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Facilitating multidisciplinary forensic research using a unique computed tomography dataset

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Project Summary:

Major goals and objectives

The Problem
Scientific researchers often ask questions that are unanswerable at the time they ask them, due to technological limitations. As technology catches up with the creativity of researchers, new projects become possible. Such is the case for many projects that would require a large, diverse, high-quality decedent image dataset. Researchers are stymied, because while they could answer their questions if such a database existed, at the moment it does not.

The solution
This project created the first such database with postmortem computed tomography (CT) scans. The importance of postmortem CT scans is well documented[1-5]. The resource we have created is allowing many basic questions in forensic pathology and anthropology to be answered. We have developed a complete, free to *bona fide* users, ready to use, user-friendly, large-scale, next generation data resource that provides data for research in multiple forensic fields. We originally sought to provide *bona fide* researchers CT scans of 11,000 unembalmed decedents, documented with metadata and delivered via a searchable website. Each individual is represented by ~12,000 images. Researchers will request the scans that meet their research requirements and will receive the scans on portable hard drives.

At project completion, we have created a database and website with CT scans of 15,242 individuals represented, documented with up to 69 metadata variables. This database and website is known as the New Mexico Decedent Image Database (NMDID), available at nmdid.unm.edu.

Because the work funded in this project created a research resource rather than addressed a specific research question, we do not address specific research questions here. Instead, we will describe several research questions already being addressed by users of our database under the Outcomes section of this report.

Research design, methods, analytical and data analysis techniques

The sample
The Office of the Medical Investigator (OMI) is a centralized medical examiner's office for the entire state of New Mexico, housed at the University of New Mexico (UNM) Health Sciences Center. With a few exceptions, any individual who dies in the state in a sudden, violent, untimely, or unexpected manner, and any person who is found dead and the cause of death is unknown, is routed to the OMI where an autopsy may take place.

The Center for Forensic Imaging (CFI) was built by the State of New Mexico at the OMI, and contains a CT scanner for the facility. Between 2010 and 2017, 85% of decedents that

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underwent an autopsy received a high resolution, full-body CT scan. This produced over 15,000 whole-body 3-D CT images. Each decedent is associated with two sets of CT scans, optimized for soft tissue and bone. Each image set consists of an average of 4,000 axial image slices, with a 512 x 512 matrix. The CT images have a slice thickness of 1 mm, with 0.5 mm overlap. Each decedent's record also includes scout images that are comparable to whole body X-rays.

At the CFI, a CT-certified Radiologic Technician uses a standardized postmortem protocol with a Philips Brilliance Big Bore 16 slice scanner for CT image capture. The images are then archived on a Philips iSite picture and archiving system (PACS). Phillips Advanced Visualization and OsiriX software are used for all additional post-processing of the CT images, such as rendering, measurement of skeletal dimensions, and volume capture. A pilot study using reconstructed CT images from the Virtopsy project in Switzerland has found no significant difference between traditional osteometric skull measurements and those made from the reconstructed CT image[6]. Additionally, Zamora and colleagues[7] assessed the difference in measurement values between software packages and found no significant difference. As a result, the rendered CT images produced by this system are able to support a wide variety of research across differing software packages. For this specific research, the stored images were converted from PACS to DICOM format, for which there are several readers freely available.

The decedents in NMDID with associated manner of death information (*n* = 15,236) include 38.6% accidents, 34.6% natural, 7.4% homicides, 15.4% suicides, and 4% undetermined. Overall, 11% of deaths in New Mexico from mid-2010 to mid-2017 are included in the database. Excluded from the sample are most expected deaths, such as elderly persons in nursing homes, and physician-attended deaths. Thus, the analyses and results presented here are biased such that they underrepresent the very oldest in the living population, and over represent younger individuals. Over two thirds of the scans have no discernable decomposition. Of the sample, 10,750 are male, 4,475 are female, and 17 unknown. Thirty percent are Hispanic, and 13% are American Indian. Ages are presented below.

Table 1. Age demographics.

Age (years)	**Count**
0-18	1007
19-25	1213
26-35	2126
36-45	2236
46-55	3170
56-65	2808
66-75	1525
76-85	770
86+	362

For this project, the minimum data set (MDS) was selected by a consensus method to provide information for future research in multiple domains. To create the MDS, an electronic, iterative, consensus method (Delphi) was used, as well as a separate validation in order to remove any bias our research team may have. A list of 59 metadata variables was developed with a high level of consensus by querying experts from a wide variety of domains (anthropology, forensics, demography, dentistry, public health, etc.). (See Table 2).

The UNM Institutional Review Board (IRB) was approved a protocol to determine and validate a MDS for the full-body, 3D, decedent CT images housed at the OMI (Human Research Protections Office #13-229). The IRB also determined that the development of the database and website did not require an approved research protocol. However, we did develop and use a protocol designed to protect privacy of decedents and next of kin. This protocol also included protections for the students who contacted next of kin, including access to grief counselors.

Metadata for NMDID was collected from two sources: the existing OMI database, known as VAST, and next of kin interviews. The OMI VAST database is the primary database used by the OMI to store and organize information regarding the cause of death, lifestyle and health information in order to conduct investigation into the cause of death. The current process of information gathering at the OMI involves a Death Investigator contacting the next of kin and primary care physician. Depending on the circumstances of the death, certain information is gathered from the next of kin regarding the decedent to assist the investigators. This information could include factors such as alcohol usage, drug usage, and history of disease, depending on the manner and cause of death. As a result, this information is not standardized and is dependent upon how the individual died. In order to complement the data present in VAST, student assistants on this project contacted next of kin, in order to gather the remaining unknown metadata fields. We attempted contact with over 10,000 next of kin, and were able to gather at least some data from them in over 4,000 cases. Next of kin interviews lasted between four and 45 minutes.

Workflow

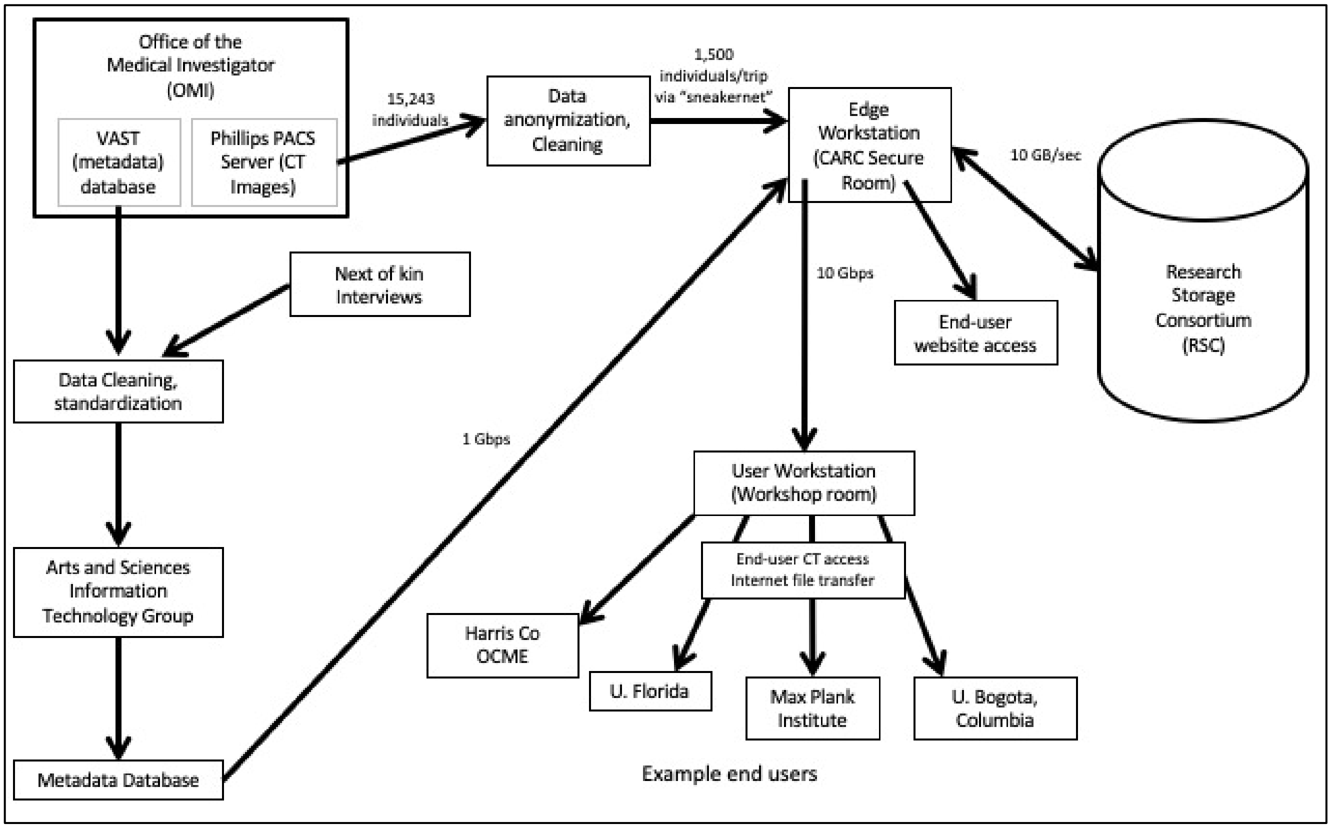
Project managers met approximately every two weeks throughout the life of the project. These individuals represented the OMI (Heather Edgar), CFI (Natalie Adolphi), the students collecting data from next of kin (Emily Moes), the informatics consultant (Shamsi Berry), UNM Center for Advanced Research Computing (CARC; Patrick Bridges and Hussein Al-Azawi), UNM Arts and Sciences Information Technology (A&S IT; Erik Reichart and Ron Estrada), and UNM Office of the Vice President for Research (Grace Faustino). All metadata from VAST came from a data "dump" provided by J and J Technical Services, the information technology consultant for the OMI at the time. The metadata in VAST is not standardized, so the Death Investigator can enter information into free text fields. For example, "male" can be entered in multiple ways, such as: M, m, Male, and male. The metadata was cleaned and standardized by the informatics consultant before being imported by the A&S IT into NMDID. Berry standardized fields and created and applied terminology standards such as LOINC and SNOMED. Where no standards existed, Berry created appropriate standards. A data dictionary was also created by Berry to allow for future expansions. All CTs were converted to DICOM and simultaneously de-identified and anonymized using a program custom developed by Bridges.

Table 2.
Sixty-nine metadata fields available in NMDID.

Census	Health	Circumstances of death
Sex	Cancer	Primary cause of death
Birth year	Congenital and genetic disorders	Contributing cause of death
Death year	Chromosomal abnormalities	Manner of death
Zip code	Dental health as an adult	Identification method
Age in years	Dental health as a child	Bone density
Age in months	Scoliosis	Death city
Gender	History of broken bones	Death county/tribal land
Number of pregnancies	Facial trauma	Cadaver condition
Number of live births	Plastic surgery	Cadaver length
Marital status	Surgery	Cadaver weight
Living weight	Implants	CT scan settings
Living height	Radiation therapy	Time delay after death
Race	Medical diagnoses	Name of person entering data
Tribal affiliation	Notes on medical diagnoses	
Ethnicity	Medications	
Hispanic identification	Substance usage	
Birth weight	Quit date of substance	
Birth weight category	Years of substance usage	
Birthplace	Tobacco type	
Years in the US	Tobacco usage	
Mother's birthplace	Drinking status	
Father's birthplace	Dietary pattern	
Mother's mother birthplace	Occupations	
Mother's father birthplace	Duration of occupations	
Father's mother birthplace	Activities	
Father's father birthplace	Strenuous lifting	
	Educational level	
	Socio-economic status as a child	
	Socio-economic status as an adult	
	Carcinogens	

These data were then transferred to CARC for secure, permanent storage. The complete workflow for data is shown in Figure 1.

Figure 1. Data flow for project development.



Website development involved creating a user-friendly interface for a large, complex database. The background SQL database format was developed first, and data was transferred to it from the cleaned data that came from VAST. Additional data from next of kin interviews was added as such interviews were conducted. As database population was nearing completion we developed the user interface through an iterative process of development and testing, drawing on a variety of difference potential user audiences.

We also developed methods for researcher access approval and image use approval, as well as a data use agreement. A researcher can access metadata and the search engine if they: 1) have an email address that indicates their affiliation with a research or education institution, and 2) approve the research access agreement. Researchers submit a research request for images, addressing these questions:

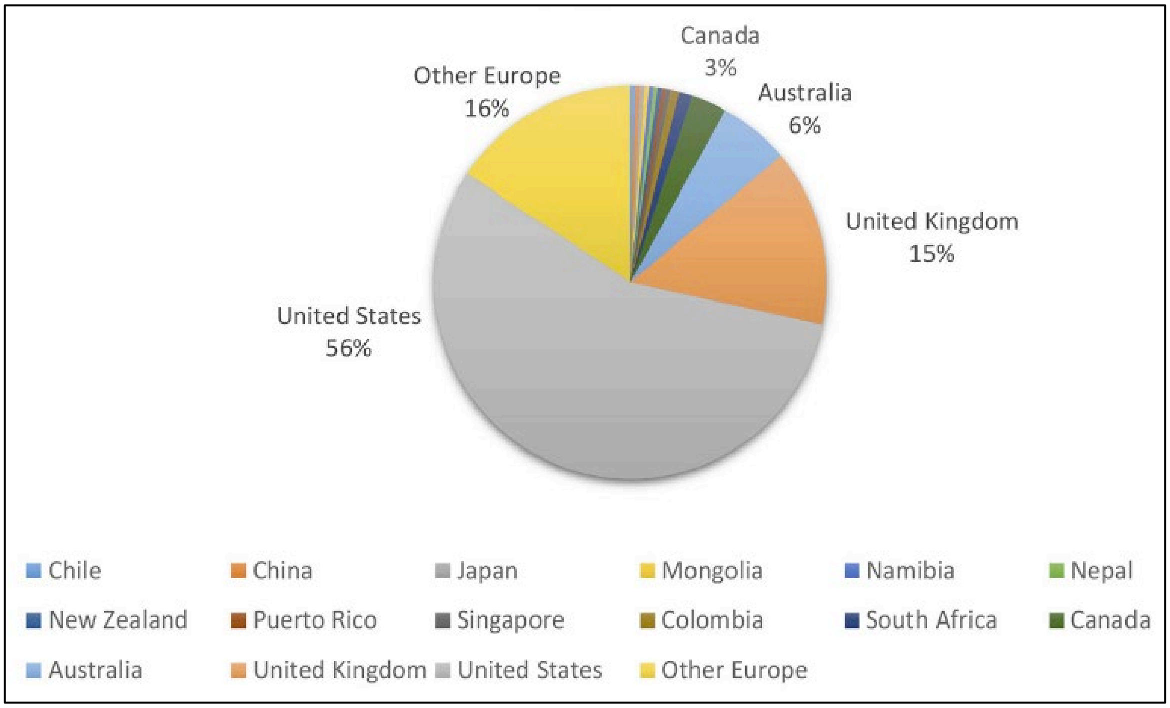
"Your research request should describe your inclusion and exclusion criteria, the research you plan to conduct, any specific hypotheses you have, results you expect, and benefits that might accrue. Click "Submit" and your request will be sent to our research committee. If your request is approved, you will receive an email describing how to access the scans you have requested. Limit: 750 words; include the number of individuals for whom you are requesting scans."

If a request is approved by our three-member research committee, users can log into website and download images directly from there. When possible, we also work with researchers who do not completely address all questions to help them develop a research request that is approvable.

Expected applicability of the research

In the first seven months that NMDID was available, it was accessed by 275 researchers from 37 countries. The research team approved 66 image requests. Figure 2 shows the frequencies of these approved request by nation. Today, 13 months into availability, over 120 image requests have been approved from over 50 countries. These approved requests relate to forensic anthropology, forensic pathology, forensic radiology, automobile safety, anatomy education, biomechanics, respiratory illness, nephrology, and many other fields. **The future applicability of this work is the primary outcome of this project.**

Figure 2. Approved research requests in first seven months of NMDID accessibility.



Participants and other collaborating organizations

Several organizations internal to UNM collaborated on this project. These included the Department of Anthropology, the OMI, the Department of Radiology, CARC, A&S IT, and the Office of the Vice President for Research. External to UNM, we collaborated with J and J technical services and with researchers at many other institutions that donated their time as beta testers through various iterations of the project.

Changes in approach from original design and reason for change, if applicable

One important change in approach related to the loss of the Co-PI before the project was funded, due to a change in his contract. This required bringing in an alternate expert in radiology.

The second important change was a significant upgrade to our image delivery system. Flexibility in this regard was built into the original grant application. In that application, we projected that the only way to transfer the CT's to end users would be to mail them hard drives with the images. This related to the very large size of the files. However, our collaborators at CARC were able to develop a system that made direct download possible. This process can still be lengthy, depending especially on the end user's internet access. We recommend that users download with hardwire Ethernet connections at their institutions, which is usually much faster than home wireless connections.

Outcomes

Activities/accomplishments

The primary accomplishment and result of this project is the website and database, **nmdid.unm.edu**. Exploring that website provides the best perspective on the purpose and value of this work. In addition, we traveled to several national and international venues to promote the use of NMDID and published papers on the informatics components of the work. As an adjunct project, we developed a series of four webinars on how to use the site, search engine, and CTs available in NMDID. These webinars are permanently available on the RTI FTCoE website.

Results and findings

We are pleased to say that the results of this project have already been of high value, and can expected to increase exponentially over time. The new research resource we provide meets many research needs, some we could anticipate, and some we could not. For example, prior to the project's start date, we expected that the CTs in the database could be used to improve automobile safety. In fact, a French research institute is using the contents of the database specifically for that work. On the other hand, there is no way we could have predicted that CTs of individuals who died in 2010-2017 of respiratory disease, such as pneumonia, would be useful for comparison to individuals who died in 2020 of COVID-19. Additionally, while we foresaw that NMDID would be of value in education, we could not foresee that a pandemic would greatly increase the need for tools useful in distance education. As NMDID became available in mid-February, 2020, the timing could not have been better.

Limitations

- As proud as we are of NMDID, there are recognizable limitations we hope to address in the future:
- The sample reflects the diversity of New Mexico. This means Hispanics/Latinos, Native Americans, and Non-Hispanic Whites are well represented. However, African Americans and Asian Americans are not (although they are still useful samples, simply because the overall sample is so large).
- The sample reflects the mortality pattern of New Mexico. Therefore, it is lacking in children 3-12, an age group of significant forensic interest. It is still the best available sample of CTs of children in that age group, but it could be better.
- It is not currently possible to search by a very refined set of medical diagnoses or histories of drug use.

Artifacts

List of products (e.g., publications, conference papers, technologies, websites, databases), including locations of these products on the Internet or in other archives or databases

Website and database
nmdid.unm.edu Edgar, HJH; Daneshvari Berry, S; Moes, E; Adolphi, NL; Bridges, P; Nolte, KB (2020). New Mexico Decedent Image Database. Office of the Medical Investigator, University of New Mexico. doi.org/10.25827/5s8c-n515.

Peer Reviewed Journal Articles
Daneshvari Berry S, Edgar HJH, Mosley C, Hunley K. In press. Refined, regionally-specific data standards reveal heterogeneity in Hispanic death records. AMIA Joint Summits on Translational Science proceedings 2021.

Daneshvari Berry S, Edgar HJH. 2021. Announcement: The New Mexico Decedent Image Database. Forensic Imaging. doi.org/10.1016/j.fri.2021.200436.

Berry SD, Edgar H. 2020. Extracting and Standardizing Medical Examiner Data to Improve Health. AMIA Joint Summits on Translational Science proceedings 2020: 63–70.

Daneshvari Berry S, Edgar HJH. Standardizing Data from the Dead. Stud Health Technol Inform. 2019; 264:1427-1428.

Daneshvari Berry S, Edgar HJH. Development of a large-scale, whole body CT image database. AMIA Annual Symposium Proceedings. 2017: 1951.

Peer Reviewed Abstracts
Berry SD, Edgar HJH. 2021. NMDID: a new resource for forensic anthropology. National Institute of Justice Forensic Science Research and Development Symposium, 2021.

Edgar HJH, Daneshvari Berry S. NMDID: A new research resource for biological anthropology. American Journal of Physical Anthropology Supplement. 2019;66.

Daneshvari Berry S, Edgar HJH. Research from records: retrieving and sharing useful data from a non-research database. American Journal of Physical Anthropology Supplement. 2019;19.

Edgar HJH, Daneshvari Berry S, Adolphi N. Developing a large-scale, whole body CT image database for research and teaching. Program of the 7th annual meeting of the International Society for Forensic Radiology and Imaging, 2018.

Edgar HJH, Berry S. 2019. A new, large-scale documented database of forensic whole-body CT images available for research. IEEE 16th annual International Symposium on Biomedical Imaging.

Edgar HJH, Daneshvari Berry SD. An upcoming large, whole body cadaver CT database: Potential applications in evolutionary medicine. Program of the 4th annual meeting of the International Society for Evolutionary Medicine and Public Health, 2018.

Edgar HJH, Berry SD, Adolphi N. 2018. Developing a large-scale, whole body CT image database for research and teaching. Program of the 7th annual meeting of the International Society for Forensic Radiology and Imaging.

Edgar HJH, Daneshvari Berry, S. Standardizing a Large-Scale, Whole Body CT Image Database. American Academy of Forensic Sciences' 70th Annual Scientific Meeting, 2018; 17.

Daneshvari Berry S, Edgar HJH. Large-Scale Computed Tomography Database with Associated Lifestyle and Health Data. NAME 2017: Annual Meeting Program. 2017: 75.

Data sets generated (broad descriptions will suffice)

15,242 full body decedent CT scans, averaging 10,000 images per scan, documented by up to 69 metadata variables, totaling approximately 50 TB of usable data.

Dissemination activities

Professional and public presentations

Invited webinar, The New Mexico Decedent Image Database: Expanding research in imaging informatics, AMIA Biomedical Imaging Informatics Working Group. Presented by: Shamsi Berry, 2021.

Overview of accessing and searching the NMDID database. Forensic Technology Center of Excellence Webinar, 2020.

“NMDID: Development of a large-scale, whole body image database.” Presented with Shamsi Daneshvari Berry, Biomedical Informatics Seminar Series, UNM Health Sciences Library and Informatics Center, 2019.

Podcast, Just a Whole-Body CT image database, Just Science, Episode 56. Presented by: Shamsi Berry. 2018.

Public outreach

Pannett R. Augmented reality offers a promise of incision-free autopsies. September 30, 2020. https://www.wsj.com/articles/augmented-reality-offers-a-promise-of-incision-free-autopsies-11601485158

Hayes P. OMI providing data to Johns Hopkins to help find treatment for COVID-19. April 16, 2020. https://www.kob.com/albuquerque-news/nm-office-of-the-medical-investigator-providing-data-to-johns-hopkins-to-help-find-treatment-for-covid-19/5702734/?cat=500.

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