ANALYSIS AND QUANTIFICATION OF COMMINGLED HUMAN SKELETAL REMAINS IN SYRACUSE UNIVERSITY'S HISTORIC MEDICAL TEACHING COLLECTION USING THE CORA ECOSYSTEM

by

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Abstract

The Anatomical Era of medical education and training in the United States, beginning in the late 18th and early 19th century, marked the transition from textbook and lecture-based education to the highly sought-after hands-on experience through the dissection of human cadavers and anatomical demonstrations. The increasing need for dissection subjects resulted in unethical methods of procurement, including graverobbing and the use of bodies of unclaimed persons, which disproportionately affected immigrant groups, minorities, and the poor. Along with written histories and archival records, evidence of human remains used for dissection and anatomical training can be found in anatomical or medical teaching collections. The Syracuse University Medical Teaching Collection is an assemblage of skeletal human remains believed to have an ethically questionable background, but its true origin is currently unknown. In addition to completing a basic specimen inventory, this research addresses three questions to further knowledge about the individuals within the collection and its origin. The first was to determine whether there was evidence to support the claim that this collection is indeed a contemporary collection rather than from an archaeological context. A review of the history of dissection and autopsy in Upstate New York as well as observation of similar taphonomic traits, such as hardware attachments, cut marks, and sectioning of the cranium present in other known medical teaching collections support the theory that the collection at Syracuse University is likely a contemporary teaching collection. The second goal was to estimate the number of individuals in the collection. The MNI calculated using the traditional MNI method was 43 individuals based on the frequency of the left scapula and radius and 49 individuals based on the right scapula. The MNI calculated using the zonation MNI was 43 individuals based on the frequency of the left radius and 43 individuals based on the frequency of the right scapula. The third goal was to determine whether the CoRA web application could be applied to unique contexts of commingled remains, such as medical teaching collections. CoRA's ability to provide a standardized recording database, data analysis tools, and data visualization features proved to be extremely useful for inventorying, documenting, and analyzing the Syracuse University Medical Teaching Collection. Therefore, it is likely that CoRA can be successfully used to inventory, document, and analyze other types of assemblages and collections of human skeletal remains. Overall, this research provides a solid foundation for future research involving this collection and brings awareness to some of the ethical concerns surrounding the use of historical medical teaching collections.

Analysis and Quantification of Commingled Human Skeletal Remains in Syracuse University's Historic Medical Teaching Collection Using the CoRA Ecosystem

Introduction

Anatomical and medical teaching collections

Osteological collections are collections of human skeletal remains used by anthropologists for research, education, or preservation. They may be archaeological or contemporary and are housed by museums, forensic anthropology laboratories, or universities (1, 2). How and why human remains are accumulated for these collections differ greatly. For instance, the Samuel G. Morton Cranial Collection is mainly comprised of skulls that were used for craniology research as an attempt to classify humans based on morphological typologies associated with racial profiling (1, 3, 4). Contemporary osteological collections are often comprised of body donations or the remains of unclaimed individuals. These types of skeletal collections are often used to study human variation, pathological conditions, and skeletal anomalies. (1, 2).

One special type of osteological collection is anatomical or medical teaching collections. Medical teaching collections are assemblages of human skeletal remains procured for the purpose of education or demonstration and are often the by-product of dissections, surgical training, autopsy, or experimentation (5, 6, 7). Skeletal remains in these types of collections typically exhibit unique taphonomic traits such as cleaning and bleaching, attached hardware for articulation, various types of cut marks and sectioning, post-mortem trauma, writing, and more (6, 8). Although teaching collections can be used as vital tools for research and education, their complex history and formation through structural violence pose some ethical dilemmas that must be considered.

History of the use and trade of bodies for anatomical study in New York

The entire history of the use and trade of bodies in New York, let alone the United States, could be several papers in of and itself. For readers interested in learning more about the history of anatomy and dissection in the United States and bioarcheological ethics, see “A Traffic of Dead Bodies” by Michael Sappol (2002) and the series “Bioarchaeology and Social Theory” edited by Debra L. Martin (2016-2024). It is important to examine some of this history in order to better understand how bodies were obtained for use by medical schools and what types of individuals may be present in these historical anatomical collections. Beginning around 1760, formal medical education began to replace midwives and folk healers. Medical professionals frequently traveled to Europe to receive high-quality anatomy-based training. By the late 1700s, it was no longer sufficient for medical students only to attend lectures, read textbooks, and witness demonstrations, as students began to seek out institutions that offered advanced anatomy courses and dissections as part of their programs (5). However, as more medical schools began to open throughout New York and the United States, providing subjects to students for dissection became increasingly more difficult. Initially, medical institutions obtained the bodies of executed criminals for dissection, but as the demand for cadavers increased, institutions and their practitioners had to find other ways to procure anatomical subjects (5). Besides a few isolated cases of philanthropic donation by individuals donating their bodies to be used for autopsy (9), the only other method of procuring anatomical subjects was by “body-snatching” or medical grave robbing. This method of obtaining anatomical subjects did not go without criticism and panic from the public, who feared body-snatchers, often acting under the cover of the night, would steal the bodies of their loved ones from their graves. An increase in grave robbing of individuals buried in the Negro Burial Ground during the 1780s resulted in the April 1788 “Doctor’s Mob,” where Black Americans and members of the lower class rioted against bodies of their family members and loved ones being stolen from the burial ground and used for dissection (5). In response to the riot, New York passed the 1789 “Act to Prevent the Odious Practice of Digging up and Removing for the Purpose of Dissection, Dead Bodies Interred in Cemeteries or Burial Places” which gave statutory legitimacy to the dissection of executed criminals, with the purpose of reducing medical grave robbing (10). However, the act did little to calm the mania of the public, and body-snatching continued as the number of medical institutions in New York increased. The struggle to legally obtain anatomical subjects continued into the 1850s with a fierce debate between the public and New York medical schools over how bodies should be procured for medical education. On April 3rd, 1854, the New York Governor signed the “Act to Promote Medical Science and Protect Burial Grounds,” more commonly known as the “Bone Bill,” which allowed the bodies of executed prisoners and members of the poor who were unclaimed or could not afford a proper burial to be used for medical education and science. Although the “Bone Bill” did help New York’s medical schools obtain more anatomical subjects, the bill's restrictions were not consistently enforced, and therefore, body-snatching and the trafficking of bodies from other states without anatomy laws continued (5). By 1900, most states had adopted similar anatomy laws to promote legal methods of cadaver procurement. Systemic racism resulted in many prisoners being from black or immigrant communities, and the harsh labor and poor living conditions of prisons resulted in high mortality rates. Therefore, individuals from minority groups still comprised most of the anatomical subjects used by wealthy, primarily white medical students (5).

Bioarchaeological analysis and supporting documents of skeletal remains from historical anatomical collections support the documented history and records about the types of individuals used as anatomical subjects in the 19th and 20th centuries. One well-known skeletal collection from New York City is the George S. Huntington Anatomical Collection. It consists of approximately 3070 partial human skeletons obtained from dissections done by students at the College of Physicians and Surgeons at Columbia University in New York City between 1893 and 1921. Researchers note that over 40% of individuals in the Huntington Collection came from a network of public institutions, such as hospitals serving the almshouse, workhouse, penitentiary, and mental asylums on Blackwell's and Ward's islands (11, 12). Moreover, skeletal remains of black people are over-represented in the Huntington Collection by over six times compared to the city population (13). The types of individuals in the Huntington Collection and the context in which they came from corroborate the history of 19th-century anatomy and dissection in New York and the United States. Although it can be speculated that the Syracuse University Medical Teaching Collection likely shares a similar history with other anatomical collections formed during this period, the lack of supporting records detailing the origin and life histories of individuals in the collection makes confirming this theory impossible at this time. Although missing documentation may resurface, it is possible that documentation may have never occurred in the first place. This could be due to purposeful dehumanization by anatomists and curators who aimed to view anatomical collections, and human remains only as specimens and tools for education rather than as deceased human beings (13). Additionally, anatomists may not have known anything about the bodies they received from "resurrectionists," or body snatchers; therefore, no information could be documented (5, 14). To learn more about the possible origin and context of the skeletal remains in the Syracuse University Teaching Collection, it may be helpful to examine the history of medical education and the use of bodies in Upstate New York.

Fairfield, Geneva, and the Syracuse University College of Medicine

The roots of the Syracuse University College of Medicine can be traced back to the Fairfield Academy and the College of Physicians and Surgeons of the Western District of the

State of New York (1809-1840) and later to the College of Medicine at Geneva[a] (1835-1872) (15). Circular and course catalogs from the time of operation of the College of Medicine at Geneva mention the use of an anatomical museum and specimens for education and hands-on experience. For example, the 1834 Circular and Catalogue of the Medical Institution of Geneva College states:

> "An Anatomical Museum, equal or superior to many of the Medical Schools, which have been long in successful operation, will be provided by the Medical Faculty; and arrangements are made for affording Students every facility for acquiring a knowledge of *practical* Anatomy." (16).

Additionally, the Annual Circular of the Medical Institution of Gevena College and Catalogue of the University Officers (1841) provides a more in-depth description stating:

> "The Anatomical Rooms will be opened at an early period of the session, under the direction of the Demonstrator, subject to the general supervision of the Professors of Anatomy and Surgery. A ticket fee of three dollars to the Demonstrator, will secure to the student access to the dissecting rooms, and, to those engaged in dissecting, all necessary assistance and instruction…Careful Arrangements have been made by the *Faculty*, to secure an ample supply of *subjects*, at a reasonable rate, to be furnished to the students *at cost*" (17).

These curriculum descriptions of anatomical demonstrations and dissections align with common anatomy and medical education trends in the United States during the 19th century (5). Private schools of anatomy and dissecting rooms, such as those established by Frederick Hyde and Miles

[a] Name changed to Hobart College in 1851 (Wright, 1994).

Goodyear (from 1845-1854) and John Morgan Thomas Spencer (from 1849-1851), were also available for students (5, 15). As more medical schools began to be established in New York in the mid-19th century, rural Geneva began to have trouble competing with more significant urban institutions. By 1871, the Medical College at Geneva was ready to close.

On August 30th, 1871, the Syracuse University Board of Trustees received a proposition from the Medical Department of Hobart College at Geneva to transfer the program to Syracuse University (18). Later that night, Professor John Towler and Professor Fredrick Hyde met with the board to discuss the transfer of the faculty and staff as well as the medical library and anatomical museum. When the Hobart Committee at Geneva denied the transfer of the medical department, library, and anatomical museum without cost, Towler, the dean of the Geneva Medical College, purchased the library and museum to donate the materials to Syracuse University. Towler and Hyde's proposition to donate Geneva's anatomical museum and medical library to Syracuse University was accepted by Syracuse Trustees on December 4th, 1871 (15, 18). Hyde worked to integrate medical faculty and students from Geneva into the new program at Syracuse University, and on October 3rd, 1872, the College of Medicine in Syracuse opened. Proof of this transfer also exists in the Syracuse University circular and course catalogs of this time, stating that it "had the good fortune to…obtain the Medical Library, Museum and other means of illustration, collected at Geneva Medical College, and to secure as part of its Faculty several of its well known Professors" (19). Today, Towler's library is contained in the Geneva College archival collection (15), but the fate of the anatomical museum and its specimens are unknown.

As the Syracuse College of Medicine continued to grow, it established connections with local hospitals and expanded clinical opportunities for students. For instance, the Syracuse University circular and course catalog from 1874 to 1875 states that the "St. Joseph's Hospital and House of the Good Shepherd are Institutions now in successful operation, and will be made…available for clinical teaching." (19). In 1915, due to financial difficulties, the Hospital of the Good Shepherd[b] was transferred to Syracuse University, and the name was changed to University Hospital (15, 20). However, the Hospital of the Good Shepherd was already being used as a teaching hospital by the College of Medicine as early as 1887 (15). In 1888, the Syracuse Free Dispensary, which housed several different clinics, began incorporating students into clinical practice. Syracuse University established a new and improved Syracuse Free Dispensary in 1914, which housed faculty offices, laboratories, and clinics and provided students with more clinical training opportunities in various medical subjects (15). Despite hundreds of medical students attending the College and generous donations made to the University Hospital and Syracuse Free Dispensary, the College of Medicine continued to drain the University financially. This continuous financial struggle is documented throughout the Syracuse University Board of Trustees meeting minutes, in which the representatives from the College of Medicine often asked for more funding for faculty and resources, and the toll this lack of support was taking on the students and staff. In 1950, it was decided that the Syracuse University College of Medicine and the University Hospital would be sold to the State University of New York (15).

Syracuse University's Medical Teaching Collection

The medical teaching collection at Syracuse University is currently housed in The Physical Anthropology Lab in Lyman Hall and curated by Dr. Shannon Novak. The origin and age of these specimens are unknown. One theory is that some or all of the collection specimens were part of the Gevena College Anatomical Museum, which John Towler gifted to the Medical

[b] Name changed from "House of the Good Shepherd" to "Hospital of the Good Shepard" in 1901, when it became a public institution (Wright, 1994).

College at Syracuse in 1872. However, there is little to support this claim, as currently, no information has surfaced in archival records about the museum's contents and what became of these specimens when the Syracuse University College of Medicine was sold to the State University of New York in 1950 (15). The College of Medicine likely continued to procure additional skeletal specimens through donations, purchases, and other means after the transfer of Geneva in 1872. Interestingly, there is one mention of a gift of human remains donated to the College of Medicine in the Syracuse Board of Trustees Minutes for January 1892. Specifically, it states:

> "…Mrs. M. Elizabeth Wieting has recently donated to the Medical College of Syracuse University a rare collection of manakins, skeletons, paintings, charts, etc. obtained by the late Dr. Wieting at great pains and expense in Paris…" (18).

Additionally, the meeting minutes of June 1894 mention a request from the faculty of the College of Medicine for "among other things, the appropriation of $500.00 for the Anatomical Department…" (*18*). It can be speculated that the money requested by the Anatomy Department was used to obtain human cadavers and specimens for dissection or other educational materials to meet the medical education needs of students in the 19th and 20th centuries.

As mentioned previously, The Syracuse University College of Medicine collaborated with local hospitals and clinics to provide students with clinical experience and demonstrations. The Good Shepherd Hospital and St. Joseph Hospital even had amphitheaters used for dissection or clinical demonstrations, which were viewed by faculty and students (15). However, obtaining bodies for dissection likely was not as straightforward. Meeting minutes from the Fairfield Academy and the College of Physicians and Surgeons in the early 1800s make mention of the "exhumation" of bodies for use by the medical school (5, 19) and, later, the bodies of executed prisoners from the state prison at Auburn (5, 21). When these arrangements were insufficient, professors may have traveled to New York City or other states to purchase cadavers (5, 22). Similarly, during the operation of Geneva, Thomas Spencer obtained bodies from the state prison at Auburn and transported them to the medical school for use in anatomy courses and dissection (15).

The New York “Bone Bill” passed in 1854, and similar bills passed in other states likely affected how Geneva and Syracuse procured anatomy subjects for students. Although there are not any clear records about how and where Syracuse obtained its subjects, body snatching likely decreased, and the acquisition of unclaimed bodies from hospitals, infirmaries, poorhouses, almshouses, and prisons became the preferred method, with these bodies being purchased using student fees. However, even with anatomy laws in place, newspaper reports of body snatching by students continued into the late 1800s (5). In summary, there are many different theories about the origin of the human remains in the Syracuse University Medical Teaching Collection. Because no specific records about the collection have surfaced, other methods must be used to explore the leads provided by historical documents and accounts in order to learn more about the individuals in the collection as well as the collection’s origin.

Students in various fields, such as anthropology, archaeology, forensic science, and the arts, have utilized the collection throughout its existence at Syracuse University. Anthropology and archaeology students have used the collection to learn basic human osteology and more advanced topics like pathology and determination of the biological profile. The large number of each element present in the collection allows for the unique opportunity for students to observe the vast range of human variation in skeletal remains. Forensic science students have used bone fragments from the collection in various research projects. Fine arts students at Syracuse University have spent time in the Physical Anthropology Lab drawing and sculpting various specimens from the collection. The medical teaching collection has served as an important resource for students in various fields at Syracuse University. However, the current state of the collection, including lack of documentation and commingling of remains, limits some of the potential uses of the collection.

The collection consists mainly of adult skeletal remains with some sub-adult specimens. Most skeletal elements are disarticulated and sorted into drawers by element and side. Some articulated groups of bone elements, such as a pelvis and foot, and several articulated skeletons with varying completeness are present. Various identification numbers are written on most specimens in black pen. Unfortunately, there is no corresponding database or inventory for these identification numbers. The commingled nature of this collection and the lack of prior inventory or documentation prompted the need for a databasing ecosystem explicitly designed for inventorying, documenting, and resolving commingled human skeletal remains.

Commingled Remains Analytics (CoRA)

The Commingled Remains Analytics (CoRA) ecosystem is a web application, database, and application programming interface (API) designed to help forensic anthropologists inventory and analyze commingled human skeletal remains (23). It was created by Dr. Sachin Pawaskar, a professor at the University of Nebraska Omaha College of Information Science and Technology. His main goal was to create a databasing and analytics tool to address common data organization problems faced by forensic anthropologists working to identify individuals from mass graves or other commingled contexts. Specifically, Dr. Pawaskar designed CoRA to assist forensic anthropologists affiliated with the Defense POW/MIA Accounting Agency, who work to find and identify the remains of missing U.S. service members and reunite them with living family members or provide a proper burial. He collaborated with experts in the fields of forensic anthropology and bioarchaeology to make a user-friendly application equipped with the tools needed to assist anthropologists in identifying remains more efficiently (24). Recently, institutions other than the DPAA have used the web application to document commingled remains for other contexts. For example, researchers at the University of Milan, Milan, Italy, used CoRA to inventory and analyze human remains associated with a Renaissance-era hospital and crypt, Ca' Granda. CoRA was used to document the age, sex, ancestry, pathology, taphonomy, and human modification of over 300,000 specimens from the site. The researchers stated that CoRA was specifically chosen for this project due to its ability to organize and process large amounts of data and its data analysis features to assist in resolving commingled remains and determining the Minimum Number of Individuals, or MNI (25).

CoRA provides forensic anthropologists with many features to assist in data collection and analysis. Figure 1 illustrates how the features of CoRA interact within its ecosystem of organizations, users, projects, and specimen data. Specimens can be added to the database individually or by bone group. Users have the flexibility to input as little or as much data as wanted, from just the element and side to assigning specific pathological observations. Moreover, each bone specimen or group has the option to record trauma, taphonomy, pathology, and anomalies. For example, Figure 2 shows a screenshot from the CoRA web application demonstrating how taphonomic data for individual specimens is recorded within the database. CoRA provides the option to record measurements and completeness of a specimen as well, based on measurement and recording standards outlined in Langley et al. (2016) and Knüsel & Outram (2004), respectively (Figures 3 and 4). Visual guides are also provided with the web application to assist with measuring and recording specimens accurately following the standard methods (Figures 3 and 4). Age, sex, and ancestry can also be recorded in CoRA using common peer-reviewed methods. CoRA also allows users to input data for DNA or isotope analysis. Data can be added or changed for specimens at any time, and these changes will be tracked for all users. The wide array of fields that can be recorded for a given specimen within CoRA allows for customizability based on project needs while keeping recording methods uniform within and between projects and users. Figure 5 shows a screenshot of the Project Dashboard, where users can view basic data and the amount of progress made for a given project.

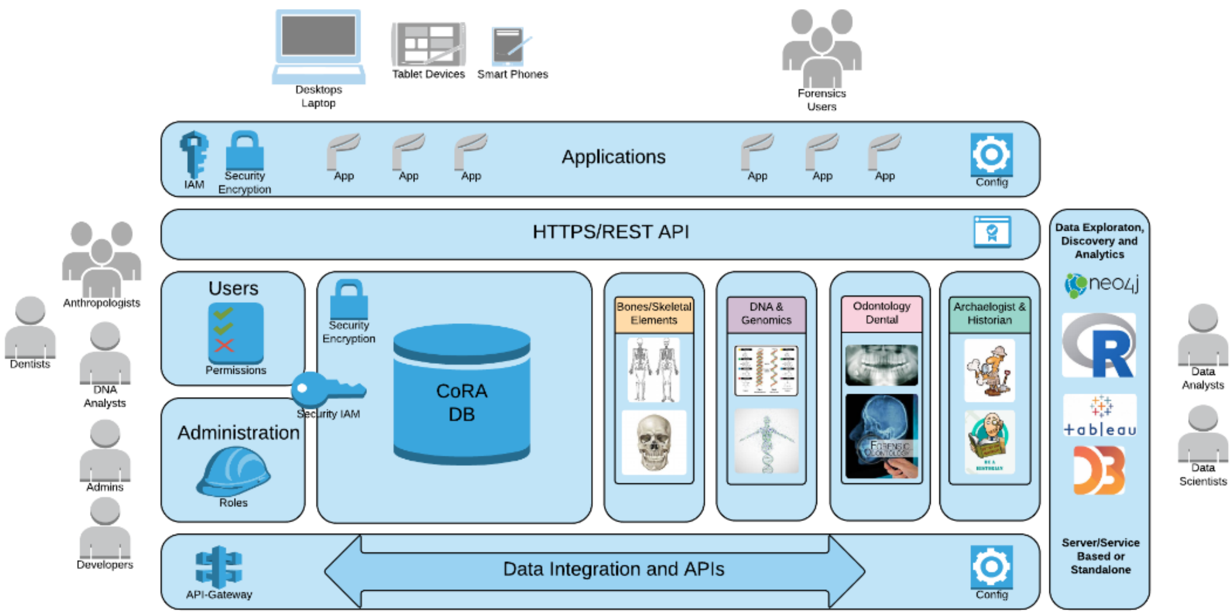

Figure 1. CoRA ecosystem modules diagram. This diagram illustrates how all the components and features of CoRA work together to create the CoRA ecosystem. Each user can access the database and enter specimen data such as skeletal trait observations, DNA profiles, dental inventory, and historical data, depending on their role in the project. This data can then be analyzed using the data analysis and visualization features within CoRA, and reports can be generated for them (23).

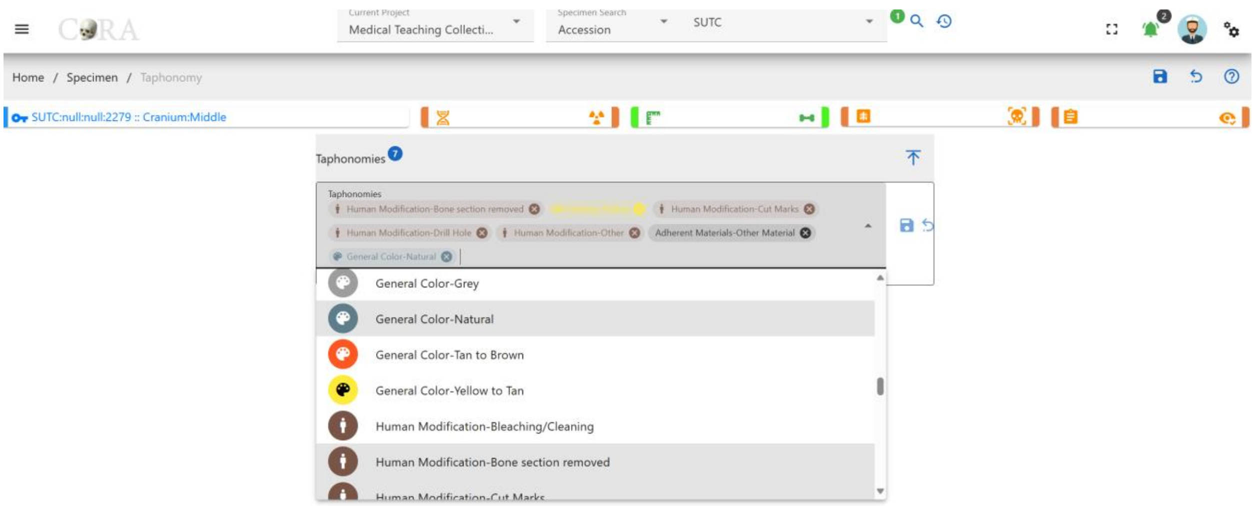

Figure 2. Taphonomic data within CoRA. This figure provides a screenshot from the CoRA web application demonstrating how taphonomic data for individual specimens is recorded within the database. Any number of taphonomic characteristics can be added for a given specimen. For example, for specimen 2279, seven different taphonomic traits were recorded, including human modifications, staining, and general coloration of bone (23).

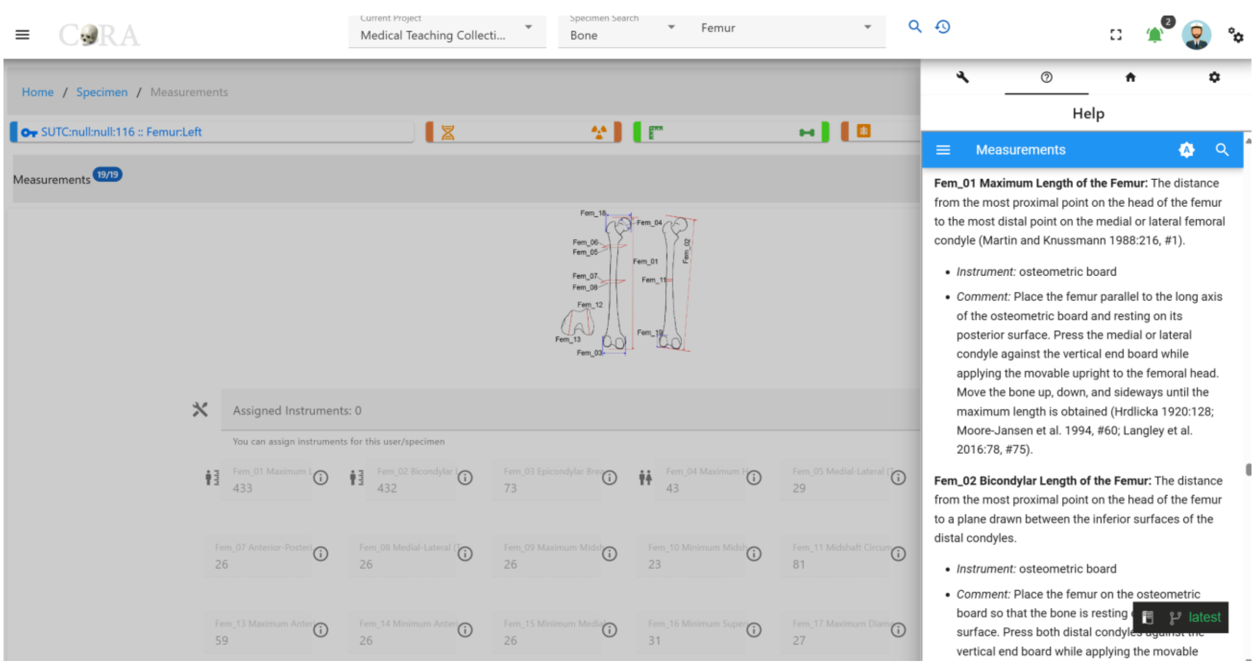

Figure 3. CoRA measurement interface and guide. This figure provides a screenshot from the CoRA web application showing the interface for entering specimen measurements. For example, each measurement for the femur has a designated data entry box. The interface allows the user to enter as few or as many measurements as needed. Each measurement has a range of "normal" values, and values outside this range will be marked to prevent any data entry errors. Additionally, CoRA provides the option to have a measurement guide on-screen (right) during data entry. This measurement guide provides a diagram and description of the measurement (23).

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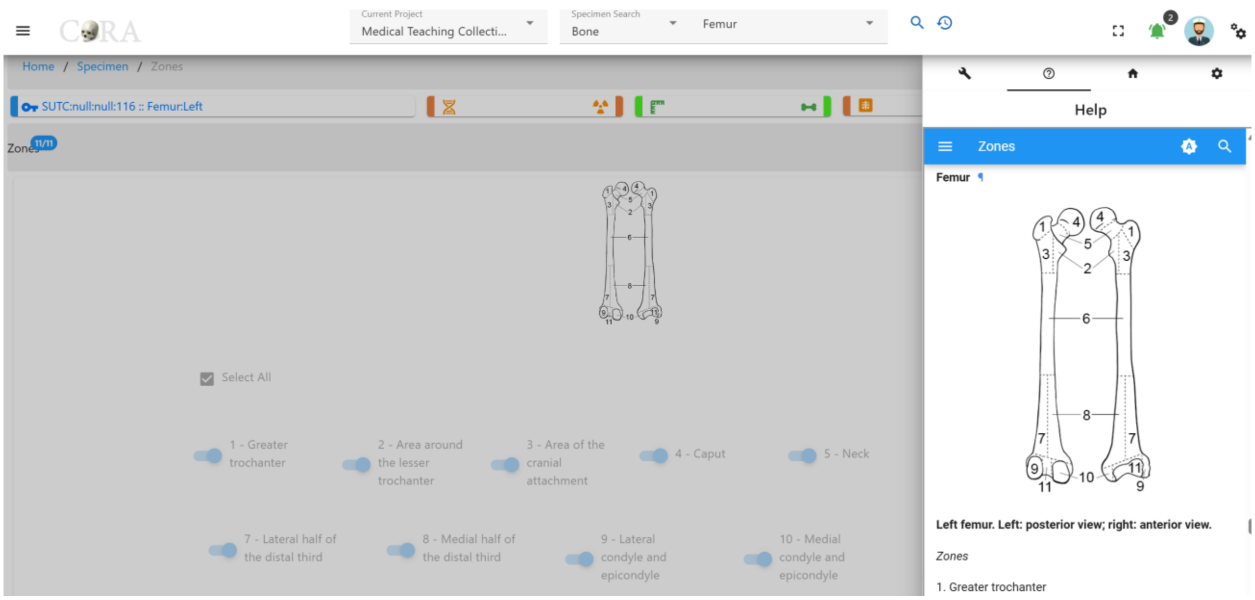

Figure 4. CoRA zone inventory and guide. This figure provides a screenshot from the CoRA web application showing how the completeness of specimens can be more accurately documented through the inventory of zones. The specific zones for a given specimen can checked or unchecked based on their presence or absence. Additionally, the guide on the right provides additional details about the zones for each skeletal element (23, 26).

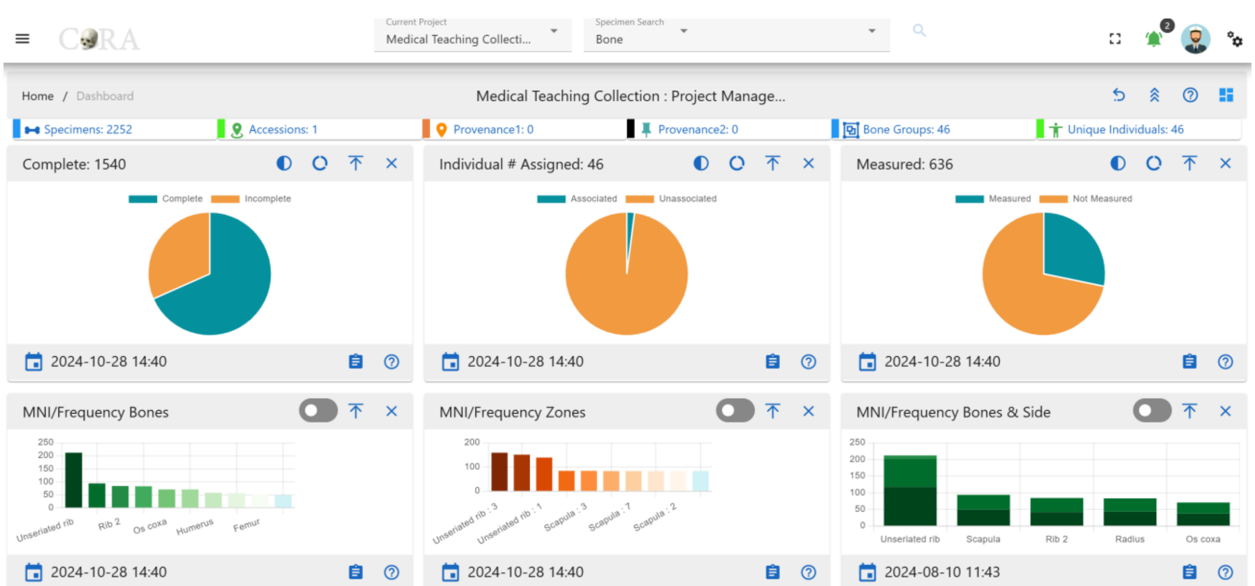

Figure 5. CoRA Project Dashboard. This screenshot from CoRA depicts the Project Dashboard, which shows basic statistics for a current project, such as specimen count, the percentage of specimens measured, and MNI. The types of project statistics present on the dashboard are customizable based on project goals and needs (23).

CoRA also has various data analysis tools for better visualization of the Minimum number of individuals (MNI) and zones, specimen completeness, and DNA profiles (Figure 5).

Many of the tools within the CoRA ecosystem have been implemented to assist forensic anthropologists in reducing the number of specimens in the search space when associating the remains of individuals or determining possible refits of fragmented remains. These tools include osteometric sorting regression, measurement scatter plots, hierarchical edge building, hierarchical clustering, refits, and single/ multiple relationship graphs. The refits analysis tool allows for the visualization of possible bone refits based on recorded zones. Figure 6 shows an example of how the zones present for the right scapula specimen 642 could be compared to other scapula fragments to determine a possible refit match. Filters were used to show only right and unsided scapula fragments and highlight the specimens that included the missing zone in specimen 642. This visualization tool, within CoRA, can narrow down the possibilities for specimen refits, increasing the efficiency of reassociating commingled elements and identifying individuals. Another tool within CoRA is the single/ multiple relationships graphs. Single/multiple relationship graphs show which specimens share similar characteristics. Figure 7 provides an example of a single/multiple relationship graph showing which elements have the same colors of staining. The orange box highlights the specimens with brown staining and specimens with grey/silver staining. The specimens exhibiting both staining colors (cluster circled in red) are linked with lines connecting the specimen to the center of each color (Figure 7). Because specimens that share taphonomic characteristics are more likely to come from the same context, this visualization tool can reduce the search space for an anthropologist working to associate elements of an individual. In addition to taphonomy, single/multiple relationship graphs can be generated for pathology, trauma, anomalies, pair matches, articulations, and DNA. Elements determined to be associated with one individual can be associated with one another within the ecosystem. In summary, the CoRA ecosystem provides users with many different tools for documenting and analyzing skeletal remains, particularly in cases where commingled remains must be resolved (23).

Figure 6. Refits analysis and visualization tool. This screenshot from the CoRA web application shows an example of the refits analysis and visualization tool. Specifically, it shows an example of how the zones present for the right scapula specimen 642 could be compared to other scapula fragments to determine a possible refit match. Filters were used to show only right and unsided scapula fragments and highlight the specimens that included the missing zone in specimen 642 (23). Based on this graph, a forensic anthropologist would likely want to see if specimens 923 and 917 may be a possible refit for specimen 642.

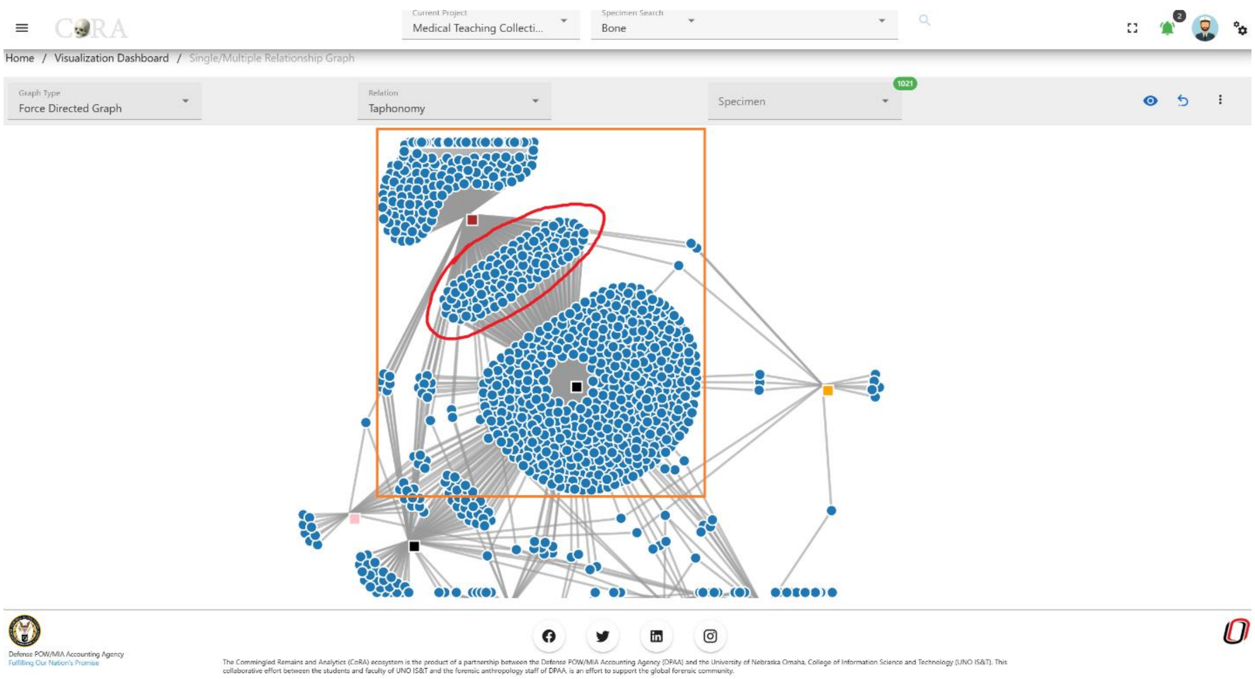

Figure 7. Single/multiple relationships graph. This is a screenshot taken from CoRA of the single/multiple relationships visualization tool (23). Specifically, this screenshot shows which elements have the same colors of staining. The orange box highlights the specimens with brown staining and specimens with grey/silver staining. The specimens exhibiting both staining colors (cluster circled in red) are linked with lines connecting the specimen to the center of each color. Because specimens that share taphonomic characteristics are more likely to come from the same context, this visualization tool can reduce the search space for an anthropologist working to associate elements of an individual.

Current methods for inventorying skeletal collections

Current methods for inventorying archaeological and modern skeletal collections are limited. Some sources recommend handwritten records, including photographs and sketches, to avoid data loss due to rapid technological advancement, which can result in computer programs and operating systems becoming obsolete and unusable. However, the longevity and accessibility of physical records must be considered, as written records are confined to one place and can degrade over time. Additionally, data analysis may be more challenging without using a computer database or software, and transferring written data to a digital format by hand could result in errors (27). Spreadsheets, including Microsoft Excel or Google Sheets, are the most popular method used for recording skeletal collections (27-29). This is likely because they are free to use, have flexibility for creating custom recording fields, have the ability for basic data analysis and visualization, and can be shared digitally with others. However, inventorying specimens using a spreadsheet may be time-consuming, as each specimen and associated information must be inputted individually. Likewise, researchers will need to spend time designing a spreadsheet for their project, as general spreadsheet programs are not specifically designed for inventorying skeletal human remains. Storing sensitive and personal information about human remains and archaeological sites in a spreadsheet program owned by large corporations like Google or Microsoft may pose security risks. Anthropologists working on a project must use a common recording method and vocabulary when entering data into a spreadsheet, as using different recording methods and vocabulary may cause confusion when data is combined and analyzed later. A similar issue occurred during the beginning of this project, as multiple students conducted the initial inventory and documented taphonomy and pathology differently. Standardization issues may be mitigated using standard recording methods or osteological coding.

In addition to physical records and general spreadsheets, several database systems have been specifically designed for documenting human remains. Osteoware®, developed by the Smithsonian Institute, is a free database tool that allows researchers to inventory human remains and document information about the biological profile, taphonomy, metrics, pathology, and other nonmetric traits and anomalies (30). However, it lacks specific tools for documenting and resolving commingled and fragmented remains. The Osteoware® software would be most useful in documenting collections of mostly complete skeletal remains without the goal of associating commingled elements with individuals. Similar database tools, such as STARC OSTEOARCH (31) and Çatalhöyük Human Remains Database (32, 33), were initially developed for individual projects but have since been expanded for use by other researchers. OsteoSurvey, developed by Anne Austin, is another data collection tool for documenting skeletal remains. It is open-source and works with an Open Data Kit to assist anthropologists in standardized data collection from commingled remains. The tool is customizable and emphasizes collaboration between anthropologists and researchers within and outside the field of bioarchaeology (34, 35).

Although these other recording methods and tools may be helpful for researchers, the CoRA web application was chosen as the primary database and data analytics tool for this project based on several factors. First, CoRA provides users with an ecosystem of tools and features that can all be used within the web application. This ecosystem is customizable on the project and member level to mold CoRA around a project's specific goals and needs. Additionally, CoRA was designed to document and resolve commingled remains and identify individuals. It also includes data analysis tools specifically for this purpose (23). Many other programs and tools designed for the documentation of human remains did not offer specific features to assist with the analysis of commingled remains. The recording methods used by CoRA rely on known standards and research commonly relied upon by experienced forensic anthropologists and include visual guides to assist project members with following these recording methods. Lastly, CoRA provides users with several unique data visualization tools not offered by other programs. These tools greatly enhanced the data analysis process of the current research project.

The primary goal of this project is to inventory and document the Syracuse University Medical Teaching Collection within CoRA to preserve the information provided by its current condition. Additionally, this research will aim to answer three main questions. The first question is whether this collection is indeed an anatomical or medical teaching collection. Despite its name and theories about its origin, the collection's age, provenience, and original purpose are currently unknown. Therefore, this research aims to review the history of anatomy and dissection in New York State and the history of the medical schools and institutions leading up to the closure of the Syracuse University College of Medicine to better understand the possible origin of the collections' remains. Certain taphonomic traits, such as evidence of autopsy/ dissection or the presence of hardware for articulation, could support claims that this is a historical medical teaching collection rather than an archaeological assemblage. Second, this research aims to estimate the minimum number of individuals (MNI) present in this collection based on traditional and zonation MNI quantification. Determining the MNI of any collection of skeletal remains, human or animal, is essential for understanding the context of the collection, as well as for making more complex calculation estimates for the number of individuals. Lastly, this research will determine whether CoRA can be used as a valuable database and data analysis tool for documenting and analyzing anatomical and medical teaching collections of skeletal remains. Although CoRA was initially developed for documenting, identifying, and resolving commingled remains from post-conflict and mass grave contexts, it may also have the potential to be valuable for use with historical or modern collections of skeletal remains. Comingled remains from anatomical or medical teaching collections, museums, and universities share some of the same characteristics and challenges as mass graves, but also some differences. Using CoRA to document and analyze the collection at Syracuse University will, therefore, determine whether the application can be used for collections from different contexts, and possible modifications or additions may need to be made within the program to expand its capabilities to better fit collections of different types.

Materials and Methods

All physical analysis of the skeletal remains was conducted in the Physical Anthropology Lab in Lyman Hall 406. Before any documentation or analysis of remains from the collection could be done, all potential specimens belonging to the collection had to be located and separated from other anthropological and zooarchaeological specimens. Only specimens with a curation identification number written on them or hardware attached were considered part of the collection. Additionally, all bones belonging to the feet and hands were not included in the inventory except those attached to articulated skeletons. Once all relevant specimens were identified, basic information for each specimen, including element, side, completeness, and specimen identification (ID) number, was recorded in a Microsoft Excel sheet. White et al. (2011) and other osteology reference books assisted in element and side determination. Determinations about completeness were initially recorded as "Complete" or "Incomplete" to assist in locating and identifying specimens further in the documentation process. The ID number on each specimen was recorded as written. A new ID number was assigned for specimens in which there was no identification number or the number was unreadable.

After the initial inventory of the specimens in the collection, measurements were taken for all relevant elements following the "Measurements" guide[c] within the CoRA ecosystem. Measurements were taken using spreading calipers, sliding calipers, an osteometric board, and flexible tape measure following instrument recommendations in the CoRA guide and recorded on physical recording sheets.

The next step in the inventory process was transferring the initial inventory data and measurements into the CoRA ecosystem database. The element and side (if applicable) were added to the database, along with the ID number written on the specimen as an "External ID." Along with the original ID number (or External ID), the CoRA system automatically assigned a unique designator for each specimen for further designation within the ecosystem. Single specimens were added individually, while articulated remains were added as bone groups and assigned an individual number. Completeness of each specimen was recorded using the zonation

[c] Measurement definition and guidelines referenced from Meadows & Jantz (1992), Byrd & Adams (2003), Berg & Ta'ala (2014), and Langley et al. (2016). Reference images created by Elizabeth Locket and Nandar derived from Langley et al. (2016).

method outlined in the CoRA guide[d], based on Knüsel & Outram's (2004) zonation method for inventory of fragmented human remains. Next, each specimen was inspected for notable taphonomy. Recorded taphonomic traits included overall color, staining, adherent materials, biological changes, burning, physical changes, and human modification[e].

Lastly, the embedded data analytics and visualization tools within the CoRA ecosystem were used to analyze the data about the inventoried specimens. Specifically, the project dashboard provided a high-level overview of the collection data, including the total number of specimens, specimen completeness, number of unique individuals, traditional and zonation MNI, and bone group frequency. The hierarchical clustering tool was used to visualize the number of specimens in each taphonomy category and sub-category. Using the data provided within the project on CoRA, additional charts and statistical calculations were made to analyze smaller data groups.

Results

Overall Inventory

The total number of specimens recorded, excluding bones from the hands and feet, was 2252. Over two-thirds of the specimens (1540 or 68%) were complete, while the other third of specimens (712 or 32%) were incomplete (Figure 8). Specimens that could be associated with at least one other specimen comprised 45% of the collection (1005 specimens), with a majority of these associated specimens belonging to articulated skeletons. Specimens not clearly associated with each other through refits, articulation, or attachment comprised 55% of the collection (1247 specimens). The most common element recorded in the collection was "uinseriated ribs"

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[d] Zonation methods referenced from Knüsel & Outram (2013). Reference images created by Elizabeth Locket and Nandar derived from Knüsel & Outram (2013) and Langley et al. (2016)

[e] All taphonomic categories listed on the CoRA Docs guide https://docs.coracore.org/en/latest/

meaning ribs or rib fragments that could not be identified as one of the specific rib numbers (212 specimens), followed by scapulas (94 specimens) and Rib 2 (84). The total inventory of all identified elements can be found in Table S1, and the element inventory by side in Table S2.

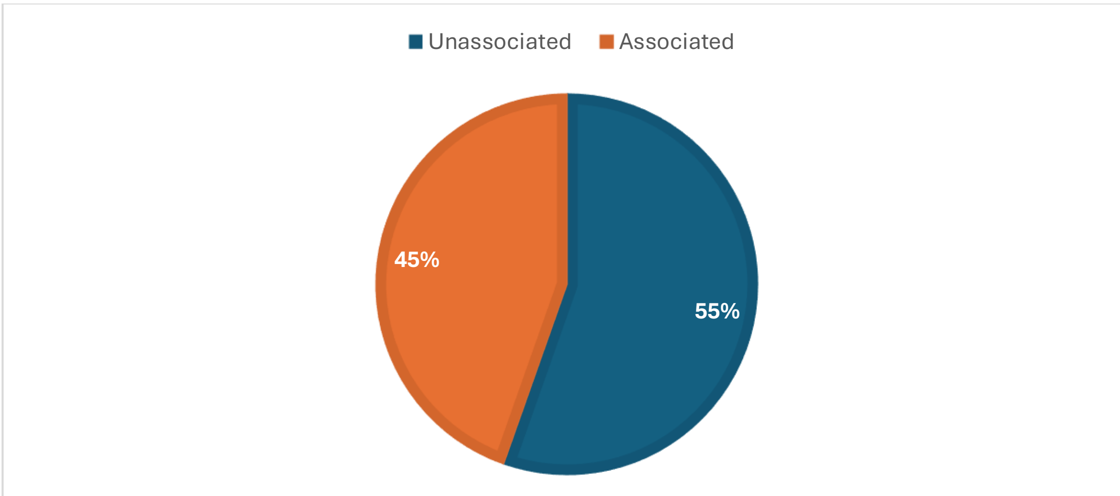

Figure 8. Associated vs. unassociated specimens. This pie chart shows the proportions of associated and unassociated skeletal specimens in the collection. Specimens that could be associated with at least one other specimen comprised 45% of the collection (1005 specimens), with a majority of these associated specimens belonging to articulated skeletons. Specimens not clearly associated with each other through refits, articulation, or attachment comprised 55% of the collection (1247 specimens).

Traditional MNI

The traditional MNI was calculated by counting the number of complete and incomplete specimens identified for each skeletal element. The MNI values for each element based on the total bone frequency and the bone frequency for each side (when applicable) were automatically calculated and reported within the CoRA project dashboard. Although the number of each element is reported within the dashboard, the elements used for the estimated MNI determinations for this collection were paired elements that could be easily sided visually (See Table 1). The most frequent right-side element was the scapula, with 49 total specimens (Table 1, Figure 9). The most frequent left-side elements were the scapula and radius, each with 43 total specimens (Table 1, Figure 9). The number of specimens recorded for each skeletal element and side using the traditional MNI quantification method is reported in Table 1 and Figure 9. Additionally, Figure 9 illustrates the difference in frequencies of the left and right sides for each element. Right-sided elements were more abundant for the scapula, os coxa, humerus, femur, fibula, and patella, while left-sided elements were more abundant for the radius, clavicle, and ulna (Figure 9). Of the ten elements (577 specimens) considered for the determination of MNI, 53% (303 specimens) were right-side elements, while 47% (247 specimens) were left-side elements (Figure S1).

Table 1. Frequency of skeletal elements based on traditional MNI calculations.

Element	Left	Right
Scapula	43	49
Radius	43	40
Os Coxa	33	37
Humerus	24	34
Clavicle	29	27
Femur	24	28
Tibia	23	26
Ulna	26	22
Fibula	17	22
Patella	12	18

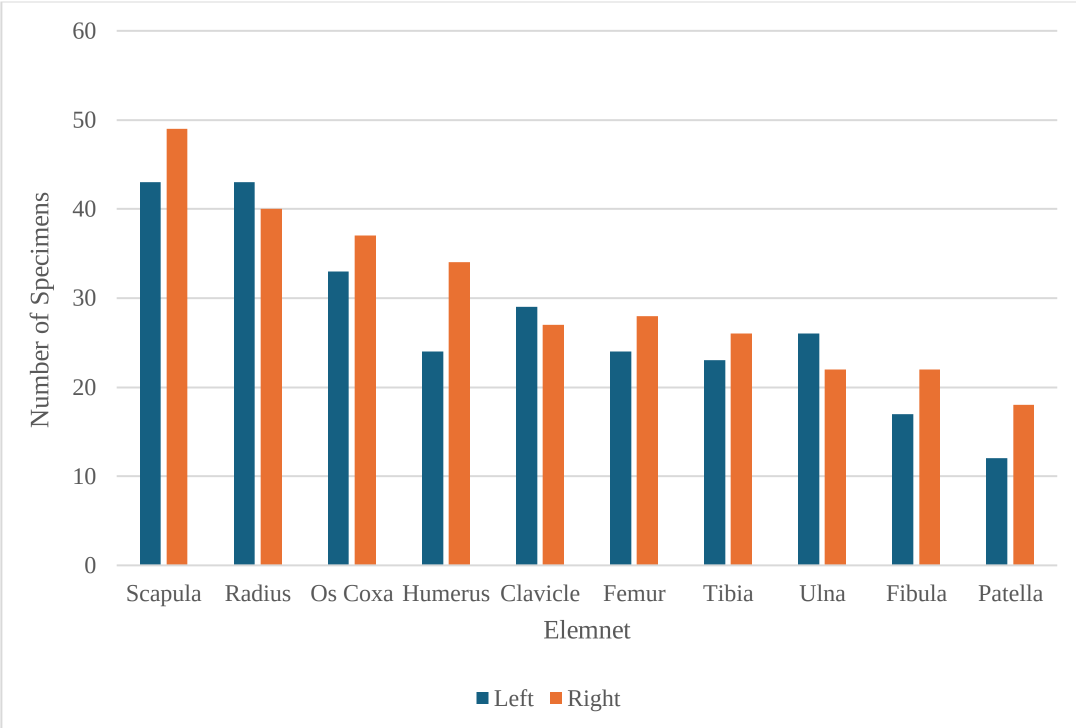

Figure 9. Frequency of skeletal elements based on traditional MNI calculations. This bar chart shows the number of specimens recorded for each skeletal element and side using the traditional MNI quantification method.

Zonation MNI

The zonation MNI was calculated based on the number of element zones recorded based on Knüsel & Outram's (2004) zonation method for inventory of fragmented human remains. The zonation MNI values for each element zone based on the total zone frequency and the zone frequency for each side (when applicable) were automatically calculated and reported within the CoRA project dashboard. Although the number of each element zone is reported within the dashboard, the elements used for the official MNI determination for this collection were paired elements that could be easily sided visually (See Table 2). Table 2 shows the frequency of left and right skeletal elements based on zonation MNI calculations. The zonation MNI value reported in Table 2 corresponds to the most frequent element zone or zones. Table S3 and Table S4 list the most frequent zones for each skeletal element and side used for the zonation MNI calculation, and Table S5 lists the frequency of each element zone for all elements in the collection. The most frequent left-side element was the radius, each with 43 total specimens (Table 2, Figure 10). The scapula was the most frequent right-side element, with 43 specimens in total (Table 2, Figure 10). Additionally, Figure 10 illustrates the difference in frequencies of the most frequent zone of the ten selected skeletal elements for the right and left sides. Right-sided element zones were most abundant for the scapula, humerus, femur, tibia, fibula, and patella, and left-sided element zones were most frequent for the radius, os, coxa, clavicle, and ulna (Figure 10).

Table 2. Frequency of skeletal elements based on zonation MNI calculations.

Element	**Left**	**Right**
Scapula	42	43
Radius	43	40
Os Coxa	27	25
Humerus	24	33
Clavicle	29	26
Femur	24	27
Tibia	23	26
Ulna	25	22
Fibula	16	21
Patella	12	18

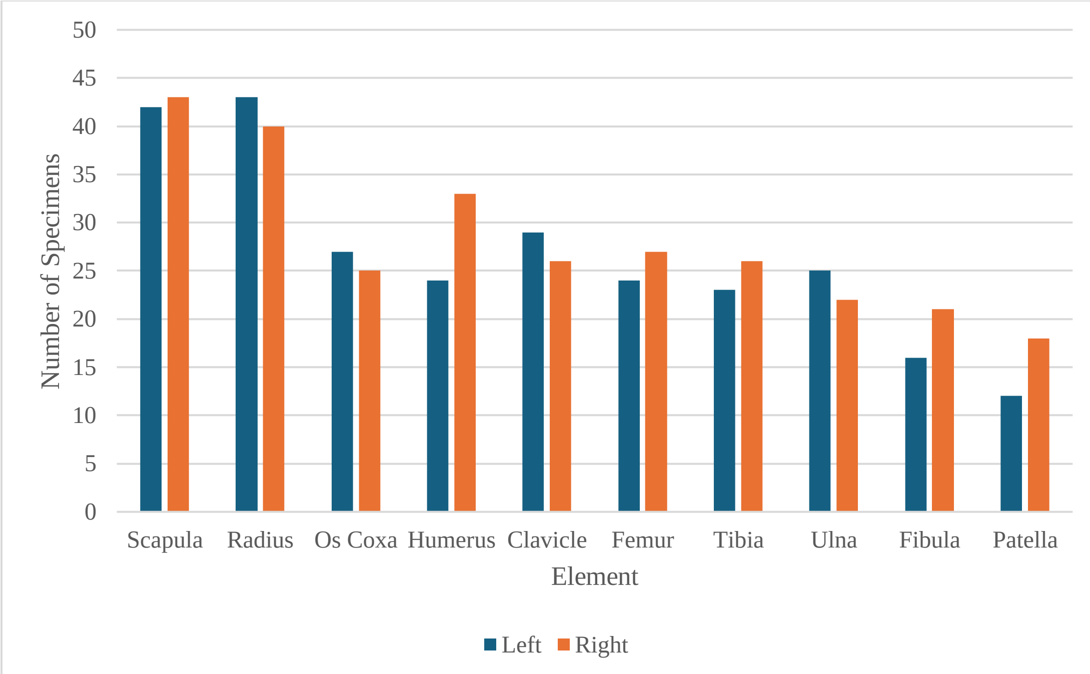

Figure 10. Frequency of skeletal elements based on zonation MNI calculations. This bar chart shows the number of specimens recorded for each skeletal zone and side using the zonation MNI quantification method (from Knüsel & Outram 2004). The value reported corresponds to the zone most frequent for a given element (Table S5).

Traditional MNI Vs. Zonation MNI

The MNI calculated using the traditional MNI method was 43 individuals based on the frequency of the left scapula and radius (Table 3) and 49 individuals based on the right scapula (Table 4). The MNI calculated using the zonation MNI was 43 individuals based on the frequency of the left radius (Table 3) and 43 individuals based on the frequency of the right scapula (Table 4). A two-sample t-test assuming unequal variances conducted using Microsoft Excel indicated no statistically significant difference between the MNI determined using the traditional and zonation MNI methods.

Table 3. Traditional MNI vs. zonation MNI values for selected left elements.

Element (left)	Traditional MNI	Zonation MNI
Scapula	43	42
Radius	43	43
Os Coxa	33	27
Humerus	24	24
Clavicle	29	29
Femur	24	24
Tibia	23	23
Ulna	26	25
Fibula	17	16
Patella	12	12

Table 4. Traditional MNI vs. zonation MNI values for selected right elements.

Element (right)	Traditional MNI	Zonation MNI
Scapula	49	43
Radius	40	40
Os Coxa	37	25
Humerus	34	33
Clavicle	27	26
Femur	28	27
Tibia	26	26
Ulna	22	22
Fibula	22	21
Patella	18	18

Taphonomy

Recorded taphonomic traits included general color, staining, adherent materials, biological changes, burning, physical changes, and human modification. Table 5 lists the number of specimens in each general color category. Figure 11 shows the percentage of specimens recorded for each color category, with the most frequent color being “Yellow to Tan” (894 specimens, 39%), followed by “Natural” (815 specimens, 36%).

Table 5. General color of bone specimens.

General Color	Number of Specimens
Yellow to Tan	894
Natural	815
Tan to Brown	358
Brown to Dark Brown	115
Grey	86

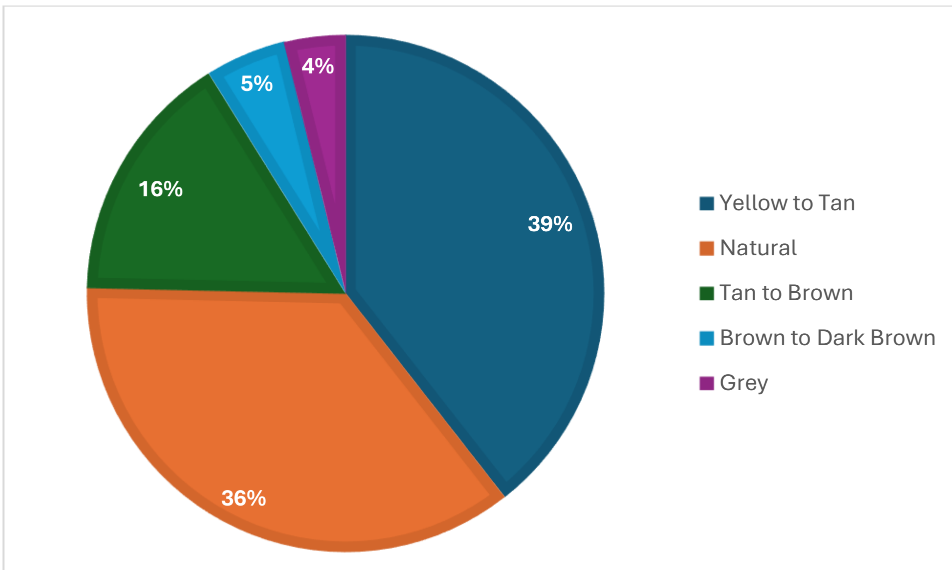

Figure 11. General color of bone specimens. This pie chart shows the proportion of bones in the collection exhibiting each general color category. The most frequent color category recorded for specimens in the collection was "Yellow to Tan" (894 specimens, 39%), followed by "Natural" (815 specimens, 36%). Grey was the least frequent color recorded, with only 4% (86 specimens) recorded for this general color category.

Eleven different colors of staining were observed on specimens during the documentation process (Table 6), with some specimens exhibiting more than one color. The most common color of staining observed on the remains from the collection was grey/ silver (727 specimens), followed by brown (338 specimens) (Table 6). Figure 12 shows the proportion of specimens exhibiting staining compared to the total number of specimens in the collection. Adhering soil was observed on 290, or 13% of specimens (Figure S2).

Table 6. Number of specimens exhibiting each color of staining

Color of Staining	Number of Specimens with Staining
Grey/Silver	727
Brown	338
Black	87
Red	47
Pink	25
Green	19
Orange	14
Blue	11
Yellow	8
White	4
Purple	3

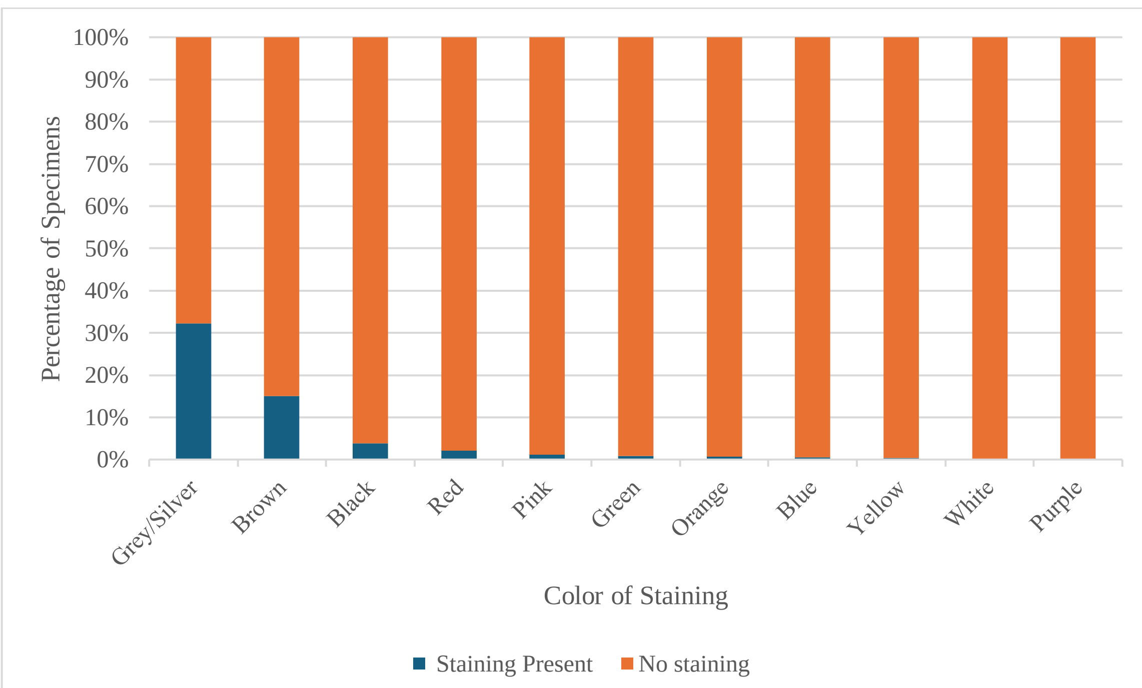

Figure 12. Percentage of specimens exhibiting each color of staining. This bar chart shows the percentage of specimens exhibiting a particular color of staining (blue) compared to the proportion of specimens not exhibiting that color of staining (orange).

Ten different types of human modification were observed on specimens from the collection (Table 7), with some specimens exhibiting more than one type. Table 7 shows the number of specimens exhibiting each type of human modification. Figure 7 shows the percentage of specimens in the collection that exhibited a certain modification type compared to those that did not. The most frequent type of human modification observed was “writing,” with 1566, or 69.5% of specimens exhibiting this type of modification (Table 7, Figure 13).

Table 7. Types of human modification observed on collection specimens.

Human Modification	**Human Modification Present**
Writing	1566
Drill Hole	559
Hardware Attached	551
Plaster/ Reconstructive Materials	202
Adherent Material: Other	158
Cut Marks	104
Bone Section Removed	57
Textile/Impression	4
Preservatives	2
Intentional Fracture	1

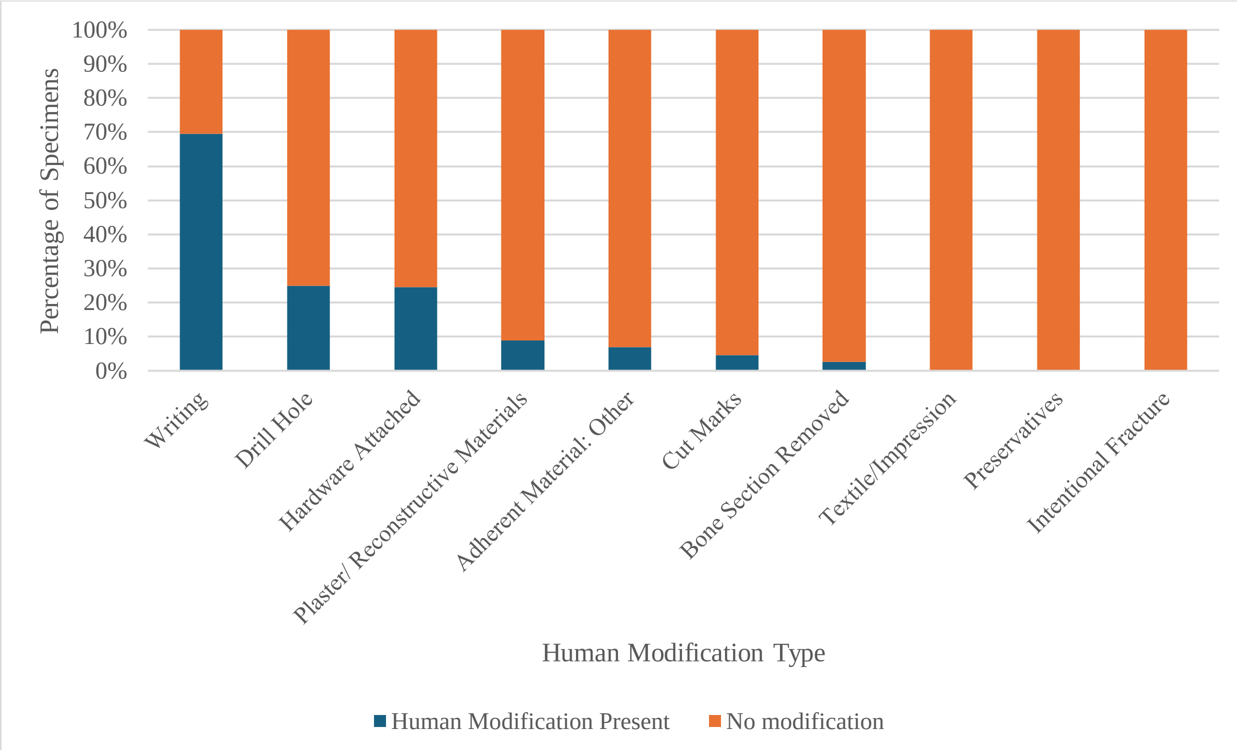

Figure 13. Percentage of specimens exhibiting each type of human modification. This bar chart shows the percentage of specimens exhibiting a particular type of human modification (blue) compared to the proportion of specimens not exhibiting that modification type (orange).

Discussion

Overall Inventory

The majority of specimens being complete as opposed to incomplete supports the theory that these are more modern specimens that have been curated and taken care of over time. Archaeological specimens tend to be more fragmented, as they are likely to be exposed to taphonomic processes such as weathering, soil acidity, freeze and thaw cycles, temperature and climate, and animal scavenging (36-38). Many of the remains recorded as "incomplete" within the CoRA database were missing only one or two landmarks used for inventory purposes and, therefore, were primarily complete. Each specimen within the CoRA database has more specific completeness information based on the zones present. Recording the completeness of a specimen in detail is essential for refitting fragmented remains and locating specific specimens in the collection using the database. Although a majority of specimens were considered to be “unassociated,” it is possible that they could be later associated with other remains in the collection, as this study did not pursue the reassociation of single elements. The number of “unassociated” remains would likely decrease after using taphonomy, visual element matching, metrics, and analysis tools within CoRA to associate and resolve commingled elements.

The most common element recorded in the collection was “uinseriated ribs” meaning ribs or rib fragments that could not be identified as one of the specific rib numbers. This outcome is unsurprising, as ribs and rib fragments were frequent in the collection, likely due to two major factors. First, the number of ribs in the human body (usually 24) is disproportionate to the number of long bones (only two in a pair). Therefore, unsided and unnumbered ribs being combined into one category results in a value that cannot be compared to single long bone elements. Moreover, ribs can be difficult to side and assign a specific rib number when fragmented, which can result in inflated counts of both identified and uinseriated ribs. The following three sections will discuss the significance of certain elements used for MNI calculations.

Traditional MNI

The Minimum Number of Individuals (MNI) is the most common method used by forensic anthropologists and archaeologists to quantify assemblages of commingled human or animal remains (39). Traditional MNI was calculated by counting the number of complete and incomplete specimens identified for each skeletal element (39-43). Because the primary purpose of the MNI quantitation method is to avoid counting the same individual twice, ten paired elements are easily distinguished by element and side based on morphological analysis and included in the MNI evaluation (see Table 1.) Elements such as the ribs, vertebrae, and skull fragments were not considered for MNI analysis as they can be challenging to identify by side and number when fragmented and commingled (42, 44). Interestingly, the most frequent element considered for MNI in the collection was the right scapula. This is unexpected, as the scapula is relatively thin and, therefore, would be more likely to experience breakage and loss over time. Long bones would be expected to be the most frequent, as they are more resistant to breakage and loss due to their size and thickness (40). However, most data sets containing MNI values and element counts are based on assemblages from archaeological contexts, which differ significantly from anatomical or medical collections. More data from anatomical collections regarding MNI and the frequency of elements would need to be analyzed to determine whether the element distribution recorded from the Syracuse Medical Teaching Collection differs from other teaching collections. The imbalance in the number of left and right scapulas could be due to bone fragments from a single element being counted as multiple individuals, therefore artificially inflating the MNI. This theory can be easily tested using the zonation MNI method, which will be discussed in the next section. Additionally, it is possible that an element from a pair could have been lost or that a specimen may not have entered the collection individually without the matching element. Similar explanations may account for the imbalance of overall left and right elements represented in the collection. Limbs or partial limbs may have been acquired for or left the collection, resulting in more of one side element being present than another. Knowing more about how Syracuse University and previous associated medical schools and institutions acquired the remains in the collection would provide more insight into the element makeup of the collection.

Zonation MNI

Knüsel and Outram (2004) developed the zonation recording method (adapted from Dobney & Rielly, 1988), which relies on inventorying human remains by element zone rather than the general element. This recording system was developed specifically for documenting fragmented human remains, as using traditional MNI calculation methods on fragmented human remains can result in inaccurate determinations, usually much higher than the actual number of individuals. Additionally, the zonation recording method reduces observer subjectivity, inter-observer error, and double counting of individuals (26, 42, 45, 46). The same ten elements used for the traditional MNI calculation were used for the zonation MNI method. The superior half of the glenoid cavity of the right scapula was the most frequent region and, therefore, was the element and region used to calculate the zonation MNI. As discussed in the previous section, the scapula is unexpectedly the most frequent element in the collection due to its fragile nature. However, a higher frequency of this zone of the scapula is expected, as the zones associated with the glenoid cavity are less fragile and more identifiable than other regions. The medial distal third, superior half of the distal third, and lateral distal third regions of the radius were the most frequent regions of the left radius. Zones including the diaphysis, such as the ones most frequently recorded for this case, are less likely to be broken off or lost over time, therefore resulting in a higher frequency compared to other elements. Differing quantities of element zones across left and right elements are likely the result of post-mortem loss over time or intentional human modification, such as the removal of bone sections in past or present use of the collection. Although not among the most frequent elements or zones, several crania in the collection show evidence of the removal of portions of the face or calvaria that were likely done during the dissection process or thereafter to expose the internal features of the crania for teaching purposes. Removal of these bone sections resulted in partial crania missing certain features or zones no longer present in the collection. More recently, a portion of vertebrae from the collection was found to be cut transversely into sections as part of a former Syracuse University student's research project examining the structure of bone in vertebrae. The other half and transverse sections of the vertebrae were not recovered, therefore rendering the specimen incomplete. Again, having more knowledge about how Syracuse University acquired the remains in the collection and how the collection has been used in the past would provide more insight into the element and zone makeup of the collection.

Traditional MNI vs. Zonation MNI

Traditional MNI and zonation MNI are both methods used by forensic anthropologists and bioarcheologists to estimate the minimum number of individuals in a given assemblage. In addition to traditional MNI calculations based on element side and count, CoRA allows for recording skeletal remains by zone, allowing users to see MNI values based on element and side easily. This is essential for forensic anthropologists, such as those working at the DPAA Laboratory, involved in cases of mass graves and assemblages of commingled and fragmented remains. While traditional MNI methods may provide fairly accurate values for assemblages of complete remains, these same methods likely won't be as accurate for assemblages of highly fragmented remains (26, 42, 45, 46). This is because element fragments being counted as different individuals may actually belong to the same element, therefore resulting in an overestimation of individuals. Both the traditional MNI and zonation MNI values were reported for this study, as the medical teaching collection contains both complete and incomplete or fragmented remains. However, due to the fairly complete nature of the collection and lack of a significant amount of highly fragmented remains, the MNI calculated using each method was hypothesized to be fairly similar. Indeed, this turned out to be the case, with the results of a two-sample t-test indicating no significant difference in the MNI values reported using each method. The MNI estimated using the traditional MNI method was higher than the value calculated using the zonation MNI method in all ten elements. This is expected, as each fragment was counted as an individual using the traditional MNI method, while the zonation method helped to reduce instances of double counting, where the fragmented remains of one individual were counted as multiple individuals. Based on the ability of zonation MNI to reduce observer subjectivity, inter-observer error, and double counting of individuals, it is therefore likely that this value, 43 based on the left radius and right scapula, is the most accurate estimation of the minimum number of individuals in the collection. Potential methods that could be used to increase the MNI estimation will be discussed in the "Future considerations" section later in this paper.

Taphonomy

During the documentation process, taphonomic traits for each specimen were recorded for three main reasons. First, documenting the current condition of the collection is essential for tracking any future alterations to specimens, such as postmortem damage, specimen loss, or bone sections removed for sampling. Second, taphonomic traits can help determine the original context of remains, such as whether they are archaeological in nature or were used for dissection or medical training. Lastly, taphonomic and physical characteristics of specimens can be used to reassociate specimens in commingled contexts.

The general color was the first taphonomic trait recorded for all specimens during the documentation process. Overall color can be used to help reassociate commingled remains, as remains that are similar in color are more likely to come from the same depositional environment than remains that differ in color (28, 41, 47). However, visual pair matching using color should only be used in conjunction with other resolution methods as it is not the most reliable association method when used on its own (47). The overall color of bones can provide information about the original context of the remains. A majority of the specimens from the collection were yellow to tan or natural colored, which indicates little to no significant taphonomic changes. Slight color differences, such as specimens yellow in color, may be the result of dirt or residue from overhandling in a teaching setting (48). Tan, brown, and dark brown coloration of specimens is likely the result of particles leaching from soil (38, 39, 48), freezing, or bone marrow seeping into the surrounding bone (*49*). Grey specimen color could be due to weathering or exposure to grey clay or sediment (39). Further analysis of natural-colored specimens should be conducted to determine whether these specimens had been subjected to bleaching or cleaning, as this could indicate remains prepared for museum or commercial purposes (38, 48).

The next taphonomic trait recorded during the documentation process was staining, in which 11 different staining colors were observed. Although CoRA provides the option to pair a color to the source of staining, only the color was recorded, as the source of staining could not be confirmed for most specimens. Staining color and pattern can be used to help reassociate commingled remains. For example, multiple specimens with the same staining color may indicate that those specimens were near each other within a depositional environment (28 39, 41*,* 47). Staining could prove to be an especially useful association method for this collection, as the highest proportion of staining observed for any one color was only 30%. Therefore, unique staining colors and patterns may be able to help reassociate specimens in this collection. Staining colors and patterns may also be able to provide information about the previous use of a specimen or its original context. Grey/silver, the most common color of staining, was in most cases likely to be the result of dirt and dust from handling or an unclean storage facility. Grey/ silver staining may have also been caused by exposure to metals, such as those in soil or from attached hardware (39, 48). Brown staining on bones most likely originated from soil particulates, residue from decomposing organic materials, or oxidation of metals (39, 48). Most black staining appeared to be from archival ink spills or drips. However, black staining can also result from textile dyes, charcoal exposure, or decomposing organic materials (48). Mineral precipitates in soil, such as salts or calcium carbonates, can cause white staining on the bone (48). Unnatural staining colors, such as red, pink, green, orange, blue, yellow, and purple, could most frequently be attributed to marking of certain features or landmarks for teaching purposes. For example, an entire vertebral column had all facets colored red. This presumably indicated that these vertebrae articulated and belonged to one individual. However, it is unclear when these markings were placed; therefore, it cannot be confirmed whether these vertebrae are indeed from the same individual. Even so, staining and markings such as this should be recorded, as it can provide potential leads for associating specimens later on. These less frequent colors may also have natural explanations, such as blue or green staining from copper hardware. Dupras and Schultz (2021) provide an extensive overview of staining colors and potential sources of staining on bone.

The presence of adhering soil was also recorded during the documentation process. Documenting the presence or absence of soil was essential for determining the original context and age of specimens in the collection, as bones with adhering soil are more likely to come from burial or archaeological contexts. In contrast, clean bones may indicate use in an educational setting or museum. The low proportion of bones in the collection with adhering soil supports the theory that these remains were once part of an anatomical museum or used for teaching purposes. The presence of archaeological specimens in the current collection could be due to the accidental inclusion of specimens from other assemblages in the lab or the use of archaeological specimens for teaching purposes. Additionally, there is a history of medical institutions removing bodies from burial contexts for anatomical use, which could explain the soil present on remains. However, instances of grave robbing typically involved freshly deposited bodies that were obtained for dissection or anatomical demonstration purposes, with skeletal remains being a "byproduct" of dissection (5). Of course, the presence or absence of soil, along with other taphonomic traits, can help reassociate remains. Chemical analysis of soil composition or the presence of microorganisms in the adhering could be used to associate specimens with higher accuracy (50).

The last type of taphonomy recorded for each specimen was human modification. Like other taphonomic traits, human modification of specimens can help reassociate commingled remains and provide context about their previous use and origin. Writing, which included identification numbers and other markings, was the more common human modification type. All individual specimens had an identification number written in a permanent black marker. Unfortunately, these numbers did not correspond to any previous documentation or records and, therefore, were used as unique external ID numbers for locating specific specimens within CoRA. The only specimens without identification numbers were the articulated skeletons, each assigned an individual number. "Plaster/ Reconstructive Materials" refers to plaster used to repair damaged elements or glue securing fragments together. Plaster was most commonly observed on the os coxa and sacrum. Glue seemed to be used most frequently for securing teeth to the mandible and repairing fragmented ribs and cranial fragments. Reconstructive materials such as glue and plaster have been observed on specimens in other anatomical collections (8, 38). However, reconstructive materials can be used for repairing archaeological specimens and, therefore, are not indicative only of teaching specimens. Few specimens had apparent signs of a preservative coat or varnish. Varnish or other preservatives are likely used in some preparation methods but not others. If human remains were seen as a "byproduct" of dissections as compared to a museum specimen or teaching aids, this would explain the lack of preservatives and other preparation methods. Few specimens also exhibited impressions from textiles or fabric tapes.

“Adherent materials” refers to tape, adhesive labels, or tape residue observed on specimens in the collection. In other teaching collections, tape has been found to mainly be used to secure broken areas or keep cut specimens together (8, 38). In this collection, however, mostly smaller pieces of tape and adhesive were primarily observed on specimens, presumably used for the purpose of labeling. Further analysis of the types and ages of reconstructive materials, preservatives, and adherent materials present on specimens may be able to provide additional information about the history of the collection and specimen use.

Drill holes, hardware, cut marks, and bone section removal are all forms of human modification that are fairly indicative of the use of human remains for teaching and educational purposes (5, 8, 38, 51, 52). Drill holes and hardware were most frequently observed for the fully articulated skeletons in the collection, with the exception of some articulated feet and hands (not recorded at this time), limbs, and skulls. The specimen counts for drill holes and hardware attached are similar because holes had to be drilled through the bone to attach the hardware. A slightly higher number of specimens exhibiting only drill holes is likely the result of previously attached hardware that is now missing. Although some hardware can be used to repair damaged specimens, the most common use of hardware is to articulate skeletal remains for teaching or display purposes. Screws, bolts, and robust hooks were used secure long bone elements into anatomical order and provide movement of joints. Smaller and more fragile elements, such as the clavicle and digits, were articulated to the skeleton with metal wire. The ribs of the articulated skeletons also exhibited multiple lengths of wires drilled through the rib shafts and necks, attaching the ribs to the sternum/ cartilage and body of the vertebrae. The vertebral columns of the articulated skeletons were kept aligned with metal rods protruding through the vertebral foramina. Felt pads were placed in between the vertebral bodies, pubic symphyses, and between the scapula and ribs to prevent damage between bone surfaces and simulate soft tissue. Several crania exhibiting a full craniotomy (or removal of the skullcap) had metal small metal rotating hooks drilled and attached to the superior portion of the temporal bones, directly inferior to two metal pins drilled into the parietal bones of the removed calotte. Additionally, holes were drilled vertically around the cut perimeters of both crania portions, with metal pins being inserted into the calotte to further secure it to the cranium when articulated. These pins and hooks allow for the reattachment of the calotte to the inferior portion of the cranium. Springs were installed to some mandibles, allowing for the attachment of the mandible to the cranium. Most or all of these hardware types are common taphonomic characteristics related to the display and use of human remains in educational settings (5, 8). The presence of drill holes and attached hardware further supports the claim that these specimens likely originated from or were part of a historic medical teaching collection.

As mentioned earlier, sectional cuts or purposeful removal of portions of bone can provide evidence of medical experimentation, dissection/education, or autopsy (8, 51, 52). Sectional cuts were most commonly observed on the sternal ends of the ribs and the crania but were also observed on the mandible, clavicle, long bones, vertebrae, and pelvis. Sectioning cuts on the sternal ends of the ribs, which have been observed in other anatomical teaching collections (8, 51, 52), are consistent removal of the breastplate in autopsy but not typical of anatomical preparation (8). Several crania exhibited full craniotomies or removal of the calotte, some with hardware attached. Sectioned skulls with clean cuts and hardware attached were likely anatomically prepared (8, 38), while specimens without hardware are likely to be the product of dissection or autopsy (51, 52). For some mandibles of juvenile individuals, a portion of the body was removed to expose teeth in development. Only a few specimens exhibited transverse cuts along the shaft of long bones, a type of modification observed frequently in other medical teaching collections (52). This could be explained by the fact that this particular collection was not used for experimentation or amputation training or that cut remains were disposed of after use. Transverse sectioning was also observed for some vertebrae in the collection and has been recorded for specimens in other anatomical collections as well (52). One instance of the pubic symphysis being removed from an os coxa was observed, as well as a sacrum cut in half sagittally. In summary, the types of bone section removal observed in the collection are consistent with other skeletal collections used for surgical training, dissection, and teaching.

The last human modification type observed for specimens in this collection was cut marks. Cut marks can occur as the result of antemortem or perimortem sharp-force trauma or post-mortem human modification (38). The location, severity, and type of kerf observed on a bone can provide information about when the mark was made and for what purpose. One location in which cut marks were commonly observed in this collection was on the cranium, especially on specimens that had undergone a full craniotomy. Kerfs along the perimeter of the calotte and lower cranium are likely the result of false starts, repositioning, or mistakes made during the craniotomy process, where a saw is used to remove the calotte or skull cap and expose the brain. The cleanness of the sectioning or cuts can provide information about the type of tools used, as well as the experience of the dissector. Specifically, crude or incomplete cuts and false starts are likely to indicate a less experienced dissector and, therefore, could indicate that the individual was used for dissection or surgical training, as opposed to an autopsy done by a professional (51, 52). Additionally, sectioning of the cranium explicitly for specimen preparation is likely to result in a clean cut rather than multiple uneven cuts, as sample preparation does not require the brain to be intact (8). Yucha et al. (2021) claim that complete sectioning of crania can provide temporal information about the post-mortem interval as the types of saws used for this procedure have only been available commercially since 1948 (8, 53). However, removal of the skull cap has been observed in earlier 19th-century skeletal collections associated with surgical training, dissection, and autopsy (51, 52, 54). Therefore, further examination of the types of kerf marks present on crania is necessary to determine the procedures used and for what purpose the skull cap was removed. Cranial specimens in the Syracuse University Medical Teaching Collection exhibited clean sectioning and more crude cuts to remove the calotte, indicating a mix of specimens used for dissection or education and anatomically prepared specimens. Only one specimen exhibited what appeared to be an intentional fracture, where the calotte was sectioned around the circumference but was fractured towards the posterior portion of the cranium. Prying tools used to separate bones of the cranium to expose the intact brain and intentionally fracturing the cranium to remove the calotte has been observed in other 19th-century anatomical collections (51, 52). However, it is also possible that this fracture was made in error during the removal of the calotte. Additionally, some knicks and shallow cut marks were observed on crania without craniotomies, which can likely be attributed to the removal of the scalp during specimen preparation (55). Several other element types in the collection exhibited shallow cut marks, including vertebrae, ribs, long bones, the mandible, and the pelvis. Shallow cuts and nicks observed on post-cranial elements may be attributed to defleshing or skeletal preparation. Further analysis into the specific locations of these cut marks could possibly differentiate between the removal of soft tissue for specimen preparation and surgical training or experimentation (51, 52). Other types of post-mortem trauma and bone loss were observed for specimens in the collection, however, it was not possible to record this type of post-mortem damage within CoRA.

Future Considerations

Given the minimal inventory and documentation previously conducted for the Syracuse University Medical Teaching Collection, establishing a comprehensive inventory became the top priority to prevent any further deterioration or loss of items. The hand and foot bones should also be included in the inventory in the near future and preferably entered into CoRA by groups belonging to individuals. Having the collection documented within the CoRA ecosystem provides a great starting point for future research to learn more about the individuals and their life histories. CoRA offers many additional features and data analysis methods to assist with documenting and identifying individuals that should be utilized in the future. Last year, bioarchaeology students began to record information about age, sex, ancestry, and pathology for remains in the collection. However, this information has yet to be transferred over and standardized within the CoRA ecosystem. Recording this type of data within a standardized database will reduce inconsistencies in recorded data that are currently housed on several Excel spreadsheets. Moreover, pathological and taphonomic traits recorded in CoRA can assist in pairing elements or identifying multiple remains that could belong to a specific individual. Measurements were also taken for relevant elements in the collection but were not used for this specific research project. Future research could utilize metric analysis tools within CoRA for stature estimation, osteometric sorting regression, and measurement scatter plots. CoRA also allows for the entry of DNA and stable isotope data, which can further assist with identifying individuals. It is important, however, to consider the pros and cons of molecular testing methods, as they are destructive processes. Therefore, the data visualization and analysis features of CoRA may be able to help reassociate the commingled remains in the collection. Resolving comingled remains is necessary to examine the remains of individuals and gain a better understanding of their overall health and life history. Additionally, commingled remains would need to be separated for purposes of repatriation if necessary.

CoRA provides data analysis tools for calculating traditional MNI and zonation MNI, two popular methods for quantifying skeletal remains discussed earlier in this paper. However, other variations of these methods may provide an even more accurate estimate of the number of individuals in the collection. One of these methods is the Lincoln Index (LI), initially developed for population studies of living animals and later adapted for zooarchaeological assemblages of faunal remains. This method relies on pair-matching of elements to avoid "recapturing" the same individual twice. The LI method does not require all skeletal elements to be recovered but estimates the number of individuals based on a population sample. Therefore, LI works best for assemblages in which the recovery of remains is less than 100% (40, 56). Some modifications by Serber (1973) and Adams & Konigsberg (2004) have made the LI formula more suitable for the quantification of human remains (40, 56, 57). The Most Likely Number of Individuals (MNI) represents the maximum likelihood estimate for the number of individuals in an assemblage. Similarly to LI, MLNI uses pair matching of elements to more accurately estimate the number of individuals in an assemblage. Pair matching reduces the number of individuals counted twice while accounting for unpaired elements from individuals in the assemblage (40, 56). The MNI quantification methods tend to be the most popular due to the ease of calculation. However, through computer simulations, Adams and Konigsberg (2008) have shown that the MLNI value estimates the true population even at low recovery rates. Additionally, Robson and Regier (1964) suggest that bias in the MLNI will be negligible if there are more than seven element pairs, therefore indicating that MLNI provides even more accurate estimates for larger assemblages (56, 58). MLNI can also be extended to multiple elements, but this requires more complex calculations and may introduce potential complications (40). Considering these factors, calculating the MLNI for the Syracuse University Medical Teaching Collection may provide a more accurate count for the number of individuals in the collection compared to the MNI.

In order to calculate the MLNI, right and left elements must be pair-matched. Pair matching and resolution of commingled remains of elements can be achieved through visual pair matching of general size and morphology, element articulation, osteometric comparison, taphonomic patterning, and process of elimination (41, 43). Fortunately, CoRA offers several tools to assist with pair matching of elements. First, the osteometric sorting regression and measurement scatter plot visualization tools compare measurements of left and right elements and determine the most likely pair based on metrics. The single/multiple relationships graph also shows elements that share taphonomic or pathological characteristics, trauma types, anomalies, or articulations. Specimens with similar characteristics may be more likely to come from the same deposition context or individual. DNA and stable isotope data can be used for pair-matching and identification. However, multiple methods of pair-matching and element association should be used to confirm the most likely element matches for purposes of quantification and resolution of commingled remains. Future research should involve recording pathology, trauma, anomalies, and biological profile information for each specimen. Then, pair-matching utilizing the quantitative and qualitative tools within CoRA or other peer-reviewed methods should be conducted to reassociate commingled remains. Once pair-matching has been completed, the MLNI can be calculated, providing a more accurate estimation of the number of individuals in the Teaching Collection. Comparing the MLNI to the MNI may provide information about the context in which specimens were obtained for the collection. For example, an MLNI that is significantly lower than the MNI would indicate that paired elements likely entered the collection from complete individuals. In contrast, a greater MLNI would likely indicate that elements were entering the collection from partial cadavers or as individual specimens. Therefore, additional research to further document the collection and determine the MLNI using the features within CoRA is crucial for learning more about the origin and history of Syracuse University's Medical Teaching Collection.

Conclusion

In addition to inventorying and documenting the Syracuse University Medical Teaching collection, this project had three main goals. The first was to determine whether there was evidence to support the claim that this collection is indeed a contemporary collection rather than from an archaeological context. Reviewing the history of dissection and autopsy in New York, as well as Syracuse University's College of Medicine, revealed that bodies of unclaimed, executed, and the impoverished were being acquired by medical institutions for purposes of medical instruction and training (5, 15). Additionally, similar taphonomic traits, such as hardware attachments, cut marks, and sectioning of the cranium present in other known medical teaching collections, were observed in many specimens in the collection at Syracuse (8, 51, 52). The second goal was to estimate the number of individuals in the collection. The MNI calculated using the traditional MNI method was 43 individuals based on the frequency of the left scapula and radius (Table 3) and 49 individuals based on the right scapula (Table 4). The MNI calculated using the zonation MNI was 43 individuals based on the frequency of the left radius (Table 3) and 43 individuals based on the frequency of the right scapula (Table 4). Due to the zonation, MNI's ability to reduce the chances of double counting individuals (26, 42, 45, 46), 43 is likely the most accurate estimate. However, other quantification methods, such as MLNI using pair-matching of elements, would likely produce an even more accurate estimate (56). The third goal was to determine whether the CoRA web application could be applied to unique contexts of commingled remains, such as medical teaching collections. CoRA's ability to provide a standardized recording database, data analysis tools, and data visualization features proved to be extremely useful for inventorying, documenting, and analyzing the Syracuse University Medical Teaching Collection. Therefore, it is likely that CoRA can be successfully used to inventory, document, and analyze other types of assemblages and collections of human skeletal remains.

Documenting collections of skeletal remains is necessary for many reasons. For example, laws and regulations concerning protecting and repatriating human remains and cultural objects, such as NAGPRA and AABGPA, require the documentation of human skeletal remains and cultural objects in anthropological collections (58, 59). Documentation and publication of information about the contents of a collection ensures that institutions are transparent and held accountable for repatriation if it is deemed necessary. A basic skeletal inventory is necessary for conducting more complex collection analysis, including quantitation, metric analysis, and estimation of biological profiles. Completing an extensive inventory and documentation of skeletal remains in a collection can also help with ease of use for research and education purposes.

When discussing the importance of osteological collections for education, medical training, and research, it is essential to consider the possible problematic history behind acquiring such collections. Until recently, Black people, the poor, criminals, prostitutes, Native Americans, the Irish, and members of other immigrant groups made up a greatly disproportionate number of anatomical subjects (5, 60). People from these groups did not donate their bodies through anatomical gift programs or for research purposes but rather had their bodies stolen from burial grounds, taken from the arms of their family members and loved ones, or sold to medical schools and institutions without their consent (5). Not only does the trade of bodies in this way violate the consent of the dead, but it also can have detrimental effects on the living. History seems to repeat itself as violations of living and dead bodies continue into modern times. For example, several scandals have occurred involving the theft and trade of human remains from unclaimed persons and individuals who have donated their bodies through anatomical gift programs (61, 62). Additionally, while donated bodies make up a majority of the dissections in the United States today, unclaimed bodies are still being used in medical institutions (14). Therefore, it is important to be aware of the ethical concerns posed by the use and acquisition of human remains used for education, research and training. It is our duty as anthropologists, forensic scientists, students, and educators to be the voice of the voiceless and uphold the highest ethical standards while working with both living people and human remains.

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