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Exploring Cranial Macromorphoscopics from Adult Computed Tomography Scans Using an Anatomage Table

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by

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Abstract

Virtual anthropology has become popularized within the past decade providing ease of access to anthropological data and increasing the diversity of digital skeletal samples. This paper uses computed tomography scans of adults to test the efficacy of using the protocol developed by Stull et al. (2021), to collect macromorphoscopic (MMS) trait data from subadult computed tomography scans. This paper not only tests the potential application of these protocols on adults but also tests a technology new to the field of biological anthropology, the Anatomage Table. While Anatomage virtual dissection tables are commonly used in medical and educational settings, they provide a new technology for viewing 3D renderings of digitized images in biological anthropology. This project uses an Anatomage Table to produce 3D renderings of computed tomography scans obtained from the New Mexico Decedent Image Database (NMDID) to test the virtual MMS trait collection protocol.

KEYWORDS

Biological Anthropology, Macromorphoscopic Traits, Anatomage, Computed Tomography Scans, Virtual Anthropology, Digital Imaging Methods

Highlights

- Virtual anthropology creates an ease of access for research.
- The first project using Anatomage tables to analyze computed tomography scans to collect Macromorphoscopic traits.
- Macromorphoscopic data collection from computed tomography scans for adults is possible.
- Anatomage technology can make learning important topics within biological anthropology easier.

INTRODUCTION

The utilization of digital imaging practices is commonplace within and outside of the medical industry and has aided in the development of many scientific innovations. Anthropologists have also taken advantage of digital imaging developing the field of virtual anthropology (VA). Virtual anthropology has become a driving factor in the expansion of method development and standards creation for data collection in biological anthropology. Biological anthropologists can use 3D renderings developed from various digitization methods including computed tomography (CT) scans, radiographs, and laser scanning. These images can be used for data collection, research, teaching, and consultations within the medicolegal system. Biological anthropologists' interests in VA will continue to lead to further developments in data collection methods using digital imaging practices. For example Stull et al. (1) describe data collection methods using VA protocols for macromorphoscopic trait data collection from subadults using computed tomography scans. Protocols were developed for image rendering in Amira^{TM} software (2). These protocols were validated for subadults (3) but were not tested on adult populations.

This study aims to ascertain the efficacy of using the data collection protocol developed by Stull et. al (1) for MMS trait collection from adults using CT scans. Computed tomography scans were obtained from the New Mexico Decedent Image Database (NMDID) and rendered using an Anatomage virtual dissection table (AT). To the best of the author's knowledge this is the first study to use an AT for analyzing computed tomography scans in biological anthropology. This paper has two central foci. First, to determine the applicability of the previously developed protocol by Stull and colleagues (1). Second, to highlight the utility of an AT to render CT scans for research in biological anthropology.

BACKGROUND

Virtual Anthropology

Virtual anthropology can be defined as "… a multi-disciplinary approach to studying morphology… in three or four dimensions (4; Page 22)." Virtual anthropology combines methods from various fields including engineering, statistics, anthropology, and medicine, to produce digital imaging methods (4). The use of VA became popularized in the late 20th century with the advancement of computer technology and software (4,5). As a result, the field of study has continued to become more commonly applied and standardized in recent decades.

Multiple methods for creating and viewing digital renderings exist within the field. Methods to create digital renderings fall into two main categories, contact and non-contact methods (6). Contact methods are when a tool, such as a microscribe, is used to touch artifacts or human remains physically recording the objects shape and dimension to produce a digital rendering (6). Non-contact methods do not require the physical contact with the object (6)- examples include photogrammetry, laser scanning, and CT scans (4,6–12). Both contact and non-contact methods have their advantages and disadvantages regarding cost, labor, transportability, storage, applicability, and visualization (6,8,12). Depending on the research being completed certain methods of digitization (contact vs non-contact) are more appropriate (12) and it is important that the most suitable methods are selected to ascertain the most amount of data available. A variety of options exist for computing and manipulating digital images after recording surface data for rendering.

Software programs such as Amira™ (2), OsiriX Lite (13), 3DSlicer (14), Autodesk® AutoCAD (15), Agisoft Metashape (16), PIX4Dmapper (17), and TableEDU 8.0.2® on the AT (18), can produce complete digital 3D models. Some of these programs can also allow users to produce physical renderings of these images through using a 3D printer.

Virtual anthropology has been used in archaeology (11,12), as well as, bioarchaeology and paleoanthropology (4,4,9,12,19–21). Numerous projects have explored the use of 3D imaging and encompass a variety of topics including reconstruction for identification (9,11,19,20,22,23), estimations for the biological profile (9,21,22,24,25), and generally the study of human phenotypic variation (7,23). In conjunction with research using digital imaging, anthropologists have begun to develop tools and programs to aid in the standardization and applicability of previously developed software (5,23,26–28).

Applying methods of VA can produce many positive benefits. Three-dimensional modeling software can increase the ease of access for anthropologists (29). Virtual anthropology can also improve research equality as many researchers can have access to the same renderings (29,30), expanding the concept of open source osteology (30). Open source digital imaging can negate accessibility issues due to deficient financial resources or scarcity of access to modern or archaeological physical skeletal collections on an institutional level (31). There are numerous ways in which digital images can be rendered and analyzed (4,11), providing options for researchers to choose the most appropriate software and programs. Virtual images are available in perpetuity and can be accessed simultaneously worldwide (4,11,32) increasing the ability for collaborative work and continued data collection as technology and methods advance (4,5,29).

Using digital imaging methods can alleviate the damage caused by handling and storing remains or archaeological artifacts (10,12,22,25,32). With image renderings anthropologists can more easily manipulate objects in space to analyze materials in new ways (22) while not needing to handle the remains. Remains do not need to be physically adjusted prior to digitization, meaning original burial and anatomical contexts will not be altered (9). Researchers can analyze extremely damaged remains through reconstructions (9,12,22) and observe objects from an internal view which would not be possible without 3D modeling (4,5,11,12,30). Alternative viewpoints and reconstructions can allow for increased data collection and areas of research that cannot be accessed when viewing physical remains without destructive processes. Analysis can also be done on dry or wet bone creating more research potential, in turn increasing the amount of viable data (5,9,31).

New Mexico Decedent Image Database

The development of the NMDID was a multi-step process that encompassed multiple research projects. In 2010, the Center for Forensic Imaging within the Office of the Medical Investigator (OMI) in New Mexico was awarded a grant from the National Institute of Justice to collect postmortem high-resolution, full-body CT scans (33,34). These scans were used to evaluate if CT scans could circumvent or support traditional autopsy methods (33,34). Scans were taken from over 15,000 individuals within a seven year period (2010-2017) (33,34). Four thousand axial image slices at 1mm thickness with a 0.5mm overlap were taken for each individual; the image slices developed two sets of full-body scans for soft and hard tissues, respectively (33). All CT scans taken by the OMI between the initial dates (2010-2017) are in the OMI’s CT database. Scanning efforts continue today and approximately 2,500 individual’s scans are added annually to the OMI database (35).

In the OMI database, and many other databases, crucial metadata is either absent or exceedingly difficult to delineate (33–36). Missing data prolongs research and can render projects impossible to complete. The concept of a comprehensive database came into fruition during 2014, when researchers from diverse career backgrounds came together to determine what types of metadata would be most beneficial to include with CT scans (36). The project developed a Minimum Data Set (MDS) of 59 different variables that are crucial to producing meaningful research in multiple fields of study including metadata like “cause of death,” “birthplace,” “sex,” and “surgery” (36). The variables established as vital in this study form the basis for the development of the NMDID in the following years.

In 2016, researchers were given a National Institute of Justice grants to develop a database (what would become the NMDID) composed of CT scans from the OMI CT database along with the associated metadata for individuals in the hopes of producing a database that is a new resource for multiple fields of research (33–35). The metadata consist of associated census (e.g. birthplace, age, sex), health (e.g. medical history), and death information (e.g. cause and manner of death) (33,34) that were deemed important for research efforts from the 2014 study (36). Within the NMDID there are scans of 15,248 individuals with corresponding metadata (33). Metadata were collected through the original OMI database and phone interviews with next-of-kin (33–35). All information in the database is HIPAA compliant and individuals are “deidentified” to the highest required standards in hopes of adding other states’ information to the database in the future (33). The database works to streamline metadata and CT scans to make them more user-friendly through standardization and simplification of vocabulary and variables for ease of interpretability and searchability within the database while not losing important metadata (33,34). Users can download CT scans as DICOM files[1] and metadata as a PDF file. The NMDID became available for researcher use in 2020 (33) and numerous research projects and publications have already been produced (33–36).

Anatomage Table

Established in 2004, Anatomage Inc. is a California-based company that develops technology for medical visualization and rendering of 3D images (18). Anatomage has made advances in many sectors of image rendering within the medical industry including the development of technology that allows for the virtual dissection of cadavers and high-quality image segmentations, setting standards for virtual imaging across the globe (18). The company has created various technologies and software for visualization of 3D images and virtual dissection allowing for applicability in numerous scenarios (18,37). Anatomage increases the accessibility and effectiveness of digital imagery by streamlining the processes for viewing renderings.

The AT was initially created to supplement or replace physical autopsies and dissections in an educational or medicolegal setting using integrated software and high-resolution imaging scans. Anatomage tables include software that allow for the visualization of CT scans, cone beam computed tomography (CBCT) scans, or magnetic resonance imaging (MRI) scans and have libraries filled with these types of images to

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[1] DICOM stands for Digital Imaging and Communications in Medicine. These files are used for managing and sharing medical imaging information and their related data.

allow for educational teaching and practice (18) without requiring separate database access. Anatomage also incorporated activities for studying and the ability to have instructors create practical exams using the software on the table (38,39). Within the integrated software individuals can view fully rendered scans, change rendering settings, make cuts, and take measurements.

Anatomage tables have become prevalent in multiple institutions for research and education around the world (38–59) and several avenues of research are being pursued using ATs (38–44,60–66). Such research focuses on either the effectiveness of using the tables in education (38–44,60,63–65) or using the table's virtual capacity to study the potential effects of novel medical technology (61,62,66,67). While many publications and research efforts surround the use and applicability of ATs, these works are centered within the medical industry. Currently, no studies assess the capabilities or usefulness of ATs in an anthropological context.

Macromorphoscopic Traits

In biological anthropology, types of data collected from the skeleton can be broken into two larger groups: metric and nonmetric. Metric data are quantitative and continuous, while nonmetric data are qualitative and categorical data that assess morphological features. Both analytical approaches can be used across the skeleton. Macromorphoscopic traits (MMS) are considered nonmetric trait data in the most general sense. However, they differ from traditional nonmetric traits since MMS traits are quasicontinuous morphological variables of the cranium rather than present/absent characteristics (68–72).

In the early 2000s, Hefner (68–71,73) redefined and standardized MMS traits to comply with the parameters of the *Daubert* ruling while creating a standard for trait collection.[2] The 17 identified traits fall into one of five classes: (1) bone shape, (2) bony feature morphology, (3) suture shape, (4) trait presence or absence, and (5) feature prominence or protrusion (69,71). For brevity unabridged definitions and features of each MMS trait will not be discussed but can be found with associated line drawings and photographs in Hefner & Linde (69). Shortened definitions and trait classes can be viewed in *Table 1*. Traits are recorded on either ordinal or binary scales (68). Hefner discovered no significant difference in the distribution of morphological characteristics between biological sexes (69,71,73). The MMS traits are used for estimates in the biological profile for the identification of individuals (75) or to investigate relationships among populations based on changes in cranial morphology, known as biodistance analysis (68,73,76–79).

In conjunction with standardizing collection methods for MMS traits, Hefner also created a data collection program, *Macromorphoscopic Traits* (MMS v1.6), and a databank, the *Macromorphoscopic Databank* (MaMD) to house MMS trait data (69,72). The MMS v1.6 uses a data entry form to guide users through the process of collecting the 17 MMS traits with definitions and accompanying line drawings (70). The MaMD currently contains data from~7,500 individuals from archaeological and modern populations (69,72). Demographic information and other metadata is also included within

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[2] The *Daubert* ruling (1993) determined that there needed to be empirical support, estimated error rates, method standardization, and validation studies through peer review for methods used in the biological profile. (74)

the database. (72).[3] Researchers can use the MaMD Analytical Tool, which uses 10 MMS traits that are placed into an adaptable artificial neural network (aNN) to generate predicted group membership and associated measures of model accuracy (78).

Stull et al. (1) developed methods that expanded the applicability of MMS trait collection to VA for subadults. The protocol provides brief definitions of each of the collected traits and associated images so researchers have a comprehensive understanding of each trait with respect to being viewed in 3D renderings (1). The protocol was developed to collect 13 of the 17 MMS traits; four traits focused on suture morphology, were not included since the protocol was developed for trait collection within subadults. Corron et al. (3) validated the use of the protocol for subadults developed by Stull and colleagues (1) and found low error rates.

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[3] Demographic data include age, biological sex, geographic ancestry, peer-perceived ancestry, geographic origin, tribal affiliation, etc.

TABLE 1: *Each macromorphoscopic trait with respective abbreviations, trait class, scoring range, and definition.*

MMS Trait	Abbreviation	Trait Class	Scoring	Definition
Anterior Nasal Spine	ANS	Prominence/Protrusion	1 to 3	A bony feature located at the inferior border of the nasal aperture.
Inferior Nasal Aperture	INA	Bony Feature Morphology	1 to 5	The shape of the transitional area from nasal floor to maxillae.
Interorbital Breadth	IOB	Bony Feature Morphology	1 to 3	The distance between orbits, relative to the width of the overall breadth of the facial region.
Malar Tubercle	MT	Prominence/Protrusion	0 to 3	A protruding tubercle that can be located on the maxillae, zygomatic bones, or along the zygomaxillary suture where the bones meet.
Nasal Aperture Shape	NAS	Bone Shape	1 to 3	The shape created by the lateral contours of the nasal opening.
Nasal Aperture Width	NAW	Bony Feature Morphology	1 to 3	The width of the nasal aperture relative to the overall breadth of the facial region.
Nasal Bone Contour	NBC	Bone Shape	0 to 4	The curvature of the nasal bones and the frontal process of both maxillae.
Nasal Bone Shape	NBS	Bony Feature Morphology	1 to 4	The contour of the lateral borders of the nasal bones.
Nasal Overgrowth	NO	Absence/Presence	0 or 1	Projection of the lateral nasal bones at their inferior edge.
Orbital Shape	OBS	Bone Shape	1 to 3	The shape of the bony sockets that houses the eyes.
Postbregmatic Breadth	PBD	Absence/Presence	0 or 1	A slight broad depression located posterior of bregma along the sagittal suture.
Posterior Zygomatic Tubercle	PZT	Prominence/Protrusion	0 to 3	The posterior projection of the zygomatic bone.
Palate Shape	PS	Bone Shape	1 to 4	The curvature of the hard maxillary palate.

Terminology

Problems resulting from terminology and lack of clearly defined terms have become a topic of discussion within biological anthropology in the past few years. Terms tend to be used interchangeably and can have multiple associated definitions that are employed based on research and researcher preference. It is crucial to define terms for clarity to avoid research being misconstrued by the public and other researchers (80,81). By creating clear definitions scientists begin to ensure repeatability within future work. The terms outlined below are defined and solely used based on their use within the NMDID database to describe individuals. Terminology defined in this section will be used throughout this paper and is used based on the original source, not by the preference of the current author. The purpose of this section is not to analyze the appropriateness of the terms and definitions chosen by the creators of the NMDID database but rather to define them in the context of this project for clarity and succinctness. The NMDID database categorizes the following terms as census data. Definitions, collection methods, and categories used within each term will be provided below and can be found in more detail on the NMDID website (35).

Race: "The race of the individual" Race was collected for individuals from the OMI database and next-of-kin interviews. Race categories are: Native American, Asian Indian, Black or African American, Chinese, Filipino, Guamanian or Chamorro, Japanese, Korean, Native Hawaiian, Other, Other Asian, Other Pacific Islander, Samoan, Vietnamese, White, Hispanic, and Unknown.

Ethnicity: "The ethnicity of the decedent." Ethnicity is collected from the OMI database and next-of-kin interviews. Categories included within ethnicity are: Hispanic or Latino, Middle Eastern, Not Hispanic, Latino or Middle Eastern, and Unknown.

Tribal Affiliation: “The tribal affiliation of Native American decedents.” Collected from OMI database and next-of-kin interviews. Tribes that constitute this list are federally recognized tribes within New Mexico.

Sex: “Biological sex of the decedent.” Sex was collected from the OMI database and falls into five categories: Male, Female, Other (hermaphrodite), Transsexual, and Unknown.

MATERIALS AND METHODS

Search Strategy and Reference Samples

The MMS trait data was collected from full body computed tomography scans from 311 deceased individuals from the NMDID. Sample individuals were chosen based on minimum inclusion criteria including: no cranial or neck trauma, be 20 years or older, male or female, and fell into one of five of the “race” categories. These requirements were entered into the search form on the NMDID; individuals were randomly selected from the results. For this project race categories used include Asian, Black, Hispanic, Native American, and White. The Asian “race” category does not exist in the NMDID but for simplicity purposes was created for this project. The Asian “race” category constitutes of the following race categories in the NMDID: Chinese, Asian Indian, Japanese, Korean, Other Asian, and Vietnamese. The age range for the reference sample extends from 20 years of age to 102 years of age at death. The reference sample’s demographic breakdown is exhibited in *Table 2*.

TABLE 1*: The number of males and females for each race for the reference population (n=311).*

Race	Number of Males	Number of Females
Asian	30	23
Black	36	34
Hispanic	31	35
Native American	30	30
White	30	32
Totals	157	154

Data Allocation and the Anatomage Table

This section discusses the use of the developed protocol and its application on the AT. As previously mentioned this paper relies on definitions developed by Hefner (69–71,71) and collection methods created by Stull et al. (1); detailed versions of these definitions and methods can be found in the respective articles and will not be discussed here. The methods outlined here utilize the Stull protocol with minor adjustments to account for the use of the Anatomage rather than Amira^{TM} for volume rendering. All traits are collected based on remains being first place in standard anatomical position in the table view. Images were rendered automatically by the AT to -500HU to 1500HU; the author kept these rendering settings for all individuals.

The MMS traits were collected as defined below according to Stull et al. (1).

Anterior Nasal Spine (ANS)- Scored on a scale from 1-3, ranging from not pinchable to not pinchable. Observed in a lateral position.

Inferior Nasal Aperture (INA)- Scored on a scale of 1-5, ranging from a sloping nasal floor to pronounced nasal sill. Observed on the left lateral side of the nasal aperture in an anterior position or from a lateral perspective in CT slices.

Interorbital Breadth (IOB)- Scored on a scale from 1-3 ranging from a narrow to broad breadth. Observed in an anterior view and measured between left and right dacryon.

Malar Tubercle (MT)- Scored from 0 to 3, ranging in no observable projection to pronounced when tubercle extends 4mm past bone edge. Observed in an anterior view and side with greatest should be recorded.

Nasal Aperture Shape (NAS)- Scored from 1 to 3 ranging from pear shaped to bowed dependent on location of the greatest projection of the lateral margins. Observed in an anterior view.

Nasal Aperture Width (NAW)- Scored from 1 to 3, ranging from a narrow to broad width based on the ratio of the nasal aperture to the overall facial skeleton. Observed in an anterior view.

Nasal Bone Contour (NBC)- Scored from 0 to 4, ranging from low and rounded to a triangular shape based on the contour of the nasal bones and frontal process of maxillae. In anterior view a 10 mm line should be drawn from nasion using the measure function. Manipulate the skull to view the individual from a superior view or superior lateral view to best assess how the line sits. Comparison photos should be used to best assess the trait as NBC has a high inter and intra observer error rate (82).

Nasal Bone Shape (NBS)- Scored from 1-3, ranging from no pinching to extreme pinching where the lateral nasal bones form a triangle.

Nasal Overgrowth (NO)- Scored from 0 or 1, indicating the presences or absences of projection of the lateral border of the inferior nasal bone. Observed on the left nasal bone from a lateral perspective.

Orbital Shape (OBS)- Scored from 1-3, representing rectangular, circular, or rhombic orbital shape. Left orbit is observed in an anterior view.

Postbregmatic Breadth (PBD)- Scored 0 or 1indicating presence or absence of a broad depression along the posterior of the sagittal suture near bregma. Observed from a lateral perspective.

Posterior Zygomatic Tubercle PZT- Scored from 0 to 3, signifying a range that encompasses no projection to 6mm of projection on the posterior zygomatic bone. Observed from a lateral view on the side with the most projection.

Palate Shape (PS)- Scored on a scale of 1-4 based on length and width of the palate, and location of third molars. Scale ranges from elliptical to hyperbolic. Observed in an inferior view.

Intraobserver Error Calculation

The author rescored approximately 10% of the sample, 31 individuals, using the same collection protocol from the first collection iteration. The MMS trait data were recollected 4 weeks after the initial iteration of data collection. The data set was numbered with a randomized data set (1-311); when the numbers were numerically sorted, the first 31 individuals were chosen as a representative sample. These 31 individuals were used to calculate intraobserver error to gauge the efficacy and accuracy of using the protocol and Anatomage table to collect MMS trait data.

Intraobserver agreement rates were calculated in the R programming environment (83) using Cohen’s kappa. Cohen’s kappa calculates the consistency and agreement rates between individual scores and can be used for non-continuous data, like MMS traits (84). Cohen’s kappa analyses were run to compare each trait separately (e.g., first and second round scores of ANS and so on).

RESULTS

Protocol Applicability

The author was able to observe and score all MMS traits in the protocol developed by Stull et al. (1) without difficulty or alterations to the original collection protocol. The protocols for each MMS trait were comprehendible and applicable when viewing adult CT scans from the NMDID. The MMS trait data were successfully scored and collected for all 311 individuals within the reference sample. Frequency distributions for MMS trait expressions for each race can be seen in *Tables 3-15*. It is important to note that any missing data within this project are attributed to missing features on the skeleton or problems with the DICOM files, not because of deficiencies in the collection protocol or complications with the AT. While the protocol developed by Stull et al. (1) was created using Amira, it has also been successfully used on the AT’s software. The protocol developed by Stull and colleagues (1) has proven to be applicable to adult CT scans and can be adequately used to assess the 13 MMS traits that can be collected via CT scans.

TABLES ***3- 15****: Frequency distributions for each MMS trait in five race groups.*

TABLE ***3****: Frequency distributions for the Anterior Nasal Spine in five race groups.*

	Asian N= 53		**Black N= 70**		**Hispanic N= 66**		**Native American N= 60**		**White N= 62**	
ANS	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
1	15	28.30%	27	38.60%	20	30.30%	25	41.70%	12	19.40%
2	24	45.3%%	29	41.40%	22	33.30%	18	30.00%	15	24.20%
3	14	26.4%%	14	20.00%	24	36.40%	17	28.30%	35	56.50%

TABLE 4: *Frequency distributions for the Inferior Nasal Aperture in five race groups.*

	Asian N= 53		**Black N= 70**		**Hispanic N= 66**		**Native American N= 60**		**White N= 62**	
INA	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
1	10	18.90%	16	22.90%	7	10.6%%	11	18.30%	4	6.50%
2	11	20.80%	16	22.90%	15	22.70%	16	26.70%	18	29.00%
3	30	56.50%	32	45.70%	41	62.10%	31	51.70%	26	41.90%
4	2	3.80%	6	8.60%	3	4.50%	0	0.00%	8	12.90%
5	0	0.00%	0	0.00%	0	0.00%	2	3.30%	6	9.70%

TABLE 5: *Frequency distributions for Interorbital Breadth in five race groups.*

	Asian N= 53		**Black N= 69**		**Hispanic N= 66**		**Native American N= 60**		**White N= 62**	
IOB	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
1	4	7.50%	2	2.90%	5	7.60%	2	3.30%	7	11.30%
2	49	92.50%	63	91.30%	61	92.40%	57	95%	55	88.70%
3	0	0.00%	4	5.80%	0	0.00%	1	1.70%	0	0.00%

TABLE 6: *Frequency distributions for the Malar Tubercle in five race groups.*

	Asian N= 53		**Black N= 70**		**Hispanic N= 66**		**Native American N= 60**		**White N= 62**	
MT	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
0	0	0.00%	7	10.00%	4	6.10%	0	0.00%	6	9.70%
1	29	54.70%	33	47.10%	36	54.50%	36	60.00%	33	53.20%
2	15	28.30%	18	25.70%	18	27.30%	15	25.00%	18	29.00%
3	9	17.00%	12	17.10%	8	12.10%	9	15.00%	5	8.10%

TABLE 7: *Frequency distribution for the Posterior Zygomatic Tubercle in five race groups.*

	Asian N= 53		**Black N= 70**		**Hispanic N= 66**		**Native American N= 60**		**White N= 62**	
PZT	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
0	0	0.00%	2	2.90%	0	0.00%	0	0.00%	6	9.70%
1	6	11.30%	23	32.90%	15	22.70%	6	10.00%	19	30.60%
2	29	54.70%	25	35.70%	19	28.80%	14	23.30%	19	30.60%
3	18	34.00%	20	28.60%	32	48.50%	40	66.70%	18	29.00%

TABLE 8: *Frequency distribution for the Nasal Overgrowth in five race groups.*

	Asian N= 53		**Black N= 68**		**Hispanic N= 63**		**Native American N= 58**		**White N= 62**	
NO	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
0	35	66.00%	44	64.71%	32	50.79%	25	43.10%	34	54.80%
1	18	34.00%	24	35.29%	31	49.21%	33	56.90%	28	45.20%

TABLE 9: *Frequency distribution for Nasal Aperture Width in five race groups.*

	Asian N= 53		**Black N= 70**		**Hispanic N= 66**		**Native American N= 60**		**White N= 62**	
NAW	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
1	3	5.70%	1	1.40%	6	9.10%	11	18.30%	8	12.90%
2	46	86.80%	63	90%	59	89.40%	47	78.30%	53	85.50%
3	4	7.50%	6	8.60%	1	1.50%	2	85.50%	1	1.60%

TABLE 10: *Frequency distribution for Orbital Shape in five race groups.*

	Asian N= 53		**Black N= 70**		**Hispanic N= 66**		**Native American N= 60**		**White N= 62**	
OBS	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
1	18	34.00%	15	21.40%	32	48.50%	25	41.70%	35	56.50%
2	32	60.4%%	51	72.90%	25	37.90%	22	36.70%	23	37.1%%
3	3	5.70%	4	5.70%	9	13.60%	13	21.70%	4	6.50%

TABLE 11: *Frequency distribution for Nasal Aperture Shape in five race groups.*

	Asian N= 53		**Black N= 70**		**Hispanic N= 66**		**Native American N= 60**		**White N= 62**	
NAS	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
1	40	75.50%	39	55.70%	45	68.20%	37	61.70%	47	75.80%
2	4	7.50%	21	30%	1	1.50%	7	11.70%	2	3.20%
3	9	17.00%	10	14.30%	20	30.30%	16	26.70%	13	21.00%

TABLE 12: *Frequency distribution for the Postbregmatic Depression in five race groups.*

	Asian N= 51		**Black N= 69**		**Hispanic N= 66**		**Native American N= 59**		**White N= 62**	
PBD	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
0	37	72.50%	56	81.20%	58	87.90%	55	93.20%	48	77.40%
1	14	27.50%	13	18.80%	8	12.10%	4	6.80%	14	22.60%

TABLE 13: *Frequency distribution for Palate Shape in five race groups.*

	Asian N= 47		**Black N= 61**		**Hispanic N= 59**		**Native American N= 54**		**White N= 56**	
PS	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
1	12	22.50%	22	36.10%	28	47.50%	19	35.20%	19	33.90%
2	27	57.40%	15	24.60%	18	30.50%	12	22.20%	24	42.90%
3	4	8.50%	9	14.80%	3	5.10%	6	11.10%	4	7.10%
4	4	8.50%	15	24.60%	10	16.90%	17	31.50%	9	16.10%

TABLE 14: *Frequency distribution for Nasal Bone Contour in five race groups.*

	Asian N= 53		**Black N= 70**		**Hispanic N= 66**		**Native American N= 60**		**White N= 62**	
NBC	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
0	29	54.70%	31	44.30%	43	65.20%	32	53.30%	28	45.20%
1	12	22.60%	25	35.70%	11	16.70%	15	25.00%	21	33.90%
2	6	11.30%	2	2.90%	7	10.60%	8	13.30%	8	12.90%
3	2	3.80%	5	7.10%	5	7.60%	3	5.00%	4	6.50%
4	4	7.50%	7	10.00%	0	0.00%	2	3.30%	1	1.60%

TABLE 15: *Frequency distribution for Nasal Bone Shape in five race groups.*

	Asian N= 53		**Black N= 70**		**Hispanic N= 66**		**Native American N= 60**		**White N= 62**	
NBS	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
1	29	54.70%	41	58.50%	25	37.90%	31	51.70%	26	41.90%
2	12	22.60%	17	24.30%	30	45.50%	22	36.70%	29	46.80%
3	12	22.60%	7	10.00%	11	16.70%	7	11.70%	6	9.70%
4	0	0.00%	5	7.10%	0	0.00%	0	0.00%	1	1.60%

Calculating intraobserver reliability rates allows for scientists to understand the rate of agreement and validity of using a specific method or in this case protocol. Intraobserver agreement focuses on the consistency of observations for a single feature for one observer recorded over multiple attempts (82). Intraobserver agreement rates can be non-weighted and weighted. Weighted agreements take into account the impact varying degrees of separation between scores (85). The upper limit of agreement is 1 and the lowest limit is -1 for Cohen’s Kappa (84). The categories of agreement are as follows: values ≤ 0 as indicating no agreement and 0.01–0.20 as none to slight, 0.21–0.40 as fair, 0.41– 0.60 as moderate, 0.61–0.80 as substantial, and 0.81–1.00 as almost perfect agreement (86). All intraobserver agreement rates, non-weighted and weighted, can be seen in *Table 16*. For this project IOB’s agreement rate is the highest with κ=1 and NBS has the lowest agreement rate at κ= 0.2. ANS, IOB, and PZT have near perfect agreement falling above the κ= 0.81 threshold. The INA, MT, NAW, NBC, NO, OBS, PBD, and PS all fall within a substantial agreement rate. The NAS has moderate agreement and NBS has only slight agreement rates.

TABLE 16: *Weighted and non-weighted intraobserver agreement rates when using Cohen's Kappa for each observed MMS trait between two collection iterations.*

Intraobserver Agreement

MMS Trait	Weighted	Non-Weighted
IOB	1	1
PS	0.967	0.734
PZT	0.939	0.853
ANS	0.927	0.855
INA	0.857	0.678
OBS	0.831	0.703
MT	0.821	0.686
NO	0.806	0.806
NAW	0.75	0.723
PBD	0.738	0.783
NBC	0.66	0.619
NBS	0.636	0.2
NAS	0.479	0.52

The NMDID

There are important components to take note of when using the NMDID for CT scans in biological anthropology. Separate sections for individuals cannot be downloaded; when an individual is requested, the researcher will receive a zipped folder of all 40,000 segments of the entire body. These DICOM files take up large amounts of space and require extra time for downloading and unzipping. If considerable amounts of storage are not available, researchers can download individuals multiple times for analysis. However, it is important to note that requested scans are only available to the researcher in the cart for a limited amount of time before needing to be requested again.

Not all individuals will have the same grouping of scans; for example, this project primarily used soft tissue head scans but for some individuals, these scans are unavailable, and another section of scans had to be used (soft tissue head and neck).

There is a lack of standardization between what sections are included in file categories; for some individuals the *Head and Neck* segments produced a rendering that was just the head and neck but for other individuals could produce the renderings of the entire upper torso. These differences could be attributed to scan preferences for individual offices of the OMI system. Perimortem damage to remains is not mentioned within the corresponding metadata; lack of acknowledgement of perimortem damage can create time delays within projects because data may not be able to be collected from the requested scans. Perimortem damage can occasionally be seen prior to requesting in scout images, however, scout images are not available for all remains.

With 15,000 individuals in the database there is diversity; however, the number of individuals meeting specific criteria can be low. For example, when distinguishing individuals by "sex" and "race" in the database a minimal number of individuals may meet these criteria. The reference sample was initially meant to include 70 individuals, 35 male and 35 female for each race. The disproportionate sample size for races and sex is due to the availability of the population sample within NMDID due to being limited to New Mexico. The original age range for this project was 20 to 60 years old. However, due to decreased population in certain "race" categories individuals aged above 60 years old had to be included for categories to comparable. Data limitations are a product of NMDID's restricted locational sample which is not representative of the diversity within the United States as a whole.

How the Anatomage Table was Used

The software on the AT, TableEDU 8.0.2, is highly intuitive. When users have questions on best practices, they can find these answers within the *Help* section of the table’s software. Through this project, recommendations for the use of the AT to collect MMS trait data have been developed. It is best that the table is in a location where the overhead lights can be dimmed or turned off as reflections from overhead light sources can make it difficult to see the tables screen. The table’s touch screen should be recalibrated prior to use, this will increase the touch accuracy and ease frustrations of manipulating the 3D renderings on the table. The author also recommends changing the background color to “black” in the rendering settings; the dark background will provide more contrast between the table and rendered CT scans.

The author suggests using the “dissection cut” function on the table to remove the post-cranial skeleton and the “craniotomy cut” function to remove the mandible creating access to the maxillary palate to view the PS. Using the pen tool can prove to be beneficial to outline regions such as the orbits or palate to better assess shape for OBS and PS. The author also recommends that tables operators utilize the segmentation tool to allow the user to visualize individual segments of the scans when collecting INA trait values. Using the segmentation function will produce a cross-section view allowing the user to isolate the left inferior portion of the nasal aperture and more easily see the slope of the nasal floor. It can also be helpful for new table users or researchers new to MMS trait collection methods to use the “measure tool” on the table to help assess certain MMS traits like IOB, NAW, NBC, and OBS. The author also recommends adjusting the table’s contrast and level of soft tissue present as needed to better assess each trait.

DISCUSSION

The author was able to adequately assess the 13 MMS traits described in the protocol from Stull et. al. (1), and collected data are largely comparable to the findings of

Hefner (2009) (70). The intraobserver rates further substantiate this finding, as 85% (11/13) of the collected MMS traits fall within the categories of substantial or almost perfect rater agreement. The high agreement rates indicate that MMS trait collection with the Stull et al. (1) protocol can be consistently replicated, speaking to the validation of the protocols efficacy. Low intraobserver error rates for the collection of two MMS traits does not negate the efficacy of the protocol. The MMS traits with low intraobserver error rates in this project, NBS and NAS, can be attributed to multiple factors including but not limited to lighting, author error, and the use of the AT. It is also important to note that NBC and NBS have historically low intraobserver agreement rates for both physical (82) and virtually rendered human remains (3). However, the potential effects of all factors must be tested in future iterations of this project, to provide clarity to and mitigate the causes of low intraobserver error.

Testing the applicability of the AT is a significant portion of this project and simplifies the data collection process. Other 3D rendering programs such as OsiriX Lite (13) and Amira^{TM} (2) require extensive training to appropriately use the software. The interactive software for rendering 3D images within Anatomage streamlines this process and requires less learning time. The table automatically renders the uploaded files to the best quality, increasing the visibility of morphological features without much work. Three-dimensional renderings are colored and are life-sized on the table which increases the visibility of phenotypic variation on the cranium greatly facilitating the collection of MMS trait data. The application of the table's touch screen makes image manipulation easier than other 3D rendering programs that require the use of a mouse and keypad.

The NMDID was fundamental to this process as it is one of few databases that combines metadata with CT scans. The database is easily accessible from any browser and easy to use after an initial learning curve. Documents on the website provide insight into terminology, metadata categories, and the database's innerworkings, which all aid in using and understanding the capabilities of the database. While the metadata was not essential to the testing of the applicability of the Stull et al. (1) protocol, it could prove to be essential in future iterations of validity testing of this protocol and application of MMS trait data for estimates of the biological profile.

The Future of this Project and Virtual Anthropology

There are many ways this project can be improved in future iterations and the author hopes to continue pursuing these avenues of research. Additional examinations of intraobserver error rates must occur to determine if the AT or the protocol has an effect on consistently assessing MMS trait data from CT scans. The project needs to be expanded to include interobserver error rates. This analysis would provide another line of validation for the protocol and use of the table. The initial protocol developed by Stull and colleagues (1), tested within this project, did not include the four MMS traits associated with cranial sutures due to the focus on subadults. These four cranial sutures can be observed and scored in adults. Future research can focus on creating additional protocols for collecting these traits on an AT. Creating protocol for collecting the MMS traits from the post-cranial skeleton within CT scans using the AT can also prove to be useful.

This project is hopefully the first of many to take advantage of an AT in biological anthropology. The table has the possibility to be very relevant within the field as it can be used for research and education. Students enjoy using ATs, and test scores indicate they help them learn anatomical and physiological concepts better when combined with other coursework (38–44,60,63–67). Having individuals be excited about learning and research is crucial to increasing interest and diversifying the field of anthropology. The AT also fosters a community approach by encouraging users to participate in conferences, webinars, and Anatomage tournaments, increasing collaborative efforts (18,87).

The pursuit of VA is becoming more popularized as technology advances. The use of 3D renderings can begin to decrease the need for skeletal collections or cadavers by supplementing teaching and research methods with metaphysical data that can be reused in perpetuity without damage. The 3D renderings can be printed using a 3D printer, creating on-demand physical collections that can be manipulated (e.g., enlargement, cutting, etc.) without altering the original files. The ease of access and manipulation places VA at the forefront of the field. While VA is becoming more applicable and standardized, more work still needs to be done. Efficacy and validity studies of these new methods, software, and technology must continue (5,8,26,88). Nevertheless, the ease of access and manipulation allows VA to become more prevalent within the field as dynamics continue to change and the field undergoes a paradigm shift.

CONCLUSIONS

This project successfully applies the protocol developed by Stull et al. (1) to computed tomography scans of adults for the collection of MMS trait data. Research done in this project also shows that the use of AT technology for viewing CT scans is promising and creates new avenues of research in biological anthropology. Virtual anthropology is clearly becoming more popularized within biological anthropology and the discipline of anthropology as a whole. The development of protocols, software, and technology will continue to aid with the standardization of virtual anthropology while expanding its applicability in the discipline. It provides opportunities for more equitable research and can lead to further collaboration between researchers in various fields on a global scale.

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