# Forensic Facial Reconstruction: Soft Tissue Thickness from Medical Record Computed Tomography Images

by

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## Abbreviations

CT = Computed Tomography

DICOM = Digital Imaging and Communications in Medicine

FSTT = Facial Soft Tissue Thickness

IRB = Institutional Review Board

PACS = Picture Archiving and Communication System

PHI = Protected Health Information

UVA = University of Virginia Health System

## Definitions

**Computed Tomography (CT)** – a form of tomography in which a computer controls the motion of the X-ray source and detectors, processes the data, and produces the image.

**Digital Imaging and Communications in Medicine (DICOM)** – is a standard for handling, storing, printing, and transmitting information in medical imaging. It includes a file format definition and a network communications protocol.

**Forensics -** relating to or denoting the application of scientific methods and techniques to the investigation of crime.

**Frankfort horizontal (FH) plane** – a line approximating the base of the cranium, passing from the infraorbital ridge to the midline of the occiput, intersecting the superior margin of the external auditory meatus; the cranium is in the anatomic position when the base line lies in the horizontal plane and right and left sides are level.

## Abstract

Unidentified human remains are examined using a multitude of forensic techniques (i.e., DNA and fingerprinting) to identify the individual. The last-resort is facial reconstruction, which aims to produce a likeness of the individual that can be recognized by someone familiar with the

person (Wilkinson C. , Forensic Facial Reconstruction, 2004). Facial soft tissue thickness (FSTT) datasets allow forensic artists to transform the unidentified skull into a representation of the individual’s face. Over the years, several methodologies have been studied and recommended to create these datasets (needle puncture, ultrasound, CT, MRI). This paper assesses the use of medical record computed tomography (CT) images to improve the accuracy of forensic facial reconstructions. The vastness of available data in medical records can improve the specificity of each forensic reconstruction.

Additionally, using medical records can provide geographical region-specific FSTT values. Region-specific values will be valuable as more cultures and ethnicities migrate and connect. This paper randomly selected 30 medical records of individuals ages 21-38 from three different ancestral groups: Caucasian, African American, and Hispanic. This study grouped subjects by sex and race for statistical comparison. FSTT was collected at eight facial landmarks using a DICOM viewer called PACS. The tissue depths measured were analyzed and compared with previous CT datasets.

ANOVA results showed two statistically significant ($p<0.05$) landmarks at the infraorbital and zygomatic arch. Due to time restrictions, the sample size used for this study was very small resulting in a large percent error. Understandably the data from this study alone is not helpful to the field of forensic facial reconstruction, but the future potential described in this paper is promising.  One way to increase the accuracy of facial reconstructions is to identify groups of similar morphology. The more we expand the dataset across individuals of various ages and races, the more narrowly the groups can be defined. This paper shows that FSTT collected from medical records is a valuable source of data for facial reconstruction datasets, but the risk for error is significant. Therefore, an automated method of data extraction that minimizes the risk for error would be a viable future project.

## Objectives

**Primary Objective:** To determine the reliability of Computed Tomography (CT) facial soft tissue thickness (FSTT) values from medical records for Forensic Facial Reconstruction (FFR)

**Secondary Objective:** Advantages and disadvantages of acquiring medical data to aid in forensic investigations

## Background

In facial reconstruction, the skeletal structure of the skull is first assessed to determine its sex, approximate age, and ethnicity. Once this information is known, forensic artists use datasets to look up the appropriate facial soft tissue thickness (FSTT) at various landmarks on the skull. These values will guide the artist as they apply a layer of "skin" to the face of the skull. Artistic skills used for creating human portraits can then be utilized to make the recreation more realistic. For this reason, facial reconstruction is often considered a science and an art. (Wilkinson C. , 2010) The "science" has evolved considerably over the years with the addition of advanced imaging technology (i.e.CT and MRI) and accessibility to different ancestral populations.

At the beginning of facial reconstruction, anatomist Welcker studied sketches of cadaver skulls. (Wilkinson C. , Forensic Facial Reconstruction, 2004) It was only after his attempts to superimpose two sketches that he realized the unique relationship between skull and soft tissue. Anatomists expanded upon his work and began taking measurements of the facial tissue of cadavers using sewing needles, chisel-shaped knives, and calipers. This acquisition technique limited their sample population to cadavers, but this helped anatomist understand the uniqueness of each face.

An analytical review of a variety of measurement techniques, needle puncture, clinical calipers, (2D and 3D) ultrasound, computed tomography, and magnetic resonance imaging (MRI) showed a small magnitude of difference between the groups. (Stephan & Simpson, 2008) As technology advanced in the 1900s, new studies highlighted the need for more raw data for better comprehensive analyses. New studies also addressed problems associated with standardization, measurement error, and application error. (Stephan & Simpson, 2008)

The new FSTT studies magnified the need for a dataset on a larger scale covering multiple geographical areas in order to see a greater difference between the groups. There have been numerous studies publishing FSTT of different races and ethnicities, African, American, American Indian, British, Chinese, Japanese, Taiwanese, Turkish, Pakistani just to name a few. The differences in acquisition techniques among these studies make comparing the data for facial reconstruction challenging; facial reconstructionists do not know which dataset is best.

There are three techniques used in facial reconstruction over the years, the Russian method, the American method, and the combination Manchester method. In the Russian method, each facial muscle is molded onto the skull, one by one. A thin layer of clay or “skin” is then placed over the muscles. This method did not rely on tissue depth. The American method introduced after the Russian method, “employs average tissue thickness data from a variety of tables relating to different ages, ethnic groups, and sexes.” (Wilkinson C. , 2004) The clay is placed on the various anatomical landmarks at the appropriate thickness. Open spaces in between are filled in and connected roughly together. The third method is known as the combination method from the University of Manchester, “uses all the skeletal detail of the skull to establish facial detail and form and relies on the tissue thickness data as a guide to the soft tissue depth" (Wilkinson C. , 2004). This is the method most used by forensic artists today. "Although the tissue depth data are important, it must be noted that these are only mean sets…and cannot take into account the individuality of each skull, and therefore each face." (Wilkinson C. , 2004)

The tissue depth datasets available to the Forensic Facial Reconstructionist (FFR) vary considerably in demographic content and acquisition techniques. (Parks, Richard, & Monson, 2014) The invention of advanced imaging technology helped to broaden the demographics of the datasets by allowing measurements on living individuals, which produced more accurate reconstructions than measurements taken from cadavers. Most datasets used today were created using ultrasound technology on living adults and children.

Ultrasound is one of the safest methods of acquiring FSTT due to its lack of radiation exposure. For this reason, methods that involve radiation exposure do not recruit volunteers on a large scale to create theses datasets. Manhein et al. (2000) studied ultrasounds of 551 children and 256 adults of various ages and races increasing the available tissue data for Americans. He relied on volunteers from a pediatric dental clinic in New Orleans. Their paper notes the need for standardized protocols to improve the repeatability of results. The biggest issue with using ultrasound is often accurately locating the landmarks. Researchers should consider CT over ultrasound due to the many disadvantages of using ultrasound technology for collecting FSTT:

- the risk of depressing the facial tissue with the ultrasound probe during the scan
- the length of time to acquire the scan is long
- FSTT data is acquired manually due to no current technology automating the ultrasound process

- Difficulty locating landmarks with the ultrasound probe
- ultrasounds of the face are not routinely done in the medical setting, which requires recruiting volunteers
- mediocre imaging resolution
- inability to manipulate the images after the scan

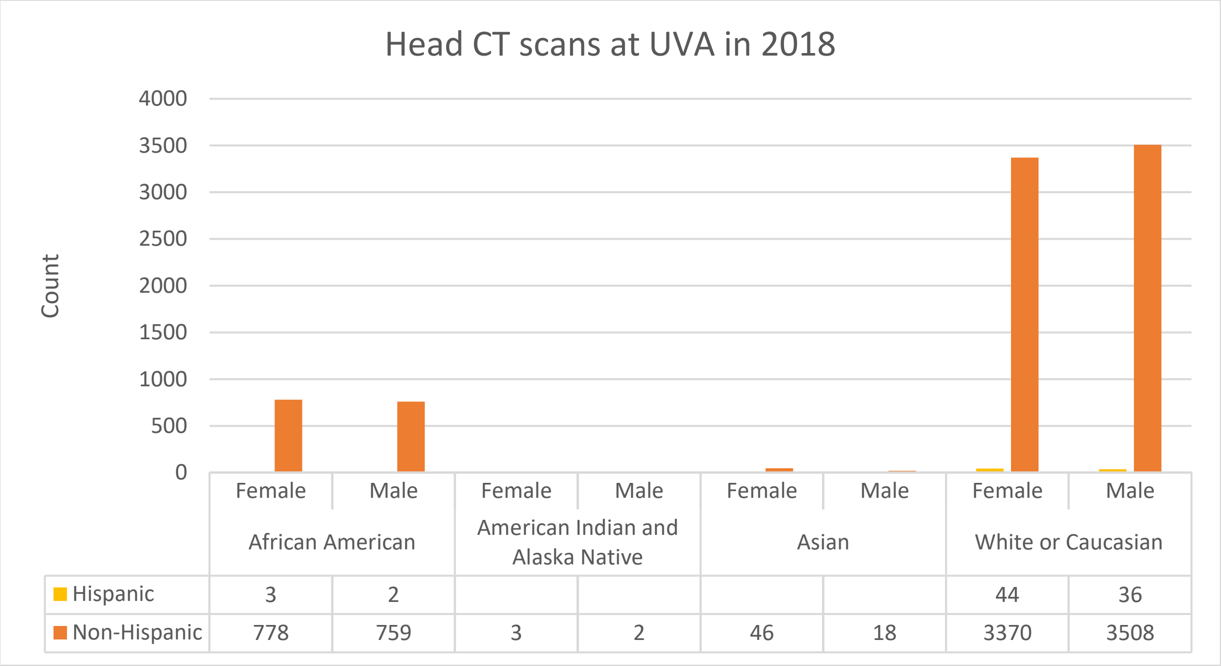
Despite the many advancements over the years, there is still a need for improvement; there are thousands of unidentified bodies in the United States. NamUs, funded by the National Institute of Justice and The National Crime Information Center (NCIC) are two of the nation’s information repositories for missing, unidentified and unclaimed person cases in the United States. NamUs reports about 4,400 unidentified recovered bodies each year, with about 1,000 still unidentified after one year. (Unidentified Persons Database, 2019) The sheer number of cases that go unsolved may be due to several reasons. One possible area of improvement is the datasets used for facial reconstructions. The more data collected for these datasets, the narrower the groups can be defined, which will likely lead to greater accuracy.

## Computed Tomography

One of the most significant advantages of CT over ultrasound technology is the large number of head CT scans archived in medical records. Ultrasounds of the head require the collection of volunteers for FSTT collection because there is no large repository of this kind like there is for CT scans. FSTT collection via ultrasound is both time-consuming and challenging to replicate. According to the annual CT market summary report, over 80 million CT scans are performed a year in the United States. This repository of CT scans is not only useful for studying the individuality of the human face. It could also serve as a forensic resource for skull cross-matching using facial recognition software.

A report of CT scans showed that in 2018 at the University of Virginia (UVA) medical center, over 8,000 head CT scans were performed. Figure 1 below shows the number of CT scans by race and sex. The graph shows in orange, patients of Non-Hispanic ancestry totaled 3,370 White females, 3,508 White males, 778 African American females, and 759 African American males. Then in yellow patients of Hispanic ancestry were 44 White females, 35 White males, 3 African American females, and 2 African American males. Creating a FSTT dataset using medical record CT scans would be less time consuming than ultrasound because the scans have already been performed. In addition, radiation exposure is not a factor because the CT scans will be acquired for medical diagnostic purposes and collected retrospectively for FSTT measurements.

Figure 1: Head CT scans performed from 1/1/2018-12/31/2018 at the University of Virginia



| | African American | | American Indian and Alaska Native | | Asian | | White or Caucasian | |
|---|---|---|---|---|---|---|---|---|
| | Female | Male | Female | Male | Female | Male | Female | Male |
| 🟨 Hispanic | 3 | 2 | | | | | 44 | 36 |
| 🟧 Non-Hispanic | 778 | 759 | 3 | 2 | 46 | 18 | 3370 | 3508 |

Additionally, more advanced computer software is available with CT imaging in order to create an automated method for standardization and efficiency. An automated statistical model was proposed by (Gietzen, et al., 2019) using head CT scans and optical face scans. They generated face – estimations/ approximations even from incomplete skulls. This principle allowed for head variations that could be adjusted. The combination of all these advancements method shows promise for the analysis of multiple scans very quickly and accurately.

Disadvantages also exist when using medical record CT scans for the soft tissue thickness datasets. "For CT, variables that may additionally interfere with this accuracy include scanning resolution and hardware, non-standardized head position, hard tissue segmentation algorithms, 3D rendering algorithms, and landmark positioning." (Caple, Stephan, Gregory, & MacGregor, 2016)  The inability to control for head position during the scan requires the images to be manipulated and appropriately aligned before taking measurements. Head alignment is important because although CT is a 3-dimensional image taken along multiple body planes, 2D slices are required to analyze the interior aspects of the head. The accuracy of the measurements is highly dependent on the standardization of the 2D slices. In the Caple et al. study, they analyzed the percent difference for two different measurements taken along different planes. They found that measurements taken parallel to the Frankfurt horizontal (FH) plane provided a consistent angle and better accuracy.

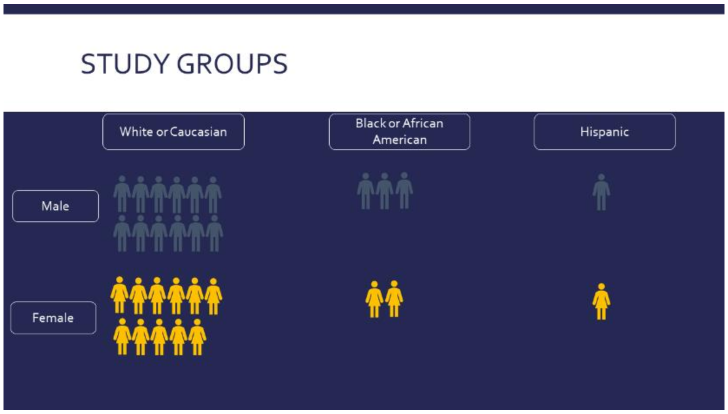
The purpose of this study was to collect a sample of FSTT values from medical record CT scans to identify the advantages and disadvantages of using medical records as a data source. The magnitude and statistical significance of the differences were compared to previous FSTT studies using CT technology. This paper proposes a multi-site study using medical record CT scans in order to create a larger and more accurate dataset for improved forensic facial reconstructions.

## Study Design

A stratified random sampling of 30 subjects ages 21-38 containing head computed tomography (CT) scans were collected from the University of Virginia (UVA) medical records. Figure 2 below shows the sample population divided into 6 study groups for data analysis, Caucasian males, Caucasian females, African American males, African American females, Hispanic males, and Hispanic females. FSTT was collected from 16 male subjects and 14 female subjects of Caucasian, African American, and Hispanic ancestry. This study received approval by George Mason University and The University of Virginia (UVA) Institutional Review Boards (IRB) before the collection of any patient data. The study was approved for exception from informed consent due to minimal risk to patients.

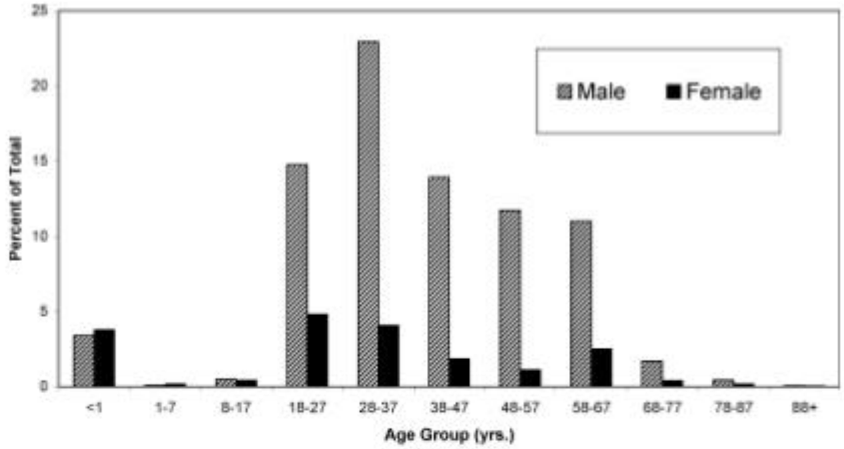
The records were categorized by sex, race, and age range using the data provided in the patient chart. The type of CT scan and CT slice thickness was recorded for comparative purposes. Seven of the scans were CTAs of the head, and 23 were plain CTs of the head. The slice thickness ranged from 0.63 to 3.00, with most slices being 2.50 thick. This variation in scanning protocols means there was some difference in image resolution between the subjects observed.

*Figure 2: Sample FSTT study groups*



The age range for this study was limited to adults at least 21 years of age for quicker IRB approval. From 1979 to 2004, 46.6% of unidentified decedents were estimated to be between 18-37 years old. (Paulozzi, Cox, Williams, & Nolte, 2008) Figure 3 shows the distribution of deaths by sex and age group from the Paulozzi et al. study. Concentrating on this age range would be most beneficial towards helping to identify the majority of unidentified cases.

*Figure 3:Paulozzi et al. distribution of unidentified decedents*



* Figure excludes 6,211 deaths, 59.3% of the 10,473 deaths in the study, which did not have an estimated age.

FIG. 2—*Estimated distribution of unidentified decedents* by sex and age group, U.S., 1979–2004.*

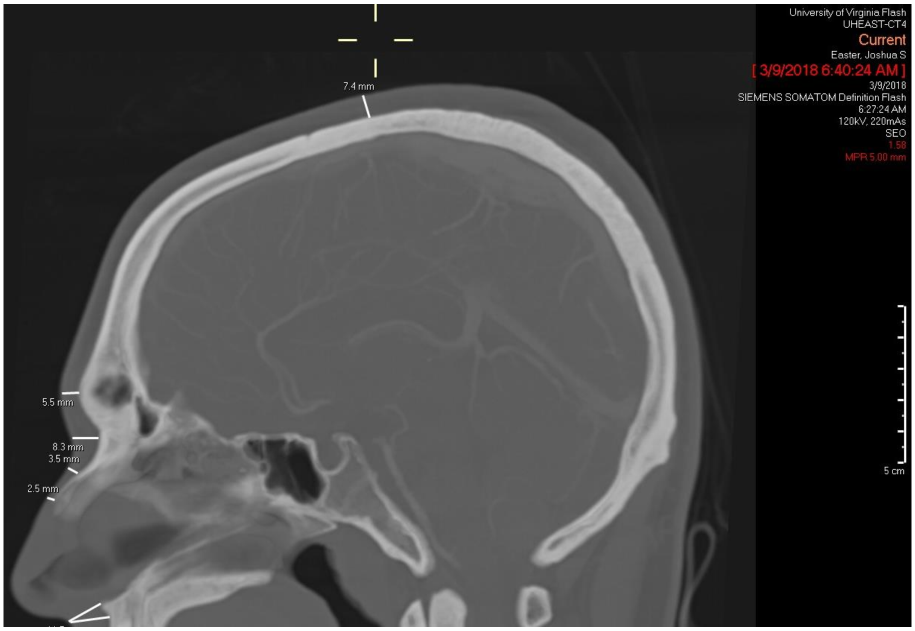
The head CT scans were uploaded into PACS, a picture archiving and communication system used for viewing medical images in Digital Imaging and Communications in Medicine (DICOM) files. Within the viewer window of PACS, the measurements were collected from magnified views of the landmarks. Images in the viewfinder were rotated using the scrolling feature to align the head perpendicular with the viewing window. The contrast was adjusted to the spine view setting for greater resolution and contrast between bone and soft tissue. Using the ruler function measurements were taken at eight landmarks on the skull in first the sagittal view and then double-checked in the coronal view of the skull. Adjustments were made between the two views, and visual confirmation was used to align the ruler to the bone perpendicularly. All data collected was performed on the same personal computer with an IPS display with a resolution of 1920 by 1080 FHD.

## Methods and Materials

A system-generated report was created from the EPIC electronic health record portal to extract the subject’s sex, age, and race at the time of CT imaging. The report was generated for all patient encounters from 2018 with a head CT with IV contrast, head CT without IV contrast or CTA of the head. All data was documented in a de-identified CSV file for analysis. BMI was not recorded or analyzed for this study.

The DICOM (Digital Imaging and Communications in Medicine) files from the CT images were evaluated using the imaging viewer PACS (Picture Archiving and Communication System), shown in figure 4 below. Subjects were screened for the following exclusions: neck stabilizing collar, endotracheal tube, head or face trauma including edema, hematoma, or fractures, cranial surgery resulting in head deformities. Subjects were also excluded if the CT scan was of poor resolution or poor positioning often due to patient movement during the scan. All measurements were performed by one observer using the distance tool available in the PACS software. In order to standardize the location where landmarks were made, this study followed a list of landmarks and their definitions (Wilkinson C. , Forensic Facial Reconstruction, 2004) commonly used for facial reconstructions.

*Figure 4: Head CT sagittal view*



In order to be consistent with previous FSTT studies, this study used the traditional landmarks of Rhine and Moore. (Greef, et al., 2006) The benefits of using these landmarks were their unique locations on the skull which help to standardize measurements. Using these pre-defined landmarks allowed the dataset to be reliably compared with other studies that used the same landmarks. Each landmark was measured twice, once in the sagittal view and once in the coronal view. If the two values measured differed, an average of the two was recorded. Differences in value was not observed at most landmarks.

## Results and Discussion

Data collected for this study can be found at the conclusion of this paper in Table 2. Note that 8 out of 24 facial landmarks were measured for each subject due to the various scanning protocols used for medical diagnostic purposes. These landmarks were consistently visible in all images acquired. Also, this preliminary study was restricted to a small sample size of 23 subjects of White or Caucasian ancestry, 5 subjects of African American ancestry, and 2 subjects of

Hispanic ancestry between the ages of 21 and 38. The body mass index was not collected for this study, so this data could represent a range of body sizes. The ages of the subjects were restricted to a typical age range used for the analysis of unidentified remains. An analysis of variance was performed to assess differences in FSTT collected from medical record CT scans among sexes and ancestry groups. The data was then compared to past studies using the same CT technology. Table 1 below lists the mean and standard deviation for each landmark measured. The group labeled Female Other represents the single Hispanic female included in this study, and the group labeled Male Other represents the single Hispanic male included in this study. There is no standard deviation for these two groups.

*Table 1: ANOVA*

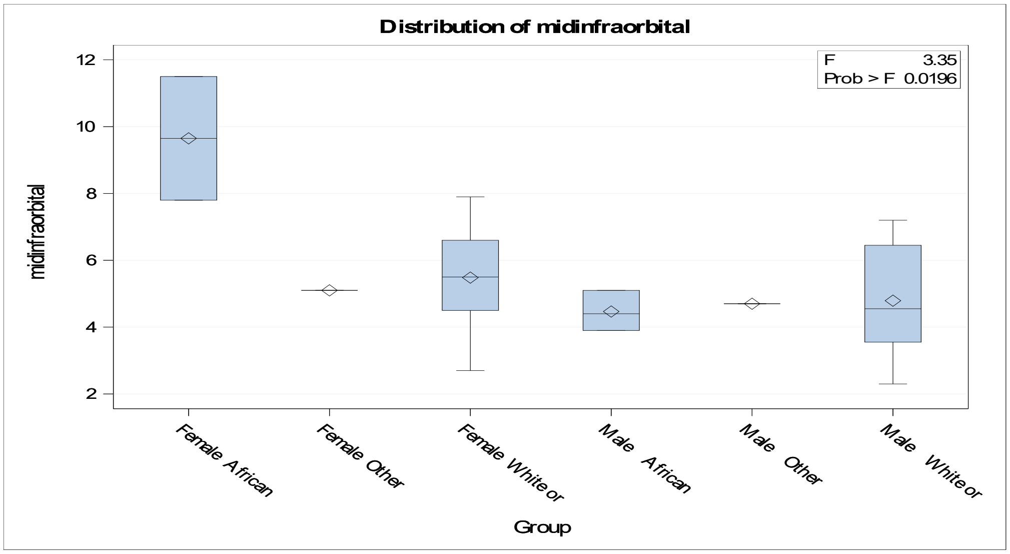
| **Level of Group** | **N** | **Vertex** | | **Glabella** | | **nasion** | | **midnasal** | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Mean** | **Std Dev** | **Mean** | **Std Dev** | **Mean** | **Std Dev** | **Mean** | **Std Dev** |
| **Female African** | 2 | 5.00000000 | 0.00000000 | 5.80000000 | 0.98994949 | 5.75000000 | 0.91923882 | 3.15000000 | 0.21213203 |
| **Female Other** | 1 | 2.60000000 | . | 4.60000000 | . | 5.00000000 | . | 1.30000000 | . |
| **Female White or** | 11 | 3.29090909 | 0.71896390 | 4.62727273 | 0.96238340 | 4.74545455 | 1.29411254 | 2.17272727 | 0.83197465 |
| **Male African** | 3 | 3.70000000 | 0.60827625 | 4.63333333 | 1.05987421 | 4.73333333 | 1.60104133 | 2.96666667 | 0.60277138 |
| **Male Other** | 1 | 4.10000000 | . | 5.40000000 | . | 5.80000000 | . | 2.50000000 | . |
| **Male White or** | 12 | 3.29166667 | 1.25151423 | 4.44166667 | 1.12690915 | 5.62500000 | 1.36256776 | 2.80833333 | 1.23983748 |

| **Level of Group** | **N** | **rhinion** | | **midsupraorbital** | | **midinfraorbital** | | **zygomatic arch** | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Mean** | **Std Dev** | **Mean** | **Std Dev** | **Mean** | **Std Dev** | **Mean** | **Std Dev** |
| **Female African** | 2 | 2.15000000 | 0.07071068 | 7.05000000 | 0.63639610 | 9.65000000 | 2.61629509 | 15.2500000 | 0.49497475 |
| **Female Other** | 1 | 0.20000000 | . | 2.00000000 | . | 5.10000000 | . | 11.9000000 | . |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Female White or** | 11 | 1.09090909 | 0.86423902 | 5.76363636 | 1.92835304 | 5.48181818 | 1.48984441 | 9.5454545 | 3.46911044 |
| **Male African** | 3 | 2.33333333 | 1.10151411 | 6.30000000 | 0.87177979 | 4.46666667 | 0.60277138 | 10.1666667 | 2.22336082 |
| **Male Other** | 1 | 0.20000000 | . | 5.20000000 | . | 4.70000000 | . | 6.5000000 | . |
| **Male White or** | 12 | 1.18333333 | 1.04257839 | 5.55000000 | 1.61216963 | 4.79166667 | 1.73124145 | 7.5250000 | 2.37415057 |

In Figure 5, the FSTT (mean, mode, SD, and p-value) are provided for the mid-infraorbital facial landmark. The mean for White and Hispanic males and females, African American Males, is approximately 5 mm. The mean FSTT for African American females is 9.7 mm. With a p-value of 0.02, the FSTT was significantly larger at this landmark for the African American female as compared to the other groups. Not only was it significantly larger than the White and Hispanic ancestry groups, but it was also larger than its male counterpart of the same ancestry. When comparing the White and Hispanic ancestry histograms, the difference in FSTT mean and range for White males and females is nearly non-existent. No outliers were seen at this landmark.

*Figure 5: ANOVA- Distribution of mid-infraorbital facial landmark*



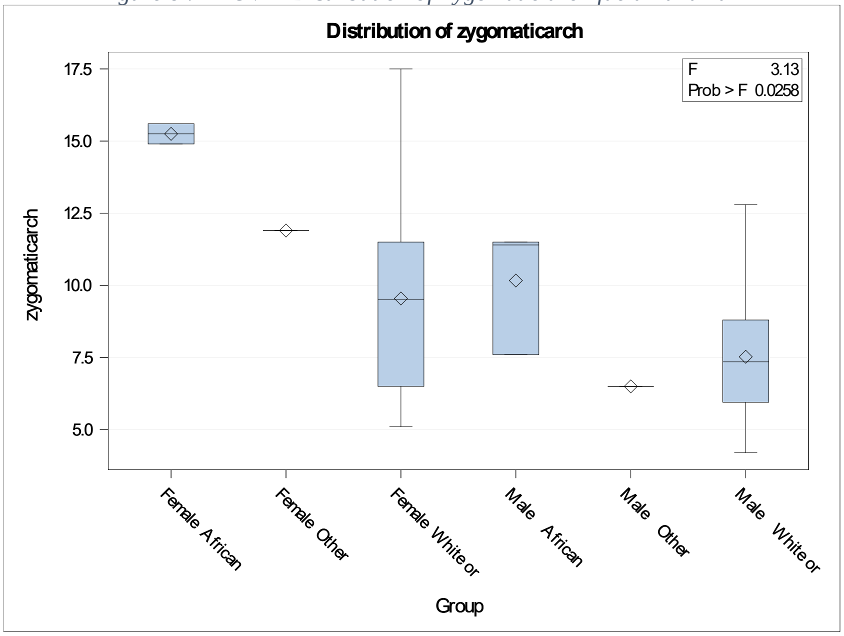
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 43.7364697 | 8.7472939 | 3.35 | 0.0196 |
| Error | 24 | 62.7371970 | 2.6140499 | | |
| Corrected Total | 29 | 106.4736667 | | | |

In Figure 6, the FSTT (mean, mode, SD, and p-value) are provided for the zygomatic arch facial landmark. The mean for White, African American, Hispanic females, and African American males was consistently greater than the other groups. FSTT mean for African American females was approximately 15 mm, and the mean for the White male was approximately 7 mm. This landmark showed the greatest range in soft tissue thickness for White ancestry. White female's FSTT ranged from 5 mm to 17.5 mm, a difference of nearly 12 mm.

White male’s FSTT ranged from approximately 4 mm to 12.5 mm, a difference of nearly 8 mm. With a p-value of 0.026, this landmark was also statistically significant.

When comparing FSTT among the groups, no significant differences were seen at the vertex, glabella, nasion, mid-nasal, rhinion, and mid-supraorbital landmarks. The range of values were within 2 to 3 mm within most groups and between the groups. The distribution of values is inconsistent due to the small sample size used, and outliers at several landmarks were noted for the White male group.

*Figure 6 : ANOVA- Distribution of Zygomatic arch facial landmark*



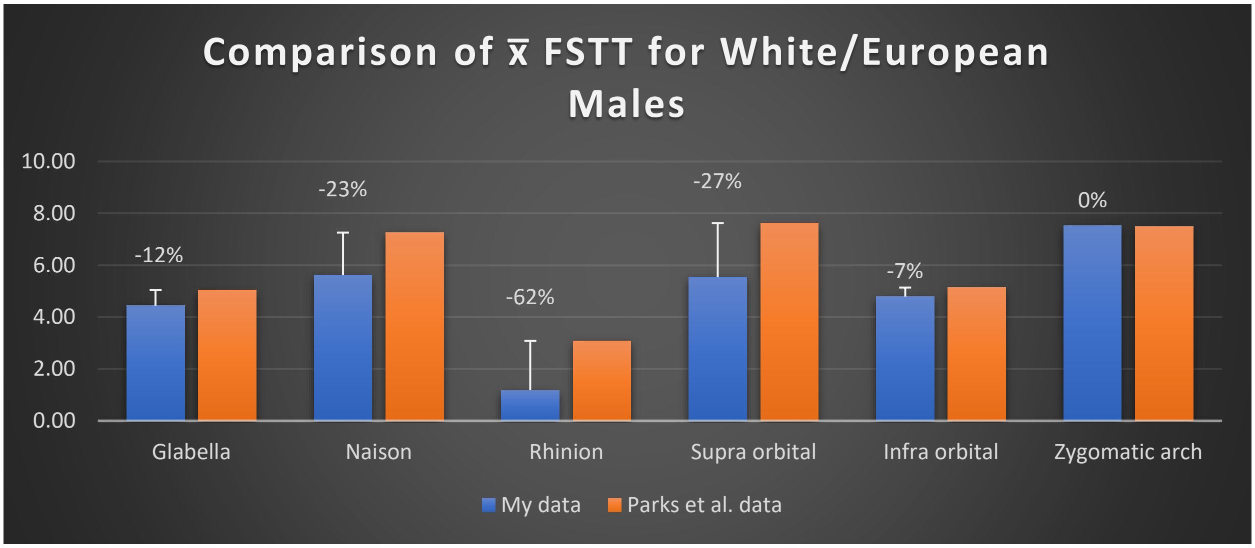
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 125.5122273 | 25.1024455 | 3.13 | 0.0258 |
| Error | 24 | 192.4814394 | 8.0200600 | | |
| Corrected Total | 29 | 317.9936667 | | | |

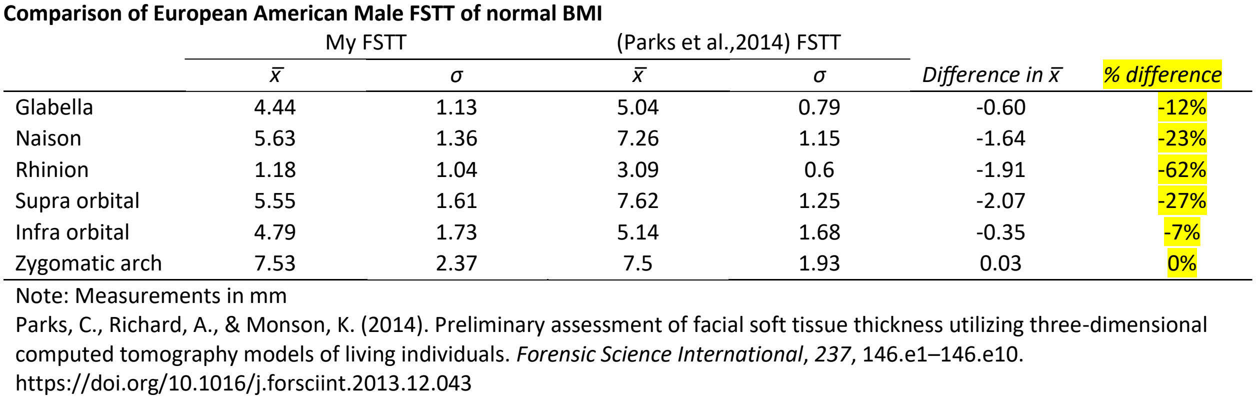
Figure 7 shows a graph and a table comparing data collected in this study with a previous CT study from 2014, the FBI study (Parks, Richard, & Monson, 2014). Parks et al. looked at CT scans for 388 living adults from 2003 to 2009 and ages 18-62. They used four self-identified ancestral groups, Caucasian, African American, Asian and Hispanic.

The White or Caucasian male ancestry was compared with the FBI study's White/ European male group of normal BMIs. The landmarks used for this comparison comprised of the glabella, naison, rhinion, supraorbital, infraorbital, and the zygomatic arch. The mean FSTT values are graphically represented, and percent differences of those means are displayed in white on the graph below. The greatest difference observed between their dataset and the one collected for this study was at the rhinion facial landmark, a value of -62 % difference in the means. Nearly all observations of FSTT in this study were much smaller than the FBI study.

Surprising, there was a 0% difference in the mean at the zygomatic arch between the two datasets. I believe this may be due to this landmark being easily standardized due to its prominence on the skull. It may also be due to the standard deviation being higher than any other landmark, 2.37 for my data and 1.93 for the FBI study. This means that the data was more spread out from the mean. So, the Caucasian males from this study are very different morphologically at this point.  Note, the FBI dataset controlled for BMI, only values representing Caucasian males of normal BMI were used to compare to my dataset. Since my dataset did not control for BMI, there is likely bias in this comparison. The FBI study used a threshold of 5% difference in means when it compared its data to previous research. Using that same criteria, only 1 out of the 6 landmarks is dependable in comparison with my dataset.

*Figure 7: Comparison of European American Male FSTT of normal BMI*





**Comparison of European American Male FSTT of normal BMI**

| | My FSTT | | (Parks et al.,2014) FSTT | | | |
|---|---|---|---|---|---|---|
| | *x̄* | *σ* | *x̄* | *σ* | *Difference in x̄* | *% difference* |
| Glabella | 4.44 | 1.13 | 5.04 | 0.79 | -0.60 | -12% |
| Naison | 5.63 | 1.36 | 7.26 | 1.15 | -1.64 | -23% |
| Rhinion | 1.18 | 1.04 | 3.09 | 0.6 | -1.91 | -62% |
| Supra orbital | 5.55 | 1.61 | 7.62 | 1.25 | -2.07 | -27% |
| Infra orbital | 4.79 | 1.73 | 5.14 | 1.68 | -0.35 | -7% |
| Zygomatic arch | 7.53 | 2.37 | 7.5 | 1.93 | 0.03 | 0% |

Note: Measurements in mm

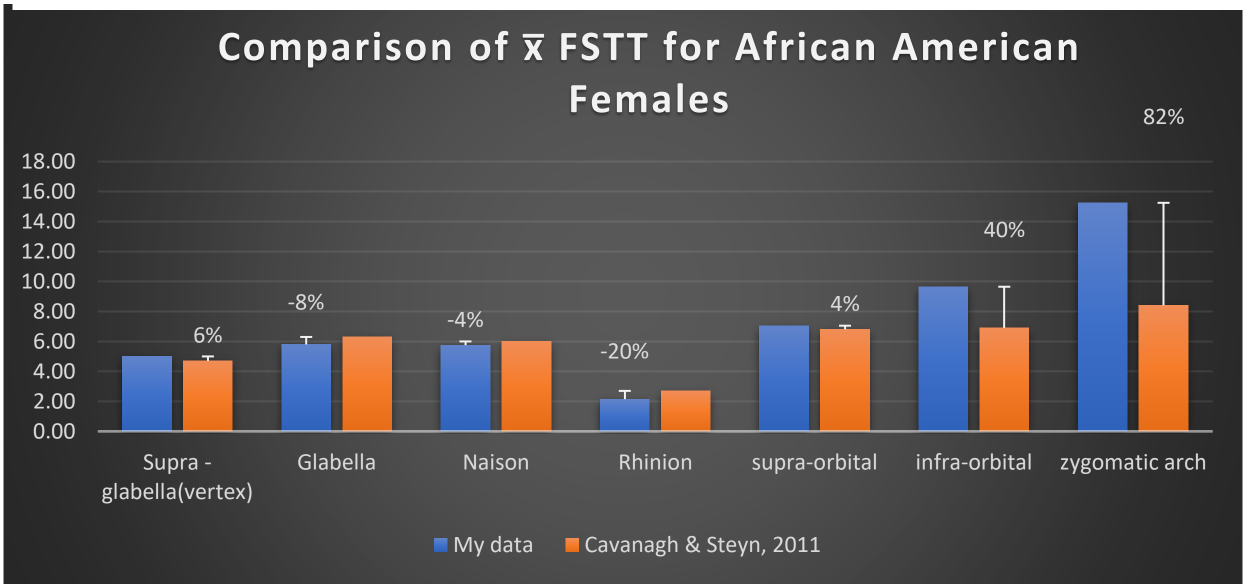
Parks, C., Richard, A., & Monson, K. (2014). Preliminary assessment of facial soft tissue thickness utilizing three-dimensional computed tomography models of living individuals. *Forensic Science International*, *237*, 146.e1–146.e10. https://doi.org/10.1016/j.forsciint.2013.12.043

Figure 8 shows a graph and a table comparison of my data with a 2011 CT study of South African Black Females. (Cavanagh & Steyn, 2011) This study looked at FSTT values from the CT scans of 154 African females ages 18-35. They found low repeatability of the data between the two observers used, which could be due to landmark identification.

Percent difference in the means was calculated for the vertex, glabella, naison, rhinion, supraorbital, infraorbital, and zygomatic arch. This comparison is not an adequate match due to the small sample size comparison between my data and their dataset of 2 to 154, respectively. The goal was to assess the magnitude of the differences. In figures 3 and 4 of this paper, African

American females showed statistically significant values at the infraorbital and zygomatic arch landmarks, when all other groups did not. There is also a large difference in measurements when compared with this South African study. The largest percent differences were 40% larger FSTT at the infraorbital and 82% at the zygomatic arch. This is considerably greater than all other points of comparison which ranged from 4% to 20%. The reasons for this difference may be due to the small sample size, measurement error or the bodyweight differences between African American females and Black South African females. The standard deviation for each of these landmarks is relatively small; therefore, the data likely represent two different populations of individuals and should not be compared further.

*Figure 8: Comparison of mean FSTT for African American Females*



**Comparison of African American Female FSTT**

| | My FSTT | | (Cavanagh & Steyn, 2011) FSTT | | | |
|---|---|---|---|---|---|---|
| | $\bar{x}$ | $\sigma$ | $\bar{x}$ | $\sigma$ | *Difference in* $\bar{x}$ | *% difference* |
| Supra - glabella(vertex) | 5.00 | 0.00 | 4.7 | 1.185 | 0.30 | 6% |
| Glabella | 5.800 | 0.990 | 6.3 | 1.287 | -0.50 | -8% |
| Naison | 5.750 | 0.919 | 6 | 1.552 | -0.25 | -4% |
| Rhinion | 2.150 | 0.071 | 2.7 | 0.975 | -0.55 | -20% |
| supra-orbital | 7.050 | 0.636 | 6.8 | 1.371 | 0.25 | 4% |
| infra-orbital | 9.650 | 2.616 | 6.9 | 2.374 | 2.75 | 40% |
| zygomatic arch | 15.250 | 0.495 | 8.4 | 2.767 | 6.85 | 82% |

Note: Measurements in mm

Cavanagh, D., & Steyn, M. (2011). Facial Reconstruction: Soft Tissue Thickness Values for South African Black Females. *Forensic Science International 206*, 215.e1-215.e7.

Soft tissue depth acquired manually by one individual, as was done in this paper, is both time consuming and ineffective. The risk of using this approach is a high level of potential error in the skull data. Previous researchers have suggested automated methods for estimating facial landmarks on radiographic images. The mean difference between tissue depth measured in this paper and the two compared studies is very high. There is likely a significant amount of error due to landmark identification and soft tissue measurements. Chen et al. showed landmark identification as a random error in cephalometric analysis. They argued that computer-aided cephalometric analysis would not introduce more measurement error compared to manual methods, only lessen it. (Chen, Chen, Yao, & Chang, 2004)

## Conclusion

The statistical data observed at the infraorbital and zygomatic arch are significant numerically, each with p-values less than 0.05. The variation of tissue thickness in this region of the face has been observed in previous studies using ultrasound technology. (Wilkinson C. M., 2002) It is likely, with more data and better control for BMI, this variation may lessen. In further research, there needs to be a larger sample size with subjects grouped by sex, race, age, and BMI.

The more narrowly defined the groups, the more likely differences between the groups will be greater, and the less likely there will be significant variation within each group.

This study focused on comparing results to other studies using CT, rather than comparing to other modalities such as needle puncture or ultrasound. Previous studies like Stephan (2013) even compared data from living subjects to cadavers. Studies comparing CT data to CT data are scarce, but these comparisons are essential in order to evaluate the difference between CT scanning protocols and measurement techniques. This will need to be evaluated for both children and adults on a larger scale.

One disadvantage of using medical records not previously mentioned in this paper is the potential to assign a subject to the wrong ancestral group. Hospital medical records use self-reported race and ethnicity for each patient. In some cases, when the patient is not mentally capable of providing this information, the registration staff will use their “best guess”. The potential for error is very high, especially in an emergency department setting. Facial reconstruction relies heavily on correct ancestry identification of the unidentified skull, and therefore datasets acquired from medical records require the same level of accuracy.

With CT computer software, the soft tissue can be removed from the 3D skull in the viewing window of the image. A 3D image of the skull is left behind with good detail and accurate proportions. With the soft tissue removed, an analysis can be performed in the same way an unidentified skull would be assessed when first found. The analysis of the skull would provide a predicted sex, ancestry and age range. A preliminary study comparing this predicted ancestry to the self-reported race may help identify the amount of incorrectly labeled subjects. This study could then be expanded on for a large-scale study using the same techniques prior to measuring FSTT.

Throughout history, the exchange of information has assisted investigators in overcoming obstacles in unsolved cases. The most recent being a case were data exchange with the genealogy site (GEDmatch) identified the Golden State Killer. (Kennett, 2019) It is important that we explore the potential of data exchange because it can help answer complex problems within criminal cases. With that, it is also important to be mindful of patient privacy. The merge between the medical field and forensics is already a useful link in several areas, forensic odontology, and sexual assault nurse examiners, just to name a couple. This paper supports the need for medical record CT scans to be accessible to forensic scientists for the purposes of facial reconstructions.

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## Table of Figures

## Data

*Table 2 : Study Data*

| Obs | Subject No | Slice thickness | Images | Age | Sex | Ethnicity | First Race | Vertex | Glabella | nasion |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 1 | 2.50 | CTA | 21 | Female | Non-Hisp | African | 5.0 | 5.1 | 5.1 |
| **2** | 6 | 2.50 | CT | 24 | Female | Non-Hisp | African | 5.0 | 6.5 | 6.4 |
| **3** | 7 | 2.50 | CT | 24 | Male | Non-Hisp | African | 3.4 | 4.8 | 4.8 |
| **4** | 8 | 2.50 | CT | 37 | Male | Non-Hisp | African | 4.4 | 5.6 | 6.3 |
| **5** | 9 | 2.50 | CT | 28 | Male | Non-Hisp | African | 3.3 | 3.5 | 3.1 |
| **6** | 10 | 2.50 | CT | 29 | Female | Non-Hisp | White or | 2.7 | 3.7 | 4.4 |
| **7** | 13 | 2.50 | CT | 25 | Female | Non-Hisp | White or | 3.6 | 4.9 | 4.5 |
| **8** | 15 | 3.00 | CT | 22 | Female | Non-Hisp | White or | 2.3 | 3.6 | 2.7 |
| **9** | 20 | 2.50 | CT | 38 | Female | Non-Hisp | White or | 3.1 | 4.3 | 3.7 |
| **10** | 21 | 3.00 | CT | 32 | Male | Non-Hisp | White or | 2.7 | 4.4 | 6.5 |
| **11** | 25 | 2.50 | CT | 29 | Male | Non-Hisp | White or | 5.0 | 6.5 | 6.4 |
| **12** | 28 | 2.50 | CT | 29 | Male | Non-Hisp | White or | 3.9 | 5.1 | 2.9 |
| **13** | 29 | 2.50 | CTA | 37 | Male | Non-Hisp | White or | 3.1 | 4.9 | 6.4 |
| **14** | 30 | 2.50 | CTA | 25 | Male | Non-Hisp | White or | 2.1 | 3.9 | 5.3 |
| **15** | 31 | 2.50 | CTA | 35 | Male | Non-Hisp | White or | 2.4 | 3.0 | 5.2 |
| **16** | 33 | 2.50 | CTA | 38 | Male | Hispanic | Other | 4.1 | 5.4 | 5.8 |
| **17** | 34 | 2.50 | CT | 35 | Female | Hispanic | Other | 2.6 | 4.6 | 5.0 |

| Obs | Subject No | Slice thickness | Images | Age | Sex | Ethnicity | First Race | Vertex | Glabella | nasion |
|---:|---:|---:|---|---:|---|---|---|---:|---:|---:|
| **18** | 35 | 0.63 | CTA | 22 | Male | Non-Hisp | White or | 6.1 | 6.5 | 8.1 |
| **19** | 37 | 2.50 | CT | 31 | Female | Non-Hisp | White or | 3.9 | 5.6 | 6.6 |
| **20** | 38 | 2.50 | CT | 28 | Female | Non-Hisp | White or | 4.1 | 5.9 | 6.9 |
| **21** | 41 | 3.00 | CT | 27 | Female | Non-Hisp | White or | 2.4 | 3.7 | 4.9 |
| **22** | 42 | 2.50 | CT | 32 | Female | Non-Hisp | White or | 3.4 | 4.8 | 3.4 |
| **23** | 43 | 3.00 | CT | 31 | Female | Non-Hisp | White or | 4.6 | 6.3 | 5.9 |
| **24** | 44 | 2.50 | CT | 22 | Female | Non-Hisp | White or | 3.2 | 4.4 | 4.6 |
| **25** | 45 | 2.50 | CT | 31 | Female | Non-Hisp | White or | 2.9 | 3.7 | 4.6 |
| **26** | 49 | 2.50 | CT | 27 | Male | Non-Hisp | White or | 3.6 | 3.5 | 6.9 |
| **27** | 53 | 2.50 | CT | 23 | Male | Non-Hisp | White or | 3.2 | 4.1 | 5.0 |
| **28** | 56 | 2.50 | CT | 29 | Male | Non-Hisp | White or | 2.0 | 4.2 | 5.6 |
| **29** | 57 | 2.50 | CT | 32 | Male | Non-Hisp | White or | 2.0 | 3.6 | 5.1 |
| **30** | 58 | 2.50 | CTA | 32 | Male | Non-Hisp | White or | 3.4 | 3.6 | 4.1 |

| Obs | midnasal | rhinion | subnasale | midphiltrum | labralesuperius | labraleinferius | mentolabialsulcus |
|---:|---:|---:|---:|---:|---:|---:|---:|
| **1** | 3.3 | 2.2 | . | . | . | . | . |
| **2** | 3.0 | 2.1 | . | . | . | . | . |
| **3** | 2.9 | 3.4 | . | . | . | . | . |
| **4** | 3.6 | 1.2 | . | . | . | . | . |
| **5** | 2.4 | 2.4 | . | . | . | . | . |
| **6** | 2.8 | 1.5 | . | . | . | . | . |
| **7** | 1.6 | 0.2 | . | . | . | . | . |
| **8** | 1.1 | 0.2 | . | . | . | . | . |
| **9** | 0.7 | 0.7 | . | . | . | . | . |
| **10** | 2.5 | 2.4 | . | . | . | . | . |
| **11** | 3.0 | 2.1 | . | . | . | . | . |
| **12** | 4.7 | 0.2 | . | . | . | . | . |
| **13** | 2.4 | 1.3 | . | . | . | . | . |
| **14** | 3.0 | 1.3 | . | . | . | . | . |

| Obs | midnasal | rhinion | subnasale | midphiltrum | labralesuperius | labraleinferius | mentolabialsulcus |
|---|---|---|---|---|---|---|---|
| **15** | 2.1 | 0.8 | . | . | . | . | . |
| **16** | 2.5 | 0.2 | . | . | . | . | . |
| **17** | 1.3 | 0.2 | . | . | . | . | . |
| **18** | 5.7 | 3.6 | . | . | . | . | . |
| **19** | 3.1 | 2.1 | . | . | . | . | . |
| **20** | 2.8 | 2.4 | . | . | . | . | . |
| **21** | 3.4 | 1.8 | . | . | . | . | . |
| **22** | 2.2 | 1.9 | . | . | . | . | . |
| **23** | 2.3 | 0.2 | . | . | . | . | . |
| **24** | 2.0 | 0.8 | . | . | . | . | . |
| **25** | 1.9 | 0.2 | . | . | . | . | . |
| **26** | 2.4 | 0.2 | . | . | . | . | . |
| **27** | 1.8 | 0.8 | . | . | . | . | . |
| **28** | 1.5 | 0.2 | . | . | . | . | . |
| **29** | 1.7 | 0.6 | . | . | . | . | . |
| **30** | 2.9 | 0.7 | . | . | . | . | . |

| Obs | pogonian | gnathion | menton | midsupraorbital | midinfraorbital | zygomaticarch | Group |
|---|---|---|---|---|---|---|---|
| **1** | . | . | . | 6.6 | 7.8 | 15.6 | Female African |
| **2** | . | . | . | 7.5 | 11.5 | 14.9 | Female African |
| **3** | . | . | . | 6.9 | 5.1 | 11.5 | Male African |
| **4** | . | . | . | 6.7 | 3.9 | 11.4 | Male African |
| **5** | . | . | . | 5.3 | 4.4 | 7.6 | Male African |
| **6** | . | . | . | 2.4 | 5.5 | 6.3 | Female White or |

| Obs | pogonian | gnathion | menton | midsupraorbital | midinfraorbital | zygomaticarch | Group |
|---:|---:|---:|---:|---:|---:|---:|---|
| **7** | . | . | . | 6.5 | 7.3 | 11.5 | Female White or |
| **8** | . | . | . | 4.2 | 4.0 | 7.5 | Female White or |
| **9** | . | . | . | 9.0 | 7.9 | 10.1 | Female White or |
| **10** | . | . | . | 3.7 | 4.0 | 6.1 | Male White or |
| **11** | . | . | . | 5.4 | 5.5 | 8.7 | Male White or |
| **12** | . | . | . | 4.8 | 5.0 | 6.3 | Male White or |
| **13** | . | . | . | 5.8 | 7.0 | 10.1 | Male White or |
| **14** | . | . | . | 5.6 | 3.6 | 5.8 | Male White or |
| **15** | . | . | . | 4.5 | 6.2 | 7.0 | Male White or |
| **16** | . | . | . | 5.2 | 4.7 | 6.5 | Male Other |
| **17** | . | . | . | 2.0 | 5.1 | 11.9 | Female Other |
| **18** | . | . | . | 8.9 | 7.2 | 12.8 | Male White or |
| **19** | . | . | . | 5.1 | 5.0 | 8.2 | Female White or |
| **20** | . | . | . | 6.1 | 6.6 | 10.9 | Female White or |
| **21** | . | . | . | 5.0 | 6.1 | 5.1 | Female White or |
| **22** | . | . | . | 5.6 | 5.0 | 6.5 | Female White or |
| **23** | . | . | . | 9.0 | 5.7 | 17.5 | Female White or |
| **24** | . | . | . | 5.6 | 4.5 | 11.9 | Female White or |

| Obs | pogonion | gnathion | menton | midsupraorbital | midinfraorbital | zygomaticarch | Group |
|---|---|---|---|---|---|---|---|
| **25** | . | . | . | 4.9 | 2.7 | 9.5 | Female White or |
| **26** | . | . | . | 6.3 | 3.5 | 7.7 | Male White or |
| **27** | . | . | . | 6.2 | 6.7 | 7.7 | Male White or |
| **28** | . | . | . | 2.7 | 2.3 | 5.0 | Male White or |
| **29** | . | . | . | 5.4 | 4.1 | 4.2 | Male White or |
| **30** | . | . | . | 7.3 | 2.4 | 8.9 | Male White or |

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