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Developing a Postmortem CT Service: Practical Considerations for Death Investigation Agencies

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Acronyms and Abbreviations

AEC	Automatic exposure control
DICOM	Digital Imaging and Communications in Medicine
DOJ	Department of Justice
FOV	Field of view
FTCoE	Forensic Technology Center of Excellence
HU	Hounsfield units
IRS	Image reconstructions system
IT	Information Technology
MIP	Maximum Intensity Projections
MPR	Multi-Planar Reformatting
MRI	Magnetic Resonance Imaging
NIJ	National Institute of Justice
NMDID	New Mexico Decedent Image Database
OIFS	Office of Investigative and Forensic Sciences
OMI	Office of the Medical Investigator
PMCT	Postmortem Computer Tomography
RTI	RTI International
UNM	University of New Mexico

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1. Introduction

This guide will help medicolegal death investigation agencies that are considering adopting postmortem computed tomography (PMCT) make informed decisions. First, the basic questions are outlined that must be considered before approaching architects or gathering information about specific CT scanners. Next, the evolution of PMCT use at the New Mexico Office of the Medical Investigator is described as just one example of how a PMCT service can function in a high-volume agency. The remainder of the guide covers, topic-by-topic, important considerations for planning, establishing, and maintaining a PMCT service in a medical examiner's or coroner's office.

In presenting this information, specific vendors are not named or endorsed, CT scanner models, or commercial software products—in part, because new products are continually available, and specific recommendations would quickly become outdated. Furthermore, because of the ubiquitous use of CT in clinical medicine, there are many reputable vendors with a range of products and services from which to choose. Given the variety of death investigation agencies (e.g., large, small, medical examiner, coroner) and the variation in the imaging technologies already available at each agency (portable X-ray, whole body X-ray), there is neither a single CT scanner nor image viewing software package that will be the best fit for every agency.

Similarly, this guide is not intended to prescribe a particular philosophy or style of PMCT usage in medicolegal death investigation, nor are research findings demonstrating the utility of PMCT in the investigation of specific case types included, a topic addressed in many excellent articles in the academic literature. Rather, for agencies that are already considering adding PMCT to their death investigation toolbox, this guide aims to provide practical guidance from a technical and operational perspective. Basic PMCT concepts and terminology, functions and features, general operational questions to consider, and potential issues are outlined to help agencies confidently gather sufficient information and spur the fruitful discussions required to make informed decisions about PMCT. This guide is provided as a digestible and practical (but by no means exhaustive) overview of developing and operating a PMCT service, and it can be a useful starting point and reference for other death investigation agencies in the years to come.

2. Getting Started

Perhaps the most important, yet difficult, task prior to developing a PMCT service is to clearly define the agency's goals for PMCT. To that end, the agency may wish to consider the following questions:

- Is the plan to eventually perform PMCT for *all* cases transported to the agency or only cases meeting specific criteria?
- Will PMCT be used to decide which cases require a full autopsy, with the intention of supplanting full autopsies for specific case types?
- Will PMCT be used to supplement autopsy findings in cases receiving a full autopsy?
- Will PMCT replace or complement X-ray routine use?
- Ideally, how will CT be incorporated into daily workflow?
- Will PMCT be used for research in addition to case work?

Perhaps the trickiest question is "Are agency's decision-makers and stakeholders in agreement about the basic goals for the PMCT service?" Indeed, there may not be agreement about some aspects of the plan—or perhaps everyone agrees that a CT scanner is a good idea for inclusion in a new facility, but no one is clear about how the PMCT service will ultimately function. An agency can, in principle, build or renovate a CT room and obtain a scanner and then subsequently flesh out a plan based on the experience of using PMCT. Indeed, if agency personnel have no prior experience with PMCT, it may seem daunting to try to envision how their future PMCT service will function 5 to 10 years in the future. However, at least attempting to envision the future purpose, workflow, and predicted PMCT caseload is an important exercise. The expected lifespan of a new CT scanner is approximately 10 years, and there is significant investment involved (i.e., money, time, construction or remodeling, bureaucratic wrangling) to reach the point of having a functional CT scanner and personnel who can operate it.

Once the foundation of a PMCT usage plan are defined, there are several fundamental practical questions to be explored:

- What type of CT scanner is suitable for an agency?
- Where will the CT scanner be located?
- Who will operate the CT scanner?
- How will the image data be viewed and stored?
- Who will interpret the images?

Guidance for exploring each of these questions is presented in more detail below. Answering these questions may lead to a redefinition of an agency's initial goals, particularly if those goals turn out to be inconsistent with workflow considerations, budget constraints, or other practical considerations. Indeed, each of the questions is associated with new costs. One must consider both start-up costs associated with establishing the PMCT service (e.g., construction, scanner purchase, installation, protocol development, and initial training of personnel) and ongoing costs associated with the established PMCT service (e.g., labor, maintenance agreements, future replacement costs). Additionally, if the PMCT service is anticipated to reduce the proportion of full autopsies performed, there may be cost savings that should also be estimated to develop a full picture of the impact of PMCT on overall costs.

3. Overview of the New Mexico OMI PMCT Service

Current caseload and PMCT usage. The New Mexico Office of the Medical Investigator (OMI) is a statewide, centralized, academically based medical examiner system serving a population of 2.1 million. Organizationally, the OMI is a program of the University of New Mexico (UNM) School of Medicine. In 2010, the OMI moved its operations into a new state-of-the art facility with purpose-designed space for imaging, including X-ray, CT, and Magnetic Resonance Imaging (MRI). At present, the OMI receives reports of more than 10,000 deaths per year, and it is standard procedure to perform a whole body PMCT on each decedent scheduled for examination by a forensic pathologist, resulting in >4,000 whole body PMCT studies performed in 2021.

Current workflow. CT scanning commences at 6 AM each day, performed by a clinically trained and certified radiologic technologist with assistance from at least two autopsy technicians (i.e., PMCT Team) who move bodies to and from the CT scanner table. Decedents remain in the body bag for scanning while clothing or medical interventions are left in place. After each scan, the resulting whole body CT image datasets are sent to a picture archiving and communications system (PACS) server, which enables image review at workstations throughout the office, including physician offices, autopsy stations, and conference rooms. These images are reconstructed into three separate image types – 1) axial slices of the whole body (3 mm), 2) thin slices (1 mm thick, 0.5 mm increment) of the head and neck, 3) and sagittal and coronal reformats of the head and neck. These images are available in PACS for most cases by 8 AM, when the day's cases are discussed and PMCTs are reviewed to determine the type of examination and ancillary tests needed for each case. Later in the morning, the PMCT Team (1) reconstructs thin slice (1 mm) image data for the whole body; (2) creates sagittal and coronal views of the whole body; and (3) may perform special reconstructions such as dental and lung views prior to sending to. On all but the busiest days, CT scanning concludes before 9 AM, when external examinations and autopsies begin. PMCT is the primary imaging modality, with other modalities (X-ray, MRI) used occasionally for specific cases.

Impact on case management. In 2021, the fraction of pathologist cases receiving a full autopsy was just under 50%, a notable decrease from the roughly 80% autopsy rate typical for the OMI in the years preceding PMCT adoption.[1] In recent years, a steady increase in the external examination rate has helped the OMI handle increasing daily caseloads during periods of less than full forensic pathologist staffing. In addition to its use for triaging cases each morning, PMCT is used for other purposes, such as augmenting anthropological or autopsy examinations (e.g., by locating foreign bodies or documenting specific findings); creating 3D illustrations for legal, research, or educational purposes; and identifying decedents, through comparison of PMCT to dental x-rays and other antemortem medical imaging. Furthermore, PMCT has enabled the OMI to honor family requests for no autopsy in a larger proportion of cases than in the past.

Evolution. The OMI's transition from performing no PMCT studies to performing more than 10 whole body studies within its Center for Forensic Imaging in less than 2 hours on an average day occurred over several years. PMCT was adopted in stages, with the first stage predominantly involving its use in research and the later stages involving its gradually increasing role in routine casework.

The initial adoption of PMCT technology coincided with the OMI's move to a new building in 2010. The new facility included a suite (CT, MRI, mechanical, and control rooms) purpose-built for advanced imaging, within a state-of-the-art BSL-3 autopsy suite. Importantly, the design of the imaging suite involved consultation with architects, medical physicists, radiologists, imaging technologists, pathologists, and other staff with experience in autopsy operations.

Daily PMCT scanning at the OMI was initially motivated by a double-blinded research study, funded by the National Institute of Justice, comparing autopsy and PMCT (interpreted by a radiologist) for more than 1,000 cases in four case cohorts—blunt force injury, firearm injury, drug poisoning, and pediatric trauma.[2] In preparation for that study, the OMI hired a clinically certified CT technologist and developed a whole body PMCT scanning protocol with invaluable input from radiology faculty within the UNM system. To support CT scanning seven mornings per week, the OMI also hired additional part-time radiologic technologists. Thus, the initial experience of working out the technical aspects of performing whole body PMCT each morning, and processing and storing the images, occurred in the context of research rather than routine casework. Therefore, during this initial period, the pathologists were neither responsible for interpreting the imaging studies, nor responsible for incorporating radiologist interpretations into their autopsy reports.

From 2012 to 2014, as the enrollment targets for each of the research study cohorts were achieved, daily CT scanning continued, but the purpose transitioned increasingly from research to casework. PMCT review became a normal part of the daily morning report case discussions. During that period, a forensic radiologist was available at the OMI approximately 4 days per week, to provide didactic training, assist the forensic pathologists and fellows with image interpretation, perform radiologic identification, and generally oversee the operations of the imaging service.

As the forensic pathologists at the OMI became increasingly familiar with PMCT, their reliance on radiologist interpretation for routine case work decreased. From 2017 through 2021, there was not a radiologist regularly on site at the OMI, and the fraction of cases referred to UNM radiologists for remote review was relatively small. (For example, a survey performed at the OMI over a 9-month period in 2018–2019 found that 2.5% of PMCT cases were referred to a radiologist.[3]) During the 2017–2021 period, forensic pathology fellows and new forensic pathology faculty received daily training in image interpretation and its use in case management from experienced attending forensic pathologists as well as didactic lectures from UNM radiologists. More recently, a UNM radiologist has been available at the OMI 2 days per week to support the pathologists and increase radiology training and research opportunities for both trainees and pathology faculty. Other Center for Forensic Imaging personnel include one full-time radiologic technologist, two part-time technologists, and a physicist (~1 day per week).

The OMI's increasing caseload, coupled with an increasing reliance on PMCT for triage, also meant that the OMI's original 16-detector row CT scanner (purchased in 2010) was soon pushed to its limits. In 2018, a major software upgrade of the 16-detector row scanner proved to be a helpful temporary measure, enabling protocol improvements and increasing PMCT throughput from three decedents/hour to four decedents/hour. In 2021, the OMI deployed a new 64-detector row CT scanner with a more powerful generator and even faster image processing software, resulting in a large increase in throughput (eight decedents/hour). The most recent improvement has meant that even on the busiest days (including during pandemic surges), it was not necessary to choose which cases received PMCT, because virtually all decedents scheduled for examination could be scanned within 3 hours (prior to the start of autopsy).

4. CT Basics

The discussion below on how to think about choosing, siting, and operating a scanner relies on having a basic familiarity with what a CT scanner looks like and how it generally functions. Because radiography (x-ray) is already familiar, radiography is a helpful point of comparison in discussing CT. Of course, there are many similarities and differences between radiography and CT, some obvious and some subtle. For this practical guide, the three primary differences to highlight are the x-ray detection geometry, how the image is created, and the image gray scale.

Detection geometry. Traditional radiography uses a stationary x-ray source that illuminates a stationary rectangular detector (the x-ray plate). The subject is placed on the detector, and x-rays are attenuated to varying degrees by the subject's anatomy before striking the detector, resulting in different grayscale values in the image. Radiographs are inherently two-dimensional (2D); if a foreign body is present in a radiograph, its depth, the missing third dimension, cannot be determined without performing at least one additional x-ray at a different angle.

CT takes the idea of performing x-rays at different angles and raises it to a high art. In CT, the x-ray source and x-ray detector are mounted on opposite sides of a ring, which spins rapidly within an upright doughnut-shaped housing (the "gantry"), shown in Exhibit 1. The subject is placed on a table with a stationary base and a movable top, which enables the subject to move horizontally through the bore (the hole in the gantry) while the source/detector pair spins. As a result, each detector captures a narrow band of x-ray data, continuously and at every angle, covering a spiral path around the anatomy of interest. If the table has a large enough range of travel, the subject's whole body can be continuously scanned in this manner.

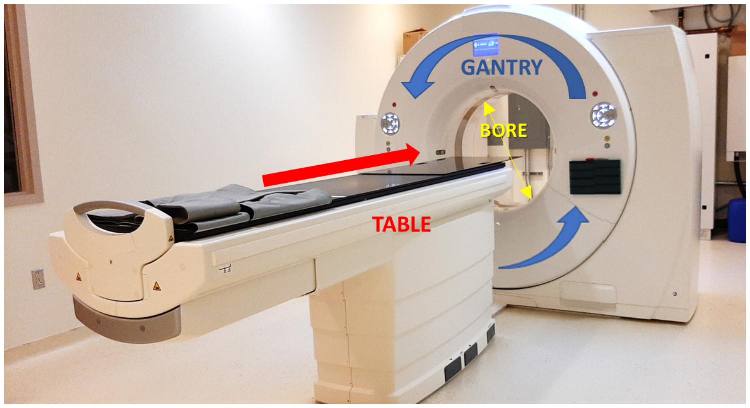

Exhibit 1. During scanning, the CT table moves horizontally (red arrow) into the gantry. The blue arrows indicate the motion of the x-ray source and x-ray detectors, which are inside the gantry and rotate around the subject on the table. The bore (labeled in yellow) is the circular opening that allows the subject and table to pass through the gantry.

Image creation. In the early decades of x-ray, radiographs were created by x-rays impinging directly on radiosensitive film housed within in a cassette. Today the preferred x-ray technology is digital radiography, which uses a flat digital detector in place of a film cassette. Although computers make capturing, storing, and distributing radiographs more convenient, **computation is not required** to form 2D radiographic images because the “raw image data” (i.e., the pattern of detected x-rays striking the detector) **are** the image. The same is not true for CT (where the C is for computed). Because of the spiral detection geometry, the raw image data in CT are a spiral of narrow lighter and darker bands resembling a Maypole wrapped in ribbons at the end of a Mayday dance. The spiral data must be mathematically transformed (“reconstructed”) to form a useful image, an essential step that would not have been practical prior to the availability of compact computers.

The CT raw data are not displayed for the user and are instead immediately reconstructed into a series of 2D images (axial slices) each representing a specified thickness (typically 1 to 5 mm) and position along the length of the body. The image series can be imagined as a stack of 2D images (as shown in Exhibit 2) that represent a cylindrical volume, defined by the axial diameter (in mm) and the total length (slice in mm, given by the slice increment multiplied by the number of slices. The diameter of an axial CT image is referred to as the field of view (FOV) and is discussed further below. The same volume may be reconstructed multiple times using different reconstruction algorithms or slice thicknesses/increments. The algorithm affects the image appearance (e.g., smooth vs. sharp; note that algorithms optimized for displaying bones result in sharper edges than the algorithms optimized for displaying soft tissues), which result in a smoother appearance, as shown in Exhibit 3.

Exhibit 2. Raw CT data (not shown) are mathematically reconstructed to create 2D cross-sectional images. An image series can be thought of as a stack of images corresponding to a particular volume.

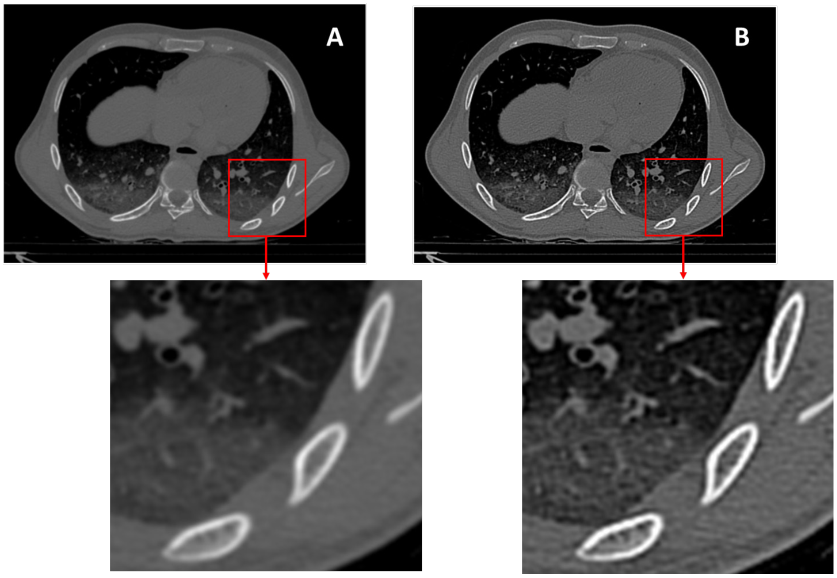

Exhibit 3. When CT raw data are reconstructed, the choice of reconstruction algorithm affects the image appearance. In this example, images were reconstructed using a soft tissue algorithm (A), resulting in a smoother appearance, and a bone algorithm (B), resulting in a sharper appearance.

An image series can be viewed by scrolling through the axial slices, or the axial images can be reformatted to obtain other views, such as sagittal or coronal sections, oblique sections, or even curved sections, a process referred to as Multi-Planar Reformatting (MPR). Note that a lateral radiograph has the same orientation as a sagittal CT section, and an anterior-posterior radiograph has the same orientation as a coronal CT section. With a fully three-dimensional (3D) dataset, specialized renderings are also possible, such as 3D surface renderings or Maximum Intensity Projections (MIPs), to better visualize particular features. Examples are shown in Exhibit 4.

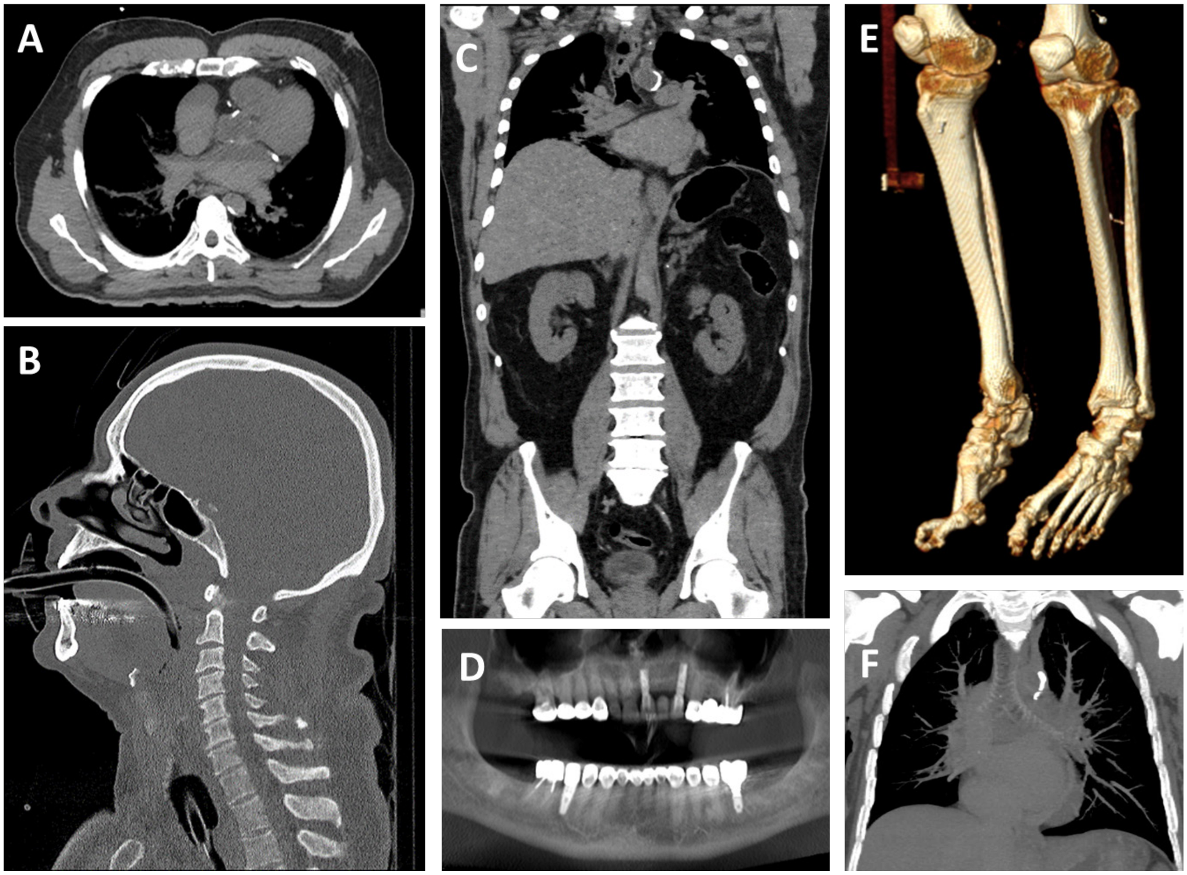

Exhibit 4. Axial reconstruction (A); Sagittal reformat (B); Coronal reformat (C); Curved MPR of maxilla and mandible for comparison to panoramic dental x-rays (D); 3D surface rending (E); MIP (F).

Image grayscale. Traditionally, the grayscale in an x-ray image runs from black (radiolucent) to white (radiodense). Bones generally appear white, and air looks black. The grayscale values in an x-ray image are not, however, calibrated to correspond quantitatively to a specific material, because the x-ray beam must pass through multiple materials of various thicknesses on its way to the flat image receptor; in an x-ray image, the grayscale value reflects the sum of everything along the x-ray path (typically some combination of bone, soft tissue, and air) rather than a specific material or tissue. However, in CT, the mathematical reconstruction of cross-sectional images results in image grayscale values that **are** calibrated to correspond to specific materials. Air is defined as having a value of −1,000 Hounsfield units (HU) while pure water is defined as having a value of 0 HU, and these two calibration points define a linear image grayscale. The normal HU scale ranges from −1,000 to +3,000 HU, with soft tissues and fluids generally spanning –100 to +100 HU and bone ranging from a few hundred up to +3,000 HU, depending on the type of bone. The calibrated HU scale is incredibly useful because it allows discrimination between, for example, normal and fatty liver or between blood and pleural effusion, based on the characteristic HU values for various tissues and fluids.

5. What Type of CT Scanner is Suitable for an Agency?

In 2021, a new CT scanner costs roughly between $500k and $2M, depending on the type and features chosen. Death investigation agencies are likely to be well-served by CT scanners at the lower end of the cost range, because many of the features available on the most expensive systems, though useful in clinical medicine, are not necessary or relevant to forensic practice. For example, software that minimizes image artifacts caused by metal implants has relevance in both clinical and forensic medicine and may be worth considering in the death investigation context. However, features aimed at measuring physiological function (e.g., perfusion) will not be relevant. Some features that have one clinical purpose (e.g., dose reduction) may be useful for a different reason in the PMCT setting (e.g., preventing the scanner from overheating). Because of the differences between clinical imaging and postmortem imaging, when obtaining quotes for CT scanners, you will likely need to remind vendor representatives on a semi-regular basis that the "patient" is dead. Various scanner features and specifications and their relevance to the postmortem imaging setting are described in more detail below.

A prominent specification for CT scanners is the number of detector rows, commonly, yet imprecisely, referred to as the number of slices. As of 2021, new CT scanners typically have 128 or 64 detector rows, with high-end models available with >300 detector rows. (In decades past, scanners were more commonly available with 4, 8, 16, or 32 detector rows.) More detector rows implies that more "ribbons" of raw data are acquired simultaneously, resulting in shorter scan times and more efficient use of the x-rays produced. Thus, more detector rows is generally better than fewer; however, in the postmortem setting, the duration of the scan is not as critical because decedents do not move or breathe. The overall speed of the PMCT workflow will be dominated by the time spent moving the decedent on and off the table and the time spent positioning the body and setting up the scan, rather than the relatively short time during which x-rays are produced and detected. Generally, the choice of scanner in the postmortem context will be guided primarily by other considerations and features that are described below (and cost) but not the number of detector rows.

The most basic CT scanner specifications that are highly relevant to postmortem imaging relate to the size and weight of decedents. These specifications include the bore size (how big is the hole in the gantry that the decedent must pass through?), the reconstructed FOV (what is the diameter of the images?), the type and weight limit of the CT table (flat or curved tabletop? bariatric?), and the maximum scan length (how far does the table travel?).

A large bore size (>75 cm) is recommended to accommodate large decedents and decedents with awkward body positioning not amenable to repositioning (e.g., because of mummification, charring) It is very important to understand that a large bore diameter does not guarantee that the diameter of the images will be sufficiently large. Keep in mind that in clinical medicine, CT is primarily used to examine the head or the interior of the torso, not the body surface or the extremities. Therefore, a standard clinical image diameter (i.e., the FOV) is 50 cm, sufficient for displaying a large adult's rib cage and its interior, even if the CT scanner bore size is larger (to facilitate moving the patient's shoulder, elbows, and belly through the scanner). This important distinction is illustrated in Exhibit 5. Some scanners offer a larger image FOV of 60 cm or greater, which enables the whole body of most decedents, including the surface of the torso and the extremities to be included in the reconstructed image volume. **The larger image FOV (60 cm or greater) is recommended for PMCT in the medicolegal context, particularly if the goal is to avoid the need for x-rays**. That said, if an agency is already planning to obtain whole body x-rays for each case, then a smaller CT image FOV may be acceptable. In summary, the vast majority of CT scanners are designed to have a maximum image diameter that is smaller than the bore diameter, and attention to both specifications is important when selecting a suitable scanner.

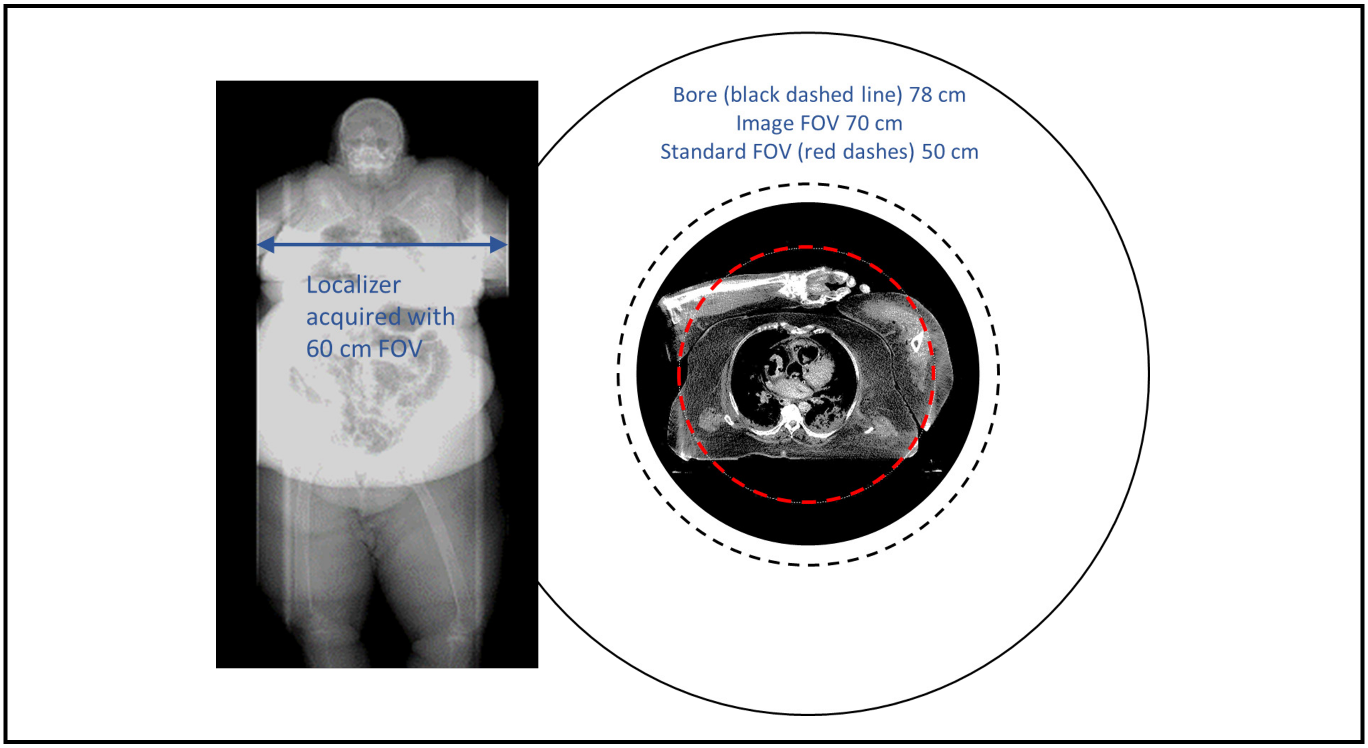

Exhibit 5. The localizer image (left) shows a decedent whose body extends outside of the 60 cm FOV of the localizer. The FOV of the axial reconstructions was therefore extended to 70 cm. The diagram on the right shows the diameter of the bore (black dashed circle) compared with the image FOV. For reference, the industry standard 50 cm FOV is also indicated (red dashes).

Regarding decedent weight, a bariatric CT table (typically with a weight limit > 250 kg, or 550 lbs.) is a reasonable upgrade to consider in the PMCT setting, although not an absolute necessity. If the scanner has a large bore diameter but a standard table weight limit, there will be decedents who could fit through the bore that nevertheless cannot be scanned without the risk of damaging the table mechanism. In addition to the weight limit, it is worth considering the table type. Regular CT tables have a curved and padded top for the comfort of living patients, who typically participate in positioning themselves on the table. A hard, flat CT tabletop (see Exhibit 1) is recommended to simplify moving dead bodies in body bags to and from the scanner. Fortunately, this special type of table is commonly available due to its clinical use in radiation treatment planning. Furthermore, the hard, flat top is much easier to clean. If there are already plans to use a hoist to assist with moving the bodies to and from the CT table, then it may not be necessary to upgrade to a flat table. Note that the CT table height is adjustable, which is helpful both when positioning bodies for scanning and when moving bodies to and from gurneys of potentially different heights.

Another geometric specification is the maximum scan length, which is the maximum distance that the table can travel horizontally during scanning. (Note that the length of the tabletop is always greater than the maximum distance the tabletop can travel.) For whole body scanning, a scan length of at least 2,000 mm (6 feet 6 inches) is ideal for scanning the vast majority of adult decedents in one continuous scan. If the maximum scan length available on a given scanner is shorter (or a decedent is extremely tall), imaging the whole body may require two or more scans, with the necessity of repositioning the body in between scans, resulting in a longer total study time per decedent. However, in an agency where whole body x-ray is already being performed routinely, there may be little additional information gained from a CT scan of the lower extremities. If the intended purpose of the CT scanner is to image selected anatomic regions (e.g., the head, chest, or abdomen)—which is the normal situation in clinical medicine—then a maximum scan length that enables coverage of the specific anatomy of interest would be sufficient (e.g., 1 m for the torso). The main downside of limited scan length is that it increases the total time per study to complete whole body scanning; therefore, scan length is a more critical consideration for offices that intend to do a large volume of whole body CT scans in a short time window or are aiming to avoid routine x-ray use.

Some other considerations specific to offices intending to do a high volume of CT scanning are the image reconstruction speed, the x-ray generator power, water vs. air cooling, and dose-reducing features, such as automatic exposure control and iterative reconstruction. At the OMI, the total number of images (2D slices) reconstructed is approximately 12,000 per decedent. The image reconstructions system (IRS) of a CT scanner will have a rating specified in images per second (ips). If the scanner has an IRS rated for 22 ips, reconstructing all images for one OMI decedent would require 9 minutes of processing time, whereas an IRS rated for 45 ips would reduce that time to 4.5 minutes. Does 5 extra minutes matter? The ips rating is important if the caseload is high and there is limited time between CT scanning and the start of autopsy because the ips rating determines how quickly the images can be delivered to the radiologists or pathologists after a scan is completed. A powerful generator (combined with an x-ray tube with good cooling performance) may be a reasonable upgrade to consider, because it will help increase throughput (cases scanned per hour) and minimize delays required for the system to cool down. X-ray generators are typically rated at somewhere between 70 and 120 kW, so opting for a more powerful generator will make sense if an agency anticipates scanning many decedents over a short period each day. Similarly, water cooling for the gantry (as opposed to the standard air cooling) may be a worthwhile investment if very high throughput is anticipated or if the temperature of the room is not well-controlled.

Some features designed to reduce the x-ray dose to living patients are also useful in the postmortem setting to help prevent overheating the scanner and to prolong the life of the x-ray tube. Automatic exposure control (AEC) allows the scanner to determine (based on a scout image) where the total tissue thickness is greater (i.e., where a higher x-ray tube current is needed to penetrate the tissue adequately), as shown in Exhibit 6. Rather than using a high tube current over the entire length of the body, a smaller current can be applied to the lower extremities and a larger current to the chest to ensure good image quality with the most efficient use of x-ray power. If the CT scan is instead performed using a fixed tube current, the high current value required to penetrate the thickest/densest tissue would need to be used over the entire length of the body (which is inefficient), or if a lower fixed tube current value is used, the image quality in regions such as the chest (which is radiodense and forensically important) would suffer. **Therefore, the use of AEC is generally recommended for whole body PMCT**. Note that vendors have vendor-specific names for their AEC features; the catchy names often include “dose,” “exposure,” or “mA” (milliamperes, a unit of current). Iterative reconstruction algorithms can be considered to reduce the overall dose required to produce an image with acceptable quality. Clinically, iterative reconstruction is primarily used for subjects where dose is a special concern (e.g., pediatric or pregnant subjects). Iterative reconstruction does, however, slightly alter the image quality, and is not generally needed in the postmortem setting where patient dose is not an issue, unless overheating is a significant impediment to the workflow.

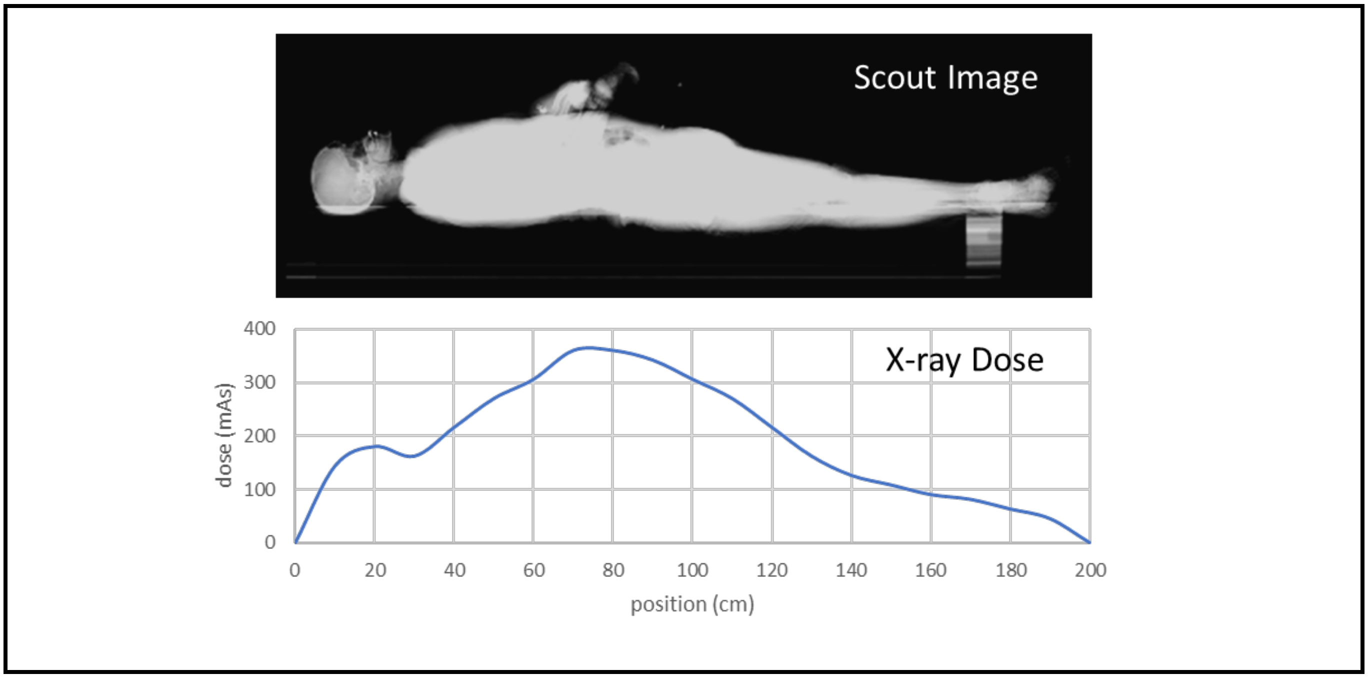

Exhibit 6. Based on an initial localizer scan or "scout image" (upper), the scanner software can calculate how to modulate the x-ray tube output to ensure relatively uniform image quality along the entire length of the body. The graph (lower) shows the "dose" (technically the x-ray tube current multiplied by rotation time) as a function of position. The use of dose modulation (also referred to as AEC) uses the x-ray tube more efficiently by only using a high output where the tissue thickness and density are high, which may help prevent overheating and prolong the life of the x-ray tube.

Foreign bodies (ranging from medical hardware to bullets) are commonly encountered in forensic PMCT. Metallic foreign bodies, in particular, cause characteristic image artifacts. Some CT scanner features that are relevant to dealing with foreign bodies include dual energy, extended HUs, and metal artifact reduction algorithms. The "energy" in dual energy refers to the x-ray tube voltage used to produce the x-rays, typically ranging from 80 kilovoltage peak (kVp) to 140 kVp. The highest energy is more penetrating whereas the lower energies produce better soft tissue contrast. Because the image contrast differs slightly depending on the energy, performing a scan at two different energies can yield additional information about the materials present. Dual energy analysis is theoretically useful in the forensic setting for identifying what materials foreign bodies are made of; however, commercial post-processing software for analyzing dual energy scans may be optimized for specific clinical applications, and adapting it for forensic purposes is challenging. (Retrieving foreign bodies at autopsy is likely an easier solution.) Furthermore, a true dual energy CT scanner has two x-ray tubes, and this increases the cost of the scanner and the annual service agreement (because the x-ray tube is the most expensive part to insure). **Therefore, a dual energy CT scanner (two tubes) is not recommended for routine death investigation.** Note that a single tube scanner can be used to produce scans at two different energies (sequentially), which could then be analyzed to learn more about the materials present using third-party software.

A simpler and faster way to get more information about metallic foreign bodies from a CT scan is to routinely reconstruct all images using the extended HU option. As stated above, the normal HU scale for clinical CT runs from −1,000 (air) to +3,000 (dense bone). The HU values for most metals are much greater (tens of thousands), far above the normal maximum. Therefore, using the normal HU scale, different metals will all appear to have the same HU as very dense bone (around +3,000), and more importantly, metal objects will appear larger in the image than their actual dimensions because of a metal artifact. The extended HU scale ranges from −1,000 to +32,000, which enables greater differentiation of high-HU materials (e.g., bullets, surgical clips, orthopedic hardware) and allows the shape and size of dense foreign bodies to be more accurately delineated in the image (see Exhibit 7). Furthermore, using the extended HU scale does not affect the normal image display (e.g., soft tissue window and bone window used for normal viewing) and generally does not increase the scanner purchase price.

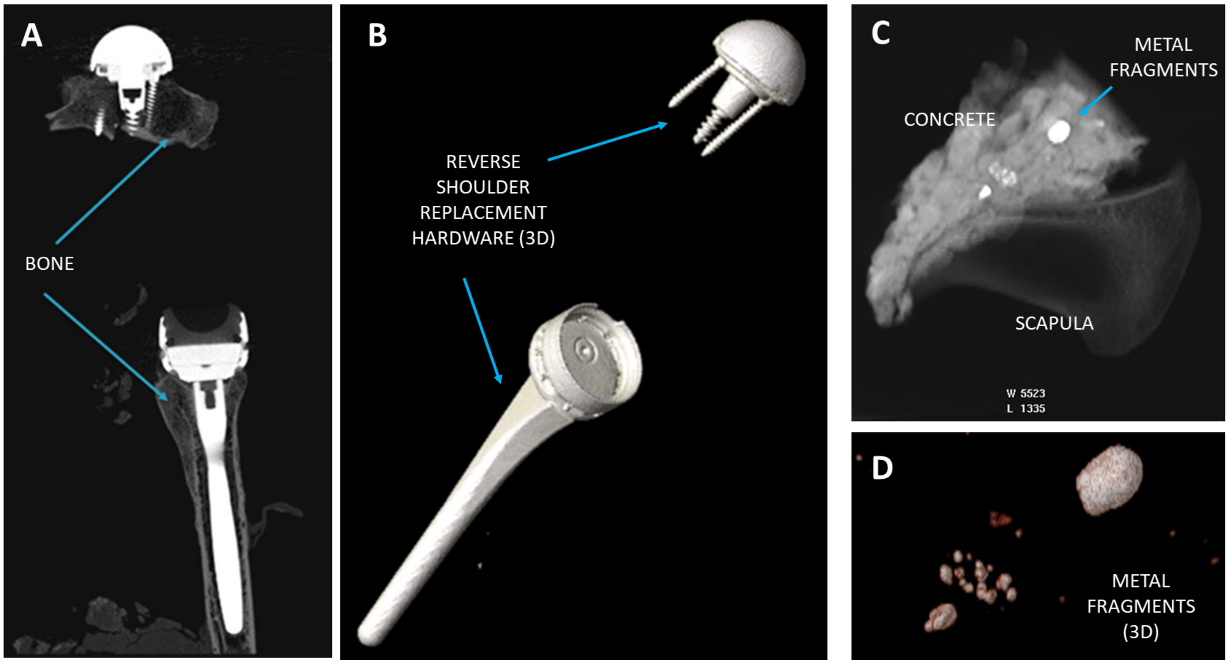

Exhibit 7. Reconstructing images using an extended HU scale is useful for assessing foreign metallic bodies. The cross-sectional image (A) shows shoulder hardware in skeletal remains. In this image, the window level has been increased, such that even dense bone (which normally looks white) appears gray. The use of the extended HU scale enables good contrast between bone and metal, which enabled a high-quality 3D surface rendering of the hardware (B). In another case, a scapula was discovered, partially encased in concrete. The extended HU scale enabled good contrast between bone, concrete, and metal (C) enabling the discovery of bullet fragments (D) encased in the concrete.

Finally, metal artifact reduction algorithms, which are designed to remove metal from the image and greatly reduce the streak artifacts surrounding metallic objects (see Exhibit 8), result in better image quality and clarity in the surrounding tissue. Using metal artifact reduction for all reconstructions is not recommended in the death investigation setting, because seeing metallic foreign bodies is forensically important. Using metal artifact reduction routinely would require reconstructing all images both **with and without** metal artifact reduction and would therefore strain the workflow and data storage by doubling the number of images to be reconstructed and interpreted. It may be helpful in specific situations to perform a second reconstruction with metal artifact reduction enabled, but generally, there is a limited need for metal artifact reduction in the death investigation context. If it is not already included in the basic software package, it may not be worth the added cost.

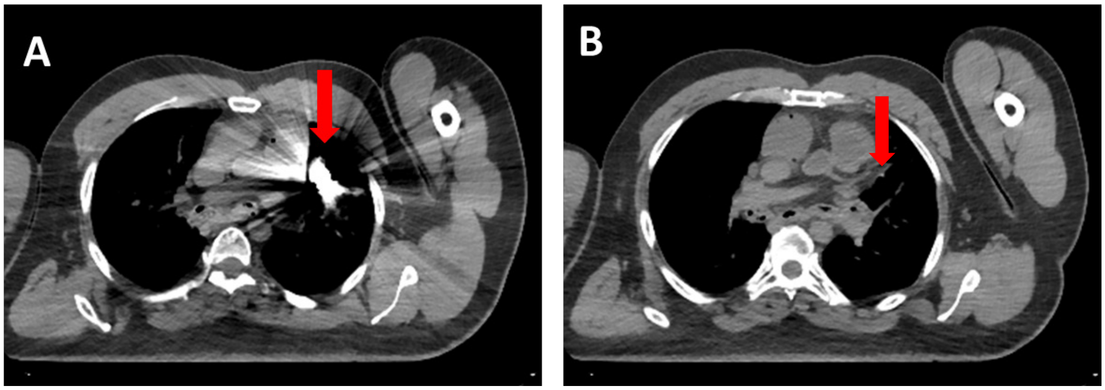

Exhibit 8. In this example, PMCT revealed a retained projectile (from an old injury) in the lung of a drug overdose death. Viewing the image (A) in a bone window, the projectile (red arrow) appears larger than its actual dimensions because of metal artifact. Also evident are the alternating light and dark streaks emanating radially from the object. An adjacent section (B) that does not contain metal is provided for comparison. Metal artifact is visible within the axial sections that include metal objects but does not affect adjacent slices.

A summary of specifications and features discussed previously, and general recommendations appear at the end of this guide. Each agency is strongly encouraged to consult a wide variety of information sources and consider their own resources, needs, and practices when choosing a CT scanner.

6. Where Will the CT Scanner Be Located?

Medical examiner and coroner agencies are familiar with portable x-ray units, which can be operated in an unshielded environment, provided the distance between the x-ray unit and personnel is sufficient, generally greater than 2 m (6 ft) during exposures. CT scanners emit significantly more radiation than a portable x-ray unit, and most CT scanners are designed for stationary installation in a dedicated room, often with lead shielding in walls, windows, or doors to protect workers in neighboring spaces. The level of shielding required depends on factors such as the size and height of the scanner room; the location of the scanner within the room; the building materials used in the walls, floor, and ceiling; and the usage of nearby spaces. The scanner vendor should be consulted early regarding space requirements and other engineering considerations (e.g., electrical, structural, and heating, ventilation, and air conditioning requirements). Most modern laboratory construction will support the addition of CT without major modifications. A medical physicist should be consulted to obtain a radiation shielding design, for either a retrofit or new construction.

The technologist operating the scanner typically sits in a separate space (the “control room”), designed to protect them from scattered radiation. The control room typically has a leaded glass window, as shown in Exhibit 9, to enable the technologist to monitor the scanner during operation, both to ensure that other personnel have exited the area before x-rays are produced and to ensure that the decedent passes smoothly through the bore of the scanner. (The technologist can immediately stop scanning if they observe an issue.) It is strongly recommended that the technologist can control who enters and exits the scanner room, to prevent accidental radiation exposure to other personnel. For example, if there is a door that opens from the CT scanner room directly into a body receiving or autopsy area, or a hallway, the door should ideally be locked during each scan and unlocked by the technologist after each scan is complete. Alternatively, the CT scanner room could be designed to have only one door that opens into the control room, such that no one can enter the scanner room without having to walk directly past the technologist.

Exhibit 9. The CT technologist (seated) controls the table and gantry from a workstation in the CT control room, which is shielded from radiation produced by the scanner. A leaded glass window allows the technologist to safely observe the scanning process and ensure other personnel have exited the room.

Recently some portable, self-shielded CT scanners have become available, designed for use in surgical suites and critical care settings. From a safety perspective, these units function similarly to portable x-ray units. A dedicated CT room is not required, but personnel should maintain a minimum distance from the scanner during operation, as specified by the manufacturer, and the operator may be advised to wear a lead apron. These portable CT scanners may be an option for death investigation agencies desiring a CT scanner but without the space or budget for a dedicated CT room. It should be noted that portable CT scanners are optimized for portability but are not optimized for whole body scanning or a high volume of scanning.

Whether the CT scanner is stationary or portable, sufficient space for safely moving gurneys and transferring bodies between the gurney and the CT table will be required. Another space consideration involves door and hallway widths. To install a stationary CT scanner (or to move a portable CT scanner from room to room), any doorway or hallway that the equipment passes through, from the loading dock to its final destination, should be at least 48" wide and 80" tall. (Verify these dimensions with the vendor!) Recalling that the lifespan of a scanner is roughly 10 years, installing a wider door is preferable to creating a temporary opening that is sealed up again later. If one is having trouble believing that a 48" door width is sufficient, it may help to know that the short dimension of a CT gantry is less than 48", and the table and gantry are moved separately, as shown in Exhibit 10.

Exhibit 10. Moving a CT gantry with the help of a tow truck.

7. Who Will Operate and Maintain the CT Scanner?

When a new CT scanner is purchased, training provided by a vendor applications specialist is typically included in the purchase price, and some level of applications support generally continues as part of the annual service agreement. The standard vendor training is designed to train a radiologic technologist, who already has experience with other CT scanners, to utilize specific features of the new scanner. It may be possible to have the vendor or other service provider train a CT novice (e.g., an autopsy technician who has previously only performed x-ray), but the learning curve will be steep.

To get the most benefit from having a CT scanner, it is strongly recommended that hiring at least one clinically trained radiologic technologist with previous CT experience to develop protocols, oversee weekly quality assurance, interact with vendor service and physicians, train other technologists, and oversee radiation safety and compliance for the agency. Whole body PMCT is in some ways less complex to perform than clinical CT. In the postmortem setting, contrast agents (e.g., iodine) are not typically administered; complex functional imaging protocols (e.g., cardiac studies) are not performed; and patient safety, health, and comfort are not a concern. Radiologic technologists (X-ray or MRI technologists) without previous CT experience can be trained to perform a standard PMCT protocol relatively quickly.

In some respects, PMCT scanning is less challenging than performing postmortem x-ray, in the sense that detailed positioning of specific anatomy is generally not necessary for CT. A whole body CT study is therefore typically faster and easier to set up than a whole body x-ray survey using a portable x-ray unit. However, the operation of the CT scanner itself (both hardware and software) is significantly more complex than x-ray; therefore, radiologic technologists with prior CT experience are needed for the high-level tasks, such as developing new protocols, trouble-shooting technical problems, adjusting existing protocols for non-standard scanning conditions (e.g., badly charred or disrupted bodies, body parts mixed with debris), and determining whether a particularly difficult scan (e.g., a very large decedent or body parts embedded in concrete) is even feasible.

A CT scanner should have a service agreement, which will include parts and labor for most repairs, software updates, and, importantly, preventive maintenance to keep the scanner calibrated, catch small problems before they become large problems, and avoid down time. After the scanner is first installed, acceptance testing by a medical physicist (third party) is recommended, although this is not strictly necessary in the postmortem setting. When obtaining quotes for a scanner, a quote for the annual service agreement for all components should also be obtained. (Beware: Sometimes a component such as a chiller or an image analysis workstation will be regarded as separate from a service contract perspective.)

Service is often provided by the same vendor that sold the scanner, although third-party service companies do exist and may have more competitive pricing. A typical vendor service contract on a CT scanner will cost $100–150k annually (in 2021). The scanner purchase price may include the first year (or more) of full service. When obtaining the quote for the service agreement, some questions to ask include whether the service agreement is priced according to the number of studies performed, the number of tube-seconds (i.e., how much time the x-ray tube is on), or some other criterion?; what happens to the pricing if an agency ends up using the scanner more than anticipated—or less?; and critically, what are the hours and days covered by the service agreement, and what is the required response time? An agency must also consider that if the scanner is only accessible from within the autopsy suite, this may limit the hours during which service can occur. If the service engineer will have to walk through the autopsy suite, are they allowed (by their employer and the autopsy facility) to don the required personal protective equipment and work on the scanner when dead bodies are nearby, and furthermore, are they **willing** to do work in the presence of dead bodies?

8. How Will the Image Data Be Viewed and Stored?

The image data resulting from a whole body CT scan represent a surprisingly large amount of data, **typically several GB per decedent.** CT studies require too much storage space to be maintained on the CT scanner for more than a few days or weeks. Therefore, soon after the raw CT data on the scanner are reconstructed to form the images, **the images must be transferred to another storage system, and the raw data and image data residing on the CT scanner computer must be deleted.** Data archiving generally uses a PACS, which enables storage, as well as image viewing at multiple workstations. It is imperative to develop a procedure for verifying that all images for a given decedent have successfully been transferred to PACS before deleting the data for that decedent from the scanner. Currently, there is not a PACS product that has been directly integrated with a death investigation case management software product. Therefore, if decedent information (e.g., identity, date of birth, spelling of name) is updated in the case management system, that information will not be automatically updated in PACS. Registering decedents at the CT scanner using a unique identifier (e.g., the case number) **that does not change**, even if an unidentified decedent is subsequently identified, is strongly recommended.

A PACS system generally consists of a server (hardware) and a software client that is installed on multiple workstations to allow users to connect to the server, select and view the image data, and perform further image processing and measurements. Users should be provided with high-quality monitors, ideally located in rooms where the lighting can be controlled adequately. It is essential that users can access the image data without having to download the data to their own device, which would be very slow (up to tens of minutes per decedent) and also would create a data storage nightmare for individual users. Ideally, the PACS server will be backed up automatically and remotely by the PACS vendor to prevent any loss of data should the physical PACS server fail. The PACS vendor, the CT scanner vendor, and the agency's local IT department should all be consulted regarding network requirements. A local mini-PACS can be created on an ordinary personal computer, using relatively inexpensive (or even free) software, but this is likely not a good solution for a busy death investigation agency, for all the reasons discussed previously. The agency should designate a PACS administrator, who may be the CT technologist or an IT professional, to maintain user accounts, resolve errors (e.g., a typo in the case number used to register the decedent), and to interact with the PACS vendor regarding installation, upgrades, and other PACS service needs.

Another question to consider is whether other software, in addition to the PACS software, will be required for viewing images, generating 3D renderings, or performing quantitative analyses. In general, between the variety of image processing and analysis features available on the CT scanner itself and the capabilities available in a typical commercial PACS platform, **additional software will not generally be needed for routine death investigation work.** (Do not forget that once the raw data are deleted from the scanner, it is not possible to perform new reconstructions or renderings for that decedent using the scanner software!) Some specialized analyses (e.g., virtual anthropology, dual energy analysis) may require that image data are downloaded in Digital Imaging and Communications in Medicine (DICOM)format and analyzed using other software (e.g., 3D Slicer and Image, which are open source), and specific users may have a favorite DICOM viewer; but in general, the need for additional image analysis software is much more likely to occur in the context of research than routine case work.

9. Who Will Interpret the Images?

It is strongly recommend that a death investigation agency starting a new PMCT service develops relationships with radiologists early in the process. In addition to being experts at interpreting imaging, radiologist input is also critical to the overall development and maintenance of a PMCT service. Radiologist involvement is recommended during the selection of the CT scanner and PACS platform, the development of scanning protocols, ongoing quality assurance, and the initial and ongoing training of forensic pathologists and fellows.

The question of who will interpret PMCT, at least initially, should ideally be decided by the time PMCT scans of decedents are starting to be acquired. PMCT images may be successfully interpreted either by a radiologist or a forensic pathologist (with sufficient experience), or both. Radiologist involvement in image interpretation may take a number of forms. The radiologist may review and report the imaging studies and record their findings in a blinded fashion (i.e., prior to learning about investigative details, ancillary test results, physical examination findings, or medical history). In this case, the radiologist would only know that the subject is deceased. Alternatively, the radiologist may receive the same history that the pathologist receives but remain blinded to the autopsy or external examination findings. The radiologist may also review the case in tandem with the pathologist, either before or after autopsy, with both physicians having access to the same information. The radiologist and pathologist may each review the PMCT independently and confer later to finalize the imaging report. Finally, the pathologist may have the primary responsibility to interpret and report PMCT findings for their cases, but the pathologist may consult a radiologist about specific cases.

For any agency that is new to PMCT, a learning period where CT scans are performed and reviewed by radiologists in tandem with pathologists but that do not include the PMCT findings in the final death investigation report is recommended. Having a radiologist on site (at least part time) is the ideal situation, both when the PMCT service is under development and on an ongoing basis thereafter, assuming an agency's PMCT volume supports this. Another option is teleradiology, remote consulting with a radiologist who can access an agency's PACS and interact with the pathologists and imaging technologists, as needed, by teleconference.

Forensic pathologists will quickly become comfortable with identifying many injuries and pathologic conditions commonly encountered in the postmortem setting and normal postmortem changes. Over time, many forensic pathologists become comfortable with interpreting PMCT on their own for most of their cases and will come to prefer having a CT scan available, even for cases that will also receive a full autopsy (e.g., multiple gunshot wound homicides). The forensic pathologist should have the option of performing a full autopsy if they are not confident in their PMCT interpretation, or the PMCT is inconclusive or negative.

10. Summary

In summary, the topics discussed and recommendations provided in this guide in outline form. The intention of this guidance is to provide a starting point for agencies in the process of gathering the information they will need to plan and operationalize a PMCT service.

10.1 Preparatory Work

- Envision future PMCT service (e.g., purpose, workflow, estimated caseload)
- Consult with experts in multiple fields (e.g., forensic pathology, radiology, medical physics, architecture/design, information technology)
- Gather information from various vendors (e.g., specifications/features, costs for purchase and ongoing service, technical/space requirements) considering both the CT scanner and PACS
- Assess the existing facility or design the new facility (e.g., space, electrical, structural, HVAC, network, radiation shielding)
- Learn about applicable regulatory requirements (e.g., licensing of radiation-producing equipment, radiation safety)

10.2 Personnel/Support for PMCT

- Radiologist (on site or remote, protocol development, image interpretation, training, radiologic identification, quality assurance)
- Radiologic Technologist (protocol development, scanning, training, quality assurance, radiation safety, interface with service personnel)
- PACS Administrator (user account management, interfacing with service personnel)
- CT and PACS Service (initial training, applications support, software upgrades, preventive maintenance, repairs)
- Physicist (part-time or consulting, quality assurance, trouble-shooting)

10.3 CT Scanner Recommendations

- Detector rows (i.e., slices): 32 or greater (recommended), 16 (adequate)
- Bore diameter: 75 cm or greater (recommended)
- Image FOV: 60 cm or greater (i.e., extended FOV) (strongly recommended)
- Maximum scan length: 200 cm or greater (ideal), 100 cm or greater (recommended)
- Table type: Bariatric, flat, hard surface (recommended)
- AEC, aka Dose Modulation (recommended)
- Extended HU (recommended)
- Dual Energy/Single Tube (possibly useful, not recommended routinely)
- Metal artifact reduction software (possibly useful, not recommended routinely)

10.4 Additional CT Scanner Considerations for a High-Volume PMCT Service

- Air cooling vs. water cooling
- X-ray tube cooling specifications
- Generator power specifications
- Image reconstruction speed (i.e., the ips rating of the processor)
- Iterative reconstruction software

10.5 CT Features Not Needed in the Postmortem Setting

- Dual energy/dual tube
- Contrast injectors designed for clinical use (i.e., assumes circulation)
- Cardiac or respiratory gating systems
- Software packages for analyzing function (e.g., blood flow), minimizing motion artifacts, or tracking patient dose

10.6 PACS Considerations

- PACS server on network (strongly recommended)
- Automatic remote, redundant back-up (strongly recommended)
- Additional image processing workstations or software (possibly useful)
- Local mini-PACS/manual back-up (not recommended as primary storage method)
- Reading room with high-resolution monitors and no windows (recommended)

11. Additional Resources

General Forensic Radiology Texts:

- *Brogdon's Forensic Radiology 2nd Edition*, by Michael J. Thali M.D., Marker D. Viner, and B.G. Brogdon (Eds.), ISBN 978-1420075625, CRC Press, 654 Pages, 2010.
- *Essentials of Forensic Imaging: A Text-Atlas*, by Angela D. Levy and Theodore Harcke, Jr., ISBN 9780367577025, CRC Press, 282 Pages, 2020.

Guidance on PMCT Protocol Development:

- Gascho D, Thali MJ, Niemann T. Postmortem computed tomography: Technical principles and recommended parameter settings for high-resolution imaging. Med Sci Law. 2018 Jan;58(1):70-82. doi: 10.1177/0025802417747167. Epub 2018 Jan 8. PMID: 29310502. (Free full text is available here: https://www.zora.uzh.ch/id/eprint/148073/)

Other Related Resources:

- A six-part webinar series introducing participants to the use of PMCT, including basic technical aspects, workflow, triage, and the PMCT appearance of many injuries and pathologies commonly encountered by forensic pathologists (originally presented in 2021) is archived here: https://forensiccoe.org/postmortem-computed-tomography-series/
- The New Mexico Decedent Image Database (NMDID), which provides forensic practitioners and researchers free access to >15,000 whole body CT image datasets and associated metadata is available here: nmdid.unm.edu
- The NM OMI's original whole body CT protocol, used from 2010-2018, is published here: nmdid.unm.edu/resources/data-information

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3. Natalie Adolphi. "Evaluation of the Routine Use of CT Scanning to Supplant or Supplement Autopsy in a High-Volume Medical Examiner's Office," Final Report to the National Institute of Justice, award number 2016-DN-BX-K002, June 2021, NCJ 304293. https://nij.ojp.gov/library/publications/evaluation-routine-use-ct-scanning-supplant-or-supplement-autopsy-high-volume

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Information provided herein is intended to be objective and is based on data collected during primary and secondary research efforts available at the time this report was written. Any perceived value judgments may be based on the merits of device features and developer services as they apply to and benefit forensic pathologists and forensic communities.

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