Forensic Technology
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A Landscape Study of Computed Tomography Scanners for Postmortem Applications

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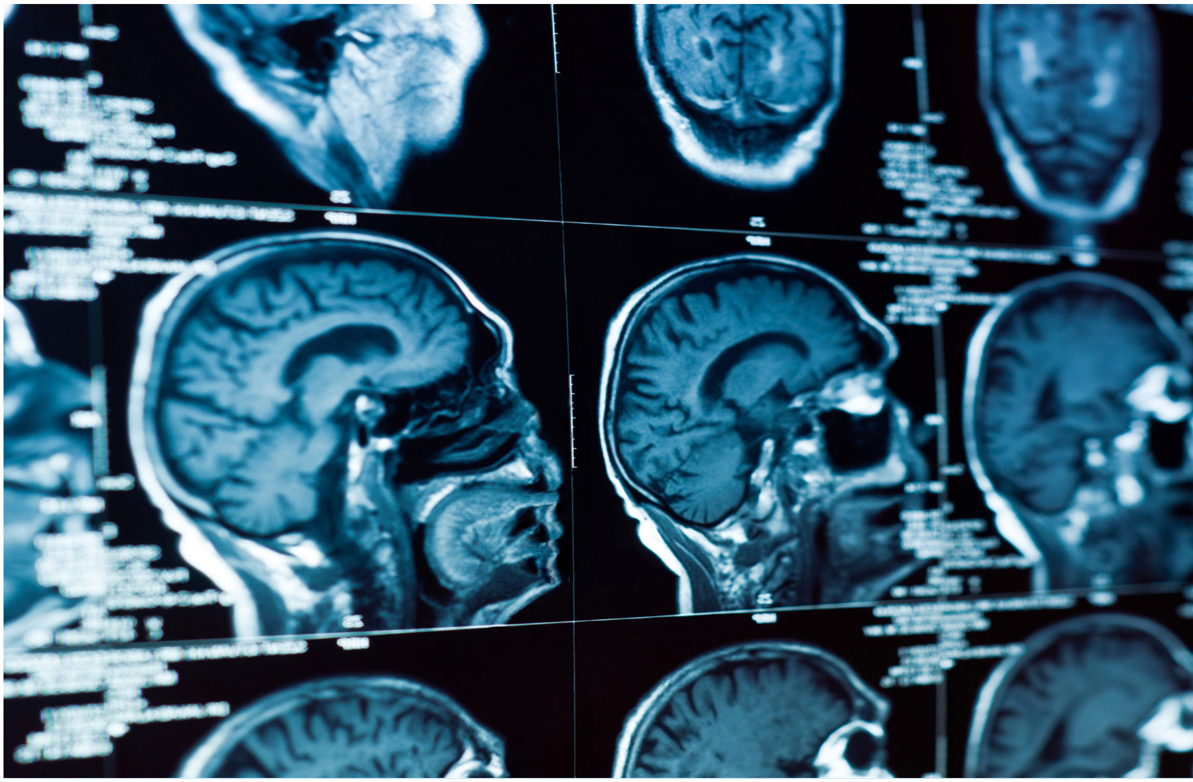

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Report Overview

Landscape Study Objectives

This landscape study will provide medical examiners, coroners, and other members of the medicolegal death investigation community with the following:

- An overview of computed tomography (CT) scanner technology and how scanners may be used in postmortem applications.
- A discussion on the potential value and limitations of postmortem CT scanning.
- Product details of a representative sample of CT scanners that may be used in postmortem CT applications.
- Considerations for implementing a CT scanner, with use cases of successful implementation.

This report builds forward from the May 2022 FTCOE guidance document *Developing a Postmortem CT Service: Practical Considerations for Death Investigation Agencies*. The original guidance document walks readers through key questions agencies should answer before choosing a CT scanner by leveraging the experiences of the New Mexico OMI, which has successfully implemented CT scanning in their workflow. This landscape provides more information on available CT products and leverages experiences from several early adopter offices.

Landscape Methodology

The Forensic Technology Center of Excellence (FTCOE) used a study process that included the following steps:

- Consulting secondary sources, including journal and industry literature, to understand how CT scanning is used in postmortem applications and who has successfully leveraged the technology;
- Attending the 2023 American Academy of Forensic Sciences Forensic Postmortem Radiology: Crossing the Border Between Radiology and Pathology Workshop[1] to understand current challenges of CT scanning implementation;
- Interviewing a sample of medical examiners from the United States to understand their experience of choosing a CT scanner and implementing into their death investigation workflows (relying heavily on the experiences of Dr. Natalie Adolphi and her New Mexico Office of the Medical Investigator (OMI) team to connect to these early adopters); and
- Conducting outreach to several CT scanning manufacturers—and significant research on publicly available sources—to gather up-to-date publicly available product information.

1. Decker, S., Mazuchowski, E., Thali, M. J., Ford, J. M., O'Donnell, C., Adolphi, N., Ebert, L., Van Rijn, R. R. (2023, Feb 13-18). *Forensic postmortem radiology: Crossing the border between radiology and pathology* [Conference workshop]. American Academy of Forensic Sciences, Science Works, 75th Anniversary, Orlando, FL. https://www.aafs.org/sites/default/files/media/documents/2023Proceedings_FINAL-june-1-23.pdf

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We would like to thank the various forensic science community stakeholders and practitioners who offered insight, analysis, and review.

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Executive Summary

Advanced imaging technologies help medicolegal death investigation (MDI) personnel assess cause of death (COD) and manner of death (MOD). The Medical Examiner and Coroner (MEC) community utilize postmortem computed tomography (PMCT) to obtain imaging data to assist in reaching informed conclusions in suspicious, unexpected, or unexplained deaths. PMCT provides comprehensive information, often at a higher level of discrimination than traditional X-ray and fluoroscopy methods, that may supplement or replace an autopsy. Effective PMCT use may alleviate some challenges that MEC offices face, including high caseloads and pathologist shortages.

MEC offices must understand that not all CT scanners are created equal, and successful implementation rests on appropriate planning and feature considerations. Offices can select either a stationary scanner, which typically offers higher power and scanning speed, or a mobile scanner, which offers flexibility and portability. MECs may either purchase new scanners directly from the manufacturer or refurbished from a number of resellers, which may alleviate costs but limit feature options and maintenance packages. In addition to the scanner, MECs must purchase a maintenance plan, pay installation fees, and acquire an appropriate Picture Archiving and Communication System (PACS) or an adequately secure cloud-based network capable of storing images. The National Institute of Justice's (NIJ) Forensic Technology Center of Excellence (FTCOE) has compiled publicly available product information for select CT scanners from the following vendors:

- Canon
- Fujifilm
- GE Healthcare
- Phillips
- Samsung
- Siemens
- Stryker

MEC leadership should consider associated changes in resources, workflow, and responsibilities before implementing PMCT workflows. Offices will need to invest time and money to configure the CT scanner to meet the office's needs and accommodate for workflow changes and personnel training. Beyond CT scanner selection, offices should consider the following implementation steps:

- Determining and selecting the MDI personnel who will be trained on CT use and scan interpretations
- Establishing strategies to ensure secure and agile data storage
- Securing funding for the allocation of the CT scanner and maintenance service contracts
- Leveraging alternative approaches to accessing clinical-quality CT scanners (while understanding the trade-offs)
- Developing structural capacity to house the CT scanner.

Offices that have successfully implemented CT within their workflow have noted the importance of community guidelines that support regular CT scanner use. Because these guidelines are still in their infancy,[2,3] the perspectives of forensic community peers are crucial in informing PMCT adoption. This report aims to help MEC leadership make informed decisions on purchasing and implementing a CT scanner and presents case studies as representative examples of previous successful implementation projects.

2. Jones, N. S., Ropero-Miller, J. D., Waltke, H., McLeod-Henning, D., Weiss, D., & Barcus, H. (2017). Proceedings of the International Forensic Radiology Research Summit May 10–11, 2016, Amsterdam, The Netherlands. https://doi.org/10.3768/rtipress.2017.cp.0005.1709.

3. Aalders, M. C., Adolphi, N. L., Daly, B., Davis, G. G., de Boer, H. H., Decker, S. J., Dempers, J. J., Ford, J., Gerrard, C. Y., Hatch, G. M., Hofman, P. A. M., Iino, M., Jacobsen, C., Klein, W. M., Kubat, B., Leth, P. M., Mazuchowski, E. L., Nolte, K. B., O'Donnell, C., Thali, M. J., et al. (2017). Research in forensic radiology and imaging; Identifying the most important issues. *Journal of Forensic Radiology and Imaging, 8*, 1-8. https://doi.org/10.1016/j.jofri.2017.01.004.

Introduction to CT for Postmortem Applications

Imaging technologies are a key tool to help MEC offices make informed conclusions related to an individual's COD/MOD. Most MEC offices have traditionally used X-ray imaging and fluoroscopy to help identify foreign bodies and injury patterns; these techniques can document the decedent's body prior to autopsy and direct the autopsy process. Although informative, these tools can only provide the investigator with limited information—these techniques cannot show a precise three-dimensional location of a foreign object in the body and can only provide a limited amount of soft tissue detail. MEC offices may require more resources (in the form of time and autopsies) to arrive at informed conclusions.

Advanced imaging technologies, such as CT, represent an opportunity to reach efficient and informed conclusions in MDI.

Informed by imaging advancements in clinical practice, the MEC community started to implement technologies that provide a more holistic and comprehensive view of the postmortem body. CT generates cross-sectional X-rays or "slices" that can be stacked into a three-dimensional representation of a decedent.[4] CT technology was developed in the early 1970s; however, it was not applied for postmortem applications until the 1990s and early 2000s as the community explored the possibility of using PMCT (among other imaging tools) to conduct a non-invasive "virtual autopsy."[5] In the late 2000s, the University of Leicester established a first-of-its-kind dedicated facility for postmortem imaging, marking a significant milestone in the integration of virtual autopsies into routine forensic investigations. This development, along with several research efforts throughout the 2000s, helped pave the way for PMCT in MEC practices. Technology advancements have enabled clinicians and the forensic community to visualize the body with high detail, including internal vasculature (angiography)[5] and lung morphology. Additionally, advancements in computer processing and high-resolution CT scanners and reduced costs have helped promote PMCT adoption.

A comprehensive PMCT scanning package for the MEC community includes the CT scanner, a PACS, and analysis software to help interpret findings. This landscape study focuses on **technical specifications of the CT scanners**, though it will reference some PACS and analysis software products.

PMCT imaging can provide MECs with increased objectivity and high-quality information used for determining and validating initial COD.

Within the MEC office, PMCT offers various benefits:

- **Comprehensive information to the MDI team, which may enable more objective analyses.** PMCT can produce three-dimensional images of the decedent without the need for invasive body procedures or previous autopsy. PMCT offers a higher level of visualization over traditional imaging techniques, potentially leading to more objective analysis and determinations of COD. CT imaging may help medicolegal death investigators make more informed decisions regarding biology (age, sex, and pre-existing conditions)[6,7] and COD. PMCT can also visualize forensically relevant information while improving capacity and efficiencies of postmortem examinations.
  - **Evidence of blunt force trauma and firearm fatalities.** PMCT can visualize blunt force trauma that may be missed during an external examination, such as bone fractures and brain hemorrhages. In the case of firearm fatalities, PMCT may help localize projectiles and assess internal damage from bullet paths. *Note: Some fractures are palpable and identification may not require CT imaging.*

4. U.S. Department of Health & Human Services. (2022). *Computed tomography (CT)*. https://www.nibib.nih.gov/science-education/science-topics/computed-tomography-ct
5. University of Leicester. (n.d.). *College of Life Sciences*. https://le.ac.uk/cls.
6. Prabhat, M., Rai, S., Kaur, M., Prabhat, K., Bhatnagar, P., & Panjwani, S. (2016, Jan-Apr). Computed tomography based forensic gender determination by measuring the size and volume of the maxillary sinuses. *J Forensic Dent Sci, 8*(1), 40-46. PMCID: PMC4799518. PMID: 27051222.
7. Vester, M. E. M., van Rijn, R. R., Duijst, W., Beenen, L. F. M., Clerkx, M., & Oostra, R. J. (2020, Jul). Added value of post-mortem computed tomography (PMCT) to clinical findings for cause of death determination in adult "natural deaths". *Int J Legal Med, 134*(4), 1457-1463. https://doi.org/10.1007/s00414-019-02219-6. PMCID: PMC7295833. PMID: 31853676.

- **Vasculature.** Angiography combines a CT scan with an injection of a special contrast dye to visualize blood vessels and tissues in a body. In clinical practice, this is used for checking narrowed or blocked arteries in the brain, neck, heart, and chest and abdominal cavities and to identify and diagnose aneurysms, blockages, blood clots, hemorrhages, and tumors.[8]

- **Neurological disorders.** CT imaging may be used to evaluate the brain, such as intracranial hemorrhages, strokes, or brain tumors. Full-body images may help medical examiners interpret if damage was pre-existing or caused by an acute attack prior to death.

To help promote the use of angiography for postmortem analysis, the Technical Working Group Post Mortem Angiography Methods (TWGPAM) was developed to cooperatively develop, evaluate, and validate methods for postmortem angiography and help facilitate and promote its widespread adoption.

- **Pulmonary information.** To help identify COD for lung-related injuries, postmortem ventilation—a technique used in conjunction with PMCT and other imaging modalities—was developed in 2013 for the detection of pulmonary pathologies. Small lung pathologies such as lung scarring and pulmonary nodules, as well as emphysema, can be identified by quantifying lung volume and airway abnormalities.[9]

- **Information that may lead to identification.** In certain situations, an unidentified deceased body may lack features traditionally used for victim identification, such as fingerprints. Detailed analysis of previous injuries, medical hardware, or skeletal anomalies can be compared to antemortem medical records to identify the deceased individual. In a mass disaster response, CT scanners may also be mounted in mobile trailers and operated in the field to accommodate high caseloads.[10] In 2019, the members of the Disaster Victim Identification (DVI) working group of the International Society of Forensic Radiology and Imaging released updated guidelines detailing the use cases and consideration for deploying PMCT in remote locations.[11]

- **Evidence of drug overdose.** Although the presence of drugs and foreign substances may be best interpreted by toxicology testing and physical examination, PMCT is valuable as a secondary and supportive tool for cases involving drug overdose. PMCT can detect body fluid accumulation that may be associated with certain types of drug overdoses, such as opioids or sedatives; detect organ abnormalities that may be a result of drug use; and help the pathologist rule out other causes of death, such as trauma. For example, gastric PMCT images can provide useful information (e.g., hyperdense stomach contents) in cases of oral drug intoxication if there is reason to expect a drug overdose.[12]

- **Data that can inform decisions, which may be comparable to data gathered from autopsies.** Researchers are investigating the ability of pathologists to reach conclusions about COD/MOD using PMCT. A 2022 study reviewed 200 cases where PMCT was performed to assess the ability of a pathologist to identify and incorporate PMCT findings in the death investigation report. The study revealed that 6.5% of the 200 cases interpreted by pathologists omitted findings determined by PMCT (coded as major errors by a modified Goldman classification); however, none of these errors changed COD while only four changed the MOD.[13] A 2020 study noted that agreement on primary COD between PMCT and autopsy, taking into consideration histological and toxicological findings, was 95.3% based on 64 samples. Results indicated that PMCT, may be comparable to assessment via autopsy when complemented by external, toxicological, and histological examination.[14] As CT imaging becomes more advanced and MEC offices become more familiar with its capabilities, there may be an opportunity to rely on CT imaging more heavily in the future.

8. RadiologyInfo. (2023). CT angiography (CTA).
9. Germerott, T., Flach, P. M., Preiss, U. S., Ross, S. G., & Thali, M. J. (2012, Sep). Postmortem ventilation: a new method for improved detection of pulmonary pathologies in forensic imaging. *Leg Med (Tokyo), 14*(5), 223-228. https://doi.org/10.1016/j.legalmed.2012.03.003. PMID: 22546246.
10. Sidler, M., Jackowski, C., Dirnhofer, R., Vock, P., & Thali, M. (2007, Jul 4). Use of multislice computed tomography in disaster victim identification--advantages and limitations. *Forensic Sci Int, 169*(2-3), 118-128. *https://doi.org/10.1016/j.forsciint.2006.08.004*. PMID: 16997522.
11. Hofman, P., Alminyah, A., Apostol, M., Boel, L. W. T., Brough, A., Bouwer, H., O'Donnell, C., Fujimoto, H., Iino, M., Kroll, J., Lee, C. T., Levey, D. S., Makino, Y., Oesterhelweg, L., Ong, B., Ranson, D., Robinson, C., Rutty, G., Singh, M. K. C., Villa, C., et al. (2019). Use of post-mortem computed tomography in disaster victim identification. Updated positional statement of the members of the disaster victim identification working group of the International Society of Forensic Radiology and Imaging; July 2019. *Journal of Forensic Radiology and Imaging, 19*. https://doi.org/10.1016/j.jofri.2019.100346.
12. Aghayev, E., Jackowski, C., Christe, A., & Thali, M. (2010, Apr). Radiopaque stomach contents in postmortem CT in suicidal oral medication intoxication: report of three cases. *J Forensic Leg Med, 17*(3), 164-168. https://doi.org/10.1016/j.jflm.2009.10.001. PMID: 20211459.
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14. Hueck, U., Muggenthaler, H., Hubig, M., Heinrich, A., Guttler, F., Wagner, R., Mall, G., & Teichgraber, U. (2020, Nov). Forensic postmortem computed tomography in suspected unnatural adult deaths. *Eur J Radiol, 132*, 109297. https://doi.org/10.1016/j.ejrad.2020.109297. PMID: 33035918.

- **Opportunities to use less invasive options to assess COD/MOD.** PMCT provides important information to decedents' families who object to autopsy.[15] These scans can also direct examiners to less invasive options such as partial autopsy or image-guided tissue extraction, which may allow examiners to remove histological samples reliably for further testing. Less invasive procedures can also provide examiners more protection from biosafety risks, which can be especially valuable during global pandemics or disaster response involving chemical, biological, radiological, or nuclear factors. MEC offices may elect to use PMCT to supplement and offset full autopsy for children or infants in non-suspicious cases. In a 2019 study to determine diagnostic accuracy of PMCT for pediatric patients, pathologists were able to use PMCT to identify the main pathologic findings concordant with findings by autopsy in 71.4% of cases. PMCT was found to be most reliable for identifying intracranial and musculoskeletal abnormalities;[16] but ongoing research and protocol optimization is needed to increase its reliability for future use.

- **Time and resource savings that can reduce strain of the forensic pathologist shortage.** MEC offices are strained by ongoing MEC capacity insufficiencies, driven by challenges that include the global COVID-19 pandemic and the opioid crisis, insufficient budgets, and a lack of available forensic pathologists.[17] Although a CT scanner is a significant upfront investment, the information offered by these scans can help speed up the imaging and data interpretation processes. Many scanners can image the full body without repositioning, reducing imaging time. Informed by the CT scan, offices may be able to reduce the number of autopsies performed, which could lower the burden on staffing. The University of New Mexico OMI, which scans every decedent that enters their facility, decreased their autopsy rate from 80% to 50% of their total cases after implementing PMCT.[18] Pathologists can also lean on radiologists for support interpreting PMCT scans and making informed conclusions, reducing their caseloads.

- **Higher-resolution outputs that simplify interpretation and presentation to juries.** PMCT imaging provides high-resolution outputs that improve upon current imaging methods. These images may be reconstructed, or processed, into various three-dimensional models that can be rotated and dissected to allow complete visualization of the decedent's body. Three-dimensional imaging can be more easily interpreted by juries and the legal community and can be less traumatizing to view than photographs.

Many offices implementing PMCT may be upgrading from a previously used X-ray or Lodox machine. CT scanners make several improvements upon traditional X-ray:

- **Increased imaging detail.** Because of the increased number of images and reconstruction algorithms, three-dimensional models can be created that increase the diagnostic power and ultimately support COD determinations.
- **Increased versatility.** X-ray—although capable of using less radiation and quicker acquisition time than CT—is mostly limited to trauma imaging and triage purposes.

A CT scanning system has multiple components.

A CT scanner consists of imaging hardware and software that take serialized X-ray data, which it transforms into a volumetric image series. Although there are many parts to an CT scanner, the major components are as follows:[19]

- A **generator** produces the large amount of power required for CT imaging (listed in kilowatts, or kW). Typical CT scanners use either single or dual generators, with dual generators capable of outputting and supplying more power for higher end CT scanners.

- The **gantry** is the circular structure that houses various components (including X-ray tubes, photon detectors, and shielding elements) that are required for the X-ray emission and image acquisition process. The internal components of the gantry rotate around the subject and the entire gantry can be tilted in different directions to improve the operator's ability to image the decedent's body.

15. Postmortem imaging is acceptable to both Muslims and non-Muslims in Libya and the United Kingdom, but Muslims have a significant preference for postmortem imaging compared with autopsy, except in cases of homicide.
16. Shelmerdine, S. C., Davendralingam, N., Palm, L., Minden, T., Cary, N., Sebire, N. J., & Arthurs, O. J. (2019, Jun). Diagnostic accuracy of postmortem CT of children: a retrospective single-center study. *AJR Am J Roentgenol, 212*(6), 1335-1347. https://doi.org/10.2214/AJR.18.20534. PMID: 30917029.
17. U.S. Department of Justice. (n.d.). *Report to Congress: Needs assessment of forensic laboratories and Medical Examiner/Coroner Offices*. https://www.justice.gov/olp/page/file/1228306/download
18. National Institute of Justice. (2022). *Postmortem CT scans: Can they effectively replace full autopsies?* https://nij.ojp.gov/topics/articles/postmortem-ct-scans-can-they-effectively-replace-full-autopsies
19. National Library of Medicine. (2023). *CT-scan image production procedures*. https://www.ncbi.nlm.nih.gov/books/NBK574548/

- The scanning **table** is the surface on which a decedent is placed to enable the body to move through the gantry. Large tables are preferred in forensic imaging because it helps facilitate easy imaging of larger or bloated decedents.
- The **image processor** reconstructs information received from the CT scanner detectors into a series (i.e., stack) of two-dimensional images (representing a three-dimensional volume) using various algorithms and image reconstruction software. These images can then be visualized using an electric monitor screen (i.e., user interface) built into the scanner to provide rapid image feedback or sent to PACS for viewing at other computers on a network.

Although not a direct component of a CT scanner, PACS systems are valuable for file storage and image visualization.

Once images are acquired and reconstructed, the CT scanner saves all images using a common file format, known as DICOM (Digital Imaging and Communications in Medicine). This format is widely adopted in clinical practice and is stored using PACS, a dedicated memory hardware. MECs who use PMCT may opt to use a PACS system or integrate their DICOM images into an organization-wide cloud storage system. MECs can take these DICOM images and view the CT images at any time using many different software analysis programs. Although most routine casework can be performed with the software visualizers at the scanner console or in PACS, offices may opt to use additional third-party visualizers and analysis tools for specific case types.[20] For example, there are two-dimensional visualization software tools suited for the radiological assessment of PMCT data because they allow the depiction of subtle details whereas three-dimensional visualization may be useful for visualizing the entire body and for demonstration purposes during judicial court hearings.

An MEC office can incorporate CT scanning at various points in their workflow.

MEC offices vary widely in resources and current imaging technology, support staff, and caseload. PMCT can be integrated at several points during autopsy workflows (see **Figure 1**). According to the 2018 Bureau of Justice Statistics (BJS) Medical Examiner and Coroner Offices Census, roughly half of all MEC offices had access to CT imaging, but only 3% have direct access to a scanner.[21] For offices with easy access to a CT scanner, most have begun implementing PMCT upon intake of all decedents. This is most common for MEC offices with high-end scanners capable of rapidly imaging each body. When an office shares the equipment, they tend to scan decedents early in the morning or at dedicated times throughout the day, scanning decedents back-to-back. When offices access PMCT through partner agencies, PMCT is typically performed on an ad hoc basis or as staffing and caseload allow. These offices may instead leverage existing imaging technologies (e.g., Lodox technology) for all decedents upon intake and choose to scan those that fit a set of parameters once the case has been reviewed.

Whether CT scanning is performed before or after the case review and external examination, PMCT can provide supplemental information during an autopsy, offering critical information via full-body images or additional testing mechanisms such as image-guided tissue extraction and angiography. In some situations, CT scanning may indicate to the MEC office that additional ancillary testing is required (e.g., toxicology testing).

Forensic pathologists are most often the individuals ordering and interpreting CT scans as part of overall postmortem analysis (with appropriate training). Radiologic technologists or autopsy technicians position the decedent within the scanner, follow the imaging protocols, and reconstruct and archive the images. Radiologists, who are trained to interpret CT images, can support interpretation efforts. They can work with the pathologist in distinguishing between typical postmortem observations (e.g., gas and air pockets, decomposition signs) and true pathologic findings relevant to COD/MOD. MECs gather this input from forensic pathologists, radiologists, radiologic technologists, and technicians to help certify COD/MOD.

Although PMCT uses instrumentation used in clinical settings, workflows differ for MEC applications. For example, decedents may not be repositioned easily, so large bore size and couch may help image as many bodies as possible. Operators can use high levels of radiation on decedents. Although the office should consider safety risks of operators, they can use higher power settings to get highly detailed images. As a result, few contrast agents are needed in postmortem applications, except for angiography.

20. Ropero-Miller, J. (2022). Developing a postmortem CT service: Practical considerations for death investigation agencies.
21. Brooks, C. (2021). *Medical Examiner and Coroner Offices, 2018*. U.S. Department of Justice. https://bjs.ojp.gov/content/pub/pdf/meco18.pdf

Opportunities for PMCT Scanning to Provide Value in a Medicolegal Death Investigation Workflow

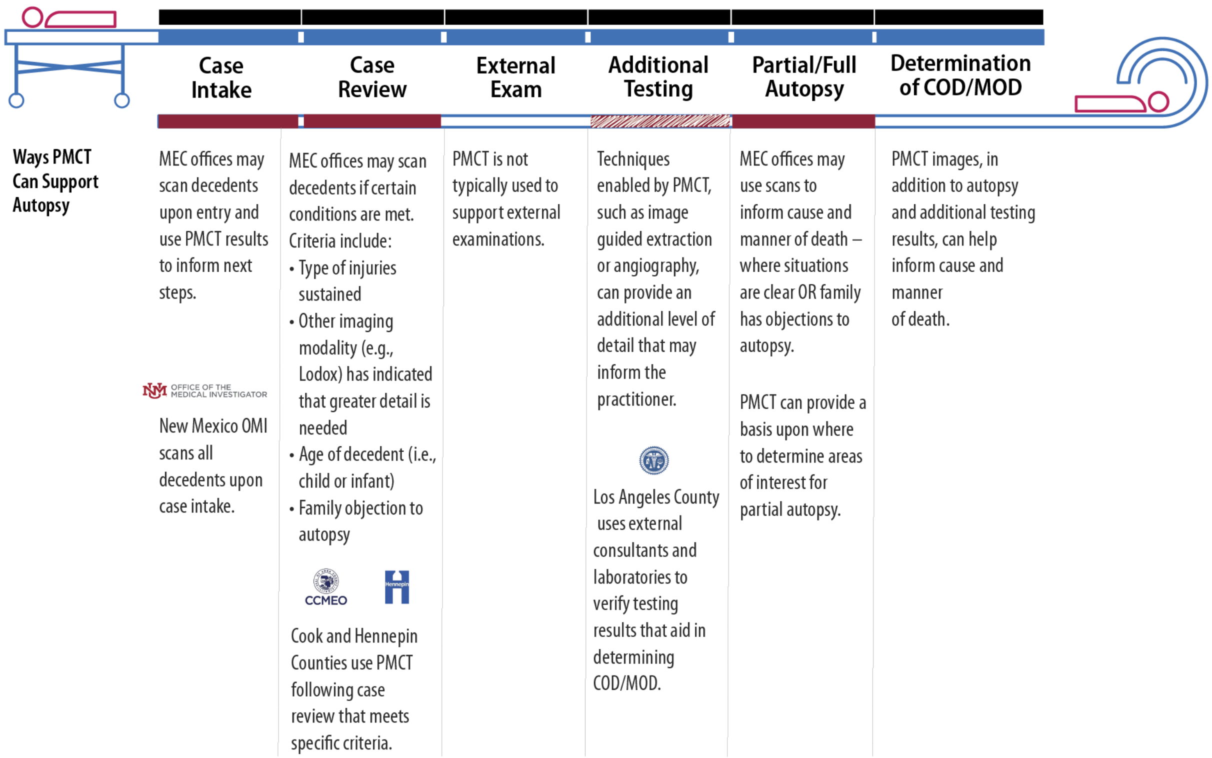

Figure 1: CT Scanning can be used to either supplement or supplant traditional autopsy workflows.

CT imaging can either be used to replace or supplement autopsy; however, certain circumstances dictate when to do so.

MEC offices may elect to use CT to replace, or further support, autopsy to classify COD/MOD—provided certain conditions are met (see **Figure 2**). Organizations implementing PMCT must continue researching and validating the applications of CT imaging and train individuals on image interpretation.

CT may be able to **supplement autopsy** for:	CT may be able to **replace autopsy** for:
Complex and unclear cases. Combining CT imaging with a traditional autopsy and ancillary testing (e.g., toxicology) can provide a more comprehensive analysis. CT imaging can offer initial insights into potential causes, guide the subsequent autopsy procedure, and help direct the focus of the examination. **Cases with strict forensic evidence requirements.** The requirements of the specific forensic investigation can also influence the choice between CT imaging as a standalone technique or as a supplement to traditional autopsy. In some cases including suspicious or unexplained deaths, traditional autopsy may be necessary alongside CT imaging to obtain the required evidentiary material. However, if it is necessary that the body remains as intact and unadulterated as possible, CT imaging is a preferred replacement strategy.	**Cases where COD is evident.** CT imaging is acceptable as a replacement to autopsy when the proposed COD is recognizable and obvious. In the case of a medical condition or external trauma that is identified as the clear COD, a full autopsy may not be required, and CT imaging may be used to confirm the diagnosis. **Cases involving fragile and decomposed bodies.** In situations where the decedent is not physically capable of being autopsied (i.e., decomposed body), CT imaging may be viable in determining small nuances that were not originally obvious from external observations. **Cases involving objection to autopsy.** CT imaging is often favored when cultural, religious, or personal considerations may opt to forgo an autopsy. Using CT imaging as a replacement to autopsy has its limitations, and under some circumstances it may be used as a replacement (i.e., noticeable situations that have a clear and obvious COD). It is less invasive, but certain scenarios may still require a full autopsy.

Figure 2: CT may replace or supplement autopsy depending on case circumstances.

PMCT implementation represents several opportunities for MEC offices, but technical and training challenges limit current use.

CT is commonly used for postmortem applications in Europe, Australia, and Japan, yet implementation is still not as widespread in the United States. Although almost half of MEC offices have access to CT imaging, only 3% have direct access.[22] Some statewide offices have access to clinical CT scanning through healthcare facilities but are only able to use it on a limited basis. As an emerging technology, PMCT use cases and research applications are continuously in development. MEC offices on the bleeding edge of implementation must be aware of current limitations, including those discussed here:

- **Lack of training opportunities for pathologists or radiologists to develop PMCT interpretation skills.** To successfully reach informed conclusions from PMCT, the individual interpreting the scans needs both (1) an understanding of normal and abnormal findings in postmortem applications and (2) experience interpreting radiological scans. Typically, the forensic pathologist and clinical radiologist do not have both sets of skills without additional training, and there are no widely available training programs to help bridge these gaps. In addition, the limited reach of CT technology in MEC applications may be attributed to the high costs of CT scanners and to the decentralized nature of the medical examiner system, which limits resource standardization and sharing across offices. Without widespread adoption, it is more difficult for forensic practitioners to find and share resources and protocols for CT imaging.

- **Errors in identifying COD/MOD using PMCT.** PMCT is not a perfect method for determining COD/MOD. In a 2023 study on identifying COD for abnormal findings, pediatric trauma, firearm injuries, and drug poisoning deaths in individuals under the age of 50, pathologists could identify the most important findings using PMCT without autopsy, but "both autopsy and PMCT were imperfect in recognizing injuries."[23] In most situations, forensic practitioners using CT imaging performed comparatively with practitioners reaching conclusions from autopsy information alone.[24] That said, pathologists or radiologists without proper training can misinterpret and misdiagnose based on PMCT results. Further research, education, and access to CT scanning is required before it is a true alternative to autopsy.

- **Inability of CT to replace autopsy in all situations.** It is unlikely that CT imaging will fully replace autopsy. Autopsy remains one of the most comprehensive measures of understanding COD/MOD, and PMCT implementation is limited by logistical hurdles (i.e., housing, funding, maintenance, and case load need), so it is not fully embraced in the MEC community.

In traditional autopsy, MECs rely on their experience and ability to manipulate the body much more than when using CT imaging. MECs cannot gather as much visual and tactile feedback about the body to assess tissue color, consistency, and textures that may be valuable indicators of COD/MOD. Additionally, CT imaging is not always capable of providing enough information to discretely identify different types of nearby tissue, particularly in instances where the body is deformed and not positioned as expected. Although CT imaging may be valuable in assisting with overdose or poisoning cases, chemical analysis is still required to detect the presence and quantity of drugs or toxins, which could not be achieved with CT imaging alone.

22. Brooks, C. (2021). *Medical Examiner and Coroner Offices, 2018*. U.S. Department of Justice. https://bjs.ojp.gov/content/pub/pdf/meco18.pdf

23. Lathrop, S. L., Wiest, P. W., Andrews, S. W., Elifritz, J., Price, J. P., Mlady, G. W., Zumwalt, R. E., Gerrard, C. Y., Poland, V. L., & Nolte, K. B. (2023, Mar). Can computed tomography replace or supplement autopsy? *J Forensic Sci, 68*(2), 524-535. https://doi.org/10.1111/1556-4029.15217. PMID: 36752321.

24. Makino, Y., Unuma, K., Nolte, K. B., & Adolphi, N. L. (2022, Nov). Accuracy of forensic pathologists in incorporating post-mortem CT (PMCT) in forensic death investigation. *J Forensic Sci, 67*(6), 2351-2359. https://doi.org/10.1111/1556-4029.15131. PMID: 36069005.

Landscape of Postmortem CT Scanners

For MECs seeking to implement CT scanning into their workflows, organizations need to be knowledgeable about the different types of CT scanners available and various models that vendors manufacture. Offices can choose from a variety of CT options with different technical specifications (see **Figure 3**):

- **Mobile or stationary.** MECs have two main choices of CT scanners, either mobile units or stationary CT scanners. Stationary CT scanners typically offer more power and are larger instruments, set up in a permanent location. Stationary CT scanners are more prevalent and accommodate a higher caseload volume than mobile CT scanners, as these models offer a shorter cooling time between whole body scans compared to mobile units.[25] Mobile CT scanners are more compact and on wheels, which may be moved within the facility to accommodate varying workflows more easily. Mobile CT scanners offer more flexibility and renovation cost savings but less power and shorter scanning length (resulting in an overall longer scanning time) and may not be optimized for whole body scanning or high caseloads.[26]

- **New or refurbished.** CT scanners can be purchased new from the manufacturer or refurbished through several aftermarket companies. Refurbished CT scanners are typically cheaper than new models and may offer savings of around 30%–40% from the original list price. Some refurbishing companies, such as Advanced Detection Solutions, offer bundles with purchase of the CT scanner that include a warranty, maintenance service contract, and training. Advanced Detection Solutions also offers a specific PACS and a mobile trailer option for MEC offices that lack space for a scanner in their facility.

Manufacturer	CT Scanning Model	Stationary	Mobile
Canon	Aquilon Prime SP	✓	
Fujifilm	Supria Plus	✓	
GE Healthcare	Revolution 256	✓	
Philips	Brilliance 64	✓	
Samsung	Neurologica BodyTOM Elite		✓
Siemens	SOMATOM Perspective 64	✓	
Stryker	Mobius AiroTruCT		✓

Figure 3: This landscape study covers five stationary and two mobile CT scanners.

Commercially Available CT Scanners

The FTCOE consulted MEC personnel, especially early PMCT adopters, to understand common vendors and CT models used for postmortem applications. In the following table (**Figure 4**), FTCOE profiled information from seven vendors, organized by major CT scanner components and other procurement considerations. This selection is meant to be representative of commonly used CT scanners in postmortem imaging and is not an exhaustive list of all available CT scanners.

25. Both mobile and stationary units may be considered "portable" if they are installed within a portable trailer. MEC offices may elect to use this option if the office does not have a dedicated radiation room or space available or appropriate for a CT scanner

26. Ropero-Miller, J. (2022). Developing a postmortem CT service: Practical considerations for death investigation agencies.

Figure 4: Technical specifications for CT Scanners used for postmortem applications vary across stationary and mobile options.

	CT Scanner Feature List	Feature Description	Stationary Scanners					Mobile Scanners	
			Canon Aquilon Prime SP (2017)	Fujifilm Supria Plus (2021)	GE Healthcare Revolution 256 (2013)	Philips Brilliance 64 (2003)	Siemens SOMATOM Perspective (2012)	Samsung Neurologica BodyTOM Elite (2017)	Stryker Mobius AiroTruCT (2013)
Gantry	Slices	Number of rows of detectors in the z-axis of the CT; additional slices provides more imaging coverage per gantry rotation and may reduce total scan time (in slice numbers)	40, 80, or 160	16, 32 (FineRecon)	256	64	64, 128	32	32
Gantry	Minimum Slice Thickness	Smallest thickness that the CT scanner is capable of imaging; thinner slices allow for more detailed analysis. (in millimeters)	0.5 mm	0.625 mm	0.625 mm	0.5 mm	0.4 mm	1.25 mm	1.0 mm
Gantry	Size of Gantry Bore	Maximum diameter of the gantry bore; for forensics imaging, a large bore size is favorable (in millimeters)	780 mm	750 mm	800 mm	930 mm	700 mm	850 mm	1070 mm
Gantry	Gantry Dimensions	Space requirements of the gantry, H x W x D (in centimeters)	187 x 215 x 87 cm	184 x 199 x 92 cm	200.5 x 236.5 x 143.6 cm	203 x 238 x 93 cm	190 x 69 x 230 cm	63.3 x 52.7 x 28.7 cm	Unknown
Gantry	Gantry Rotation Time	Rate of gantry rotation; a faster gantry rotation may lead to reduced scan time and reduced motion artifacts (in seconds)	0.35 s	0.75, 1.0, 1.5, 2.0 s	0.28, 0.35, 0.5, 1 s	.53 s	.39 s	1 s	2 s
Gantry	Gantry Tilt	Angle at which gantry can be tilted; tilt may help with image alignment and reduce radiation exposure (in degrees)	±30 degrees	±30 degrees	45 (digital)	±30 degrees	+ 20 degrees	0	Unknown
Gantry	Field of View	The entire imaging field that is being scanned; a larger field of view allows increased object visibility but may require high detector counts (in centimeters)	70 cm	2–50 cm	25–50 cm	25–50 cm	5–60 cm	60 cm	Unknown
Gantry	Imaging per Second (IPS) Rating	Number of images that can be acquired over time; higher IPS rating may lead to decreased overall imaging time (in images/second)	up to 70 images/s	up to 55 images/s	up to 65 images/s	up to 20 images/s	15 images/s	16 images/s	24 images/s
Gantry	Maximum Scannable Range	Length that the scanner is capable of scanning (in centimeters)	150/200 cm	180 cm 71"/1800 mm	200 cm	190 cm	160 cm	90 cm (Axial scanning)	100 cm

	CT Scanner Feature List	Feature Description	Stationary Scanners					Mobile Scanners	
			Canon Aquilon Prime SP (2017)	Fujifilm Supria Plus (2021)	GE Healthcare Revolution 256 (2013)	Philips Brilliance 64 (2003)	Siemens SOMATOM Perspective (2012)	Samsung Neurologica BodyTOM Elite (2017)	Stryker Mobius AiroTruCT (2013)
Gantry (continued)	Reconstructive Matrix	Array of rows and columns of pixels in the reconstructed image (in pixels)	512 x 512	512 x 512	512 x 512	512 x 512	512 x 512	512 x 512	512 x 512
	Image Spatial Resolution	Resolution that the images are outputted at; a high spatial resolution allows fine-tune ability to distinguish objects that differ in density (in line pairs per centimeter)	21.5 lp/cm at MTF 0%	17.2 lp/cm @ 0%	0.23 mm spatial resolution	24 lp/cm	0.5mm (~50 ip/cm)	17 lp/cm	0.21 mm spatial resolution
	Detector Type	Type of detector system used	PUREViSION Solid-State Technology 80 rows of 0.5 mm slice resolution	Hi-speed solid-state ceramic	Gemstone scintillator	HiLight ceramic matrix II	Multislice UFC (Ultra Fast Ceramic)	Solid-state GOS (gadolinium oxysulfide)	Solid-state CdWO4
	Gantry Power	Amount of power that the Gantry requires (in kilowatts)	72 kW Generator	48 kW Generator	103 kW	100 kW	100 kW	4 Lithium Ion batteries; constant of 1.8 kw to 4.37 kw	Unknown
Couch/Table	Couch Width	Overall width of the couch; for forensics, larger couch widths are preferred to accommodate postmortem body (in cm)	47 cm	47.5 cm	70 cm	57 cm	57 cm	None provided (No couch provided with mobile units)	57 cm
	Couch Height	Overall height of the couch; for forensics, lower, or adjustable, heights are preferred to accommodate postmortem body (in cm)	33 cm	Unknown	200 cm	70 cm	70 cm	None provided (No couch provided with mobile units)	70 cm
	Table Length	Maximum length of table; for forensics, longer table lengths are preferred to accommodate postmortem body (in cm)	195 cm	180 cm	217 cm	200 cm	200 cm	None provided (No table provided with mobile units)	190.5 cm
	Table Occupancy Weight	Maximum load capacity; for forensics, a high table occupancy weight is preferred to accommodate postmortem body (in kg)	315 kg (660 lb. capacity couch)	227 kg (550 lb. capacity couch)	247 kg	204 kg	206 kg	None provided (No table provided with mobile units)	181 kg
Cooling and Generator	Cooling System	Type of cooling system used	Air-cooled	Oil /Air Anode Max Cooling Rate - 748kHU/min	Oil/Air	Air-cooled	Air-cooled	Air-cooled	Air-cooled
	Generator Power	Power capacity of the generator (in kW)	100 kVA	51 kW Generator	103 kW Generator	60 kW Generator	112 kW Generator	42 kW	30 kW Generator

	CT Scanner Feature List	Feature Description	Stationary Scanners					Mobile Scanners	
			Canon Aquilon Prime SP (2017)	Fujifilm Supria Plus (2021)	GE Healthcare Revolution 256 (2013)	Philips Brilliance 64 (2003)	Siemens SOMATOM Perspective (2012)	Samsung Neurologica BodyTOM Elite (2017)	Stryker Mobius AiroTruCT (2013)
Housing	Installation Space	Installation space required (in square feet)	160 sq. ft (9.8 ft x 16.1 ft)	106 sq. ft (9.8 ft x 16.1 ft)	Unknown	285 sq. ft (24.6 ft × 11.6 ft)	199 sq. ft	150 sq. ft (10 ft × 15 ft)	155 sq. ft
Housing	CT Scanner Total Weight	Total weight of entire CT scanner (in pounds)	2750 lbs.	4460 lbs.	6329 lbs.	5130 lbs.	6173 lbs.	3510 lbs.	1800 lbs.
Pricing and Procurement	Pricing Model (Base) + Maintenance and Support Costs + Additional Training Modules Offered	Available pricing and additional support offered by the company	~ $900,000+	~$300,000	~$495K CT Proficient Training Tuition - $25K Service Training Tuition - $7K Tuition and Lodging - $7.6K Tuition, Lodging and Airfare - $9.1K	~$280,000	~$500,000	~ $800,000+ 1-year all-inclusive warranty covering all parts 100% On-site training led by a Neurological Clinical Applications specialist	$~400,000–$800,000

Adoption Considerations

The adoption of a CT scanner requires resources, appropriate planning, and considerations to changes in workflow and caseload management. When implementing PMCT, offices should consider the following:

Plan for resources and time to invest in the implementation of a CT scanner, including storage of data and training costs.

Offices should consider return on investment before purchasing a CT scanner. Edward Mazuchowski, one of the early PMCT pioneers in the United States, noted that the "sweet spot" of cases to justify the investment is roughly 100 per year. Offices can expect to allocate hundreds of thousands of dollars toward the cost of the CT machine, installation, PACS, and maintenance.[27] While planning resource allocations, organizations should ask themselves and vendors:

- **Who will be conducting the scans and the scan interpretation?** Offices should consider their current staff, caseload, and proposed PMCT workflow to assess additional staffing needs. Autopsy technicians or radiologic technologists may take on decedent scanning duties; radiologists may support forensic pathologists in scan interpretation and help them make informed decisions on COD/MOD and whether to autopsy. MEC leadership may need to invest in additional personnel to sustain or optimize caseload with CT implementation, such as information technology (IT) personnel to maintain the PACS or additional technicians to assist with moving bodies onto the scanner. Employing radiology consultants and partnerships with clinical or academic resources or MEC offices from other jurisdictions can be another strategy to scale staff for CT use. Imaging centers could provide radiologic interpretation services similar to radiologists for hospitals and clinics.

> The guidance document, Developing a Postmortem CT Service: Practical Considerations for Death Investigation Agencies, suggests that offices hire at least one clinically trained radiologic technologist with CT experience to help develop protocols and support implementation of the scanning technique.

- **How will individuals be trained on PMCT use and scan interpretation?** Training is key to enabling PMCT use, as interpretation can be susceptible to error when identifying features informing COD. Forensic pathologists often lack the experience to interpret CT scans and clinical radiologists lack experience identifying and understanding nuances of postmortem changes. Offices need to factor in training for both (1) operating the CT scanner and (2) interpreting radiological images created by the CT scanner (in many circumstances, the end users of this training will be different). Although few formal "forensic radiologist" training opportunities exist, offices should budget for and take advantage of available manufacturer training, workshops offered by forensic professional organizations, and peer learning from offices that have successfully implemented the technology. Currently, vendors offer initial training on the operation of the CT scanner and focus on protocols typically more relevant to clinical use.

- **What maintenance and service contracts are available?** MEC offices would greatly benefit from more cost-effective maintenance and service contracts. Currently, offices can expect to allocate approximately $100,000 annually for CT scanner maintenance and service contracts.[27] Some agencies have proposed maintenance contracts that deprioritize the speed of execution, where repairs are conducted up to 1 week later instead of within the standard 24-hour turnaround to accommodate offices' budgetary bandwidths. It would be beneficial for MEC offices to check with other local facilities for potential alignment with clinical or academic product selection to help increase access to maintenance services. This measure would prioritize cost-effectiveness of the maintenance and service contracts of CT scanners. Offices should work with the manufacturer to understand available options and tailor contracts to their needs.

27. Daly, B. (2019). *Nuts and bolts of a PMCT service.* https://www.thename.org/assets/docs/2019%20Interim%20Meeting%20Handouts.pdf

- **How might we ensure secure and agile data storage?** PACS are an important component for the retrieval of CT scan data. Although PACS are not typically developed by the CT scanner manufacturer, they may be sold by the manufacturer (or refurbisher) and purchased as part of the larger CT package. Offices noted that ideal storage conditions include an on-site PACS, internal IT support, servers allowing for indefinite storage, and a robust viewing platform. Offices using cloud-based systems appreciate their cost-effectiveness as opposed to on-site systems but note trade-offs of limited storage periods and longer data retrieval times that may impact workflow and efficiency. Dedicated on-premise PACS hardware (ideally with cloud back-up) offers the fastest image visualization and maintains secure files for reference in future cases. Offices considering cloud-only storage should look for options with an indefinite storage period for data retrieval on demand.

The Travis County Medical Examiner's Office piloted the use of cloud storage for their PACS and noted important trade-offs for this approach. Read more in the case study on pg. 20.

Consider funding for the allocation and operation of the CT scanner.

MEC offices may leverage a variety of avenues to fund or procure a CT scanner. Federal funding opportunities include the Bureau of Justice Assistance (BJA) Paul Coverdell Forensic Science Improvement Grants Program, which may be able to cover costs associated with equipment procurement, staffing, and training. BJA's Strengthening the Medical Examiner-Coroner System Program and BJA's Edward Byrne Memorial Justice Assistance Grant Program may cover training and technology acquisition.

Private funding opportunities include College of American Pathologists' 2023 Forensic Pathology Advanced Training grant[28] and opportunities through local non-profit organizations that have contributed to funding CT scanners for agencies. For example, in 2015, Los Angeles (LA) County obtained funding from the Jewish community for the purchase of their refurbished Philips CT scanner because there was a religious objection to autopsies.[29]

Leverage alternative approaches to accessing clinical-quality CT scanners but understand the tradeoffs.

MEC offices without sufficient funds or caseload to justify purchasing a scanner can consider alternative approaches to access. The 2018 Census of Medical Examiner and Coroner Offices data highlighted that although half of responding MEC offices had access to CT imaging, very few (3%) had direct access while most (47%) had indirect access through a partner agency.[30] Some offices have suggested establishing a partnership agreement between MEC offices and local hospitals where decommissioned scanners are offered to MEC offices for PMCT use. Some offices have considered use agreements between local hospitals and MEC offices (e.g., where decedents are scanned overnight using the hospital's CT scanner). Smaller jurisdictions may be able to collectively contribute to the purchase and maintenance of a single CT scanner that operates as a regional hub.

Refurbished scanners provide an opportunity to access CT technology at a lower price, but implementation may have financial trade-offs. Some companies offer a maintenance contract, but they may not have an extended warranty. The price of parts alone is well worth the price of a maintenance plan, as a new X-ray tube can cost anywhere from $150K–$250K. Otherwise, sourcing parts for a refurbished model can be difficult and end up costing the organization more in the long run.

Consider the structural and space requirements to accommodate housing the CT scanner.

CT scanners have specific space requirements to enable agile workflows. Many offices lack the available space for a CT scanner and lack the funds to develop a new facility to house the technology. MEC offices have noted that CT scanner placement can compromise their workflow, especially if operation disrupts access to certain areas of their facility. Some facilities may not be

28. College of American Pathologists. (n.d.). *2023 forensic pathology advanced training grant - list of participating medical examiner/coroner office sites*. https://foundation.cap.org/wp-content/uploads/2023-pilot-host-locations-medical-examiner-coroner-office.pdf?x38511%20some%20for%20CT%20scanning

29. Agudath Israel of America. (2015). New CT scanner at LA County Coroner's Office will respect religious beliefs and make office more efficient.

30. Brooks, C. (2021). *Medical Examiner and Coroner Offices, 2018*. U.S. Department of Justice. https://bjs.ojp.gov/content/pub/pdf/meco18.pdf

able to accommodate the weight of the scanner, and offices should consult with professionals to evaluate the building's flooring and beams. Agencies should consider the facility's electrical and HVAC capacity to determine if it can support the equipment, and invest in lead-lined walls and doors to protect staff from radiation. A medical physicist should also determine the appropriate level of shielding required.[31]

Offices with significant facility updates or rebuilds in the near future should work with local planners and decisionmakers to advocate for facility space and layouts that suit CT implementation. For example, Hennepin County's Medical Examiner's Office incorporated the cost of allocation and operation of a CT scanner in the budget for the construction of their new facility, which combatted funding and housing barriers. Alternatively, some offices have housed their CT scanners in mobile trailers, allowing offices to use the technology safely and effectively.

Greg Davis, a University of Alabama at Birmingham board-certified forensic pathologist, had access to the right instrumentation as the team was gifted a CT scanner by the local hospital. However, the office faced difficulty accessing the scanner as their office is on the second floor while the CT scanner is housed on the first floor. The logistics of transporting and scanning decedents in the hospital significantly limited use of the CT scanner, highlighting the importance of incorporating structural considerations when developing a new facility.

Identify which CT scanner features are "must haves" and "should haves" for your office.

Each MEC office has different needs, resources, workflow, and ways of operation. Therefore, proper planning (as part of the return on investment consideration) is required to establish if the CT scanner selected aligns with the office's caseload demand and workflow.

Interviews with CT adopters noted "must-have" features for PMCT applications:

- The **largest bore size and table weight available** (as shown in Figure 4, specifications range from 700 mm to 1070 mm and 181 kg to 247 kg, respectively), so that the office can accept the widest range of body sizes and positions. Of the profiled CT scanners, the Stryker Mobius AiroTruCT offers the largest bore size (1070 mm) whereas the Canon Aquilon Prime SP offers the largest table weight (315 kg).

- Short **cooling time** between scans, especially offices with higher caseloads where efficiency and speed are important. The time allocated to the cooling of the CT scanner between scans is tied to CT scanning power consumption and significantly differs between mobile and stationary CT scanners. Scanners designed for higher power output typically also have more efficient cooling. As shown in Figure 4, generator specifications for stationary CT scanners range from 51 kW to 112 kW whereas mobile CT scanners range from 30kW to 42 kW. Higher power and shorter cooling time enable a shorter **scan duration**. Of the profiled CT scanners, the Siemens SOMATOM Perspective 64 has the greatest power capabilities of the generator (112 kW).

- **Long table travel**, which helps provide a more complete scan of the decedent's full body. Insufficient table travel (i.e., maximum scan length) results in a segmented full-body scan, where the office must first scan head to shin (for example) and then adjust the decedent to scan shin to toes. Readjustment leads to longer overall scan durations. As shown in Figure 4, maximum scannable range specs for mobile and stationary CT scanners are 90 cm to 100 cm and from 160 cm to 200 cm, respectively. Of the profiled CT scanners, the Canon Aquilon Prime SP and GE Revolution 256 have the largest maximum scannable range (200 cm).

- Scanners with **variable exposure**. Variable exposure is how much current the X-ray tube is producing at a given moment and can help improve the overall quality of the images being taken. As postmortem tissue undergoes changes, postmortem gas formation and dehydration can form in the decedent. Having a scanner capable of variable exposure can help ensure that all tissues are adequately visualized and remove unwanted artifacts.

31. Knorr, C., Adolphi, N. L., & Nolte, K. B. (2021). "What do you mean it doesn't fit?" - Facility and operational considerations for next-generation forensic imaging equipment. *Forensic Imaging, 26*. https://doi.org/10.1016/j.fri.2021.200467.

Other features of the CT scanners can provide value but also require some trade-offs:

- Mobile CT scanners offer flexibility because they are not fixed-positioned in a space and require less power; however, they have lower maximum scannable ranges and require cooldown time between scanning each decedent. The Cook County Office of the Chief Medical Examiner, for example, realized these trade-offs when electing to purchase a mobile scanner, as shown on pg. 18.
- Localizers on CT scanners are helpful for the acquisition of relevant information for tube current modulation, patient positioning, and z-dimension coverage.[32] In many cases, MEC offices may need to choose between scanners that offer a localizer with a more complete field of view but reduced resolution or a restricted/limited field of view that outputs with increased resolution.

When assessing scanners and associated packages, MEC offices should ask the following questions:

- How long might it take to scan the full body of a decedent? Typically, how long can the scanner run (assuming general power needs for an average body) before needing a cooldown period?
- Can you provide an example of the localizer output? What field of view does this cover, and what is the resolution of the localizer image?
- What software packages do you offer (as standard and as upgraded models)? Are multiple reconstructions off of one scan possible, or are additional scans needed?
- What maintenance packages do you offer? Are there tiered options that are more cost-effective?
- Who will we be working with if my offer requires scanner repair or replacement of parts?
- Do you offer training opportunities tailored to individuals who are new to the CT scanning world?
- For refurbished scanners: do you provide extended warranties? What is the typical pricing for replacement parts?

Leverage perspectives of the forensic community to guide adoption of scanners for postmortem applications.

Often, full implementation of a CT scanner takes more time than originally estimated. Early implementers have noted a lack of awareness of planning and locating the correct support equipped with the experience and expertise to guide them through this process. For example, Travis County invested in a logistical consultant who helped facilitate staff training, and LA County leveraged radiology consultants. Offices should incorporate the perspectives of peers within the forensic community who have leveraged these tools, when possible, instead of relying solely on CT scanner manufacturers.

32. Hoye, J., Sharma, S., Zhang, Y., Fu, W., Ria, F., Kapadia, A., Segars, W. P., Wilson, J., & Samei, E. (2019, Nov). Organ doses from CT localizer radiographs: Development, validation, and application of a Monte Carlo estimation technique. *Med Phys, 46*(11), 5262-5272. https://doi.org/10.1002/mp.13781. PMCID: PMC7327952. PMID: 31442324.

CCMEO

The Cook County Medical Examiner's Office noted opportunities and challenges of implementing a mobile CT scanner.

Ponni Arunkumar is the Deputy Chief Medical Examiner for the Cook County Medical Examiner's Office in Chicago, IL.

The Cook County Medical Examiner's Office typical caseload is 24 cases a day (16,000+ cases reported, 5,600 accepted annually).[33] In 2018, the office purchased a Samsung Neurologica mobile CT scanner using grant funds from the Urban Area Security Initiative, costing roughly $1M.

Currently, the Cook County Medical Examiner's Office does not use CT scanning for every case but employs CT scanning for determining COD/MOD in particular conditions, including the following:

- **Blunt force trauma deaths.** In situations such as vehicle fatalities, where there may be vertebral artery tear or trauma to the face, the office injects dye into blood vessels to better image injury to vertebral arteries. Currently Cook County sees about two to four of these cases per year.
- **Religious and moral objections.** Decedent family objections to autopsy may require the use of CT scanning to visualize internal structures.
- **Bone abnormalities.** In particular, PMCT is used for cases related to child abuse.
- **Drug related cases.** In the near future, CT scans of the head and chest may be used to help to rule out other causes of death in suspected overdose cases.

The implementation of the Samsung Neurologica mobile CT Scanner spanned a few months. The office learned that mobile CT scanners, while providing flexibility in housing to the Medical Examiner's Office, need more time to cool down between CT scans. The office would be unable to scan their entire daily caseload because of the lag time between scans. For offices with high caseloads, mobile CT scanners would not be able to keep up effectively. In addition, the original scanning table provided in the Neurologica scanner was not long enough, and the vendor had to later provide a longer table to meet the needs of Cook County.

To have the team become familiar with the new CT scanner, the team compared X-ray images and PMCT images from traffic accident-related cases. Radiology support is crucial to scan interpretation, but pathologists need training. The Cook County Medical Examiner's Office is currently using contract pathologists to help with their drug overdose cases. CT scanner maintenance is performed yearly with plans to replace it by the 5- or 6-year mark to align with the progression of technology.

Key Lesson Learned

Not all CT scanners are optimized for PMCT application; mobile CT scanners offer flexibility but may not align to the needs of MEC offices with high caseloads.

33. Cook County Government. (n.d.). *Medical Examiner's Office*. https://www.cookcountyil.gov/agency/medical-examiners-office

Los Angeles County successfully implemented PMCT using a trailer when their existing facility lacked the appropriate space.

Dr. Odey Ukpo is the Chief Medical Examiner of Los Angeles County, California, Department of the Chief Medical Examiner-Coroner.

The Los Angeles County Department of the Chief Medical Examiner-Coroner (DMEC) is one of the largest medical examiner's offices in the country with an annual volume of approximately 12,500 cases. In 2015, the DMEC sought out CT scanning to supplement traditional autopsy in their community, with special consideration that the technique could provide value to the county's large Jewish population who may have religious objections to traditional autopsy. With grant writing and funding support from Los Angeles County Board of Supervisors and the Agudath Israel of California, the DMEC obtained a 16-slice Phillips stationary CT scanner. As Los Angeles County could not accommodate housing the CT scanner in their existing facility because of space constraints, they configured a trailer with the CT scanner and connected the scanner through office's pre-existing online database.

With this scanner, the DMEC scans approximately 12–15 cases per day, with each case including full head to shin body coverage. The county scans cases of blunt trauma, all homicide cases, and any cases that have an initial undetermined COD. DMEC performs all imaging analysis in house by pathologists but leans on a network of radiologist consultants for special cases. Dr. Ukpo highlighted some of the main challenges that offices struggle with today:

- **Choosing the right scanner.** Table travel and bore size were key decision factors; the 200-cm table travel and large bore that came standard with their machine have proven sufficient. However, DMEC would consider upgrading to a machine with 64-slices or greater to overcome overheating issues that have been observed with the 16-slice machine.
- **Data analysis and storage.** DMEC opted to save data using a pre-existing hospital-wide server instead of a dedicated PACS system. Dr. Ukpo has found this integration useful because the county can use a pre-existing database and software that is common among the hospital and allow permissions for doctors in the system to view the images through a secure portal.
- **Personnel.** When the county began using CT, they found that having a radiologic technologist was useful for learning the system and optimizing the machine; however, they have since found that the county can also operate the machine with staffed autopsy technicians. This has proven to be more than capable for the needs of the county. It must be further noted that either radiologic technologists or autopsy technicians can be incorporated into CT operation.

To date, the DMEC scanner is about 7 years old, and the county is planning to update and replace it. Dr. Ukpo noted that a strong maintenance plan and dedicated funding to renovate permanent housing will be strong considerations in the process.

Key Lessons Learned

1. Software compatibility should be considered to negate security concerns. Older scanners might run on Windows XP or older and may not be compatible with new operating systems.
2. Although purchasing a CT scanner is an expensive project, there are multiple funding sources available. Sometimes offices need to think outside of the box to be able to acquire the correct funding, as Los Angeles County did with their grant-funded purchase.

Travis County explored several PMCT data management options, including cloud storage, and emphasizes the value of leveraging departmental IT support.

Dr. Lauren Edelman is a forensic pathologist and Deputy Chief Medical Examiner at the Travis County Medical Examiner's Office (TMCE).

TCME moved into a new facility in 2018. As the department was in the design phase of planning, they chose to incorporate the CT scanner concomitantly with the construction of the building. In the Request For Proposal (RFP) process, Travis County was specifically looking for a scanner with a large, wide-bore, extended bariatric table and dual energy that could allow the device to be used for higher-level research application beyond everyday case work. Ultimately, Travis County selected the GE Revolution Evo, which they use to perform full-body imaging on nearly all of the roughly 3,000 cases that TMCE examines per year.

Dr. Edelman uses her experience implementing and using PMCT to teach new laboratories and organizations on the best ways to implement CT into their own workflows. Dr. Edelman highlighted some of the main challenges that offices struggle with today:

- **Data management.** Traditionally, PACS systems used to store DICOM images outputted from PMCT could be very expensive. Not every organization has the funds to spend on the additional purchase of a ~$200,000 PACS unit, and many organizations choose not to purchase high-quality systems for storage. Dr. Edelman notes firsthand experience storing images to a cloud-based server but acknowledges that a dedicated PACS is the current preferred option for some organizations. Long download times and self-developed data management may lead to lag periods in data retrieval, although cloud-based data storage and viewing space is evolving rapidly and will likely present a compelling alternative in the near future. Even if returning to old files is not a daily practice, organizations never know when a medical examiner may need access to previous records. Making sure that the files are accessible quickly on an up-to-date storage and viewing platform helps speed up the process and makes the files available in case they are needed for future reference or court.

- **IT support.** Travis County upgraded from their original local server in favor of a cloud-supported system that saves all images to the cloud. This is beneficial when IT staff are unable to support the specialized data management needs of PMCT. However, it can be troublesome to troubleshoot the system with an off-site vendor. Dr. Edelman also had to learn how to develop the system from the ground up to meet the needs of the TCME and ensure that all parts of the imaging workflow communicate together correctly. One solution involves building an internal PACS (rather than purchasing an expensive PACS from the hardware manufacturer) using imaging viewing software attached to server boxes for data storage and viewing capabilities. Although cost-effective, this may present logistical issues and require close coordination with departmental IT. A cloud-based data storage and viewing system is likely to provide a turn-key, plug-and-play solution to data management for medical examiner offices looking to implement PMCT, although it comes at an ongoing cost to the department.

Key Lesson Learned

Although it is important to purchase the equipment matching the organization's proposed use case, the device's utility will ultimately come down to how knowledgeable the staff is about the purchased system and how well the organization is equipped to support the CT system. Seeking the advice of medical examiners and laboratories that have previously implemented PMCT scanning is incredibly valuable in making sure that an organization considers all necessary factors for implementation.

Hennepin County emphasizes the importance of incorporating the costs of obtaining and housing a CT scanner into a larger facility upgrade budget.

Dr. Andrew Baker is a Chief Medical Examiner at Hennepin County Medical Examiner's Office in Minnesota serving Hennepin, Dakota, and Scott counties.

In 2013, the Hennepin County Medical Examiner's Office began planning to implement PMCT into their workflow. In 2021, the county moved into the new facility built with CT capabilities in mind. The county selected a Canon Aquilion scanner because it allowed them the most flexibility and functionality. After purchasing, Canon sent radiologic technologists to train Hennepin County staff on correct machine operation. Hennepin County purchased an upfront 1-year original purchase plan and ultimately upgraded to a 5-year extended warranty for annual service and maintenance. Dr. Baker emphasized the value of the annual service plan for their $1 million instrument, as the manufacturer can directly replace malfunctioning parts (removing the need to find expensive aftermarket replacements).

Today, Hennepin County uses CT imaging for two to three cases per day and estimates that the county performs about 700 CT scans per year. In a typical workday, Hennepin County begins by assessing all intakes to determine which cases will proceed with PMCT. Although there are many case types that Hennepin County may image, the most common include ballistic and blunt trauma. Imaging can usually be performed before 9 AM, such that the county can immediately follow imaging with autopsies. Hennepin County completes all image analysis in house using a team of about eight pathologists. Hennepin County has also found great value in bringing in a staff pathologist who trained in PMCT imaging interpretation in New Mexico.

Hennepin County tries to stay at the forefront of innovation, monitoring the latest technologies and imaging techniques. To help strengthen analysis and workflow, Hennepin County has considered implementing the following:

- **Advanced analysis software.** For medical diagnosis, various artificial intelligence software programs and analysis packages exist for making rapid decisions and improving the reconstruction accuracy of captured images. These techniques have yet to be widely adopted in the forensics space, but Hennepin County expects these technologies could provide improvements in COD analysis, particularly in offices with limited staff capabilities.

- **Three-dimensional printing.** Though still in its infancy, a few counties have begun adopting three-dimensional printing to help visualize the results. CT scanners will be able to directly output images that are ready by a three-dimensional modeling software that can print replicas of various body parts or injuries. This technique is useful as a tangible visual representation of a lesion or injury if a case is presented in court and may be more appropriate to show a jury.

Key Lesson Learned

In an ideal scenario, counties should be looking to purchase their CT scanners with a larger infrastructure purchase. This is not always possible given a county's individual operating budget, hospital affiliations, or political support for the project. If a county decides to retrofit a CT scanner to an existing space, counties should look toward purchasing refurbished models or a used CT scanner from a nearby hospital to keep costs low.

PMCT has the potential to support MEC offices with staffing and contribute to backlog reduction.

Dr. Christopher Liverman is a forensics practitioner and Chief Medical Examiner for the city and county of San Francisco, CA.

San Francisco purchased a Siemens CT scanner in 2017. Annually, the San Francisco's OCME processes approximately 1,500 cases.[34] With this purchase came a new building proposal to maintain accreditations. San Francisco county has strict purchasing requirements that required an RFP bid proposal process to be submitted to secure the best value on a scanner.

As the CT scanner was purchased and implemented, Dr. Liverman acknowledged that there was a learning curve to gain the most benefit out of the scanner. Key considerations that improved scanning efficacy included the following:

- **Staffing.** PMCT was not as universally accepted back in 2017 as it is today, and it was challenging to find people who could operate the scanner and analyze images. Although it was underused at the beginning, the county slowly understood the personnel needed for their workload requirements. Currently, San Francisco has a part-time analyst who is trained in the technical aspects of the imaging and how to position bodies for informing future autopsy. San Francisco uses the CT scanner for roughly a quarter of their cases to increase autopsy efficiency. Although the county would like to incorporate more imaging capabilities, it has been challenging with recent staffing practices.
- **Access to key CT features.** Improvements in CT processing have helped maximize CT scanner output. Understanding how a CT scanner builds multiple reconstruction is critical. Additionally, having the software capabilities to develop three-dimensional projects for dental imaging, lung contours, and bone projects has been very useful for the county and is informative to COD.

Dr. Liverman stays abreast of the newest technologies and is always planning on new ways to improve their workflow. The office sees their investment in a CT scanner as a 10-year expenditure that will ultimately need to be replaced with a newer model. CT scanning has substantially improved their workflow for cases of drug overdoses, a common case type that has increased several-fold over the past few years. In a future technology, Dr. Liverman hopes to find a scanner that can take images as cleanly as a Lodox for cases such as foreign object location of bullets. Although their current scanner can take images, an increased slice count and faster reconstruction speed may help the agency offset the longer time to acquire CT scanning compared with Lodox.

Key Lessons Learned

1. Staffing is critical in operating a CT scanner. Although an organization does not need an entire team of radiologists to interpret images, a core team with experience and hands-on training is needed.
2. CT imaging has the potential to help offset an organization's staffing problems; however, the overall workflow processes must be considered in totality.

34. Office of the Chief Medical Examiner. (n.d.). FY19-20 Annual Report.

Glossary

For this document, the following terms are defined:

Cause of Death (COD): The determination of the condition that results in an individual's deaths.

Computer Tomography (CT): An imaging modality that uses X-rays to generate cross-sectional images of a subject's body.

CT Angiography: The use of CT imaging in combination with a contrast dye to visualize blood vessels and tissue.

Digital Imaging and Communications in Medicine (DICOM): File type for medical files that contain imaging information derived from CT imaging.

Manner of Death (MOD): The determination of how the injury or diseases occurred (types include homicide, suicide, accidental, natural, or undetermined).

Medicolegal Death Investigation (MDI): Investigations performed by medicolegal teams that identify the scope and course of a death investigation.

Picture Archiving and Communication System (PACS): Systems incorporating hardware and software designed specifically for storing, viewing, and sharing medical images.

Postmortem Computed Tomography (PMCT): The use of CT imaging to aid in postmortem examination.

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