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3D PRINTING OF THE PROXIMAL RIGHT FEMUR: IT'S IMPLICATIONS IN THE FIELD OF FORENSIC ANTHROPOLOGY AND BIOARCHAEOLOGY

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Abstract: 3D Printing of the Proximal Right Femur

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3D scanning and Printing have become useful in many scientific fields over the last few years, and Physical Anthropology/ Archaeology is not an exception. With skeletal collections decreasing all over the globe and the question of preservation on the rise, it has become necessary to look towards different methods in which one can obtain important information. 3D scanning has become useful over the last few decades and therefore it is important to establish where this new technology can be of use. This paper will bring 3D scanning and printing into question and determine whether this technology should be used in certain contexts in physical anthropology, such as forensic anthropology and the preservation of archaeological remain.

This research will attempt to answer the question of whether a 3D scan and 3D print out of the proximal right femur will be identical to the original. This research will examine 11 proximal right femoral ends, all of which will come from the Forensic Anthropology Center at Texas State University. These femora will be hand measured before they are 3D scanned and printed. After the final printouts are made, an error rate will be established to determine if this technology can be utilized in scientific fields that require quantitative accuracy to gather information.

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Introduction

Over the next few decades, many skeletal remains from across the globe will be removed from various collections and will then be given back to the claimants or put up where one cannot touch them. This results in fewer supplies that can be utilized for research purposes/ Therefore, it is necessary to retain information from the remains in as many ways as possible before they wither get returned or worse destroyed. Two prime examples of this are the Brazil's National Museum that caught fire on the 2nd of September 2018 and just recently, the Monday before Easter 2019 the whole world saw what happened to the Notre Dame cathedral.

Image 1 (Left): This is a scene from when the Brazillian Museum was on fire, (https://www.townandcountrymag.com/leisure/arts-and-culture/a22986495/national-museum-rio-de-janiero-fire/) **Image 2 (right):** This is a scene not even a week before Easter of the Notre Dame cathedral on fire, (http://churchlife.nd.edu/2019/04/16/the-notre-dame-cathedral-fire-isnt-a-sign/)

Over the last 40 years, 3D scanning and printing have grown in many industries and research fields such as architecture, engineering, art, and medicine, and it can play a significant role in some forensic anthropologist/ archaeologist research (Gross et al., 2018). This research will attempt to answer the question of whether a 3D scan and a 3D printout of the proximal right femur will be identical to the original. If the measurements are not similar is there an error rate that can then be established when utilizing, there methods? If the original femurs are measured and compared to the measurements of the copy, then it is likely that these measurements will differ, and the error rates will be inconsistent. If the original right proximal femurs and the copied right proximal femurs share the same measurements than this method will be a good technique to utilize when transferring information and digital scans from one person to another.

Literature Review

History of 3D Scanners and Printers

In the mid-1980's, Charles Hull developed the first concepts and ideas for the 3D printing machine (Gross et al., 2014). These scanners and printers utilize a file format called the Standard Tessellation Language (.stl), which is commonly used in most computer-aided design (CAD) software (Gross et al., 2014). Since then, people in many fields have incorporated these technologies into their work, and around the turn of the century, people have utilized these technologies in the field of medicine and forensic sciences (Gross et al., 2014). Now almost forty years later, 3D scanners and printers are utilized in many industries and fields. They have even become an ordinary piece of technology that many universities possess.

3D scanners are also becoming smaller, which is making them more portable so long as there is a computer system that the software can download into, such as a laptop. The Next Engine is a portable and affordable 3D scanner that has one of the best resolutions for a portable scanner making it one of the best scanners if one was to need to scan something while in the field, (http://www.nextengine.com/). Today, people can even go to internet sites like Amazon and purchase a 3D scanner and printer. There are also places on the internet where one can download a .stl file so that they can print off whatever they desire. The utilization of mobile devices and wireless internet is making these tools relatively available to people from all around the world who are interested in 3D scans and models. Though one of the central questions that comes to some minds is just how accurate are these scans, and is there a point where one must draw the line in utilizing this method?

History of 3D Scanning and Printing in the Forensic Sciences

There have also been many uses of 3D printing and scanning technology that have affected the field. Even other researchers such as Carew et al. (2019) have examined the accuracy in replicating skeletal remains with different types of filaments and some of the copies actually turned out to be pretty accurate. Due to 3D printing now becoming more available lawyers have begun to utilize this machinery in the courtroom, (Gross et al., 2014). This would allow for the jury and the witnesses to see the evidence without having to deal with the actual evidence. It also provides for them to increase the size dimensions for the smaller pieces of evidence as well so that it is now easier to see, such as a skeletal injury, (Gross et al., 2014). Not only has this process become useful in the courtroom, but it also has its uses in the forensics labs across the United States. It has allowed the forensics people to explain forensic findings better and to create

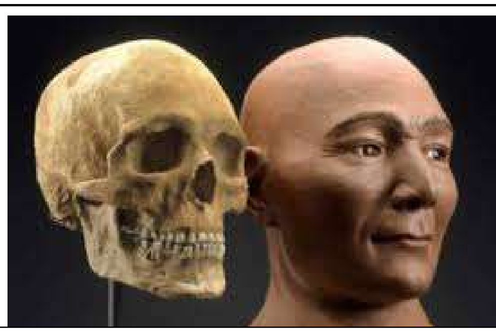

Image 3: Shows a facial reconstruction of a gentleman, (https://www.crimemuseum.org/crime-library/forensic-investigation/facial-reconstruction/)

facial reconstructions of what the unidentified person might have looked like, (Gross et al., 2014).

History of 3D Scanning and Bioarchaeology

3D scanning and printing have been in use in the biological archaeology realm for a while now. One of the ways in which people would utilize this machinery was to CT scan skeletal remains to determine trauma and what these people looked like in the ancient world, (Fatini et al., 2008). Nowadays, it has its uses in both museums and educational facilities. Museums utilize the 3D scanning machinery to allow curious onlookers to pick up the objects without having to worry about them breaking history. It is also becoming a part of some documentation processes for some museum, (Kuzminsky & Gardiner, 2012). 3D scanning and printing are also helpful preservation tools because people have utilized 3D scanning and printing tools to reconstruct ancient peoples, artifacts, features, and architecture that are quickly deteriorating, (Kuzminsky & Gardiner, 2012). 3D scanning and printing methods are also useful in an education setting, as people are now getting their hands-on 3D copies of the rare originals (bone, tomb artifacts, etc.) so that they can see what something looks like with their own eyes. This allows for universities and high school to be able to purchase or print anatomically correct specimens without having to buy or use the original skeletal materials (Carter et al., 2009).

Not only that, but Forte (2014) has shown through his experiment at Çatalhöyük that 3D various techniques can be utilized in the field during excavation. This allows one to rebuild the site and go through the excavation, again and again, possibly finding new information and facts that were missed with the first run. Typically, this would not be possible because archaeology in and of itself is a very destructive method. Utilizing 3D techniques in the way Forte did would allow one to go back and see the process in which the excavation happened. This can also be applied to a biological archaeology setting as well when dealing with burial excavations whether they are ancient, historical, or even modern.

3D scanning and printing have also had some luck with scanning ancient teeth to preserve data that would otherwise be lost, (Alfonso-Durruty et al., 2018). This study found that the measurements maintained well when the print was compared to the original. However, the non-metric traits were partially lost in the making, (Alfonso-Durruty et al., 2018). Other than teeth biological archaeologist scholars, like forensic anthropology have scanned various other parts of different parts of human and animal skeletons for multiple reasons, including the cranium and even a 3D model of an ancient Egyptian falcon mummy was created using 3D techniques, (Kuzminsky et al., 2016; Du Plessis et al., (2015). Kuzminsky et al. (2016) and her team scanned cranial vaults in the Andes and found that even outside the realm of measurement that 3D scanning can indeed be utilized in finding cranial modifications. Outside of measurements and skeletal modifications, 3D scanning has also been applied to a forensic biological archaeology case in Sicily, (Miccichè, Carotenuto, & Sìneo, 2019). Utilizing various 3D technologies such as the CT scanner and topography they were able to reconstruct the person's potential cause of death.

As we have seen, there are various ways in which 3D scanning and printing can be utilized in the daily research of a biological archaeologist. However, there are even more ways in which a scholar can use 3D scanning techniques out in the field of biological archaeology. Everybody knows about the facial reconstruction of Pharaoh Tutankhamun. Therefore, it should not be a surprise when mentioned that Loynes et al. (2017) utilized 3D scanning techniques when creating a facial reconstruction of Nebiri, who used to be Chief of the Stables back in ancient

Egypt. This technique shows that both forensics and bioarchaeology can be taken into consideration when utilizing 3D scanning techniques and both can be aided when a scan is taken.

Even though scanning remains, and artifacts have allowed more people to have access to digital data, it is essential to mention that there could eventually be some ethical implications in making this 3D data digital. Ulguim (2018), says in her article that these digital representations have allowed us to share data and scanned human remains online both in-situ (in place and ex-situ (out of place). A couple of projects that remained in-situ consisted of Çatalhöyük and Lord of Sipan, while those ex-situ projects consisted of the Kennewick man and the Jericho plastered skull, (Ulguim, 2018). She concludes that there are many benefits to sharing data and 3D scans online; however, the "stakeholders" (claimants) still need to be made aware of what is happening to the remains and to continue respecting other cultural groups and their perspectives, (Ulguim, 2018).

Materials and Methods

This research studies 18 right proximal femoral ends that were all a part of the collection at the Forensic Anthropology Center at Texas State, San Marcos, Texas. These femurs do not share any correlation like just belonging to males or females, but rather it is a mixed data set. The femora were chosen because they displayed minimal deterioration.

The proximal end of the femur was chosen because there is a lot of information that can be gathered within that small area on the bone; researchers can utilize this section of bone to help determine ancestry, stature, and some also suggest that age can also determine based off this section of the femur, (Colman, 2018; Giroux & Wescott, 2008; Malo et al., 2013). Each of the original femurs will have a set of 11 measurements taken by the researcher utilizing electronic calipers and metric tape before the femora are scanned. Measurements one through three are taken from Standards: for Data Collection from Human Skeletal Remains (Buikstra & Ubelaker, 1994), while measurements four through eight (except for 6) are taken from Colman et al., (2018). Measurement nine was designed by the researcher to measure the Intertrochanteric crest length. Lastly, measurement ten was taken from Bass (2005), Human Osteology: A Laboratory and Field Manual. The 11 measurements are as follows:

1. **Maximum Head Diameter:** Measure from the greatest anterior portion of the femoral head to the greatest posterior portion of the femoral head, (Buikstra & Ubelaker, 1994).
2. **Anterior-Posterior (Sagittal) Subtrochanteric Diameter (M2):** Measure from the greatest anterior point to the greatest posterior point on the femoral shaft, (Buikstra & Ubelaker, 1994).
3. **Medial-Lateral (Transverse) Subtrochanteric Diameter (M3):** Measure from the greatest medial point to the greatest lateral point on the femoral shaft, (Buikstra & Ubelaker, 1994).
4. **Circumference of the Head:** Measure the largest circumference of the femoral head, (Colman et al., 2018).
5. **Neck Circumference:** Measure the largest circumference of the femoral neck, (Colman et al., 2018).
6. **Superior Neck length:** Measure from the femoral heads fusion line to the point between the neck and the femoral neck, (Colman et al., 2018).
7. **Anterior- Posterior Neck Diameter**: Measure the greatest anterior-posterior portion of the femoral neck, (Colman et al., 2018)

8. **Superior- Inferior Neck Diameter:** Measure the greatest superior-inferior portion of the femoral neck.

9. **Coronal Oblique Plane/ Upper Epiphyseal Length:** Measure from the most medial part of the femoral head to the most lateral projecting part of the greater trochanter, (Colman et al., 2018). Note: Make sure the calipers are parallel to the table or else you will measure the Transverse Oblique Plane.

10. **Measurement of the Intertrochanteric Crest Length:** Measure from the most superior portion of the intertrochanteric crest, by the greater trochanter, to the most inferior portion of the intertrochanteric crest, which will end near the lesser trochanter.

11. **Platymeric Index:** M2 x100/M3=Ϫ, (Bass, 2005)

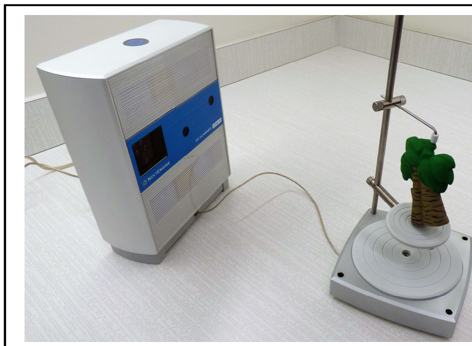

Image 4: This image shows the NextEngine Scanner being calibrated utilizing the palm tree, (https://www.dospace.org/blog/introducing-our-nextengine-3d-scanner/)

The next phase of the research requires one to hold the femur upside down over the turntable- a table in which one can place the object in the center and have it rotated over the y-axis at a fixed x coordinate- so that the proximal femur is directly over the center point of the turntable. The Next Engine also has a point called the part gripper to help hold and balance the femurs on or near the center point center, while the femur is scanning. One would have to make sure that the proximal end of the femur is not swaying, and it is staying roughly over the same spot on the turntable with each rotation and scan. It is also essential to maintain the proximal end of the femur just above the surface of the turntable so that when the machine scans the femur, the software can triangulate points in that region of the femur which would otherwise be cut out. The first scan should be a 360-degree rotation over the femur's y-axis and then multiple other one picture scans that can be stitched together with the 360 rotation. One must keep scanning and stitching the scans together until all the holes in the femur are filled in. Double checking of the center point over the table will come in handy when it comes time to stitch the scans together to get the full proximal end of the femur. Once the scan is complete it is essential to fuse the scan in the NextEngine system that way it is easier to make a watertight mesh manifold later on. Each of the femurs will be scanned using 3D hardware called Next Engine 3D systems which will then translate information back to the Next Engines' software.

Once the scans are completed it becomes necessary to water tight the mesh fitting around the design. This can be done utilizing GeoMagic, a program designed to create a water tight manifold, as well as, crop and add sections if the design requires. Once the mesh fitting is in place the .stl file can then be ran through a free software called Meshmixer to inspect all the holes within the mesh manifold making sure that it will not compromise the eventual print and if there is a compromising hole it will instruct one to fill in the hole in the mesh. After the femur manifold is established one can put the print into SketchUp Pro, a program designed mainly for architecture that helps one to build structures in a virtual software. Utilizing Sketchup Pro one needs to import the scan of their proximal femur and build structures meant to hold up the femur and to help the neck and head to print out because a 3D printer cannot print out of thin air. If one does not know how to run SketchUp or they do not have the equipment, then it will be necessary for the print structuring to be arithmetically placed by the computerized machine. However, the removal of these structures, even with leaky connections (easy to break off structures) it can either compromise the print or it can be very difficult to remove. After this final software set up one should ideally be ready to print the object out utilizing MakerBot 3D hardware and software.

The femurs will then be printed out utilizing MakerBot software and hardware with 1.75mm Polylactic Acid Filament (PLA). This type of print out is known to be one of the cheapest types of filaments that can be utilized with the printers that the University of Montana supplies for its students, (G. Kneebone, Spring 2018). These newly printed proximal femurs will then be touched up by having their support material removed. After the touch ups are complete, these femurs will then be measured utilizing the same 11 measurements that were used to measure the original proximal femurs. Once the researcher gathers all the data, it will all be compiled based on whether there is a difference between the original and the 3D printed proximal ends of the femurs. If there is a difference, the researcher will examine where the differences took place and if there is a standard error rate that can be calculated between the measurements taken at each of the two phases.

Results

18 of the right proximal femurs were measured, and their measurements are as listed in Table 1. Table 2 consist of the same 11 measurements, however, this time these measurements were taken from the femur copies. While Table 3 shows the measurement comparison chart between the original femurs and the copied femurs. The real exciting find is when Table 2 and Table 3 is compared to one another. Comparison of the two tables shows that there is some difference between the measurements of the original and the printout. However, all these measurements apart from the M5 and M11 reveal that the difference between the original femur and the copy was only a few millimeters.

Table 1: This is a table with all 11 measurements taken from the 18 original right proximal femurs. The M signifies measurements while the number tells the reader which measurement was taken. The measurements are taken in millimeters.

Femur Scan Number	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
TX-01	**46**	**31**	**31**	**147**	**103**	**33**	**28**	**32**	**91**	**46**	**100.00**
TX-02	**41**	**27**	**29**	**130**	**96**	**24**	**28**	**32**	**83**	**44**	**93.1**
TX-03	**50**	**28**	**34**	**158**	**104**	**28**	**33**	**33**	**95**	**45**	**82.4**
TX-04	**47**	**30**	**33**	**152**	**105**	**40**	**30**	**35**	**98**	**55**	**90.9**
TX-05	**41**	**23**	**29**	**132**	**81**	**25**	**23**	**26**	**81**	**43**	**79.3**
TX-06	**45**	**32**	**35**	**145**	**105**	**27**	**29**	**35**	**91**	**45**	**91.4**
TX-07	**49**	**34**	**33**	**157**	**113**	**30**	**33**	**35**	**101**	**56**	**103.0**
TX-08	**46**	**30**	**32**	**149**	**115**	**33**	**34**	**38**	**107**	**51**	**81.1**
TX-09	**52**	**37**	**39**	**170**	**125**	**58**	**41**	**43**	**116**	**54**	**94.9**
TX-10	**47**	**31**	**33**	**152**	**110**	**29**	**32**	**36**	**99**	**44**	**93.9**
TX-11	**50**	**35**	**36**	**162**	**110**	**39**	**37**	**36**	**105**	**48**	**97.2**
TX-12	**49**	**26**	**29**	**157**	**108**	**34**	**35**	**36**	**96**	**50**	**89.7**
TX-13	**44**	**32**	**35**	**140**	**102**	**27**	**33**	**33**	**92**	**45**	**91.4**
TX-14	**41**	**24**	**30**	**129**	**89**	**36**	**25**	**31**	**83**	**45**	**80**
TX-15	**47**	**27**	**31**	**144**	**91**	**32**	**29**	**29**	**95**	**45**	**87.9**
TX-16	**47**	**29**	**36**	**149**	**108**	**29**	**31**	**36**	**100**	**58**	**80.5**
TX-17	**43**	**28**	**30**	**139**	**95**	**42**	**30**	**32**	**90**	**56**	**93.3**
TX-18	**46**	**29**	**34**	**146**	**101**	**38**	**32**	**35**	**96**	**48**	**85.2**

Table 3 shows the slight differences between the original femurs and the copies. In some case's there is no difference at all and even if there is a difference, it is only slight (ex +/-1, +/-2, etc.). This chart also shows that there seems to be a more significant difference between the measurements in accordance with Neck Circumference (M5) and Neck length (M6) data. Table 3 also shows that if there is even a slight difference between original and printed measurements of the sagittal subtrochanteric diameter (M2) and the transverse subtrochanteric diameter (M3), then the platymeric index can show a more significant difference in the platymeric numbers. The range of variance between the original platymeric measurements and the copied platymeric measurements ranges from 0-9.8. This difference is shown by the slight 1-2 mm difference between the two measurements that were compared to create this table.

Table 2: This is a table with all 11 of the measurements taken from the 18 copied versions of the femurs. M signifies measurements, while the number tells the reader which measurement was taken. The measurements are taken in millimeters.

Copied Femur Number	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
TX-01	45	32	32	146	108	33	29	33	93	50	100
TX-02	41	25	30	132	99	25	26	29	83	46	83.3
TX-03	49	29	36	158	108	28	32	33	92	48	80.6
TX-04	47	30	33	151	115	39	30	37	100	55	90.9
TX-05	41	23	30	131	87	25	22	26	81	44	76.7
TX-06	45	33	34	146	112	29	29	36	93	44	97.1
TX-07	49	34	34	156	115	31	33	35	101	58	100
TX-08	46	29	38	149	120	34	34	38	105	50	76.3
TX-09	52	37	38	167	125	52	39	43	115	53	97.4
TX-10	47	30	35	151	116	28	32	37	98	44	85.7
TX-11	50	34	36	161	114	34	37	36	104	47	94.4
TX-12	49	26	28	157	114	33	35	36	97	50	92.9
TX-13	43	32	34	143	105	29	33	33	93	45	94.1
TX-14	41	24	29	133	92	33	25	30	81	45	82.7
TX-15	47	26	31	153	95	32	29	30	95	44	83.9
TX-16	46	30	36	152	111	26	28	34	98	58	83.3
TX-17	43	38	30	142	98	42	30	32	90	58	93.3
TX-18	46	26	34	147	105	37	32	35	98	50	82.3

Table 3 also shows how many of the data points out of the 11 measurements were different from each other (2 right column). This table also shows how many measurements in each column differed from the original to see if the differentiation had something to do with the points utilized for measurements (2 row closer to the bottom). While the bottom most column and the right most column show how many measurements out of each section contained no data points. The percentage of points that were spot on were 32.4% off all 191 pieces of data in the chart. The percentage of points that were off by only 1mm was also 29.8%. The 2mm difference came out to 12% of all the measurements taken, while the greater than 2mm difference was 20.5%.

Table 3: This table shows the variance of the copied measurements compared to the original versions. This table shows how different the measurements are from one another in millimeters.

Femur Comparison	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	How many are different?
TX-01	-1	+1	+1	-1	+5	0	+1	+1	+2	+4	0	10/11
TX-02	0	-2	+1	+2	+3	+1	-2	-3	0	+2	-9.8	9/11
TX-03	-1	+1	+2	0	+4	0	-1	0	-3	+3	-1.8	9/11
TX-04	0	0	0	-1	+10	-1	0	+2	+2	0	0	5/11
TX-05	0	0	+1	-1	+6	0	-1	0	0	+1	-2.6	6/11
TX-06	0	+1	-1	+1	+7	+2	0	+1	+2	-1	+5.7	9/11
TX-07	0	0	+1	-1	+2	+1	0	0	0	+2	-3	6/11
TX-08	0	-1	+1	-2	+5	+1	0	0	-2	-1	-4.8	8/11
TX-09	0	0	-1	-3	0	-6	-2	0	-1	-1	+2.5	7/11
TX-10	0	-1	+2	-1	+6	-1	0	+1	-1	0	-8.2	8/11
TX-11	0	-1	0	-1	+4	-5	0	0	-1	-1	-2.8	7/11
TX-12	0	0	-1	0	+6	-1	0	0	+1	0	-6.8	3/11
TX-13	-1	0	-1	+3	-3	+2	0	0	+1	0	-2.7	7/11
TX-14	0	0	-1	+4	+3	-3	0	-1	+2	0	+2.7	6/11
TX-15	0	-1	0	+9	+4	0	0	+1	0	-1	-4	6/11
TX-16	-1	+1	0	+3	+4	-3	-3	-2	-2	0	+2.8	9/11
TX-17	0	0	0	+3	+3	0	0	0	0	+2	0	3/11
TX-18	0	-1	0	+1	+4	-1	0	0	+2	+2	-2.9	7/11
How many were different?	4/18	10/18	12/18	16/18	17/18	13/18	6/18	8/18	13/18	12/18	15/18	

Table 4 shows the mean differences between the original and the copied version of each measurement points that were taken from the 18 femurs. The range of the mean is between -.77mm and 4mm with the highest mean coming from the M5 entry points. These two points seem to be an outlier seeing as the remainder of the measurement means lie between -.77mm and .83mm, which is not much of a difference. The median difference is for 10 out of the 11 measurements is 0 except for M5, whose median is 4. If the original measurements were compared to the copy in a paired t-test, than the significance is 0.00.

Table 4: This table shows the mean and median of the differences between the M1, M2, M3, etc. points listed on Table 3. These data entry points are still being measured in millimeters.

Femur Comparison	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
Mean	-.22	-.16	.22	.83	4.0	-.77	-.44	0	.11	.61	-2
Median	0	0	0	0	4	0	0	0	0	0	2.65

Table 5 shows a correlation between the 11 measurements taken of the original prints (ex: M1) as well as the copied prints (ex: M1_2). In a correlation for the method to be accurate the numbers have to correlate with one another. When ran though SPSS (IBM Corp., 2013)the numbers have to be as close to one as possible. The closer the correlation is to one the more similar they are, but the further the number is away from one the further apart they are from one another.

Table 5: This table shows the correlation between the original measurements (M1, M2, M3, etc.) and the measurements of the copied right proximal femurs (M1_2, M2_2, M3_2, etc.).

	M1_2	M2_2	M3_2	M4_2	M5_2	M6_2	M7_2	M8_2	M9_2	M10_2	M11_2
M1	0.991										
M2		0.974									
M3			0.802								
M4				0.972							
M5					0.977						
M6						0.972					
M7							0.973				
M8								0.956			
M9									0.984		
M10										0.954	
M11											0.853

Discussion

Based on the differences shown in Tables 3 and 4 this method can be useful in the fields of forensic anthropology and bioarcheology. This is because there was only a difference of 0mm-2mm in most of the measurements (79.5%). However, substantial differences did arise in the study in measurement 5. The Significance of this was found in a paired t-test, which was also ran through SPSS (IBM Corp., 2013) to see if the differences affected the outcome. This analysis showed that every measurement was significant, and they were all under .05. In fact, all of the significances showed up as 0.00. Even the correlation range was between .853 and .991 telling us that this method can work out in the field and that this method is useful to both forensic anthropologist and biological archaeologist. The considerable difference between the measurements could have occurred for various reasons.

The first reason these measurement differences could have occurred was that the mesh walls might have added a bit of outer layering onto the copied femur. Another possibility is that the measurement points could have gotten shifted up and/or down making the measurements off by

Image 5 (to the left): This image is of an original femur in the process of being scanned. This is a photograph taken by the NextEngine Scanner when it was in the middle of a 360-degree scan. This image shows more detail on it than we would see on a 3D copy of the bone. Note: reference Image 8 for what a 3D version of a proximal right femur looks like.

0-2mm. This could have been due to intraobserver error and the fact that some distinct points on the original bone do not always show up on a copied bone. The reasoning for this is that Bruzek et al. (1994) also shows similar findings in their study. Similar to this study, they had a 0-2mm measurement difference and a correlation of .9, (Bruzek et al., 1994). Interobserver error was not considered in this study. A third reason that the original and copied versions of M11 are different from one another is that the M2 and M3 measurements were off ever so slightly which caused the product of the equation (M2x100/M3=platymeric number) to have a substantial difference.

Even though this method can be utilized, the differences in the measurements however slight speak to the limitations of utilizing 3D scanning and printing in the fields of forensic anthropology and bioarcheology. The most significant restriction is one's expertise and experience. Experience on how to use the 3D scanner and all the software up to the point of printing the copied version out is necessary. Otherwise a person would have to rely on computerized arithmetic measurements to add in the structuring rather than using a software program that allows one to create the break apart structure themselves. This structuring is necessary when printing out things like femurs because the filament cannot be laid down onto an empty plane and too much structuring could alter/damage the print when the filament pillars are being pulled off.

Other limitation includes money and access to software. The reason that this study utilized a cheap filament (PLA) was do the fact that many places might be limited in where to print as well as money. Even if one can find a 3D printer the environment in the room has to be within a certain temperature range and the extruder tip (releases the filament) has to work just right or else the filament might come in on itself after it printed out or fall outs might occur in print itself

Image 6: This image constitutes of a group of 3D printed femurs. TX-16, on the far left and it shows that the print must be monitored every so often or else the printer might run out of filament and a change has to occur midprint. TX-17 in the middle left shows fall outs or little bumps on its surface because the extruder-point on the printer released too much filament at once, but it did not affect the overall measurements. TX-12 in the middle right shows what happens when the print gets too big for the printer. Lastly TX-14.2 is another print taken of TX-14 to show what can happen when the printer arithmetically inputs structures.

(bubbles on the print). If one is looking for accuracy in how it looks and small defects in the bone than cheap PLA is not the way to go. This is highly due to the fact that the MakerBot and PLA filament has a decent accuracy rate in terms of measurement, but it does not show all of the minuscule detail shown on the bone.

As the Carew et al. (2019) study showed, this method can be utilized in the field because it is accurate enough to the source bone and the proximal femur looks like a proximal femur, at least sufficient to determine what one is examining. This is especially important when showing the jury in a courtroom what one is talking about. So long as one can overcome the limitations of knowledge and money, this would be a good method to utilize when transferring skeletal evidence from one person to another without having to worry about extra damage in the transport, and the family or state would be able to gather the remains sooner for burial or cremation. It would also be an excellent way to get a second opinion on the remains from another forensic anthropologist if there is only one in the region and/or state.

This method would also be useful in the field of bioarcheology because several countries and counties rely on tourism for a significant source of their economic income. However, these remains, tombs, and artifacts might soon be gone, broken down by the oils and oxygen our body's release. Therefore, it would also be an excellent method to utilize in museums and tourist sites around the world to gather a digital collection so the remains and other materials can get left at their source. Thus, cultural heritage can be preserved, while the people of the world can see and appreciate them without having the worrying transition process or about the safety and security of many museums around the world that hold human remains and mortuary artifacts.

Broader Impacts

3D printing can aid forensic archaeology/anthropology in many ways. One way that 3D printing can help is in the realm of preservation of information and artifacts. Many individuals have raised the question of how to preserve human history. Many places are answering preservation questions by returning the people and the artifacts to where they were found. However, what happens to research or tourism when everybody and everything is given back to the peoples of the region the object originated? Or what happens if something worse happens to the skeletons and materials, such those that all perished in a fire at Brazil's Natural History Museum?

Depending on how variable 3D printing is, it is possible that 3D printing could be an answer to preserving material for scientific study. 3D printing will allow us to retain information in the digital world and print it out whenever and wherever one might need them, and make them more accessible to students, and allow researchers access without having to fly across the country or around the world to collect skeletal data. However, it must be kept in mind that some cultures might not want scans to be put up digitally on a computer or even transferred to another person. Therefore, one must always keep in mind the ethical implications of their scans and what they are to be used for because it could go against laws set in place by the native peoples of the land, such as the Native American Graves Repatriation Act, (1990).

3D scanning and printing can help in the preservation of sites and data collection and therefore it would be a beneficial tool for those in the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and the Endangered Archaeology of the Middle East and North Afirca (EAMENA), but it can help law enforcement agencies. Especially those agencies that are seeking assistance from a specific specialist for a specific case matter, such as forensic anthropology. 3D scanning and printing can make collaboration between different agencies and organizations easier since they would not have to track evidence around the country or world when it is in transport and potentially lose it. Instead, the remains can be scanned through any 3D scanner portable or not and be sent to the required destination via email or some other software. In doing so, the transfers would be attached to the data file which could act as a digital chain of custody in and of itself. Depending on the agency and their resources, this technique might be able to make some cases more affordable for those law enforcement agencies. If an agency or a lab does not have access to a 3D scanner then this technique will be more expensive at first but in the long run, the system can save agencies money when they need to send evidence to a specialist for further analysis. Not to mention it also decreases the chances of losing evidence.

Whether it is for preservation or law enforcement, it would be easier to scan the remains and send them digitally through a secure network when collaborations are required.

Conclusions

This study showed that there is accuracy within the compared measurements utilizing PLA filament. Even if some differences did occur, most likely due to intraobserver error this method does show statistical significance to be able to be utilized for accuracy. However, no constant error rate can be seen during the analysis. Therefore, this method has proved itself to be a useful method for the fields of forensic anthropology not only in terms of presenting to a jury, but also in terms of examination. As for bioarcheology, this method can also be useful in terms of preservation of archaeological remains that are currently on display in many countries around the world.

Many cultures believe that the dead should not be disturbed from their rest, and laws like NAGPRA state the remains have to be returned. Therefore, both forensic anthropology and bioarcheology stand at a crossroads today, but to be able to research new topics and ideas it is becoming necessary to find a new way to collect our findings and out data. 3D scanning and printing just might be the answer to a couple of these problems we face as scientist, especially since the accuracy in both the size and presentation have increased over the last decade alone.

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Image 5: Taken by the researcher utilizing the NextEngine software to show how it is hanging and the original has more visual differences in areas over the copied version.

Image 6: A set of prints taken by the researcher, to explain limitations.

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