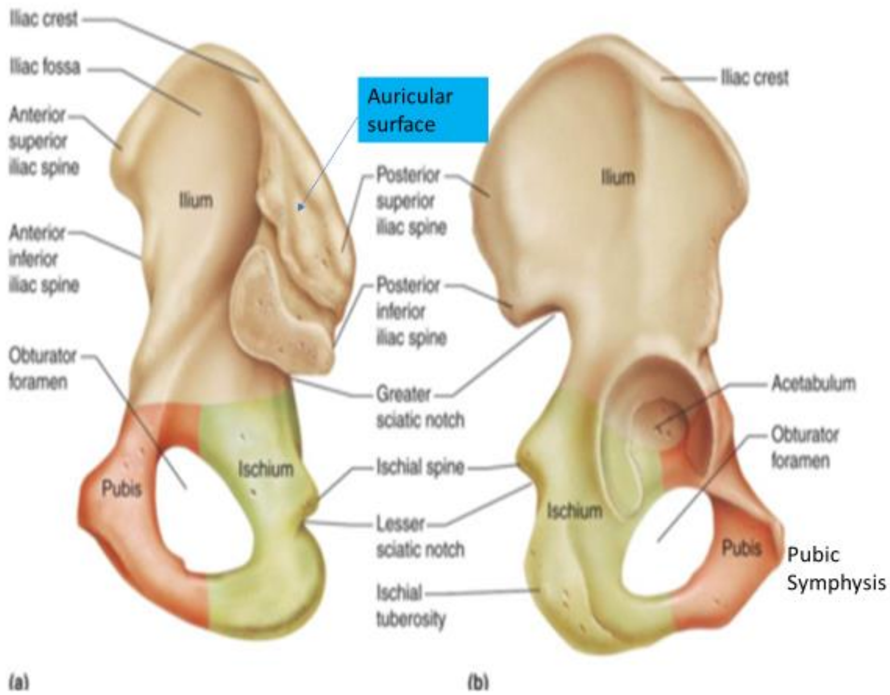
This image depicts the mandible with the features not listed (Srkessler, 2022).



This image depicts the mandible with the features labeled (Srkessler, 2022).



This image depicts the os coxa with the features not listed (Chandlerphysicaltherapy, 2014).



This image depicts the os coxa with the features labeled (Chandlerphysicaltherapy, 2014).

Appendix F

Wilcoxon Signed Rank Test

Group 1.

Wilcoxon Signed-Rank Test Calculator

Success!

Explanation of results

We have calculated both a *W*-value and *z*-value. If the size of *N* is at least 20 - see the Results Details box - then the distribution of the Wilcoxon *W* statistic tends to form a normal distribution. This means you can use the*z*-value to evaluate your hypothesis. If, on the other hand, the size of *N* is low, and particularly if it's below 10, you should use the *W*-value to evaluate your hypothesis.

You should also note that if a subject's difference score is zero - that is, if a subject has the same score in both treatment conditions - then the test discards the individual from the analysis and reduces the sample size. If you have a lot of ties, this procedure will undermine the reliability of the test (and also suggests that the requirement that the data is continuous has not been met).

Treatment 1	Treatment 2	*Sign*	*Abs*	*R*	*Sign R*
7	67	-1	60	2	-2
8	88	-1	80	5	-5
4.6	81	-1	76.4	4	-4
5.7	18.9	-1	13.2	1	-1
5.7	77.8	-1	72.1	3	-3
3.4	84	-1	80.6	6	-6

Significance Level:

Note: This is part one of the raw data and analysis for Group 1 testing of the Wilcoxon Signed-Rank Test (Social Science Statistics, 2022).

Significance Level:

- ○ .01
- ● .05

1 or 2-tailed hypothesis?:

- ● One-tailed
- ○ Two-tailed

Result Details

W-value: 0
Mean Difference: -82.27
Sum of pos. ranks: 0
Sum of neg. ranks: 21

Z-value: -2.2014

Sample Size (*N*): 6

Result 1 - Z-value

The value of *z* is -2.2014.

Note: *N* (6) is not large enough for the distribution of the Wilcoxon *W* statistic to form a normal distribution. Therefore, it is not possible to calculate an accurate *p*-value.

Result 2 - W-value

The value of *W* is 0. The critical value for *W* at $N = 6$ ($p < .05$) is 2.

The result is significant at $p < .05$.

[Calculate] [Reset]

Note: This is part two of the raw data and analysis for Group 1 testing of the Wilcoxon Signed-Rank Test (Social Science Statistics, 2022).

Group 2.

Wilcoxon Signed-Rank Test Calculator

Success!

Explanation of results

We have calculated both a *W*-value and *z*-value. If the size of *N* is at least 20 - see the Results Details box - then the distribution of the Wilcoxon *W* statistic tends to form a normal distribution. This means you can use the*z*-value to evaluate your hypothesis. If, on the other hand, the size of *N* is low, and particularly if it's below 10, you should use the *W*-value to evaluate your hypothesis.

You should also note that if a subject's difference score is zero - that is, if a subject has the same score in both treatment conditions - then the test discards the individual from the analysis and reduces the sample size. If you have a lot of ties, this procedure will undermine the reliability of the test (and also suggests that the requirement that the data is continuous has not been met).

Treatment 1	Treatment 2	*Sign*	*Abs*	*R*	*Sign R*
7	54.4	-1	47.4	4	-4
3.4	43.3	-1	39.9	3	-3
10	64.4	-1	54.4	6	-6
9	64	-1	55	7	-7
43.7	94.4	-1	50.7	5	-5
10	23	-1	13	1	-1
4.6	21.1	-1	16.5	2	-2
1	98.9	-1	97.9	9	-9
39	94.4	-1	55.4	8	-8

Note: This is part one of the raw data and analysis for Group 2 testing of the Wilcoxon Signed-Rank Test (Social Science Statistics, 2022).

Significance Level:

- ○ .01
- ◉ .05

1 or 2-tailed hypothesis?:

- ◉ One-tailed
- ○ Two-tailed

Result Details

W-value: 0
Mean Difference: -29.11
Sum of pos. ranks: 0
Sum of neg. ranks: 45

Z-value: -2.6656

Sample Size (*N*): 9

Result 1 - Z-value

The value of *z* is -2.6656.

Note: *N* (9) is not large enough for the distribution of the Wilcoxon *W* statistic to form a normal distribution. Therefore, it is not possible to calculate an accurate *p*-value.

Result 2 - W-value

The value of *W* is 0. The critical value for *W* at $N = 9$ ($p < .05$) is 8.

The result is significant at $p < .05$.

Calculate | Reset

Note: This is part two of the raw data and analysis for Group 2 testing of the Wilcoxon Signed-Rank Test (Social Science Statistics, 2022).

Appendix G

Mann-Whitney U Test

Group 1 Difference in Scores vs Group 2 Difference in Scores (Two-Tailed Test)

Mann-Whitney U Test Calculator

The value of U is 13.

You'll notice below that we have calculated a critical value for U based on alpha level and whether your hypothesis is one or two tailed. We have also calculated a value for *Z* and its associated *p*-value. Results in blue reach significance. Results in red do not.

Sample 1	Sample 2
60	47.4
80	39.9
76.4	54.4
13.2	55
72.1	50.7
80.6	13
	16.5
	97.9
	55.4

Significance Level:

○ .01

◉ .05

Note: This is part one of the raw data and analysis for testing of the Mann-Whitney U Test (Social Science Statistics, 2022).

Significance Level:

○ .01

◉ .05

1 or 2-tailed hypothesis?:

○ One-tailed

◉ Two-tailed

The *U*-value is 13. The critical value of *U* at $p < .05$ is 10. Therefore, the result is *not* significant at $p < .05$.

The *z*-score is -1.59099. The *p*-value is .11184. The result is *not* significant at $p < .05$.

Note: The approximation to the form of the normal distribution becomes less robust at sample sizes smaller than 10, so caution is appropriate here in making use the Z-*value calculation.*

Important Note

If you want full details about how the U-value was calculated, including rank order data, descriptive statistics and an explanation of the result, please click the "Calculation Details" button below.

[Calculate U] [Reset] [Calculation Details]

Note: This is part two of the raw data and analysis for testing of the Mann-Whitney U Test (Social Science Statistics, 2022).

Group 1 Difference in Scores vs Group 2 Difference in Scores (One-Tailed Test)

Significance Level:

- .01
- .05 (selected)

1 or 2-tailed hypothesis?:

- One-tailed (selected)
- Two-tailed

The *U*-value is 13. The critical value of *U* at $p < .05$ is 12. Therefore, the result is *not* significant at $p < .05$.

The *z*-score is -1.59099. The *p*-value is .05592. The result is *not* significant at $p < .05$.

Note: The approximation to the form of the normal distribution becomes less robust at sample sizes smaller than 10, so caution is appropriate here in making use the Z*-value calculation.*

Important Note

If you want full details about how the U-value was calculated, including rank order data, descriptive statistics and an explanation of the result, please click the "Calculation Details" button below.

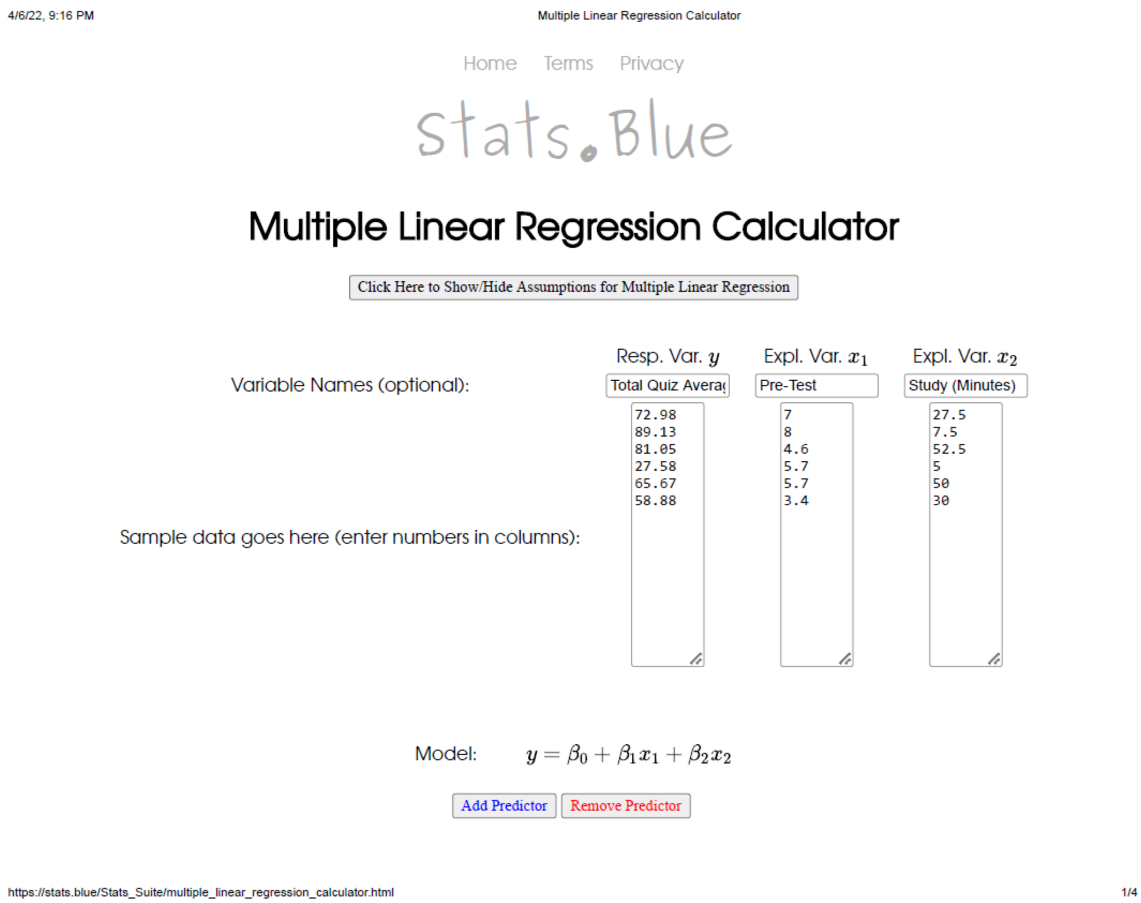
Calculate U | Reset | Calculation Details

Note: This is the analysis for testing of the Mann-Whitney U Test as a one-tailed hypothesis instead of the two-tailed test (Social Science Statistics, 2022).

Appendix H

Multiple Regression Test

Group 1 Multiple Linear Regression Data.



Note: This is part one of the data and analysis for testing the Multiple Linear Regression for Group 1 (Stats.Blue, 2018).

4/6/22, 9:16 PM Multiple Linear Regression Calculator

Display output to 4 decimal places Calculate

Include	Interaction
☐	$x_1 * x_1$
☐	$x_1 * x_2$
☐	$x_2 * x_2$

Model: $\text{Total Quiz Average} = -5.3405 + 8.8335 \cdot \text{Pre-Test} + 0.7157 \cdot \text{Study (Minutes)}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	-5.3405	46.1139	-0.1158	0.9151
Pre-Test	β_1	8.8335	6.3369	1.394	0.2576
Study (Minutes)	β_2	0.7157	0.5157	1.3878	0.2593

Summary of Overall Fit

R-Squared:	$r^2 = 0.4656$
Adjusted R-Squared:	$r^2_{adj} = 0.1094$
Residual Standard Error:	20.403 on 3 degrees of freedom.
Overall F-statistic:	1.307 on 2 and 3 degrees of freedom.
Overall p-value:	0.3906

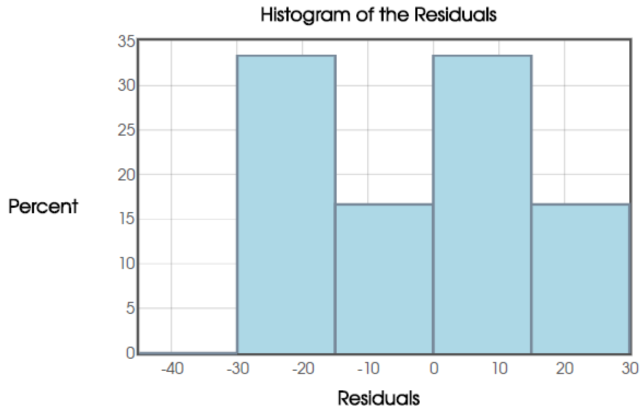
https://stats.blue/Stats_Suite/multiple_linear_regression_calculator.html 2/4

Note: This is part two of the data and analysis for testing the Multiple Linear Regression for Group 1 (Stats.Blue, 2018).

4/6/22, 9:16 PM Multiple Linear Regression Calculator

Analysis of Variance Table

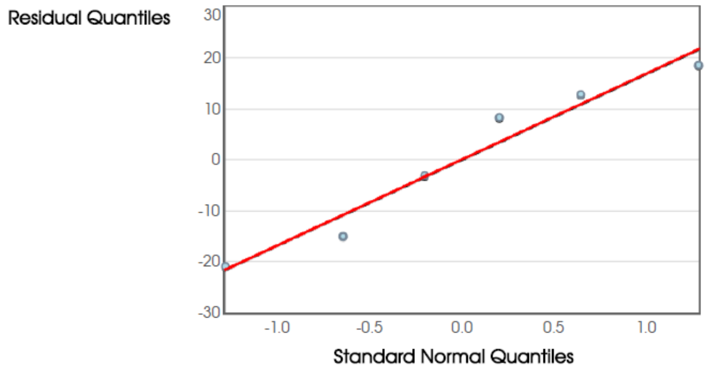
Source	df	SS	MS	F-statistic	p-value
Regression	2	1088.1934	544.0967	1.307	0.3906
Residual Error	3	1248.8421	416.2807		
Total	5	2337.0355	467.4071		



Normal Probability Plot of Residuals

https://stats.blue/Stats_Suite/multiple_linear_regression_calculator.html 3/4

Note: This is part three of the data and analysis for testing the Multiple Linear Regression for Group 1 (Stats.Blue, 2018).



Five Number Summary of Residuals

Minimum:	Min$= -21.0091$
1st Quartile:	$Q_1 = -15.1261$
Median:	$M = 2.4927$
3rd Quartile:	$Q_3 = 12.7152$
Maximum:	Max$= 18.4346$

Note: This is part four of the data and analysis for testing the Multiple Linear Regression for Group 1 (Stats.Blue, 2018).

Group 2 Multiple Linear Regression Data.

4/6/22, 9:20 PM Multiple Linear Regression Calculator

Home Terms Privacy

Stats.Blue

Multiple Linear Regression Calculator

Click Here to Show/Hide Assumptions for Multiple Linear Regression

	Resp. Var. y	Expl. Var. x_1	Expl. Var. x_2
Variable Names (optional):	Quizzes Average	Pre-test	Study (Minutes)
Sample data goes here (enter numbers in columns):	59.45	7	45
	44	3.4	18.75
	53.38	10	18.75
	68.38	9	22.5
	85.33	43.7	3.75
	44.53	10	40
	43	4.6	26.25
	87.08	1	61.25
	82.84	39	67.5
	70.78	60.9	37.5

Model: $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2$

Add Predictor Remove Predictor

https://stats.blue/Stats_Suite/multiple_linear_regression_calculator.html 1/4

Note: This is part one of the data and analysis for testing the Multiple Linear Regression for Group 2 (Stats.Blue, 2018).

Display output to 4 decimal places Calculate

Include	Interaction
☐	$x_1 * x_1$
☐	$x_1 * x_2$
☐	$x_2 * x_2$

Model: $\text{Quizzes Average} = 45.9304 + 0.4231 \cdot \text{Pre-test} + 0.2921 \cdot \text{Study (Minutes)}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	45.9304	11.325	4.0557	0.0048
Pre-test	β_1	0.4231	0.2516	1.6817	0.1365
Study (Minutes)	β_2	0.2921	0.2632	1.1099	0.3037

Summary of Overall Fit

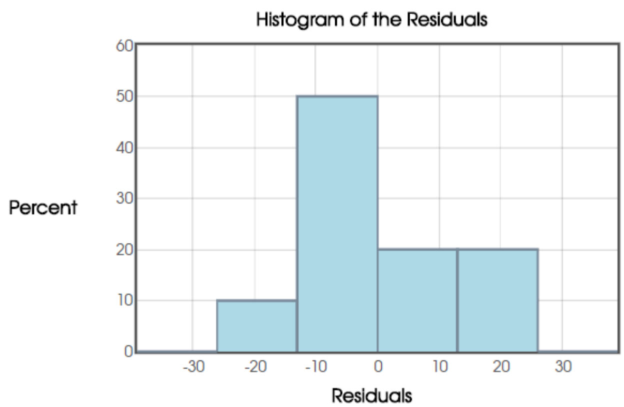
R-Squared:	$r^2 = 0.3668$
Adjusted R-Squared:	$r^2_{adj} = 0.1859$
Residual Standard Error:	15.804 on 7 degrees of freedom.
Overall F-statistic:	2.0275 on 2 and 7 degrees of freedom.
Overall p-value:	0.202

Note: This is part two of the data and analysis for testing the Multiple Linear Regression for Group 2 (Stats.Blue, 2018).

4/6/22, 9:20 PM Multiple Linear Regression Calculator

Analysis of Variance Table

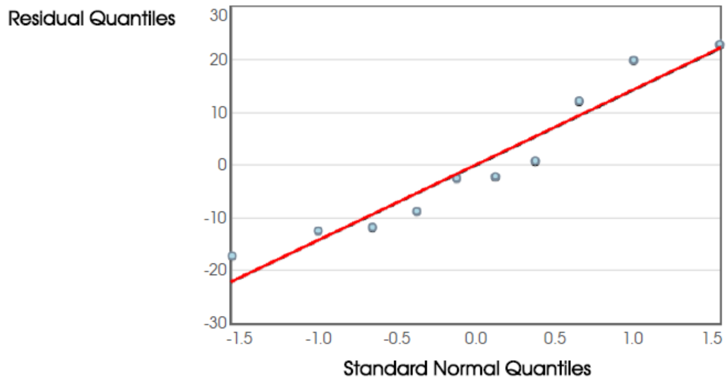
Source	df	SS	MS	F-statistic	p-value
Regression	2	1012.8008	506.4004	2.0275	0.202
Residual Error	7	1748.3694	249.7671		
Total	9	2761.1702	306.7967		



Normal Probability Plot of Residuals

https://stats.blue/Stats_Suite/multiple_linear_regression_calculator.html 3/4

Note: This is part three of the data and analysis for testing the Multiple Linear Regression for Group 2 (Stats.Blue, 2018).

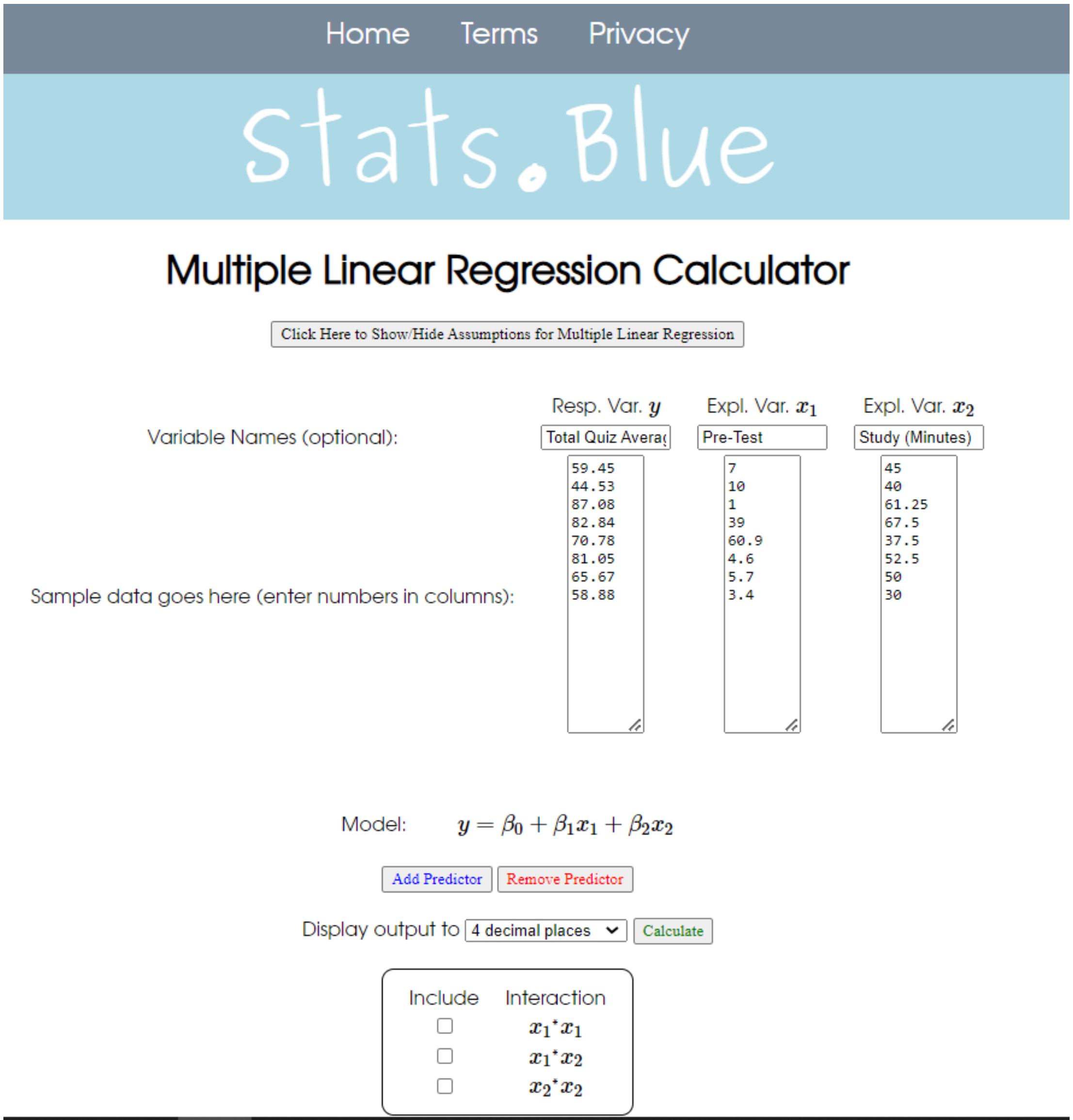


Five Number Summary of Residuals

Minimum:	Min$= -17.3143$
1st Quartile:	$Q_1 = -11.8696$
Median:	$M = -2.4216$
3rd Quartile:	$Q_3 = 12.0701$
Maximum:	Max$= 22.8369$

Note: This is part four of the data and analysis for testing the Multiple Linear Regression for Group 2 (Stats.Blue, 2018).

Participants who Studied more than 30 minutes on Average.



Note: This is part one of the data and analysis for testing the Multiple Linear Regression for the Group that Studied for an Average of at least 30 Minutes per Quiz (Stats.Blue, 2018).

Model:	$\text{Total Quiz Average} = 25.2493 + 0.1152 \cdot \text{Pre-Test} + 0.8681 \cdot \text{Study (Minutes)}$

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	25.2493	16.7603	1.5065	0.1923
Pre-Test	β_1	0.1152	0.1921	0.5995	0.575
Study (Minutes)	β_2	0.8681	0.3337	2.6014	0.0482

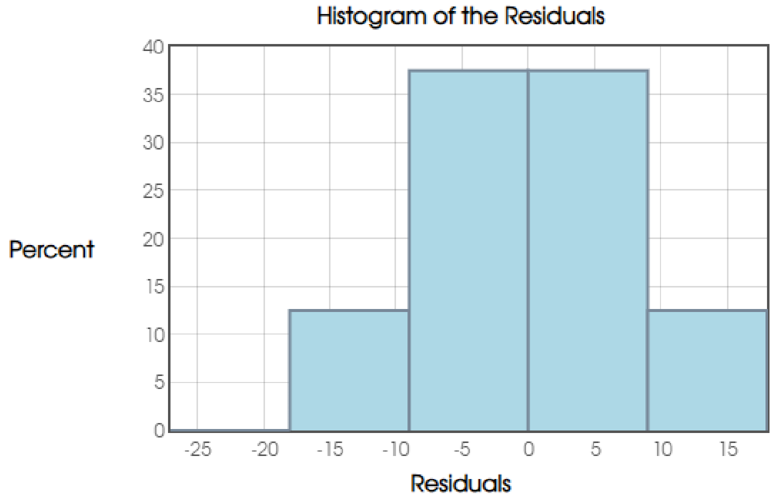
Summary of Overall Fit

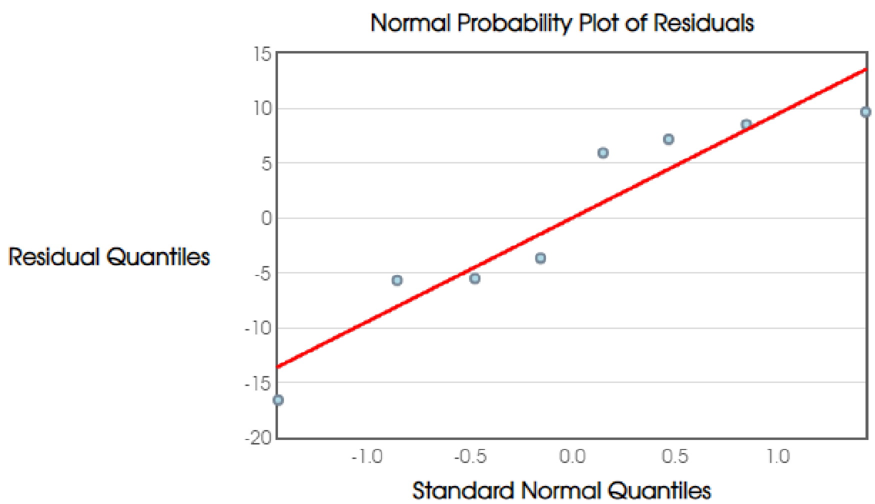
R-Squared:	$r^2 = 0.5882$
Adjusted R-Squared:	$r^2_{\text{adj}} = 0.4234$
Residual Standard Error:	11.0034 on 5 degrees of freedom.
Overall F-statistic:	3.5703 on 2 and 5 degrees of freedom.
Overall p-value:	0.1089

Analysis of Variance Table

Source	df	SS	MS	F-statistic	p-value
Regression	2	864.5418	432.2709	3.5703	0.1089
Residual Error	5	605.378	121.0756		
Total	7	1469.9198	209.9885		

Note: This is part two of the data and analysis for testing the Multiple Linear Regression for the Group that Studied for an Average of at least 30 Minutes per Quiz (Stats.Blue, 2018).





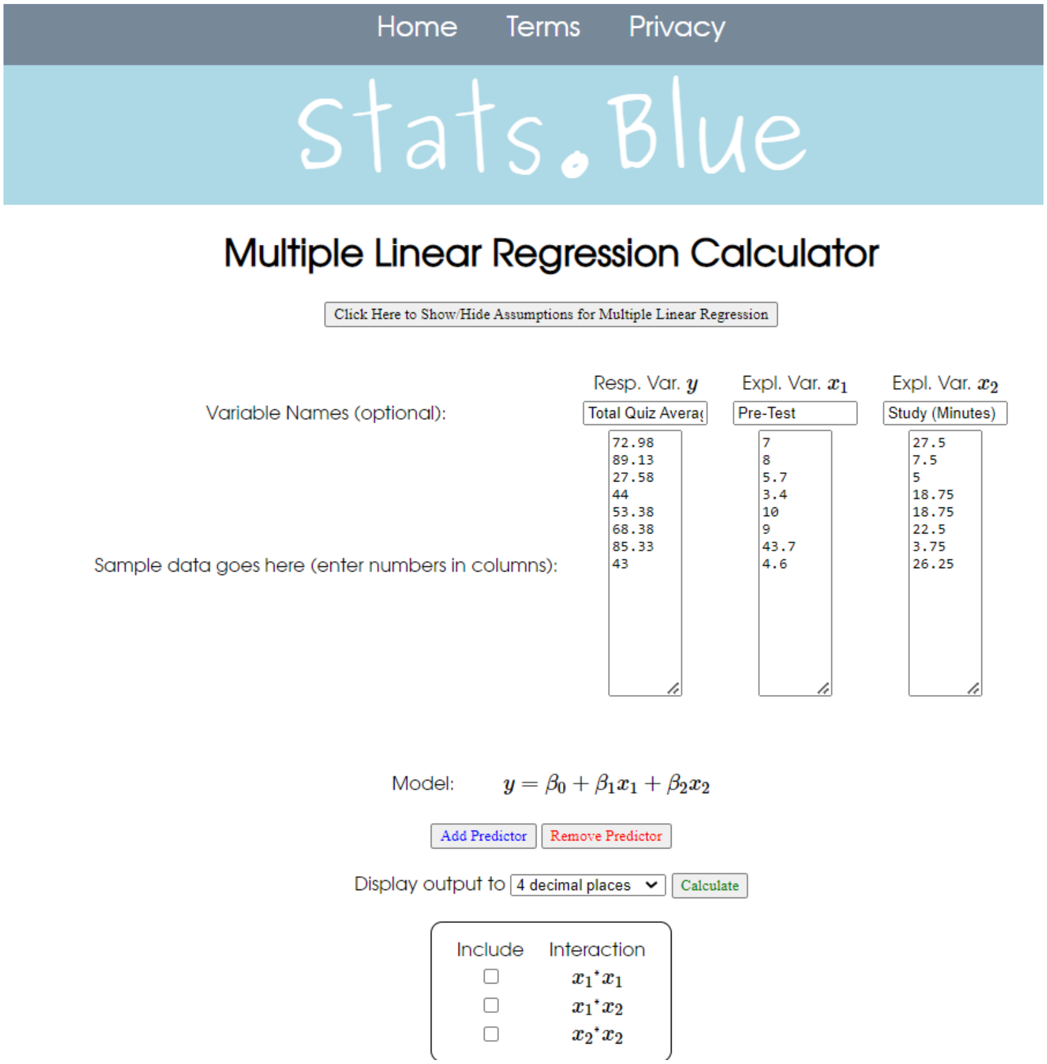
Note: This is part three of the data and analysis for testing the Multiple Linear Regression for the Group that Studied for an Average of at least 30 Minutes per Quiz (Stats.Blue, 2018).

Five Number Summary of Residuals

Minimum:	Min$= -16.5945$
1st Quartile:	$Q_1 = -5.5833$
Median:	$M = 1.1615$
3rd Quartile:	$Q_3 = 7.8709$
Maximum:	Max$= 9.6964$

Note: This is part four of the data and analysis for testing the Multiple Linear Regression for the Group that Studied for an Average of at least 30 Minutes per Quiz (Stats.Blue, 2018).

Participants who Studied less than 30 minutes on Average.



Note: This is part one of the data and analysis for testing the Multiple Linear Regression for the Group that Studied for an Average of less than 30 Minutes per Quiz (Stats.Blue, 2018).

Model: Total Quiz Average = 42.5397 + 1.0267 · Pre-Test + 0.3817 · Study (Minutes)

Predictor	Coefficient	Estimate	Standard Error	t-statistic	p-value
Constant	β_0	42.5397	23.2733	1.8278	0.1271
Pre-Test	β_1	1.0267	0.7288	1.4086	0.218
Study (Minutes)	β_2	0.3817	1.0102	0.3779	0.721

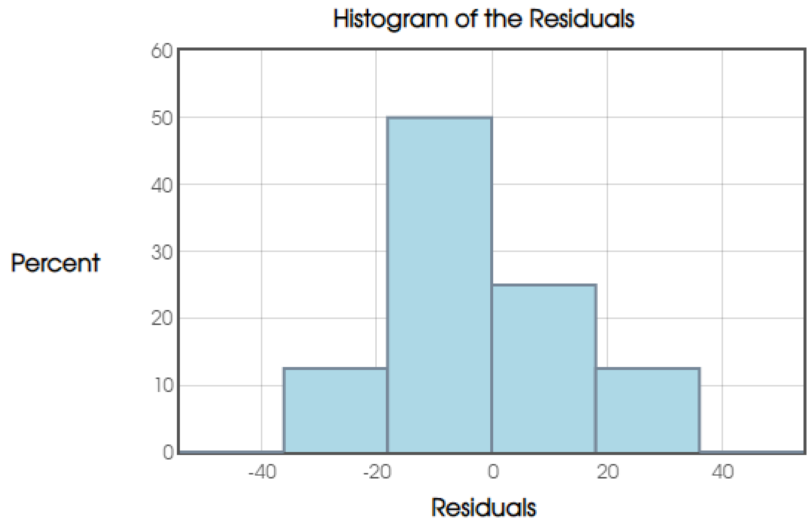
Summary of Overall Fit

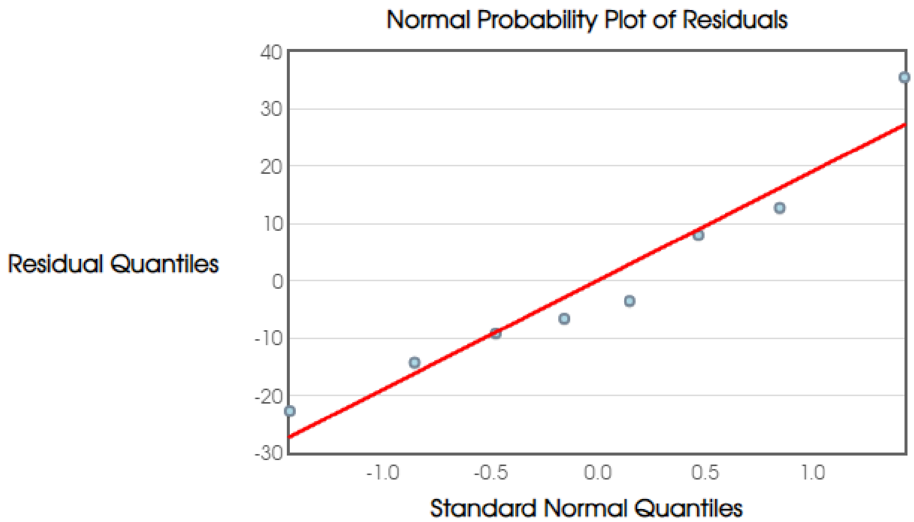
R-Squared:	r^2 =0.3025
Adjusted R-Squared:	r^2_{adj} =0.0235
Residual Standard Error:	21.6722 on 5 degrees of freedom.
Overall F-statistic:	1.0843 on 2 and 5 degrees of freedom.
Overall p-value:	0.4063

Analysis of Variance Table

Source	df	SS	MS	F-statistic	p-value
Regression	2	1018.5526	509.2763	1.0843	0.4063
Residual Error	5	2348.4128	469.6826		
Total	7	3366.9653	480.995		

Note: This is part two of the data and analysis for testing the Multiple Linear Regression for the Group that Studied for an Average of less than 30 Minutes per Quiz (Stats.Blue, 2018).





Note: This is part three of the data and analysis for testing the Multiple Linear Regression for the Group that Studied for an Average of less than 30 Minutes per Quiz (Stats.Blue, 2018).

Five Number Summary of Residuals

Minimum:	Min$= -22.7204$
1st Quartile:	$Q_1 = -11.7354$
Median:	$M = -5.045$
3rd Quartile:	$Q_3 = 10.3836$
Maximum:	Max$= 35.514$

Note: This is part four of the data and analysis for testing the Multiple Linear Regression for the Group that Studied for an Average of less than 30 Minutes per Quiz (Stats.Blue, 2018).

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