NAME Interim Meeting 2019

Nuts and Bolts of a PMCT service

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State of Maryland

NAME Interim Meeting 2019

Nuts and Bolts of a PMCT service

What kind of CT scan machine ?

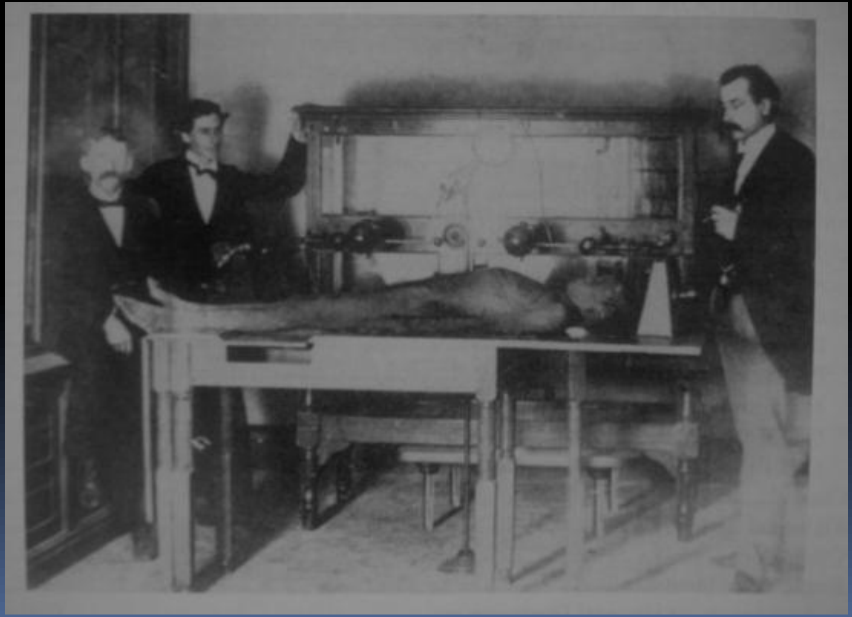
3D Workstations & PACS system ?

Interpretations by who - Radiologists or MEs?

And a (good) few other essentials…

Background

- Long history of imaging in forensic medicine
- 1898 – first forensic use of X-Ray in U.S.



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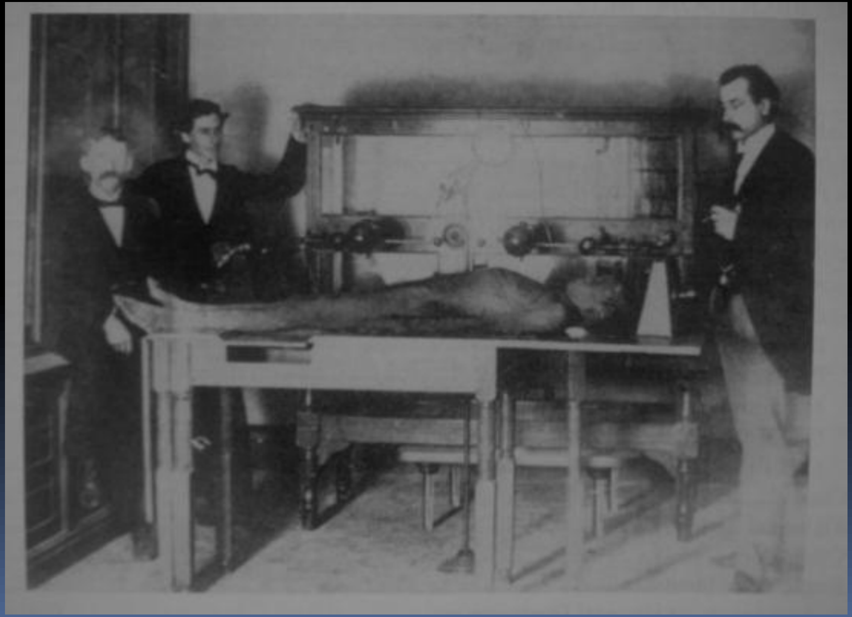


Little change in next 100 years

Development of Whole Body CT

- 1977 - First report of Forensic CT study
  - Ballistics in Brain
- Late 1990s - Development of Faster CT scanners
  - Interest in concept of “Virtual Autopsy” develops
- 2000s - Multi-detector scanner era
  - High resolution whole body CT becomes a reality

Development of “Virtual Autopsy”

- Late1990s - 2000s
  - Interest in concept of Virtual Autopsy develops
  - High resolution whole body postmortem CT (PMCT)
  - Focused postmortem MR (PMMR) in adults
  - Whole body postmortem MR in small children
  - Postmortem CT Angiography (PMCTA)

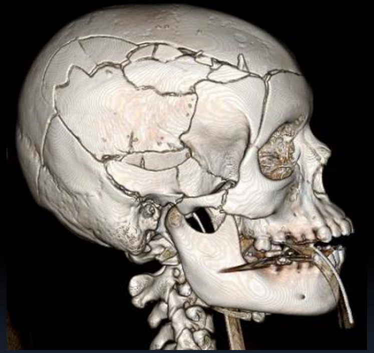
Terminology Issue:

“Virtual Autopsy” versus PMCT, PMMR, etc ?

- Concept of Virtual Autopsy may include:
  - PMCT
  - PMCTA
  - PMMR
  - Postmortem imaging-guided (CT/US) minimally invasive autopsy
  - *FOR CLARITY STICK TO SPECIFIC MODALITY*

"Virtual Autopsy"

- First developed at the University of Bern, Switzerland in 1995-2005 period
- Collaboration of Forensic Pathologists/ Medical Examiners (MEs) & Radiologists to introduce advanced imaging into routine forensic medicine practice
- CT first, PMMR and PMCTA introduced later
- **U.S. Research Initiatives limited**
  - ***Military:*** AFIP Dover AFB
  - ***Civilian:***
    - University of Maryland
    - University of New Mexico



- Now many other Centers throughout Europe, Australia, Japan, China, S. Africa ***and growing…***
- ***<u>PMCT widely used, other techniques much less so</u>***

International Society of Forensic Radiology & Imaging (ISFRI)

Applications of PMCT

- Blunt trauma
- Penetrating trauma
- Unidentified body
- Suspected NAI in young children
- Suspected Elder abuse
- Drowning
- Unknown cause of death
- Suicide
- Contraband
- Anthropology
- Historical Investigations
- Decomposition
- Burns

Nuts and Bolts of a PMCT service

What kind of CT scanner ?

PACS system/archive ?

Interpretations ?

And more…

What kind of CT scan machine is needed ?

- Number of Detector rows/slices (= speed)
  - 4 – 640 available
  - 16 slice adequate for most PMCT work
  - No moving body parts – scan whole body in 5 minutes
  - Generates 3,000+ images within 5-10 minutes
  - Look for CT scanner with large bore (80cm) and scan length 2m
- Single or Dual Energy (kV) ?
  - Single energy $250K+
  - Dual Energy $1M+
    - Not necessary for PMCT
- New or Used ? New not much more $$ for smaller capacity machines

16 detector row CT scanner @ Maryland OCME

80 cm bore

2 m (6 ‘ 6”) table length

What about Maintenance/Tube replacement Costs?

- Preventive Maintenance needed:
  - Maintenance contracts are not cheap (up to $100K annually)
  - X-Ray tube very expensive ($100K+), unpredictable lifespan
  - Get contract for next business day – not 24 hours for better deal
  - CT vendor usually provides, or third party operators

- Advice is available:
  - Local Hospital Radiology centers
    - Good advice on best vendor for sales and service locally
  - Regional Academic Radiology departments
  - MEs at other centers who got started in PMCT earlier
  - Independent consultants who can help set up all aspects of acquisition

What about Installation of the machine?

- New or Refurbished space ?
  - CT Vendor will work with construction contractors
  - Vendors usually have long experience with installations
- CT room should be close to dissection rooms
- Reading room for CT interpretations ideally nearby
- Scan data may be transmitted rapidly via the internet
  - Readings may be done off site without any delay

CT Angiography 1

Allows evaluation of major vessels, coronaries, vertebrals

Recent results encouraging:

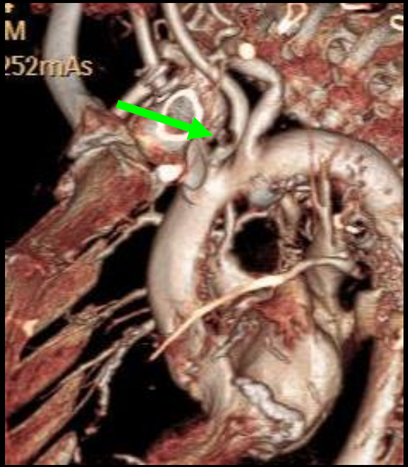
Postmortem CT/CT Angiography Compared with Autopsy:

A Forensic Multicenter Study , Grabherr et al,

(Radiology 2018)

- 500 cases (18 654 findings)
  - Autopsies identified 61% (11 433 of 18 654)
  - Postmortem CT identified 76% (14 179 of 18 654
  - Postmortem CT angiography identified 90% (16 780 of 18 654).

Potential for accurate non-invasive diagnosis in natural death, but not always cheaper



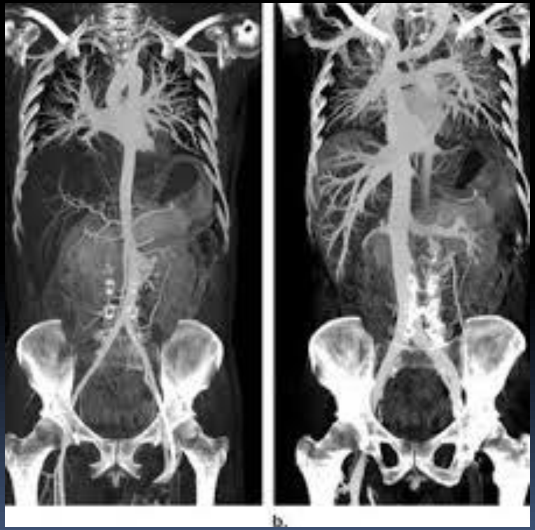
Grabherr et al, PM Coronary Angiography, 2016

CT Angiography 2

Relatively complex process

- Need pump injector to do major region or whole body
- Dedicated equipment available but expensive
- Old medical grade equipment can work
- Can work with hand injection of contrast also
  - Stand at side of machine (no scatter !)

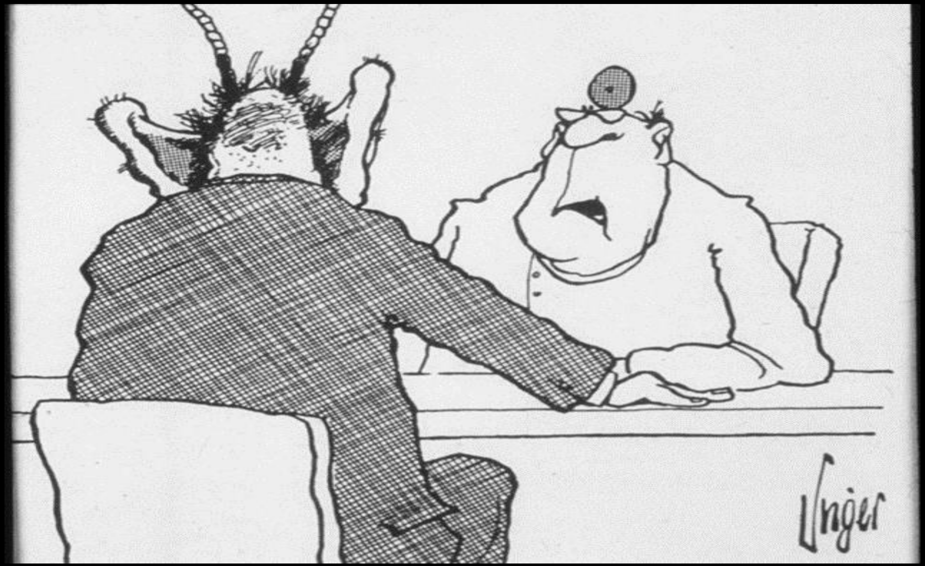
- Contrast dye
  - can use out of date contrast from hospital
  - Need to add glutaraldehyde to avoid leak into tissues
  - Barium works also - cheap
- Access from femoral arteries
- Intra or post autopsy allows easier vascular access



Ross et al, PM Angiography, 2014

CT - Radiation Safety

CT has potential for high dose to machine operators and workers in adjacent offices

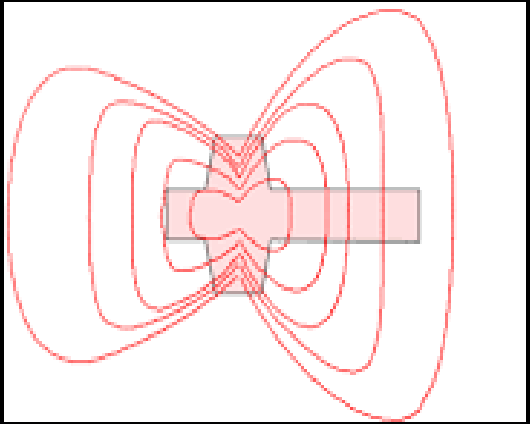


"If you remember I did mention possible side-effects"

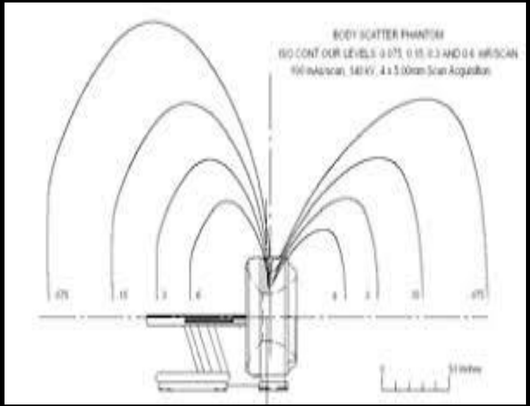
Radiation Protection for PMCT Rooms

- Protection of CT operator and workers in adjacent offices
- Shielding must protect against high energy x-rays
  - Up to 140 kVp
  - More scattered radiation than for regular x-ray machines
- May require lead/concrete shielding for walls/ceilings in the scan room
- Distance from radiation source important:
  - X-ray scatter decreases rapidly with distance from the machine
  - Large scan room means less shielding
- CT machine operator has a lead-lined console in scan room

Radiation scatter from CT machine



Scatter distribution in room
Top view



Scatter distribution in room & through ceiling
Side view

Radiation Scatter Around CT Machine

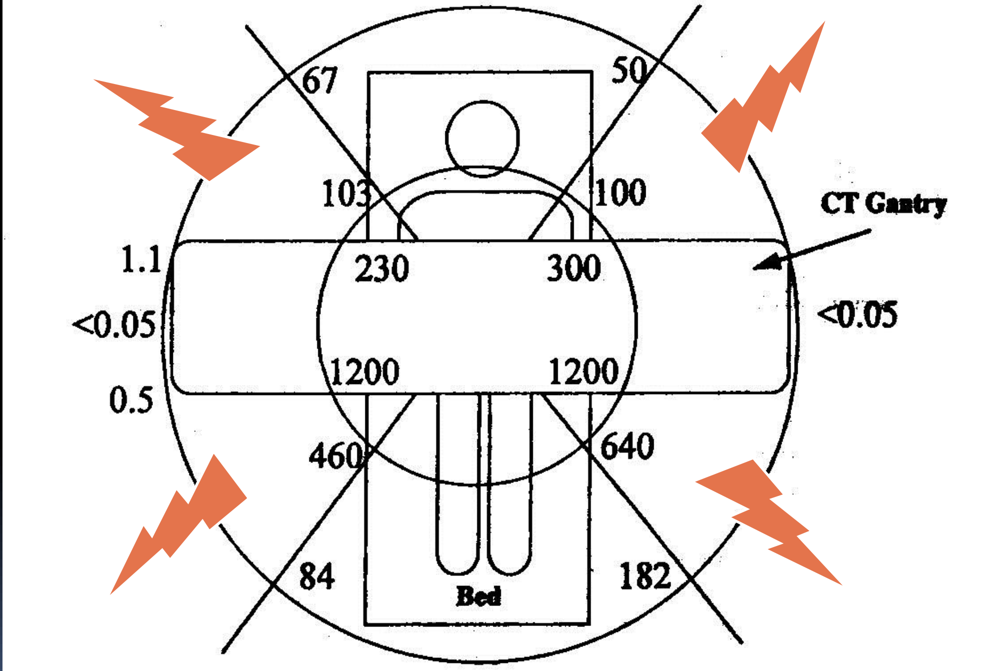
- Rotating Geometry increases scatter

Lowest doses:

1. At head end of scanner

2. With increased distance from gantry (Inverse Square Law)

3. At side of gantry



(mR/hour) (from Mellenberg et al., 1999)

Radiation Protection for PMCT

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- CT machine operator has a lead-lined console in scan room
- CT vendor will advise on construction needs

Radiation Protection for PMCT

- CT machine operator has a lead-lined console in scan room
- 1.2 mm lead
- Operator has risk of higher dose from scatter due to length of time spent at console

- Room reconstruction and radiation shielding setup can cost $50K+

PACS (“Filmless” Radiology) System

- Picture
- Archiving
- and
- Communication
- Systems

Baltimore VAMC:

Worlds first all PACS hospital

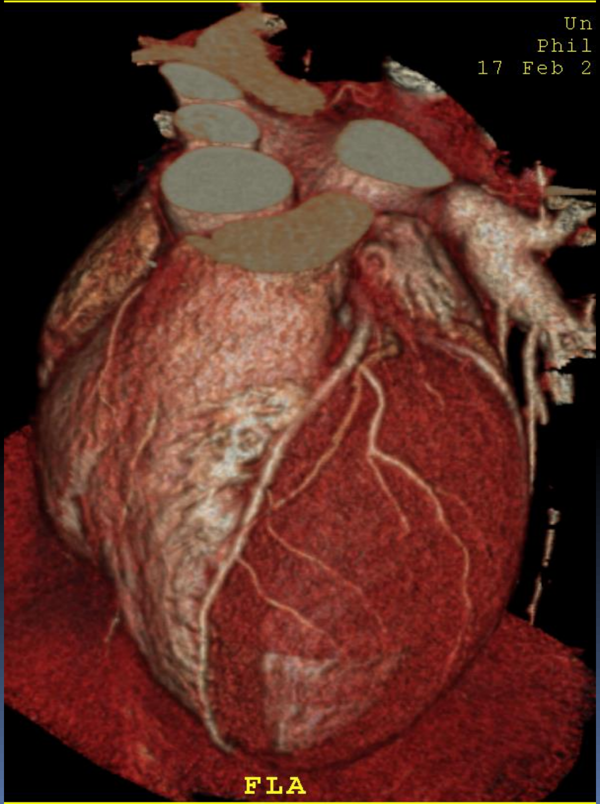
Total storage capacity in 1993 0.5 TB

PACS System

The PACS equipment must have adequate capacity and be fast enough to efficiently deal with the projected volume of studies & images

- An adult whole body PMCT typically generates 3,000-5,000 images
- Using high resolution thin slices with image generation in multiplanar transverse, frontal, and lateral planes and volume rendered or MIP 3Ds

Cardiac CT Angio for evaluation of chest pain - 16 row CT generates 3D from >2000 0.75mm slices



Functions of PACS System

- For 3D image generation
  - May have independent 3D software or built into PACS

- For image display and interpretation
  - For both onsite and web-based CT study readings
  - Typically scans can be viewed on many PCs at same time on a local area network within office/department and/or on internet

- For image data storage
  - Long term digital image storage and backup (preferably offsite) necessary
  - Data may be stored for many years based on local regulations

PACS - Web or Local Area Network based

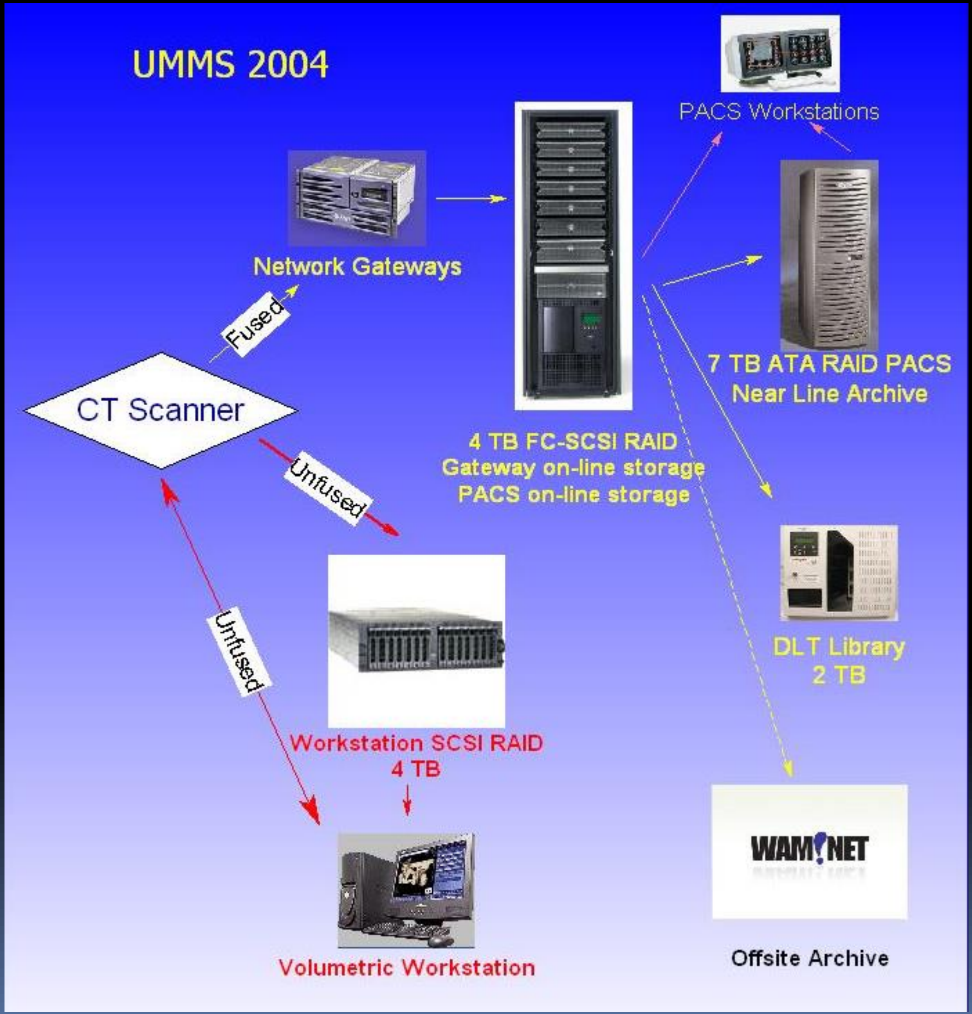
By facilitating synchronous access to multiple separate users on a Web or LAN basis, PACS allows for remote interpretation and consultation on PMCT studies

Some vendors of CT machines also manufacture PACS equipment, and may offer discounted costs for the joint purchase of both these major pieces of equipment.

Such systems must be coupled with 3D image generation software including a broad set of advanced tools for the generation of multi-planar images of the body.

The cost of a web based mini-PACS with remote access suitable for most PMCT systems users (5 users at a time) is in the US$250,000 range.

Storage Architecture



3D Image Generation

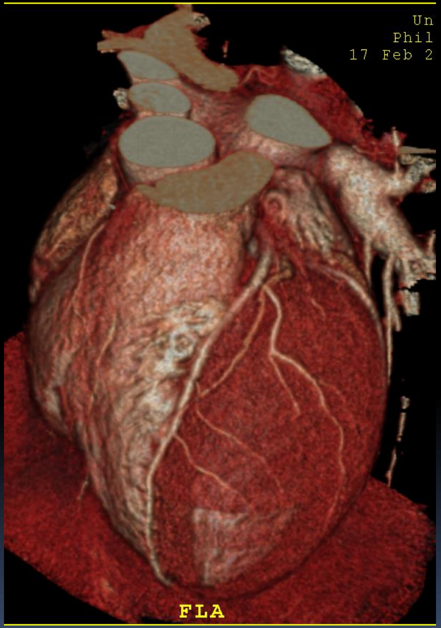
May have Independent 3D workstation or software built into PACS

3D may be used to show complex anatomy/provide overview

Can make the main findings stand out – more easily seen by the untrained eye

BUT - Can mask important details

3Ds are based on original thin section axial image set – always need to review thin section images first to ensure important details are not overlooked



Who will do the scanning ?

- Operation of a medical CT scan machine is typically performed by a CT technologist
    - cost of such a service especially on a 24/7 basis is considerable

- Training of mortuary technologists to generate PMCT scans now in use
    - Mortuary technologists often on duty 24/7
    - Have training in radiation safety
    - Can perform technically satisfactory PMCT scans using a very limited number of standard protocols
    - Should be supervised by an experienced CT technologist who provides both training and QA
    - Use will be dictated by local statutory radiation, occupational health and safety, and other legal requirements
    - In some jurisdictions, only credentialed CT technologists are allowed to operate a CT scan machine

- In other countries, Radiologists and MEs may run the CT scanner !

Who will interpret the PMCT studies ?

Experience to date varies by country/jurisdiction:

- Option 1: Medical Examiners
- Option 2: Radiologists
- Option 3: Mixture of 1 & 2

Where forensic medicine is funded on a national basis, Radiologists are more involved

- Local Hospital Radiology centers
- Regional Academic Radiology departments

Where funding is limited, Medical Examiners may read their own studies

- Ideally will have access to Radiology consultation

PMCT Interpretations – Needs in USA

- Establishment of a cohort of trained forensic radiologists and/or forensic pathologists who can interpret PMCT scans on a daily basis
- One logical approach suggests the establishment of regional forensic imaging centers based in major academic radiology (or forensic pathology) departments throughout the USA
- Medical Examiner's Offices equipped with CT scanners would transmit PMCT studies through secure intranet pathways to their regional interpretation center and receive timely, high-quality interpretations by expert readers
- Many night-time clinical CT studies at U.S. medical centers are already transmitting to day-time Australian reporting centers for this purpose. Economics of scale could allow dedicated regional forensic imaging centers to be financially self-sufficient.

Conclusions - “Nuts & Bolts” of a PMCT Service

- What kind of CT scan machine to purchase?
- Installation of CT scan machine and Radiation protection
- Maintenance and equipment service and contracts
- 3D Workstations & PACS “Filmless Radiology” systems
- Who will do the scanning ?
- Interpretations by who - Radiologists or MEs?

- Costs of CT machine, Installation, PACS, Maintenance ~ $750,000+

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- Costs of CT machine, Installation, PACS, Maintenance ~ $750,000+
- Who is going to pay for this ??

THANK YOU!

Development of a Forensic CT Service in a Medical Examiner Office

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Departments of Pathology and Radiology
Radiology-Pathology Center for Forensic Imaging
University of New Mexico
School of Medicine

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Office of Justice Programs
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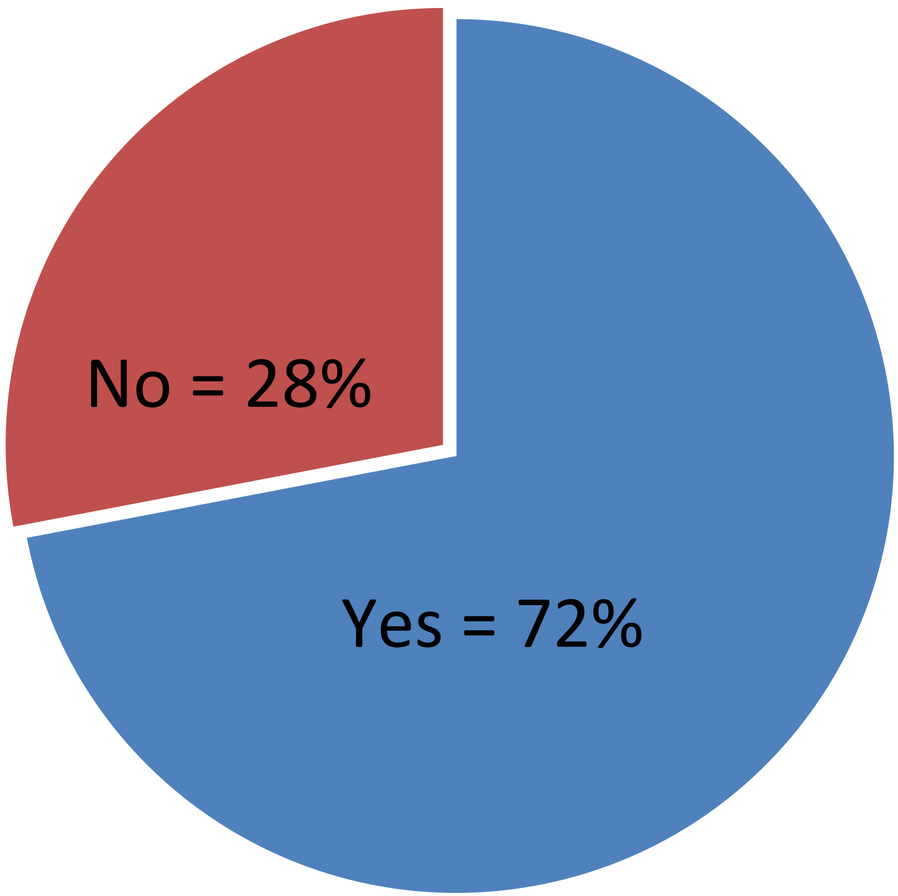
Study data were collected and managed using REDCap electronic data capture tools hosted at the University of New Mexico, supported by **DHHS/NIH/NCRR #1 UL1RR031977-01**

REDCap™
Research Electronic Data Capture

If it is was readily available and affordable, would you integrate the use of computed tomography, (CT) scans into your practice?

2010



Cina SJ. Acad Forensic Pathol 2012 2:150-7


Spy

"A grand hypothesis is not the usual path for the advancement of medical knowledge. As a rule, first comes a new or improved method whose application to a variety of problems sometimes leads unexpectedly to greater understanding."

Frank Kittredge Paddock (1841-1901)

Incorporating CT into Forensic Practice: The New Mexico Story

Office of the Medical Investigator: New Facility

1995 Office of Risk Management review

- $54M potential liability from airborne TB

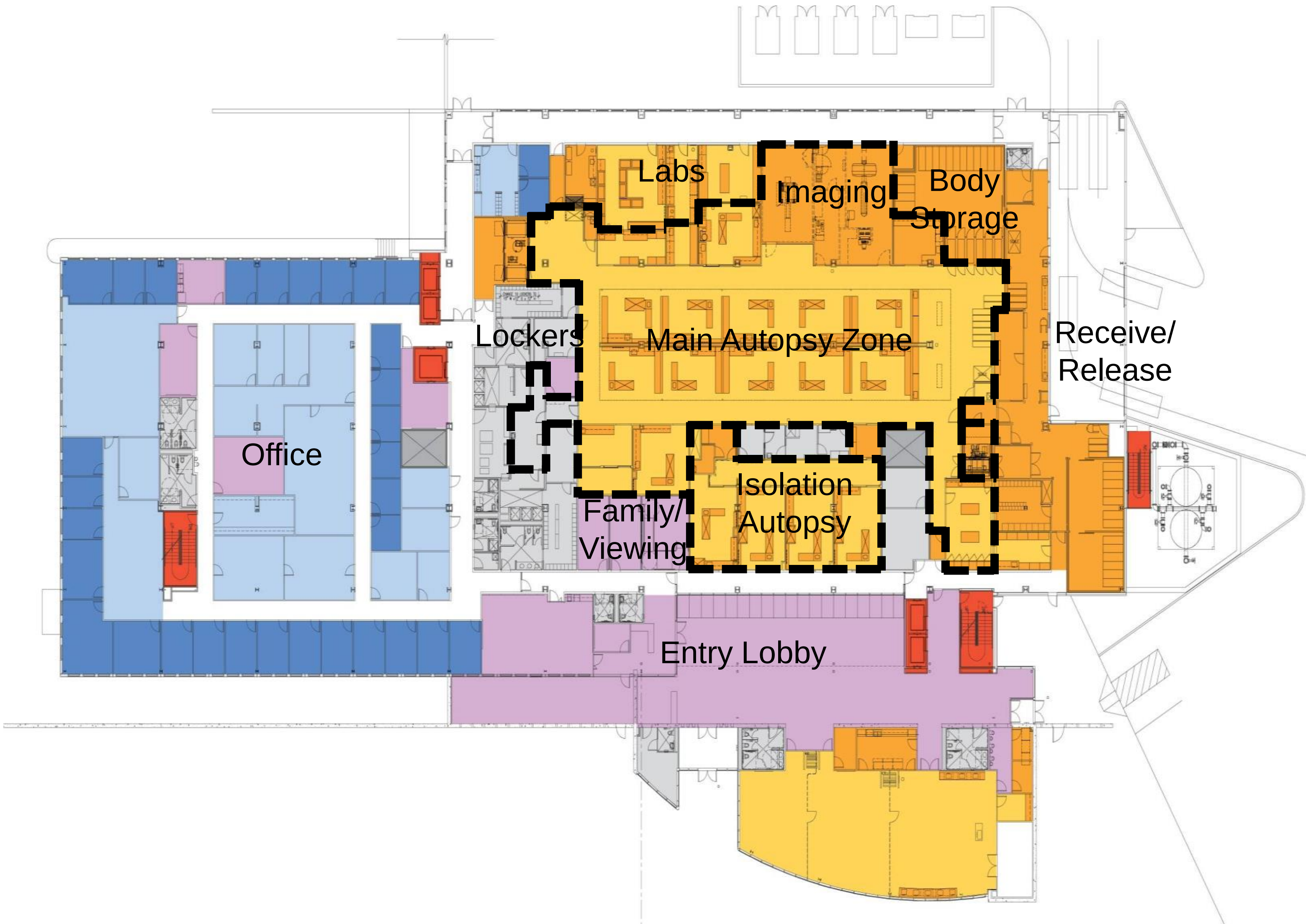
Architect review – ventilation system cannot be remediated to meet standards

Safety + space needs drove political process for new facility

Early Forensic Imaging Research

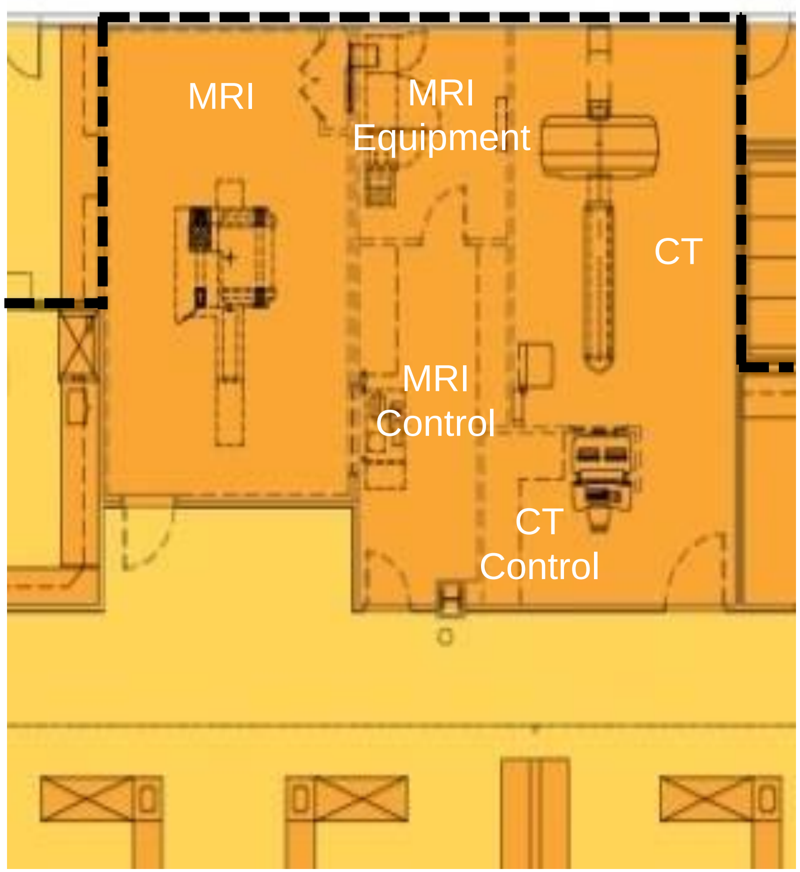
- Gil Brogdon- Father of forensic radiology
- Harris-MRI PM brains for courtroom evidence, 1991
- Hart et al- PM cranial MRI & child abuse, 1996
- Patriquin- PM whole body MRI, 2001
- Virtopsy Group, 2000s
- Armed Forces Medical Examiner, 2000s

Overall Diagram



Imaging

CT and MRI



16 slice CT

1.5 T MRI

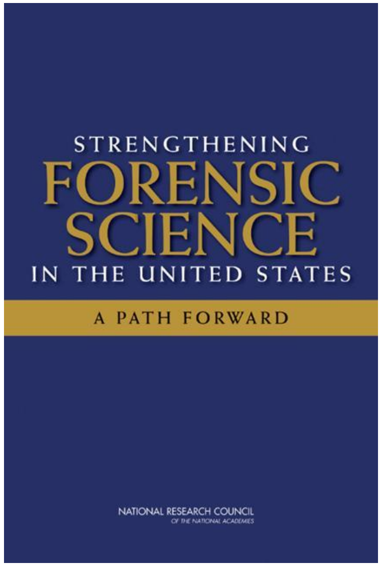
Purchasing a CT Scanner

- Competitive RFP
- Need expert help
- Philips Brilliance Big Bore 16 slice scanner
- $500K
- PACs $5/case


NEW MEXICO SCIENTIFIC LABORATORIES

NAS Report

- "Currently, little research is being conducted in .. forensic pathology in the United States."
- Advanced imaging technology should be further studied.



National Research Council. Strengthening Forensic Science in the United States: A Path Forward, 2009

Postmortem Imaging Research

- European/Australian forensic centers & US military
- Small studies: case reports and series
- Inconsistent evidence
  - Recognizing injuries
  - Identifying cause of death
- Large uniform prospective blinded studies- absent

Why is it important to evaluate this technology?

- Supplant autopsy
  - Reduce autopsy numbers and costs
  - Address shortage of forensic pathologists
  - Decrease biosafety risks
  - Honor cultural/religious wishes for no autopsy
- Supplement autopsy
  - More complete diagnostic information
  - Better courtroom illustrations

NM OMI Research Assets

- Statewide centralized academic ME office
- Radiology, physics & other collaborators
- 2100 autopsies/year
- State-of-the-art facility with 16 slice CT scanner & 1.5 T MR scanner

OMI CT scanner

Utility of Postmortem CT in Supplanting or Supplementing Medicolegal Autopsies

- Evaluate 4 subsets
  - Blunt force injuries (200 cases)
  - Firearm injuries (200 cases)
  - Drug poisoning deaths (460 cases)
  - Pediatric trauma (76 cases)

PI- Nolte

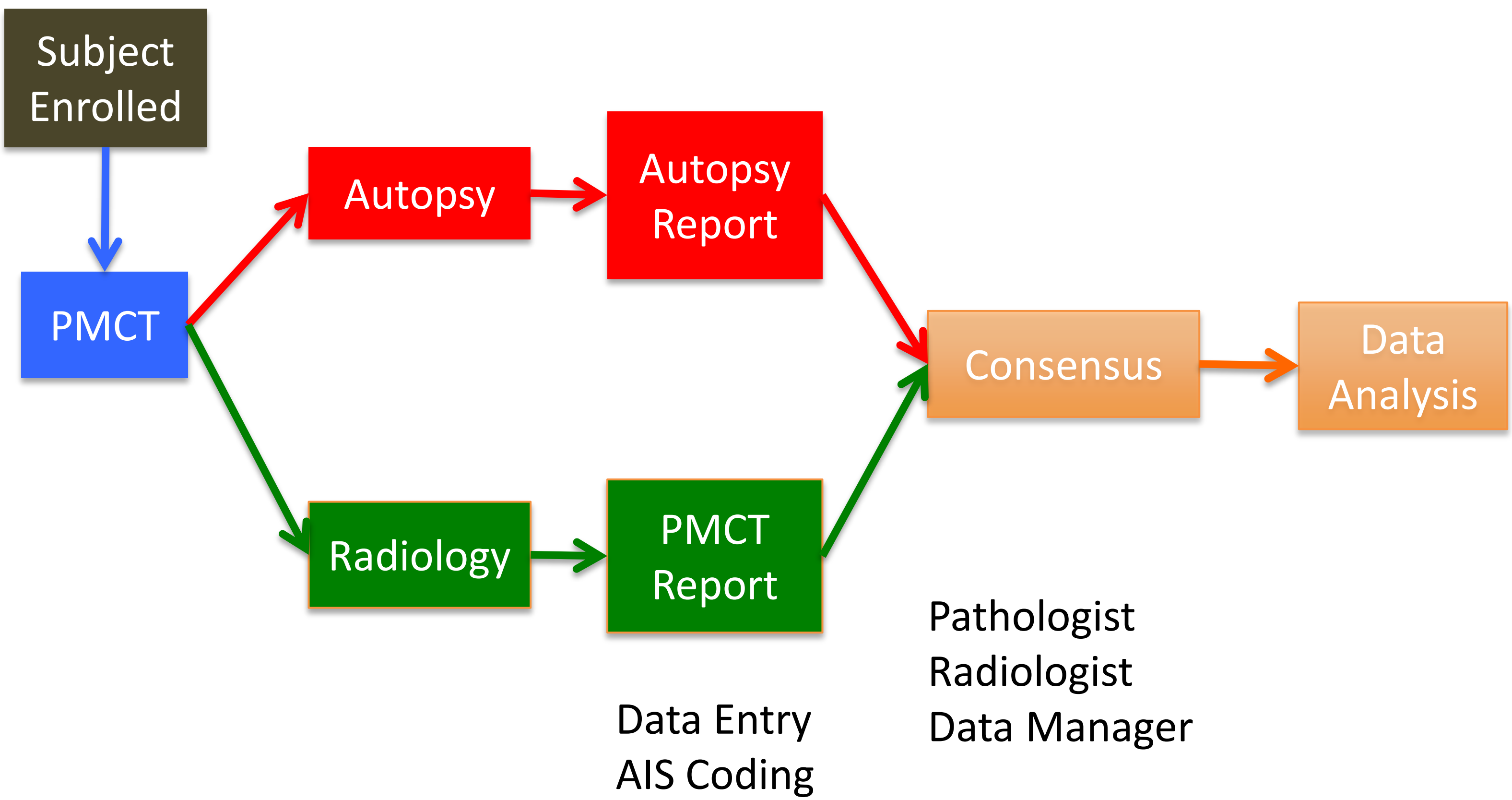
BFI- Hypotheses

- ***Hypothesis***: PMCT can recognize fatal BFIs and identify the COD so that it can supplant autopsy in certain situations (e.g., motor vehicle collisions).
- ***Hypothesis***: PMCT will identify sufficient skeletal & soft tissue injuries outside standard autopsy to justify its utility as an adjunct procedure especially where robust injury characterization is important.

Study Methods

- Prospective- CT all autopsy cases prior to autopsy
- Double blind, radiologists have access to history
- Autopsies- board-certified pathologists
- CT scans- board certified radiologists
- CT & autopsy- AIS certified coder
- Consensus conference
  - Different pathologist & radiologist
  - Congruence comparison- autopsy & CT findings, AIS codes, cause of death statements

Design Overview

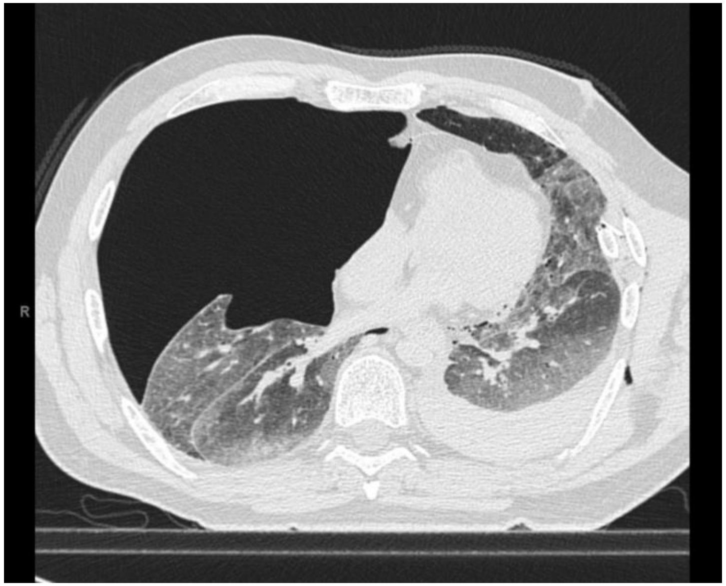


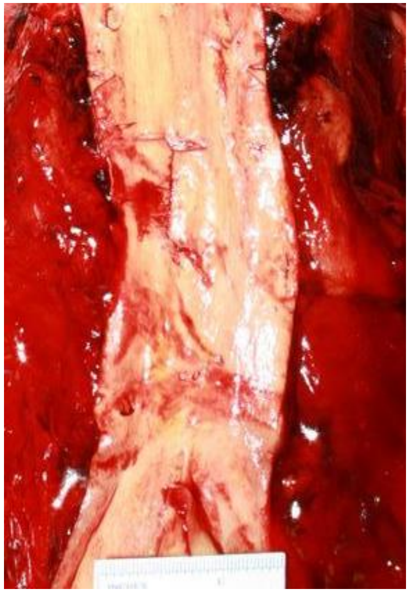
Blunt Force Results

- 126 males, 41 females (total 167)
- Mechanism of injury
  - Motor vehicle collisions (57%)
  - Assault (15%)
  - Pedestrians and bicyclists struck by vehicles (11%)
  - Falls (8%)
  - Other (9%)

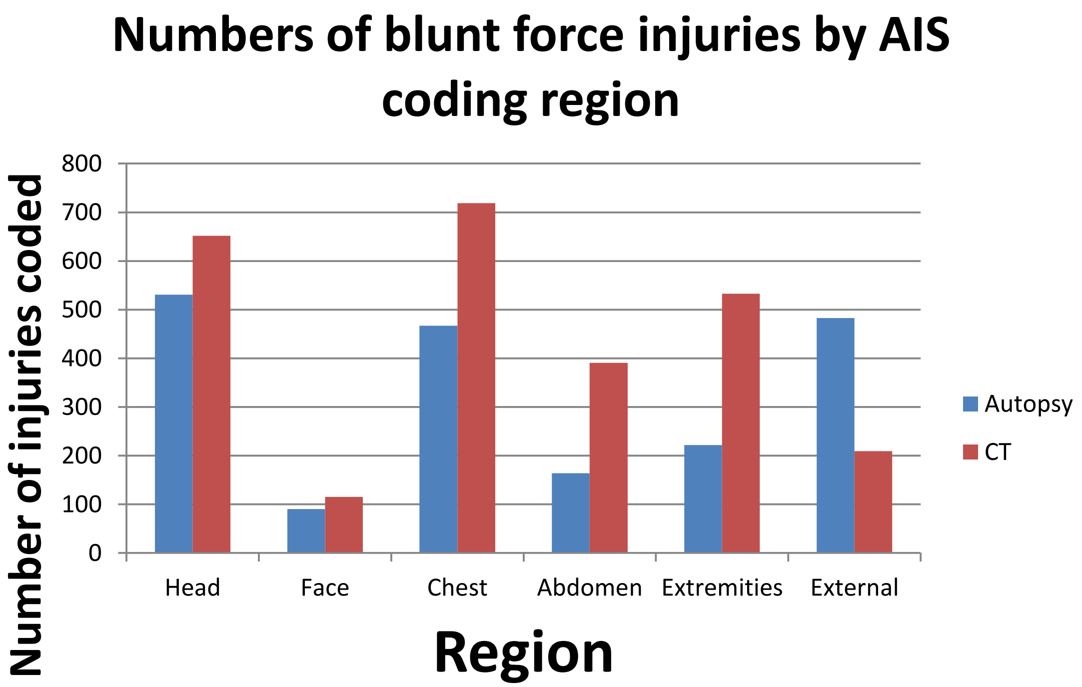
Blunt Force Results

- Total injuries- 3652
  - CT & autopsy- 922
  - CT only- 1700
  - Autopsy only- 1030
- Of total injuries
  - CT discovered 72%
  - Autopsy discovered 53%
- Head region
  - CT- 72%
  - Autopsy- 57%

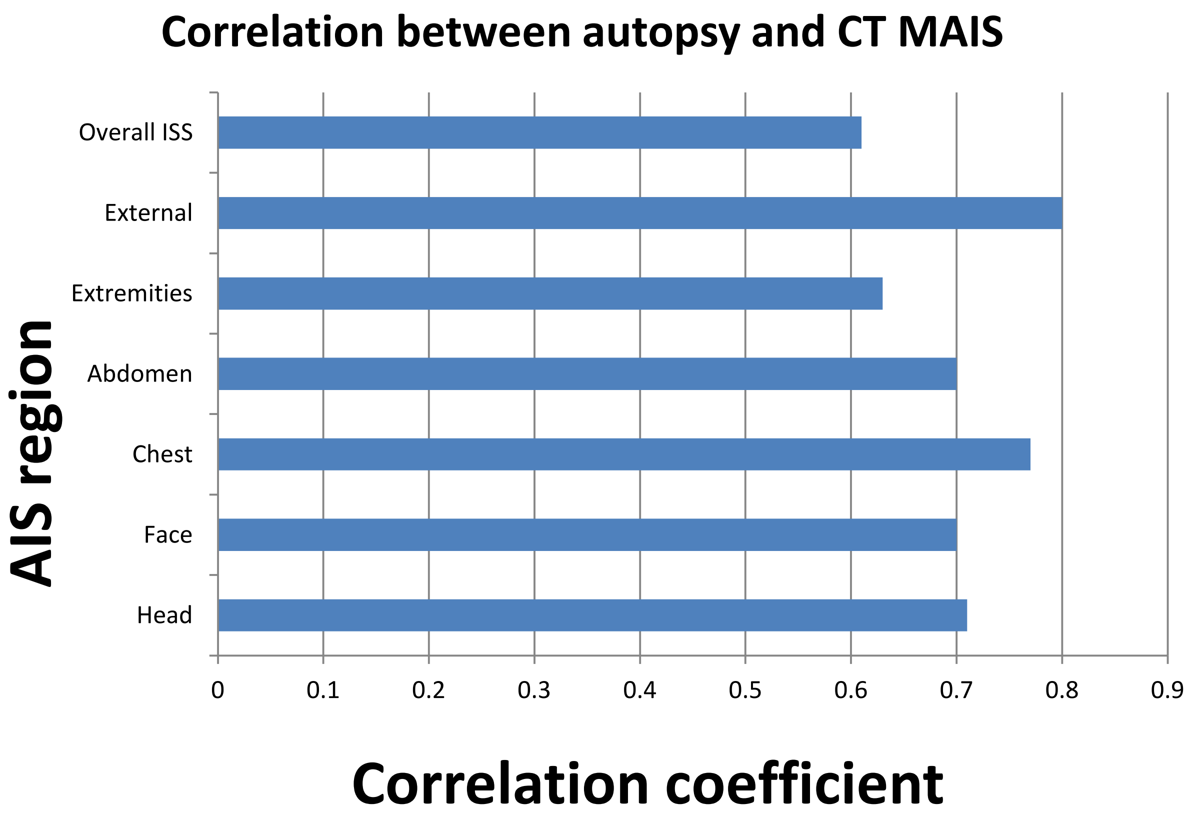




Blunt Force Results

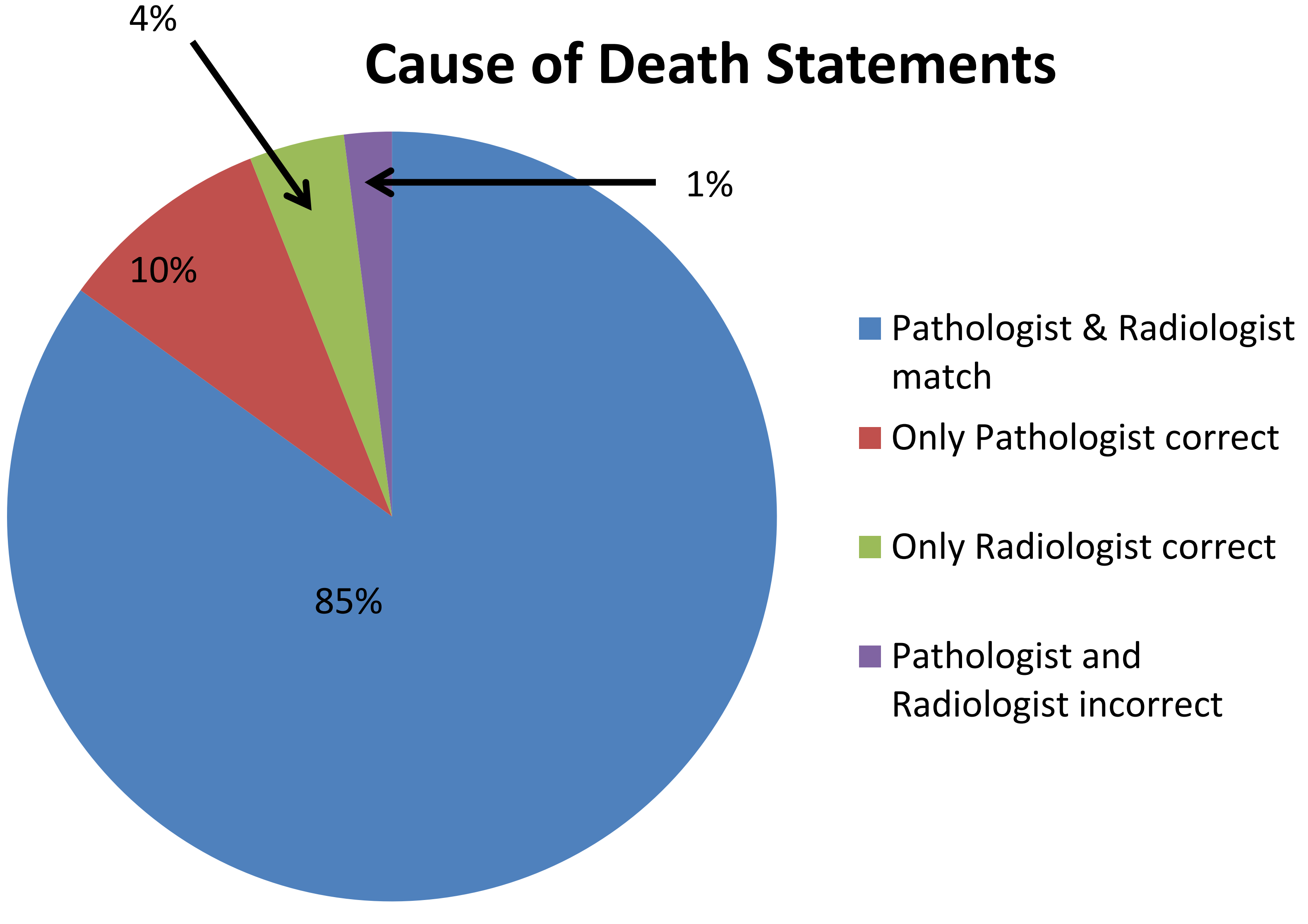


More injuries detected by CT for every coding region except external surface



Correlation between autopsy and CT MAIS
Overall ISS
External
Extremities
Abdomen
Chest
Face
Head
AIS region
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Correlation coefficient

Results


Cause of Death Statements
4%
1%
10%
85%
Pathologist & Radiologist match
Only Pathologist correct
Only Radiologist correct
Pathologist and Radiologist incorrect

Conclusions

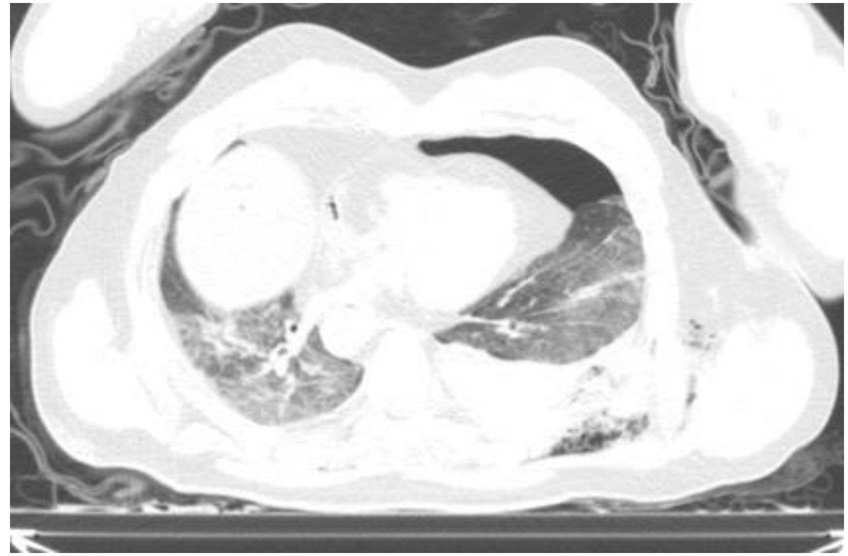
- Autopsy and CT are imperfect & complementary
- Decedents have multiplicity of injured organs & tissues
  - Neither autopsy nor CT discovers all injuries
  - Each process finds sufficient injuries to accurately establish cause of death

*Nolte KB, Lathrop SL, Hatch GM et al. Utility of postmortem x-ray computed tomography (CT) for medicolegal autopsies on decedents with blunt force injuries. IAFS, Seoul, Korea, 2014.

How has our practice of forensic pathology changed?

Morning Case Conference

50 y/o motorcyclist-lost control



65 y/o man found dead after fight

Advanced Forensic Imaging in US

- CT in house- serving 11% of US Population
  - Armed Forces ME
  - NM OMI
  - MD OCME
  - Schuylkill County, PA Coroner
  - San Francisco OCME
  - Oklahoma OCME
  - LA Co Coroner
  - Cook Co, IL OCME
  - Jefferson Co, AL Coroner/ME
  - Travis Co, TX OCME
  - Orange Co, FL OCME
  - Virginia-Western District OCME
- Use of clinical CT
  - Vermont
  - Oregon
  - Georgia
  - Wisconsin
  - North Carolina
  - New York
  - Colorado
  - 3 US military installations
- MRI in house - NM OMI

Obstacles to Implementation

- Scientifically defining areas of utility
  - Courtroom utility of CT illustrations?
    - More comprehensible? Less unfairly prejudicial?

Obstacles to Implementation

- Who acquires images?
- Who interprets images?
- Cost of equipment- no federal funding
- Threat to professional identities: beleaguered autopsy, practice, income

Opportunities

- Cost savings in high volume offices
  - Supplant autopsy with CT + external for 330 cases = 1 fewer FP
  - Victorian Institute of Forensic Medicine*
    - Screening and triage tool- 2005
    - Decreased autopsy volume 15%
- Teleradiology
- Forensic radiology fellowships

*O'Donnell C. Diagnostic Histopathol 16:552-5, 2010

Training Forensic Pathologists in CT Interpretation

Pathologist/fellow training 2011-18

- In house 80% FTE radiologist
  - Lectures & hands-on training sessions
  - Review of CTs for case triage at morning report
  - Case consultations (formal & informal)
- Daily practice on cases

Current Processes

- Fellow Imaging Lectures/Hands-on Sessions
  - Postmortem CT overview & artifacts
  - Gunshot wounds
  - Radiologic identification
  - Natural deaths
  - Spine trauma
  - Blunt trauma
- Remote radiologist case consultations

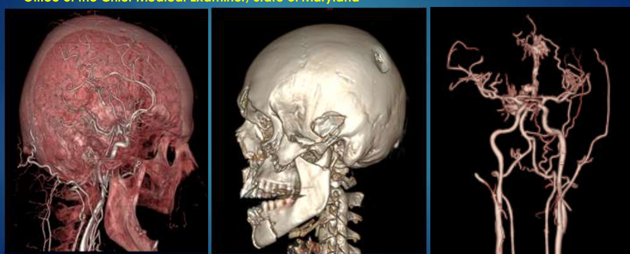
Imaging is transfoming forensic pathology

- Implications for:
  - Throughput & skills needed to practice
  - Training
  - Research

Questions?

Practical Use of Forensic Imaging

Zabiullah Ali, M. D.
Office of the Chief Medical Examiner, State of Maryland



Background

- State-wide Medical Examiner's office
- 15337 cases investigated in 2018, including 5604 autopsies (543 homicides)
- Two imaging modalities: Computed Tomography (CT) and Lodox stat scan
- Who performs the studies?
- Training

Background

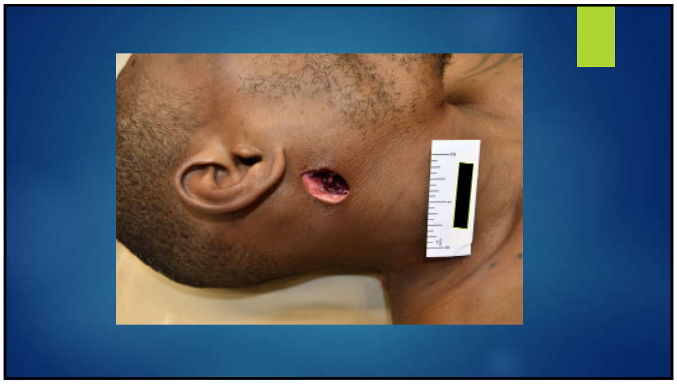
- Interpretation of CT images
- Protocol for CT imaging (BFT cases, MVAs, opposition, pediatric cases younger than 2 years, elder abuse cases, adjunct tool for diagnostic or identification purposes)
- Protocol for routine x-rays (sharp force injuries, GSWs, burned bodies, unknowns)

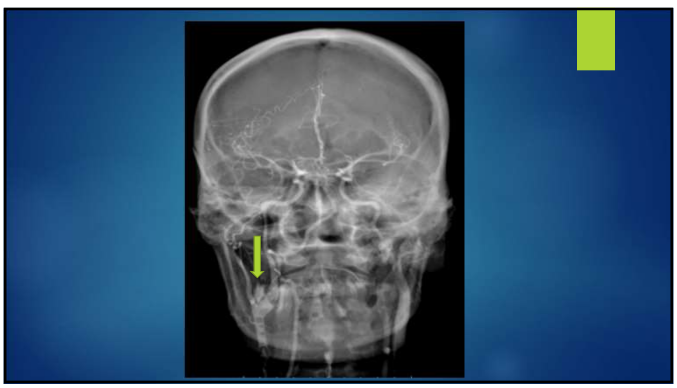
Lodox (Low Dose X-ray)

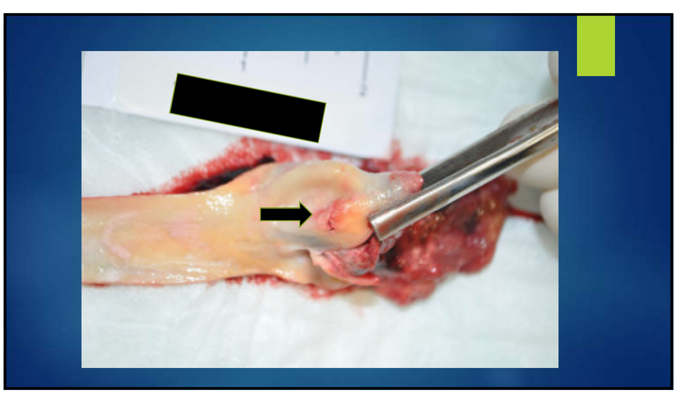
Digital format
Easy to operate
Relatively inexpensive
Fast

Out of the box use for Lodox

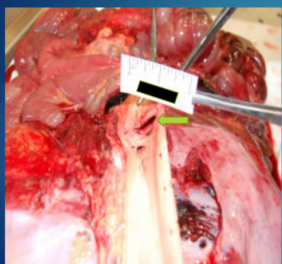
- Selective contrast imaging
- Material used (Foley catheter, water based contrast)
- Fast and easy to perform
- Cervical and cranial angiography, abdominal angiography, extremity angiography
- Saves significant amount of time
- Case selection: suspected cervical, cranial and other difficult to dissect vessels (i. e. vertebral arteries)

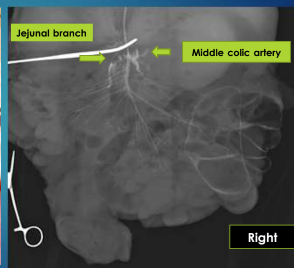


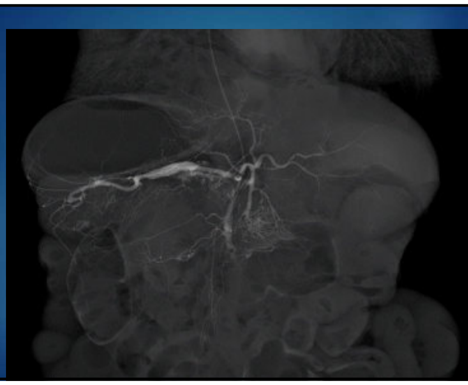


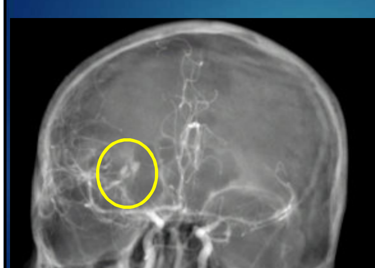


SMA and branches injury





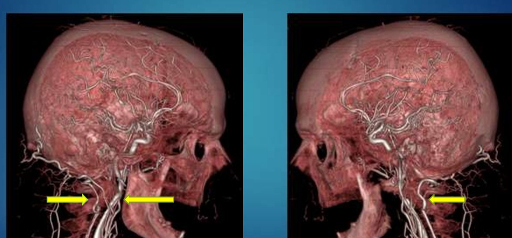




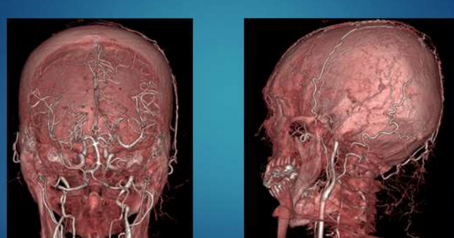
Selective CT angiography (CTA)

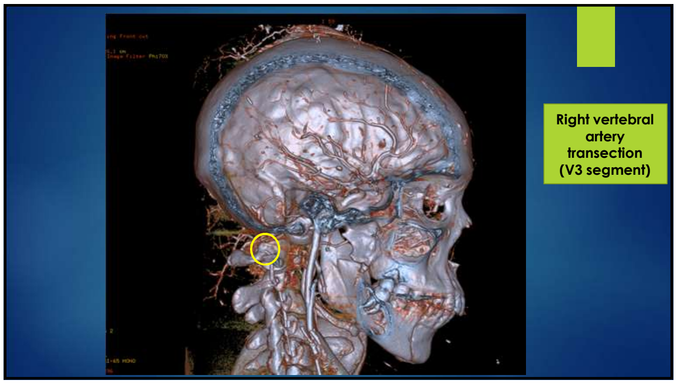
- Same method as Lodox angiography
- Contrast is diluted with water (50/50)
- Excellent detailed information
- Cervical/cranial imaging in approximately 10 minutes

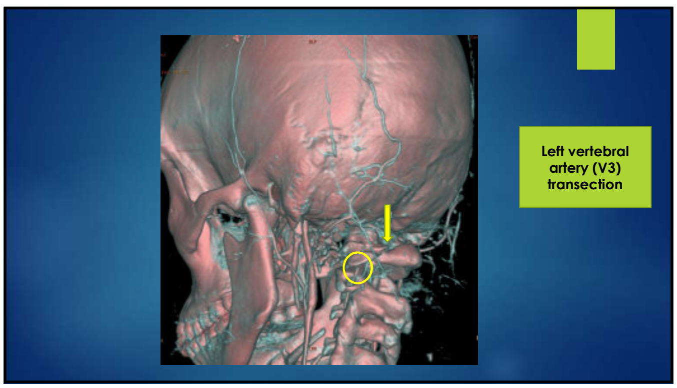
CT angiography

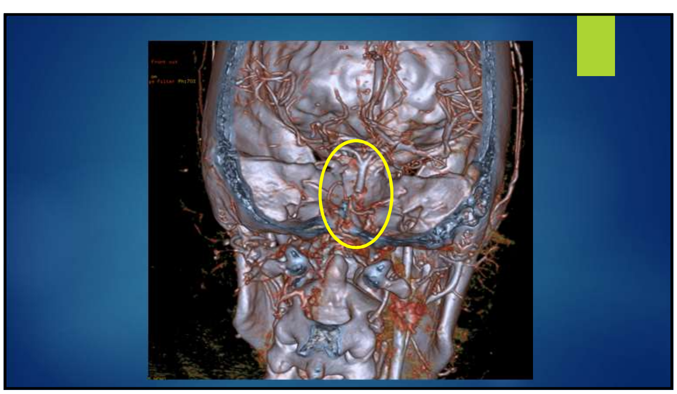


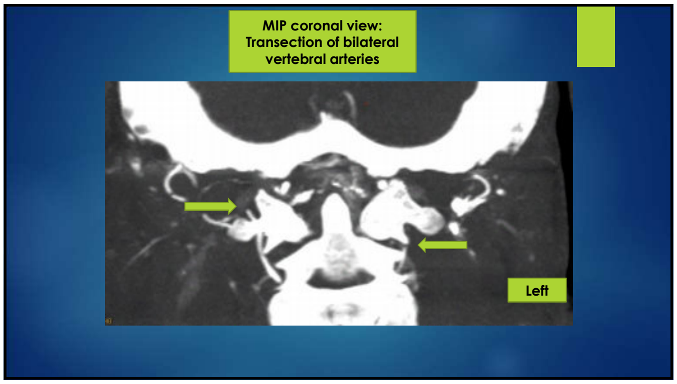
CT angiography

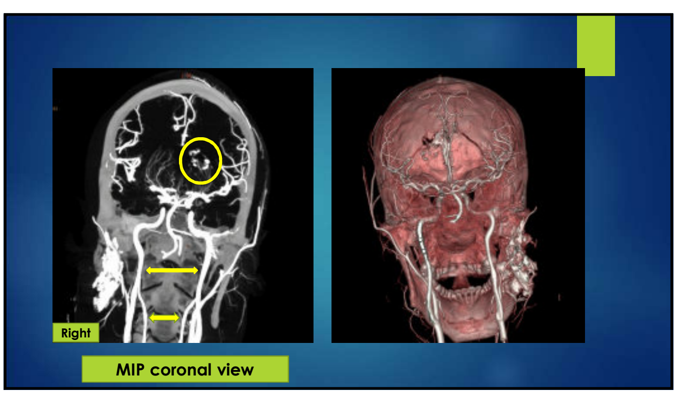



Right vertebral artery transection (V3 segment)


Left vertebral artery (V3) transection




MIP coronal view:
Transection of bilateral
vertebral arteries
Left


Right
MIP coronal view

Identification using CT/CT comparison

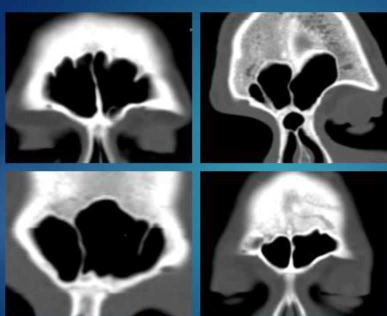
- CT scanning has proven to be a useful and scientific method of identification, especially in cases of limited radiographic studies or when partial anatomic remains available for identification
- Retrospectively and prospectively collected cases with postmortem CT images obtained from 2015 through 2017
- Cases were selected based on the availability of antemortem CT images

Identification using CT/CT comparison

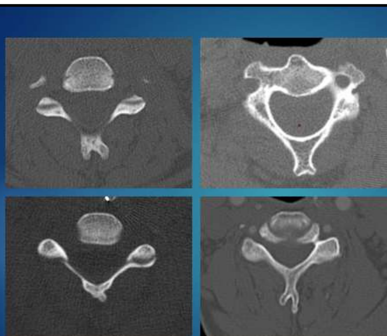
- Frontal and sphenoid sinuses have high individual variability and are very useful for CT/CT identification
- Due to their protected location, sphenoid sinuses are less prone to trauma and commonly available for comparison

Human identification

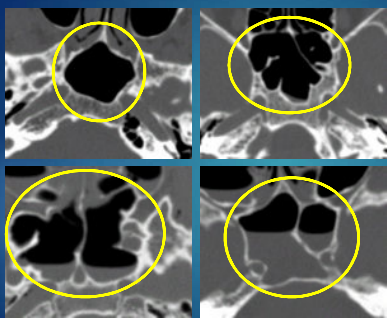
- Additional useful anatomic structures for identification include, but not limited to, contours of internal table of cranium, spinous processes, and degenerative changes
- Multiple locations, at least 3, should be used for positive identification



Frontal sinus variations

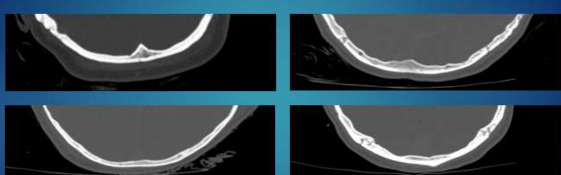


Cervical vertebra C2 variations



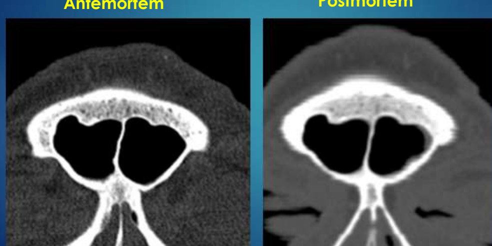
Sphenoid sinus variations

Occiput variations



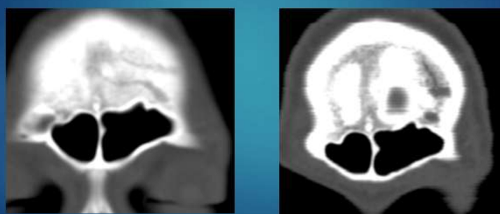
Frontal sinus match

Antemortem Postmortem



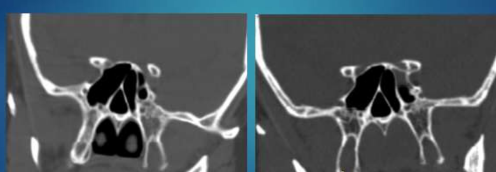
Frontal sinus match

Antemortem Postmortem



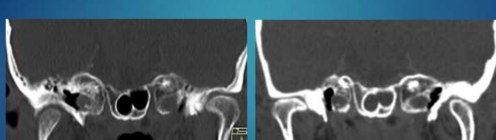
Sphenoid sinus match

Antemortem Postmortem



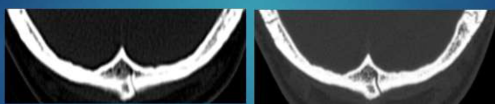
Sphenoid sinus match

Antemortem Postmortem



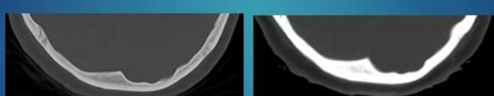
Occiput match

Antemortem Postmortem



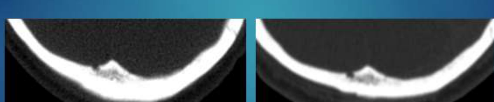
Occiput match

Antemortem Postmortem

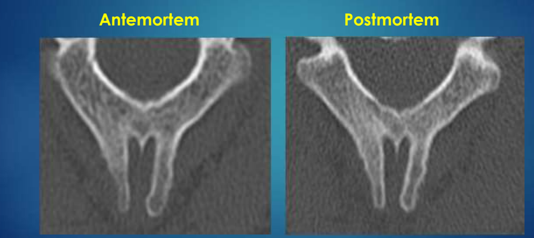


Occiput match

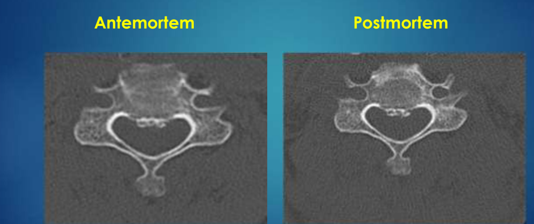
Antemortem Postmortem



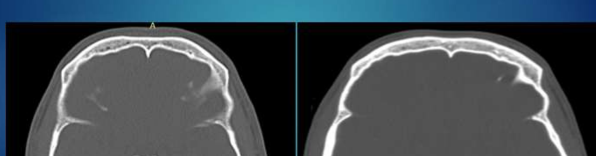
Cervical vertebra C4 match



Cervical vertebra C2

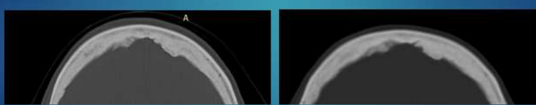


Frontal sinus comparison



Frontal bone comparison

Antemortem Postmortem



OPG image reconstructed from CT axial images

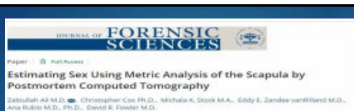
- Dental CT is a non-invasive and “no touch” method

Additional unique identifiers

Antemortem Postmortem Antemortem Postmortem

Scapula useful for sex estimation using CT images

- CT of scapulae in 290 cases were analyzed using logistic discriminant function developed in this study, showed 94.5% accuracy in estimating sex
- The results of the study showed that data obtained from volume rendered postmortem CT images can be considered reliable and treated as a practical option to standard anthropological methods, especially in mass fatalities as a rapid triage tool for sex determination


JOURNAL OF FORENSIC SCIENCES

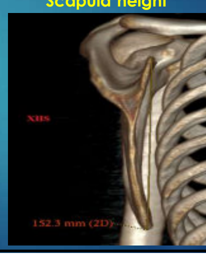
Paper | Full Access

Estimating Sex Using Metric Analysis of the Scapula by Postmortem Computed Tomography

Zabiullah Ali M.D., Christopher Cox Ph.D., Michala K. Stock M.A., Eddy E. Zandee vanRilland M.D., Ana Rubio M.D., Ph.D., David R. Fowler M.D.

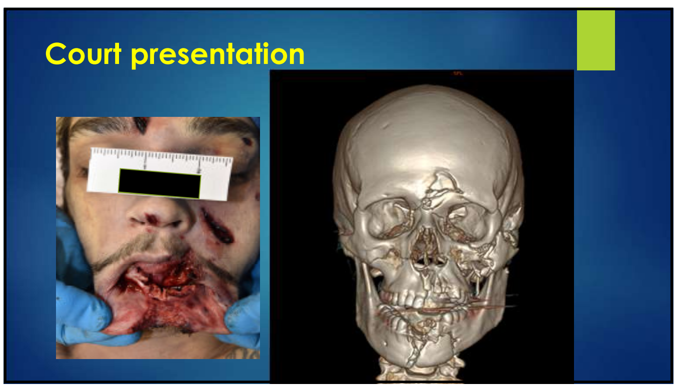
Scapula width

Scapula height



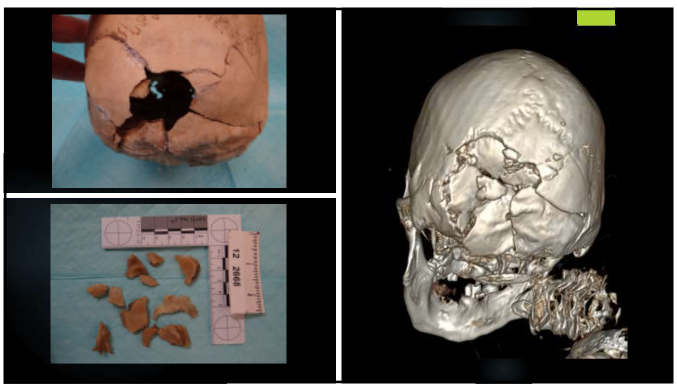
CT for court presentation


The First Use of Postmortem 3D Computed Tomography Images as Evidence in U.S. Criminal Courts: A Report of Four Cases
Zabiullah Ali, MD, Barry Daly, MD, David R. Fowler, MD
First Published December 1, 2015 | Research Article
https://doi.org/10.23907/2015.069

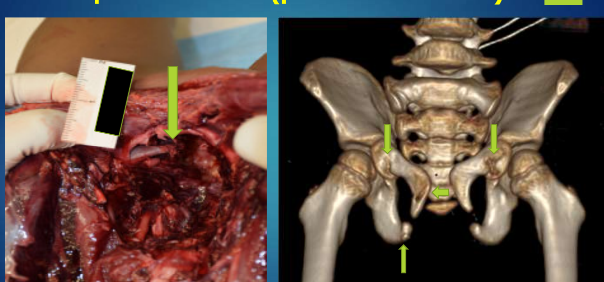

Court presentation

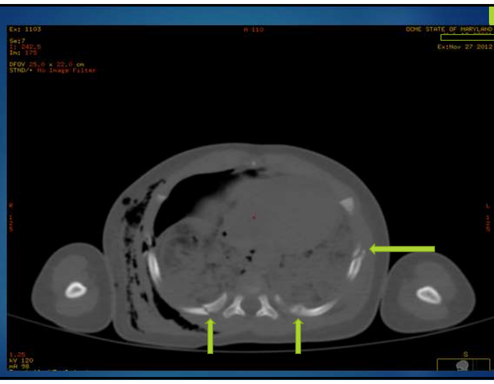

Court presentation

A 58 year-old male found in a wooded area

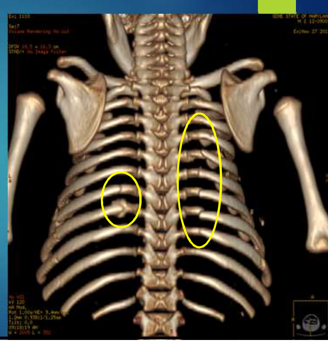


Court presentation (pelvic fractures)





Court presentation
Rib fractures



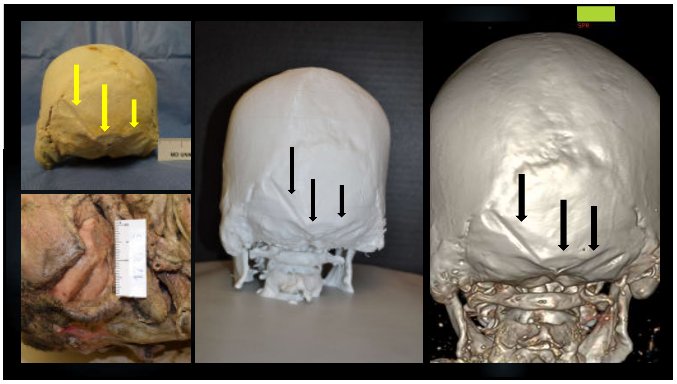
3D printing for court presentation

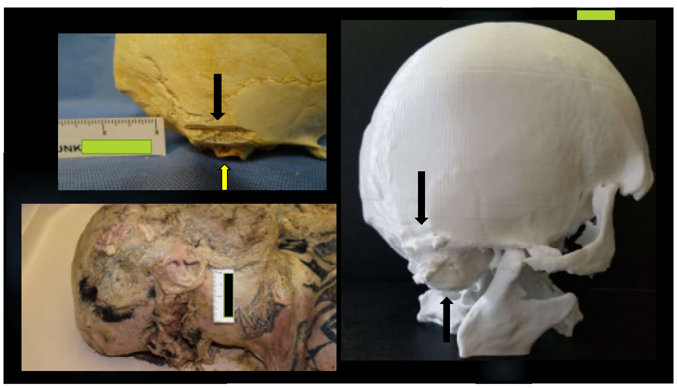
Forensic Sci Int. 2014 May;238:133-40. doi: 10.1016/j.forsciint.2014.03.005. Epub 2014 Mar 15.

Accuracy and reliability of measurements obtained from computed tomography 3D volume rendered images.

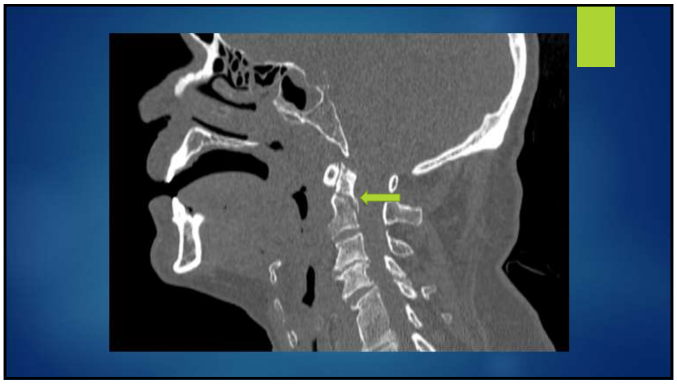
Stull KE[1], Tise ML[2], Ali Z[3], Fowler DR[4].

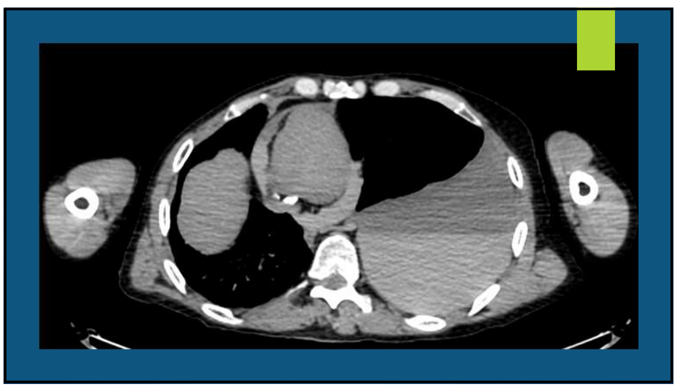
- The CT and dry bone measurements were generally within 2mm for each comparison
- Overall, minimal differences were found among the data sources and high accuracy was noted between the observers, which proved CT images are an acceptable source to collect osteometric variables

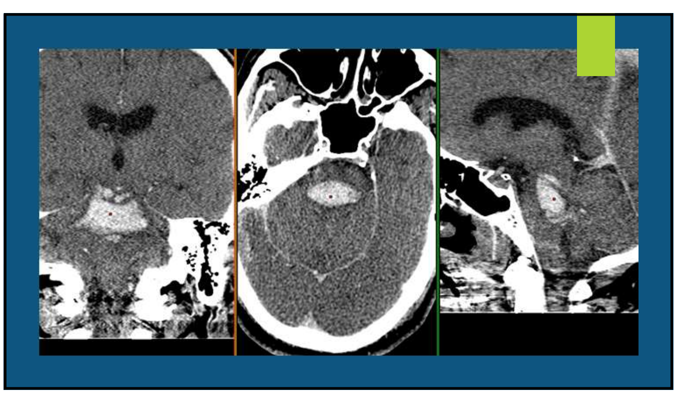


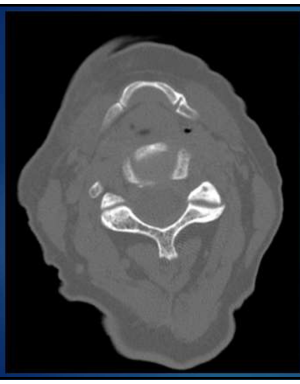


Examples of Cases in which CT helped with Diagnosis and cases of family opposition







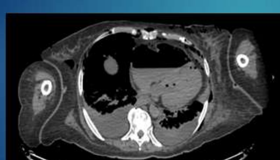


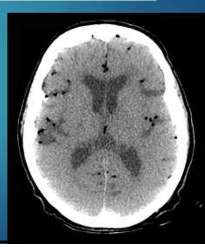
This case would have been missed…

Systemic air embolism complicating upper gastrointestinal endoscopy: a case report with post-mortem CT scan findings and review of literature

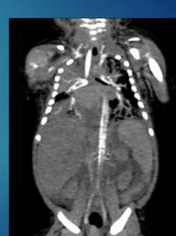
Zabiullah Ali, Ferdia Bolster, Eric Goldberg, David Fowler & Ling Li

Pages 52-57 | Received 03 Jul 2016, Accepted 22 Oct 2016, Published online: 18 Jan 2017

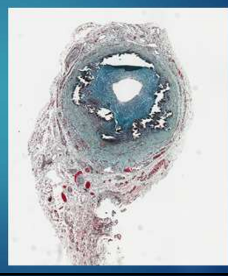




Generalized Arterial Calcification of Infancy (GACI)



Generalized Arterial Calcification of Infancy (GACI)



Conclusion

- CT is a very useful adjunct modality for forensic diagnosis
- CT volume rendered images and 3D printing are valuable tools for court presentation
- Selective CT and analog x-ray angiography are easy and inexpensive to perform and can eliminate the need for tedious dissections

Conclusion

- CT is extremely valuable in cases of family opposition and trauma cases
- Drawbacks of operating CT (expensive), lack of identification of surface injuries, visceral trauma
- CT is useful for identification
- CT measurements are accurate and can be used in anthropology without the need of soft tissue removal

References

1. Ali Z., Cox C, Stock MK, Zandee vanRiland EE, Rubio A, Fowler DR. Estimating Sex Using Metric Analysis of the Scapula by Postmortem Computed Tomography. J Forensic Sci. 2018 Sep; 63(5):1346-1349. doi: 10.1111/1556-4029.13751

2. Zabiullah Ali, Barry Daly, David R, Fowler. The First Use of Postmortem 3D Computed Tomography Images as Evidence in U. S. Criminal Courts: A Report of Four Cases. Journal of Academic Forensic Pathology. 2015 Dec1

3. Ali Z. Bolster F, Goldberg F, Li L, Fowler DR. Systemic air embolism complicating upper gastrointestinal endoscopy: A case report with postmortem CT scan findings and review of literature. Forensic Sci Res. 2016; 1 (1): 52-57 doi:10.1080/20961790.2016.1252898

4. Accuracy and Reliability of Craniometric Variables Obtained from 3D-Computed Tomography Images. Kyra E. Stull, M.S, Meredith L. Tise, M.S., Zabiullah Ali, M.D., David R. Fowler, M.D. Forensic Sci. Int. 238 (2014):133-140

5. Ferdia Bolster, Zabiullah Ali, Pamela Southall, David R. Folwer. Generalized arterial calcification of infancy—Findings at post-mortem computed tomography and autopsy. doi.org/10.1016/j.forsciint.2015.06.017

Forensic Radiologic Imaging of Blunt Force Injuries, Penetrating Injuries, and Drowning[1]

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Armed Forces Medical Examiner System
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I. Overview of Radiologic Imaging

Immediately upon its discovery in 1895, radiography was used in the courts to document and illustrate gunshot wounds. Since that time radiography has been used to aid in the determination of identity, assist in the evaluation of injury, namely bone injury in blunt and ballistic injury, and to localize metallic fragments and foreign bodies.

Today forensic organizations such as AAFS and NAME specify the use of radiography in their standards and guidelines. Conventional X-ray or whole-body radiographs are used in most centers. However, technological advances in cross-sectional imaging have made it possible for CT to be used routinely with forensic autopsy. Cross-sectional imaging makes the radiologic contribution to forensic autopsy more effective and brings the potential to increase both the speed and accuracy of forensic pathologists and anthropologists.

Radiographs (Conventional, Digital, and Fluoroscopic)

Conventional, two-dimensional radiography is the most widely used radiology technique in forensic medicine. Equipment is less expensive, easier to operate and less expensive to maintain than cross-sectional units. Radiographs are used to document fractures, injury patterns and occult injuries, localize foreign bodies and metallic fragments, and to aid in the identification of human remains when conventional methods such as fingerprinting or DNA analysis are not available or cannot be utilized. Radiography is invaluable in the forensic investigation of gunshot wounds and is universally used to locate the bullet, document the path of the bullet, and to assist in the retrieval of the bullet. Radiography is also the imaging modality of choice to evaluate subtle bone detail such as metaphyseal fractures in child abuse and in the anthropologic evaluation of skeletal remains or dissociated remains.

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[1] The opinions or assertions presented hereafter are the private views of the authors and should not be construed as official or as reflecting the views of the Department of Defense, its branches, or the Defense Health Agency, or the Armed Forces Medical Examiner System. The authors have no financial disclosures.

We consider radiography to be essential even when CT is available. Because of its excellent resolution and absence of streak artifact, radiographs complement cross sectional imaging when studying metallic fragments. Also, imaging of small dissociated remains mixed with debris is more efficient with radiography.

Conventional radiographic images can be obtained with mobile or fixed units. Some mobile units are fluoroscopic with the X-ray tube and detector mounted in a “C arm” configuration. “C-arm” units are particularly helpful when searching for small metal fragments. If mobile units are employed and radiography is performed in the autopsy rooms, radiation protection measures should be strictly enforced to protect all personnel. Mobile units may also be used as back up when fixed units are non-operational or as the primary unit for isolation or contamination cases and in field or temporary morgues. Fixed radiographic units in dedicated radiography rooms are the optimal choice in a dedicated forensic facility. Older radiography units utilized radiographic film screen systems and equipment for wet or dry processing. Newer state-of-the-art radiography units are digital and the images are viewed on the computer and archived on a picture archiving and communication system (PACS) network. Over the past decade, there has been an increase in the use of whole body digital scan units in forensic facilities. These units allow for the rapid acquisition of a whole body radiograph with little manipulation of the body. In addition, most of the units can acquire images in orthogonal planes as necessary.

<u>Computed Tomography (CT)</u>

Adding CT to forensic autopsy expands the role of radiology in forensic autopsy, allowing the radiologist or forensic pathologist to view anatomy without dissection. The multiplanar and three-dimensional capability makes the anatomic display of the CT similar to that of autopsy. Cross-sectional imaging viewed in this manner directs the forensic pathologist during dissection, allows injury patterns to be visualized in three-dimensions, detects occult disease or injury, and enables thorough evaluation of anatomic areas that are difficult to dissect. In certain causes of death and forensic scenarios, it is possible that cross-sectional imaging may serve as a triage technique to help forensic pathologists decide which decedents should have a limited or complete autopsy. In those cases that do not undergo a complete autopsy, cross-sectional imaging findings add anatomic information to the external examination and toxicology findings that were previously used alone to determine the cause of death.

The first CT scanners acquired a single slice per rotation but these have been replaced by “multidetector” (MDCT) scanners. MDCT data is acquired as a volume of data in a single scan by using a two-dimensional array of detector elements along the long (z-axis) of the body enabling the scanners to obtain 4, 8, 16, 64, or more slices with each rotation of the x-ray tube. MDCT enables rapid acquisition which is not a necessity in the postmortem imaging where motion does not occur, however, its speed in obtaining a whole body scan is advantageous. PACS networks are necessary to store and retrieve the data and post-processing workstations are necessary to view and manipulate the images for interpretation. Note: For the purpose of this presentation, MDCT and CT will be used interchangeably.

A variety of protocols can be used to obtain scans. Protocols specify the technical and anatomic parameters for obtaining scan data, reconstructing scan data into images, and reformatting images into anatomic planes. Scanning protocols can be organized for specific anatomic regions of the body similar to clinical scanning protocols or can be more generalized to obtain full body data. Protocols should be established according to the technical capabilities of the specific scanner used. Older scanners have table travel of 1.5 meters which means that whole body scans usually require repositioning and another overlapping scan to do a complete survey. Newer scanners have a table travel of 2 meters. Thus, repositioning is usually not necessary.

We scan all of our decedents with their arms at their sides. The total body scans are obtained from the skull vertex to distal point allowable by table travel (up to 2000 mm). The scanning parameters for the total body scans are dependent on the machine but since radiation exposure is not a consideration we recommend obtaining isotropic slices for maximum resolution. [Example: our parameters are detector configuration 16 x 0.625, pitch 1.375:1, table speed 13.75 seconds, reconstruction thickness 0.625 mm, and reconstruction interval 0.625 mm.] Clinical CT scanning has parameters for each body region. In whole body scanning a compromise is to use a general soft tissue protocol. We found an exception to this was needed to optimally image the brain and developed a dedicated head CT protocol. [Example: our head scans are acquired axially with a slice thickness of 2.5 mm and a slice interval of 2.5 mm, with the CT gantry angled parallel to the orbital-meatal line.] All scans can be reconstructed and typically two separate series, one using a soft tissue algorithm and one using a bone algorithm and viewed in multiple window and level settings. Special protocols such as CT angiography (contrast injections) have also been used. Images are viewed on the PACS workstations in multiple window settings to optimize depiction of pathology and injury. Three-dimensional workstations are preferred for image manipulation and reformations. The software developed for image processing in clinical radiology is also suited for postmortem imaging; no special adaptations are required.

Magnetic Resonance Imaging (MRI)

MRI has superior contrast resolution compared to CT. Consequently, it is a useful technique to image soft tissue alterations and pathologic processes. Postmortem MRI has been used to assess soft tissue and visceral hemorrhage, ischemia, and tumors. However, the technical complexity and availability of MRI make it more complicated to use as a routine imaging modality compared to CT.

Ultrasound

Although not as commonly used in forensic medicine as CT and MRI, ultrasound has been reported to be an effective imaging modality in autopsy diagnosis. Ultrasound is less expensive and more readily available than CT and MRI. It has the potential to be a useful tool when performing limited autopsy or to guide organ biopsy in a minimally invasive autopsy. A major limitation of sonography is the degradation of images by the artifacts produced by air and gas. Soft tissue gas is a major feature of decomposition and this has the likelihood to limit postmortem use.

Other Considerations

Incorporation of cross-sectional imaging modalities such as CT into a forensic facility requires careful consideration of the impact on daily workflow. In our practice, cross-sectional imaging augments standard radiography. If cross-sectional imaging is performed on every case, consistency in the workflow and imaging protocols is essential to avoid error. Our routine protocol calls for all bodies to be scanned fully clothed, in the human remains pouch (“body bag”), as they arrived at our facility. This protocol minimizes disturbance of the body and movement of forensic evidence. However, we sometimes will re-scan a body with arms raised to improve chest and abdomen resolution or to perform an angiographic study.

State-of-the-art radiography, CT, MRI, and ultrasound produce large quantities of digital data. Incorporation of these imaging modalities into a forensic facility requires careful consideration of the space, power, and personnel requirements to operate and maintain these technologies. In addition, a computer network and PACS network is necessary if digital radiography, CT, MRI, or ultrasound are to be utilized. PACS replaces traditional film and allows efficient storage and rapid transmission of images to computer workstations for interpretation or viewing of images.

II. **Blunt Force Injury**

Postmortem CT is useful to visualize and reconstruct blunt injury patterns prior to autopsy. In some cases, multiplanar and volumetric reformatted CT images may provide better visualization of blunt traumatic injuries than autopsy. Blunt force injuries may also coexist with other injury mechanisms such as blast and thermal injury. Three-dimensional display of head, spine, and pelvic injuries may facilitate the understanding of the mechanism of injury.

Crainiocerebral Injuries

Scalp lacerations and subgaleal hematomas cause focal soft tissue changes on CT. Closed lacerations or those located on the dependent surfaces of the body are usually not visible. Nondisplaced linear skull fractures appear as linear lucencies in the skull and usually involve both the inner and outer table of the skull. Depressed skull fractures have fragments that are displaced inward toward the brain. Three-dimensional volume rendered CT images are very helpful to display the skull fracture pattern, which is often more difficult to appreciate at autopsy because the fractured skull fragments tend to fall apart when the scalp is dissected away from the calvarium. Epidural hematomas are located between the skull and dura. Epidural hematomas are typically biconvex in shape and have mass effect on the adjacent brain.

Cerebral contusions occur with or without an associated skull fracture. On CT, they appear as focal punctate or linear areas of hyperattenuating hemorrhage. Small cerebral contusions are very subtle and difficult to identify on postmortem CT. Surrounding low attenuation edema may be present if the decedent survived for period of time after trauma.

Acute intracranial hemorrhage is high attenuation (80 to 90 Hounsfield units) on CT because the protein in blood has a high attenuation coefficient. During life, hemorrhage reaches its maximum attenuation in the first 2 to 4 hours at which time clot formation and retraction occur. If a decedent survives beyond the acute phase, hemorrhage becomes progressively lower in attenuation. Intraparenchymal hemorrhage will be surrounded by vasogenic cerebral edema, which reaches its maximum at 4 to 5 days. Overtime, the margins of intraparenchymal hemorrhage become less distinct.

Subdural hematomas are located between the dura and the arachnoid membrane. They are crescent-shaped and do not cross dural attachments. Acutely, they are hyperattenuating on CT but may also be mixed attenuation. Chronic subdurals are typically fluid attenuation on CT because they are composed of serosanguinous fluid. We have found it difficult to detect small subdural hematomas that are thinly layered beneath the dura because on postmortem CT the dura appears denser than the adjacent brain and the relative density of adjacent blood is similar to that of the dura.

Diffuse axonal injury classically occurs in the corticomedullary junction of the lobar white matter, corpus callosum, and dorsolateral aspect of the brainstem. CT may be normal or show petechial hemorrhages in the corpus callosum and at the gray-white junction. Postmortem MRI may be more effective at demonstrating diffuse axonal injury than CT, however the findings of diffuse axonal injury on MRI have not been reported to date.

Subarachnoid hemorrhage is seen as a thin layer of high attenuation in the cerebrospinal fluid spaces, cisterns, and sulci on CT. In our experience, it is often difficult to correlate subtle areas of hemorrhage that is suspected on CT with autopsy because blood enters the subarachnoid space during removal of the calvarium.

Vascular injuries to the carotid and vertebral arteries are difficult to diagnose on routine postmortem CT. Hemorrhage in the adjacent tissues is suggestive of an underlying laceration, but the location and extent of laceration is not detectable on cross sectional imaging unless intravascular contrast is administered.

<u>Thoracoabdominal Injuries</u>

Pre-autopsy imaging in blunt chest trauma is useful to show pneumothorax, tension pneumothorax, and the placement of tubes and lines if resuscitation was attempted. Pneumothorax can usually be distinguished from early decompositional gas in the pleural space. The presence of an associated rib fracture, hemothorax, and pulmonary contusion supports the diagnosis of traumatic pneumothorax.

Pulmonary contusions most often occur at the site of impact. Airspace consolidation and opacification in a nonsegmental distribution is a characteristic finding. Consolidation in the contralateral portion of the chest is indicative of a contracoup contusion. Pulmonary lacerations may appear as focal consolidations or cavities on CT. They may have surrounding opacity from contusion. Linear tracks of gas through the lung may also indicate communication with a bronchus and an associated tracheal or bronchial laceration. Tracheal or bronchial lacerations may also produce pneumomediastinum.

Hemorrhage in the mediastinum is indicative of a major vascular injury. Aortic lacerations are one of the most common major vascular injuries in blunt trauma. Radiography may show widening of the mediastinum from a periaortic hematoma, blurring of the aortic contour, or thickening of the paratracheal stripe. On CT, mediastinal hematoma is the most indicative finding of aortic laceration. Injuries to the aortic arch branches, pulmonary artery, and vena cava may also produce mediastinal hematomas. Pericardial and cardiac lacerations usually result in pericardial hematomas, which may cause cardiac tamponade. Cardiac contusions and lacerations are usually not evident on postmortem CT.

Diaphragm elevation should raise concern for diaphragm laceration or rupture. Intraabdominal organs may protrude into the thorax when there is laceration or rupture of the hemidiaphragm. Laceration or rupture of the liver, spleen, and other visceral organs may be difficult to identify on routine postmortem CT because of the non-contrast technique. Hemoperitoneum usually has a higher attenuation that simple ascites, which is water attenuation. Focal collections of blood adjacent to an organ or major vascular structure are indicative of injury. The site of injury may not specifically be identifiable on CT. Extraluminal gas within the abdomen is very commonly observed on postmortem CT because the earliest signs of decomposition are observed in the abdomen.

Spine, Pelvic, and Extremity Injuries

Abrasions, contusions, and minor hemorrhages into the soft tissues may not be evident on postmortem CT. Significant hemorrhage into the soft tissues increases the attenuation and thickness of the involved soft tissue. With increasing hemorrhage into the soft tissues, the fat planes become distorted and focal asymmetry develops.

Diagnosis and interpretation of fractures is generally straightforward on radiography. Vertebral body compression fractures and abnormalities in alignment are best viewed on sagittal CT images. Axial images are useful to view the pedicles and posterior elements of the vertebral bodies. Intervertebral disc injuries and spinal cord contusion or hematoma cannot be reliably assessed on CT. We have found CT very useful to screen the bony structures of the spine, particularly the cervical spine because this region is difficult to dissect at autopsy. Three-dimensional images provide an excellent depiction of the anatomic distribution of spine fractures, which can be difficult to appreciate at autopsy.

Complex, comminuted, and open fractures of the extremities are generally simple to diagnose. Fractures of the extremities, hands, and feet are best evaluated with conventional radiography. However, CT has the added benefit of providing soft tissue information that may be valuable in the assessment of the extent and volume of an associated hematoma.

III. Gunshot Wounds

In the evaluation of gunshot wounds, radiography can be used to document the presence or absence of bullets, location of bullets, skeletal injuries, and additional findings such as air in the right atrium and pulmonary outflow tract in an individual with a gunshot wound to the head. As long as the bullet or bullet fragment is radiopaque, there is excellent edge detail of its borders. It must be noted that precise measurement of the dimensions of the bullet is limited by geometric and physical factors during the capture of the image. Although tempting, the caliber of the bullet cannot be determined on radiography. It can only be determined when it is recovered. In determining the location of the bullet using radiography, orthogonal views are necessary to determine the location of the bullet in all three planes of the body. The location and extent of long bone skeletal injuries caused by a bullet is usually readily apparent. However, without orthogonal views, it is often difficult to determine the exact location and extent of axial skeleton injuries. The main limitations of radiography are the inability to determine the location of wound tracks and to detect soft tissue injuries. Additionally, radiographs may not detect non-metal fragments such as plastic or paper wadding which can be projectile components.

Similar to radiography, CT can be used to document the presence or absence of bullets or bullet fragments. In contrast to radiography, the location of these projectiles relative to adjacent anatomical structures can be determined in any plane. Even minute bullet fragments can be located. When there is embolization of a bullet or bullet fragments, the precise location of these projectiles can be demonstrated as the entire body has been scanned. Non-metal fragments such as paper or plastic wadding from a shotgun shell can be visualized with CT. A disadvantage of CT is that metallic objects create a streak artifact and the edge detail of the projectile's borders is blurred. This may make it difficult to determine the shape of the projectile prior to recovery. This is why we continue to perform radiography in conjunction with CT.

CT is effective in documenting skeletal injuries caused by gunshot wounds. The characteristics of the fracture pattern may help with the determination of trajectory of the bullet through the body. Three-dimensional images can be reformatted to demonstrate the extent of skeletal injury where there are complex fractures such as in the case of a contact gunshot wound to the head. Caution must be taken when creating these images as the 'smoothing' software can mask injury. It is our opinion that these reformatted images are best suited for demonstrative aids and that the planar views are used for the diagnoses.

The ability of CT to detect soft tissue injury due to gunshot wounds depends on the organ and the ballistic characteristics of the projectile. In soft tissue, gas ("air") and hemorrhage are the principal markers of injury. However, gas in blood vessels, organs, and body cavities is also a common feature of decomposition. Careful selection of the optimal CT window and level setting is necessary to observe all of these critical findings. In the brain, decomposition decreases the tissue attenuation and provides contrast to the adjacent hemorrhage which has high contrast. Thus, a gunshot wound that has significant hemorrhage around the bullet path due to the permanent and/or temporary cavity will be readily detected. Similarly in the lung, hemorrhage is higher in attenuation compared to the normal surrounding aerated lung. However, organs such as the heart, liver, and spleen are usually isoattenuating with hemorrhage. In these organs, linear collections of gas within the organ and disruption of the outer contours are the markers of injury. The gastrointestinal tract is difficult to evaluate for injuries due to a gunshot wound because the intestines are often collapsed and the presence of pneuomatosis is an unreliable sign. As described in the section on blunt force injury, additional findings such as a hemothorax due to injury of a major vascular structure, are usually readily apparent. However, it is usually not possible to discriminate the specific vascular injury. A technique to overcome this limitation is post-mortem angiography where radiopaque contrast material is injected into a vessel and images obtained.

In terms of determining the path of the bullet through the body, the radiographic wound track is the “visible” remnant of the temporary and permanent cavities caused by the bullet. In many cases, the path of the bullet through the body can be determined using CT. As stated above, the principal markers for injury to soft tissue (including major organs) are gas and hemorrhage. For bone, fractures and bone fragments in adjacent soft tissue are the principal markers of the wound track. In some cases, the direction of the wound track can be determined based on the location of bone fragments in adjacent soft tissue and/or the pattern of fractured bone. The beveling of the skull that has been used for decades by forensic pathologists to aid in the trajectory of the bullet through the skull can be demonstrated on CT images. Since the images can be viewed in any plane, it is possible, in select cases, to view the track of the bullet on a single image. However, it must be understood that many factors affect the trajectory of a bullet within the body and this may not always be a linear path. In addition, the body position at the time of injury maybe completely different from position at the time of imaging. As a consequence, individual injuries such as fractures of different bones may not form a straight line even though the trajectory of the bullet through the body was linear. One limitation of CT is the difficulty in determining the location of the entrance and exit wounds on the surface of the skin. Optical surface scanning and the placement of radiopaque markers on the skin surface at the location of the wounds have been used to overcome this limitation. Another limitation of CT is the determination of the range of discharge of a firearm. Even with surface rendering, it is not possible to definitively visualize soot deposition or abrasions caused by gunpowder.

IV. <u>Postmortem Changes and Artifacts</u>

Postmortem change and decomposition are always present at autopsy and on postmortem CT because they begin to occur immediately upon death. Consequently, the appearance of postmortem change and decomposition on postmortem CT can be considered normal and should not be mistaken for a pathologic process or injury. Postmortem change and decomposition are important findings on MDCT because they may obscure soft tissue injury or pathology, thereby limiting the CT assessment of soft tissue for hemorrhage, laceration, and wound tracks in cases with suspected trauma. Putrefactive gas should not be mistaken for pathologic gas collections that may have contributed or causes of death such as air embolism, pneumothorax, pneumoperitoneum, or gas forming infections. Gas in anatomic spaces and in blood vessels can generally be considered putrefactive when it is present symmetrically throughout the entire body. However, asymmetric or focal gas collections should be viewed as suspicious and related to an underlying pathologic process or injury unless there is an explanation for focal or asymmetric decomposition.

Livor Mortis

Hemoconcentration from postmortem livor mortis results in increased attenuation of the affected organs, vasculature, and tissues on CT. This finding is easily observed in large caliber arteries and veins as well as the cardiac chambers. In these structures blood separates into serum and erythrocytic components due to the effect of gravity. This produces a fluid level on CT. High attenuation erythrocytes layer dependent to plasma in the cardiac chambers and when supine, in the posterior aspects of the great vessels. The vessel wall on the nondependent side appears relatively dense because of the attenuation difference between the vessel wall and serum component of the blood. This is most noticeable in the aorta and is also frequently observed in the posterior dural sinuses of the cranial fossa. Small caliber blood vessels such as the cerebral arteries may also have higher attenuation; hyperattenuation should not be mistaken for cerebral or pulmonary thrombosis.

Visceral livor mortis is most commonly identified in the lung parenchyma on postmortem CT because of the inherent attenuation differences between aerated lung and the pulmonary vasculature. It causes an increased attenuation in the dependent lung. There may be a vertical gradient with increasing attenuation from the nondependent to the dependent portions of the lung parenchyma with increasing degrees of livor mortis. Dependent settling of pathologic pulmonary venous congestion and edema within the lungs and pulmonary consolidation from an infectious or neoplastic process must be differentiated from livor mortis. The cutaneous and subcutaneous manifestations of livor mortis are much less profound on CT when compared to gross examination of the body. There is increased attenuation of the dependent subcutaneous fat and dermis and dependent dermal tissue thickening.

Rigor Mortis and Algor Mortis

Postmortem CT shows no specific findings for rigor mortis or algor mortis. Rigor mortis is most important in positioning the body on the CT scanner table and in some cases may be an obstacle to positioning and passage of the body through the CT gantry. It is possible to physically overcome or “break” rigor and this can be considered in cases in order to permit CT to be accomplished, however, this must be done in conjunction or by the forensic pathologist since rigor status is a forensic finding and iatrogenic injury can be produced if the procedure is not done properly.

Decomposition

We have found it helpful to classify the spectrum of decomposition observed on MDCT as early, moderate, and advanced. This is specifically helpful when there are injuries or pathologic processes suspected that might be associated with the findings of gas in internal organs or vasculature.

One of the earliest signs of decomposition on CT is cerebral autolysis. There is usually some evidence of cerebral autolysis by CT in the majority of bodies that are scanned and autopsied more than 24 to 48 hours after death, even if a body has been stored in the mortuary cooling chambers. The CT features of cerebral autolysis include blurring and loss of definition of the grey-white matter junction, decrease in cerebral attenuation, and effacement of the sulci and ventricles. Within 2 to 3 days, there is progression of autolysis and complete loss of grey-white matter differentiation on CT and the cerebral ventricles and sulci become effaced. As the brain softens, it settles in the gravity dependent portion of the calvarium and gas fills the nondependent portion of the calvarium. At this stage, putrefactive gas may be present within the vascular structures and intracranial spaces. However, putrefactive gas may also be seen within the vasculature before brain settling is evident on CT. Finally, with complete cerebral liquefaction, the brain is water attenuation on CT and there is a fluid level within the calvarium.

The intestinal wall and mesenteric and portal venous systems are generally the first sites of putrefactive gas on CT in addition to the small and large intestine, which may be distended with gas from proliferation of intestinal bacteria. Body cavities such as the pleural and peritoneal spaces may contain a small amount of fluid. The fluid may be putrefactive fluid (purge fluid) or liquefied fat. The latter is more common in the abdominal cavity from liquefied omental, mesenteric, and retroperitoneal fat. Small volumes (10 to 20 ml) of pleural fluid are considered normal at autopsy and are typically easily differentiated from pathologic collections of fluid in the pleural cavity. As putrefactive decomposition progresses, gas enters all vascular structures and potential anatomic spaces. Putrefactive gas is normally symmetrically distributed throughout the body unless there is focal or asymmetric decomposition from an underlying injury or a focal cause of warming or cooling of the body.

Although the pancreas and adrenal glands are among the earliest internal organs to undergo autolysis, they generally have a normal appearance on postmortem CT until putrefactive gas is present. With moderate putrefactive decomposition, the pancreas may be observed to have a disproportionate amount of gas compared to other abdominal organs. Gas appears within the vasculature of the visceral organs in the early postmortem period at the same time that gas appears in other vessels throughout the body. The CT attenuation of the solid visceral organs such as the liver, spleen, and kidneys does not change until the advanced stages of decomposition when the organs begin to fragment, degenerate, and liquefy. In moderate stages of decomposition, visceral organs are still normal in shape and contour. Eventually, the connective tissues collapses and the organs are not recognizable in shape and appearance. Gas fills the abdominal and chest cavities as the organs collapse and liquefy.

Insect activity and animal predation are features are usually easily recognizable on gross examination; and to some degree be seen on postmortem imaging. The appearance of insect activity and animal predation should not be mistaken for pathologic processes or injury when interpreting postmortem CT. Larvae are linear and curvilinear soft tissue or surface irregularities on CT. Animal predation is characterized by one or more bite marks in soft tissues and bones. Often there are innumerable marks from small mammals such as rodents or dogs gnawing on the corpse.

The formation of adipocere in severely decomposed bodies preserves the subcutaneous tissues and portions of internal organs. It has a characteristic low attenuation appearance on CT. Because adipocere formation frequently coexists with putrefactive decomposition, both processes may be present revealing a body that has absent or partially decomposed internal organs and intact skeletal structures surrounded by adipocerous subcutaneous fat.

V. Future Directions

Integrating cross sectional imaging into a forensic environment has implications for both the practice of forensic pathology and radiology. We have found that cross-sectional imaging adds objective, reproducible anatomic data to autopsy. The ability to review and reconstruct the anatomic findings at the time of autopsy at a later date is invaluable. When used as an adjunct to autopsy, cross-sectional imaging provides an anatomic overview of the body prior to dissection. Abnormalities are localized more efficiently when the images are reviewed prior to autopsy; anatomic areas that are difficult to access at dissection are evaluated on images; complex fracture patterns are better visualized; and, occult injury may be detected. Our experience has been based upon strict radiologic-parhologic correlation because all of our cases undergo both imaging and forensic autopsy. This model is appropriate for facilities starting to do advanced forensic imaging.

Cross-sectional imaging may potentially serve to augment a limited autopsy or, in some cases, replace autopsy. CT and/or MRI may be very useful tools to exclude occult trauma or disease in a limited autopsy and to triage cases for autopsy in mass casualty scenarios. Ongoing and future study comparing the accuracy of cross-sectional imaging to autopsy is necessary to validate and establish the effectiveness of imaging modalities in the determination of the cause of death. Such material will also needed to support courtroom use of the data. Since radiographs have been accepted and CT is an extension of this technology it is not likely this will be a problem. There could, however, be questions raised about use of CT data to reconstruct 3D images.

The most important limitation in integrating cross-sectional imaging with autopsy is the cost and availability of CT and MRI scanners and personnel. Purchase and installation of state-of-the-art equipment in a forensic facility may be prohibitive for some jurisdictions. As an alternative to an on-site scanner, medical examiners may choose to collaborate with local radiology practices or hospitals in order to obtain imaging studies on decedents. When making the decision to use postmortem CT and MRI, it is important to realize the strengths and weaknesses of each imaging modality because each has unique benefits and limitations.

Workflow

Although the standard practice in forensic facilities is to radiograph and image human remains before physical autopsy begins, the timing and circumstances of the imaging can be varied based on the workflow in a particular forensic facility. All possible options that comply with prescribed forensic guidelines should be considered when establishing a forensic workflow that includes radiography and cross-sectional imaging. The decision on when to obtain radiographs and cross-sectional imaging should be based on the processing scheme of the facility and the physical location of the radiologic equipment.

At our facility, intake photography and identification precede radiologic examinations. After the radiologic exams are completed, the remains undergo forensic dental examination followed by autopsy. While this workflow has advantages of efficiency and maintains an organized chain of custody, radiographs and CT images show external debris, clothing, and personal effects on the body. In some cases, these can be detractors because they may create artifacts on the images. However, the imaging does reflect the physical relationship of clothing, personal effects, and in some cases, medical devices at the time of death. If there is significant artifact from external debris, clothing, or personal effects, re-imaging after the body is cleaned may be necessary.

There are advantages to imaging the body after it has been cleaned and had a preliminary external examination. Some facilities may find that this fits their workflow better, particularly if the imaging equipment is at another location and transport could affect external evidence. Artifacts from clothing and debris are eliminated and metallic markers can be placed on the skin surface to identify wounds so that their precise location appears on the images. If imaging is performed after external examination, medical devices (e.g., tubes, lines, and catheters) should be kept in place so their position and possibly their effectiveness can be assessed on the images. Consideration should be given to separately radiograph clothing and other personal effects to check for metallic evidence or other findings that may have been overlooked. The disadvantage of this sequence is the disruption of the continuity between external examination and dissection.

Cost effectiveness of using expanded imaging in the death investigation process has yet to be established. Will cross sectional imaging allow a medical examiner to do more cases? Can the operation of complex imaging equipment be done by autopsy technicians or will radiology technologists need to be hired? The budgetary issues are certain to impact the speed in which cross sectional imaging gets accepted and adopted. Scientific study will help to resolve the issues but this in turn has to be supported through research grants.

Other Applications of Cross-sectional Forensic Imaging

The documentation of intravascular lines, chest tubes, endotracheal or nasotracheal tubes, airway devices, tracheostomies, and nasogastric tubes, as well as less common devices such as intraosseous infusion catheters is part of the autopsy external examination. CT adds to this assessment by providing multiplanar two and three-dimensional images of the position of these devices since the internal positioning of most tubes and lines are easily established. We emphasize that CT assesses device position at the time the postmortem CT only because devices can shift position during transport and handling of the body. In addition, the clinical effectiveness of a particular device cannot be assessed because there are complex physiologic factors involved in injury and resuscitation sternum.

Second autopsy can be performed before burial or after exhumation. CT facilitates the anatomic evaluation of exhumed bodies by providing a noninvasive anatomic assessment. If no autopsy was performed prior to burial, CT assists in localization of key anatomic organs and skeletal structures that may have shifted position during the decay process. This can be particularly helpful in intermediate to advanced stages of decay.

Anthropologists study found human remains for age, gender, stature, and ethnicity by analyzing anthropomorphic features and osteometric criteria, which may help to establish identity. Reassembly of skeletal remains helps to further identify and classify findings that may help indicate the cause of death. Radiography and CT scanning of the reassembled remains is superior to imaging bones individually or collectively. Images of a partially or completely reassembled skeleton better depict injury patterns and show the relationship of wounds to one another.

Intact human remains and dissociated human remains may be found during the investigation of catastrophic trauma or large-scale disaster events such as hurricanes, floods, mass transit accidents, aircraft accidents, and explosions. Recovery and identification of all human remains is one of the most important objectives of these investigations. In addition, forensic pathologists may be asked to determine if cause of death was related to the event circumstances or was a homicide. CT has been proposed as a means of autopsy triage. On occasion, dissociated remains may be matched when specific bony landmarks or features are identified on CT.

Training and Education

Postmortem forensic imaging draws on two bodies of knowledge: forensic pathology and radiologic imaging. Educationally these have been two separate pathways. It is logical to assume that at some point they will overlap and this likely will be at the fellowship level. At this point radiologists will need to learn forensics and pathologists to learn about acquisition and interpretation of cross sectional images. The opportunity for such training will only be possible where pathology and radiology facilities have incorporated cross sectional imaging into forensic practice. This will probably be Medical Examiner Offices which have acquired equipment or arranged for a nearby radiology facility to perform the imaging. The required time for obtaining the skill set needed to be a “forensic radiopathologist” could be based upon the number and type of cases studied. In this way experienced forensic pathologists and radiologists could supplement their existing skills quickly. Current credentialing bodies like the ACGME might be involved with criteria at the fellowship level but it is also essential that organizations like CAP and NAME become involved so that standards for training and practice have appropriate oversight.

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NAME 2019:

Postmortem CT in Blunt Accidental Trauma and Suspected Elder Abuse

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Applications of PMCT

- Blunt trauma
- Penetrating trauma
- Unidentified body
- Suspected NAI in young children
- Suspected Elder abuse
- Drowning
- Decomposition
- Burns
- Unknown cause of death
- Suicide
- Contraband
- Anthropology
- Historical Investigations

Recent Advances in Forensic Radiology

Background

Recent studies have suggested a major potential role for high-resolution whole body CT scans in the forensic investigation of death following accidental trauma

C 3-4 fracture dislocation overlooked at Autopsy due to severe rigor mortis

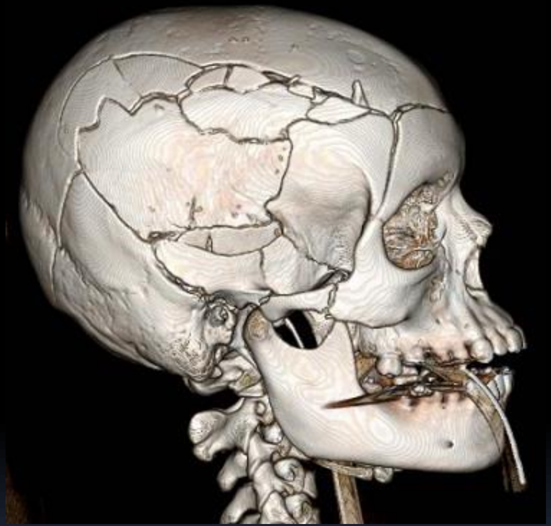
Can Postmortem CT match the Traditional Autopsy for Blunt Accidental Trauma ?

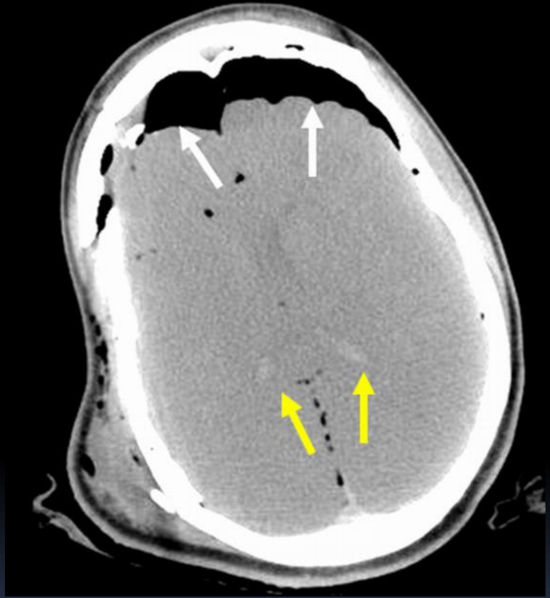
How Reliable is PMCT in fatal Blunt Trauma?

- Comparison of Whole Body Postmortem 3D CT and Autopsy Evaluation in Accidental Blunt Traumatic Death using the Abbreviated Injury Scale (AIS) Classification. (Forensic Sci Int 2013)
  - PMCT exceeds the sensitivity of Autopsy for detection of major blunt accidental skeletal injuries classified grade 3-6 (serious-unsurvivable) on the AIS scale

- Post-mortem imaging compared with autopsy in trauma victims - a systematic review *(Forensic Sci Int 2015)*
  - 563 cases
  - PMCT is more sensitive than conventional autopsy in detecting skeletal injuries.
  - For soft tissue injuries, autopsy remains superior to imaging.
  - Aortic injuries are missed frequently by PMCT

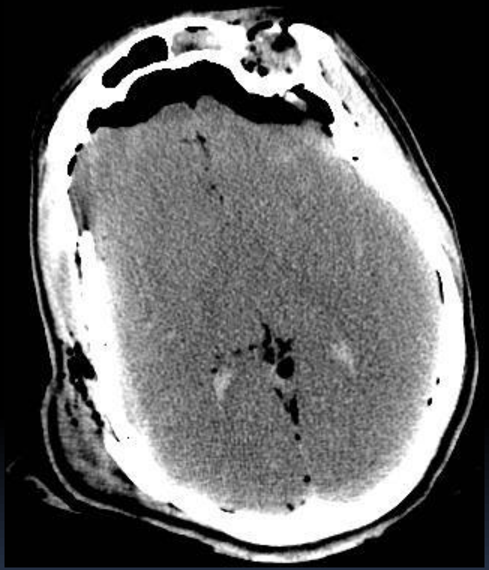
Can PMCT augment or replace Traditional Autopsy in this setting?

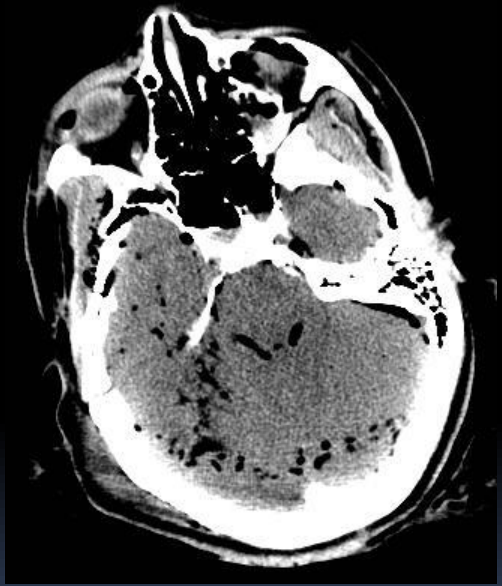




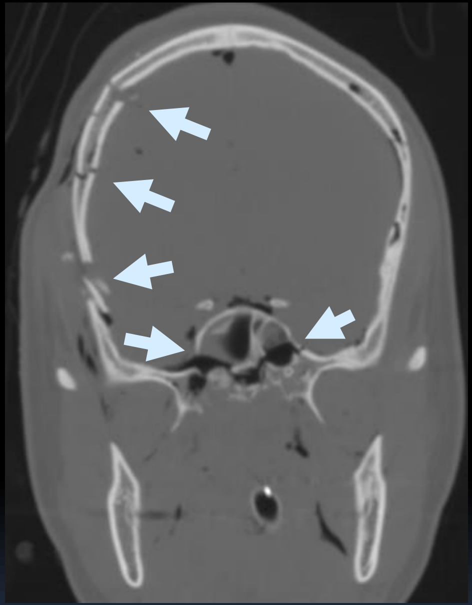
Case 1: Multiple skull fractures and severe diffuse brain injury

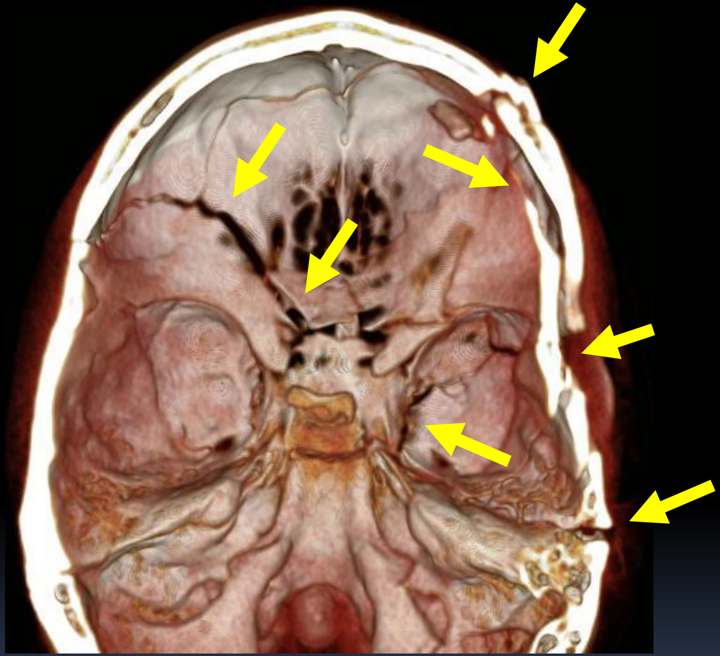
Case 2 : Multiple fractures, intracranial air and severe diffuse brain injury with intraventricular bleeding





Other views of fractures in this case

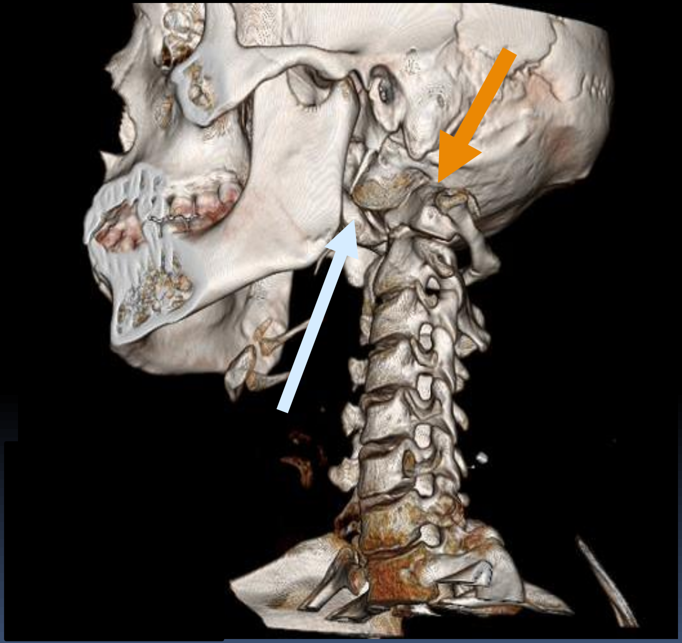


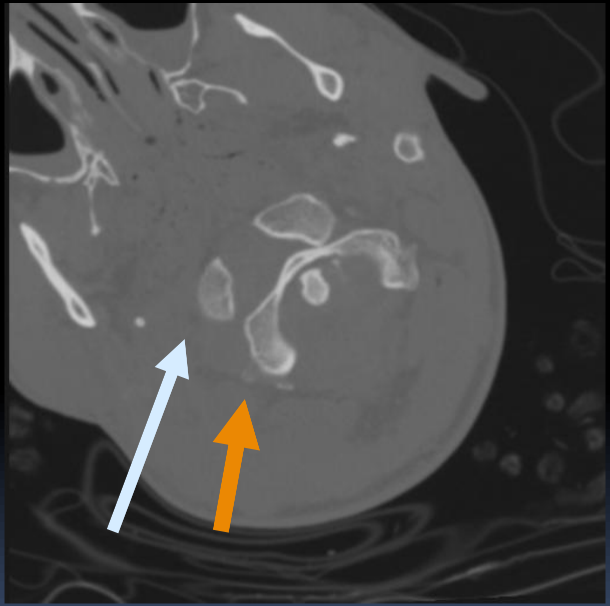


Coronal MPR view

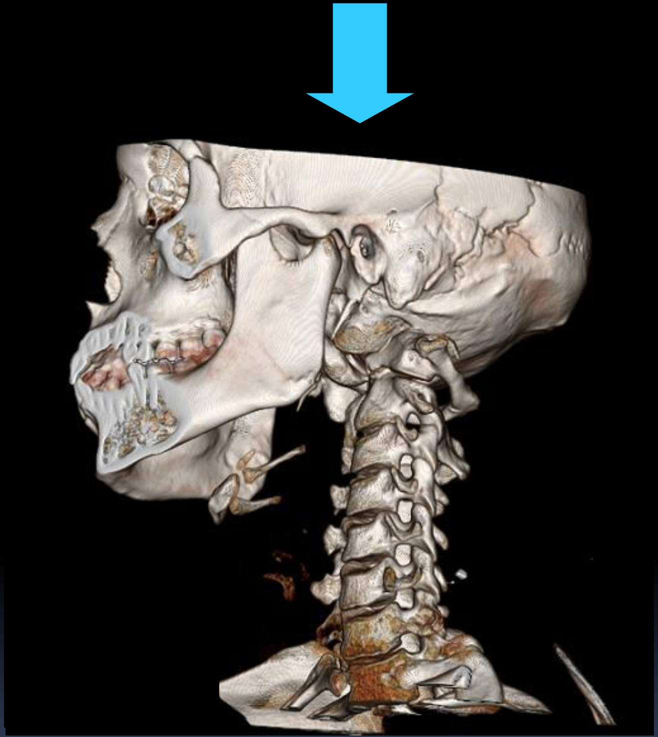
VR virtual dissection view

Case 3: Blunt Accidental Trauma:
Rotational Atlanto-Occipital Dislocation





Rotational Atlanto-Occipital Dislocation



VR 3D oblique view

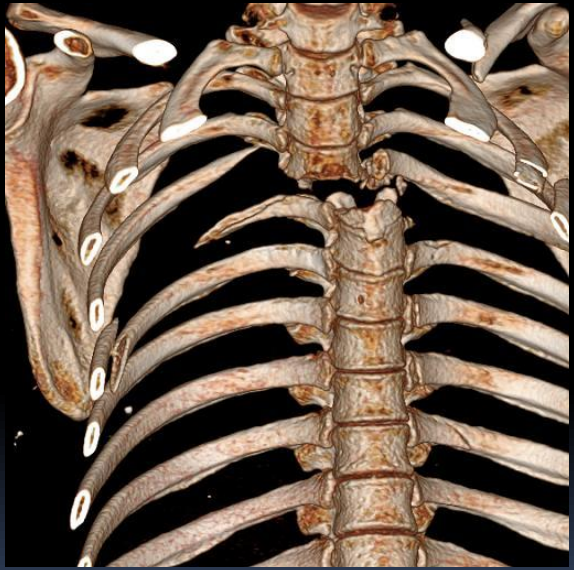
Virtual dissection view

Rotational Atlanto-Occipital Dislocation -

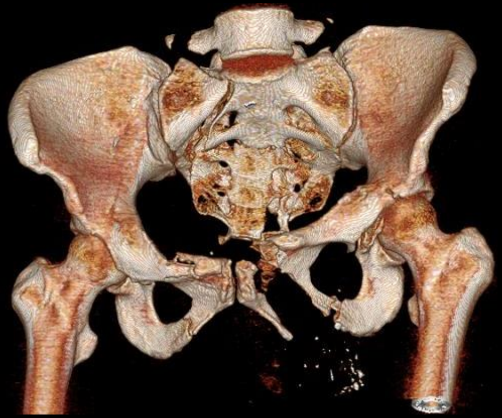
Sagital midlne view shows brain stem severed at autopsy

Case 4: Distraction Fracture-Dislocation of T3 Vertebra

Victim of high speed MVA with multiple severe injuries



Same case

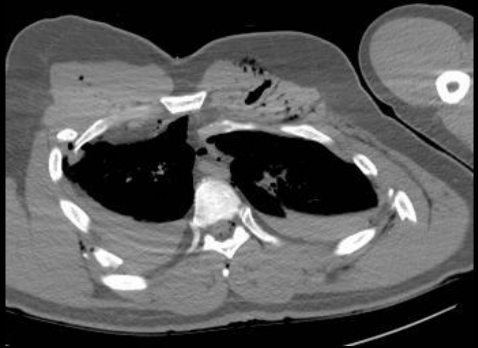


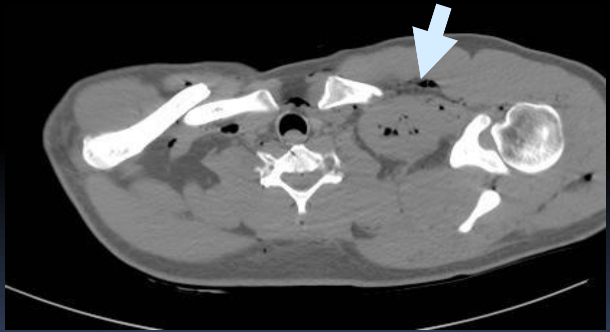
Driver dead at scene

Case 5: Severe Torso Crush Injuries – Dead at scene

Sternal & 1-12 rib fractures bilateral, Open-book bilateral pelvic fract/disloc.

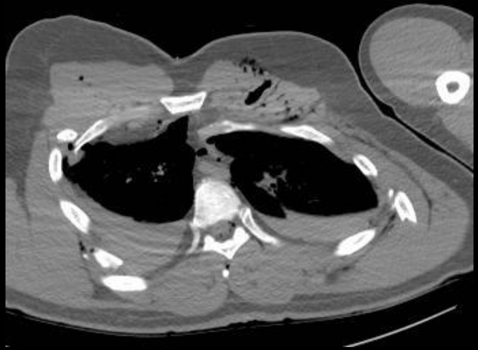
Same Case: Herniation of mediastinal and abdominal organs

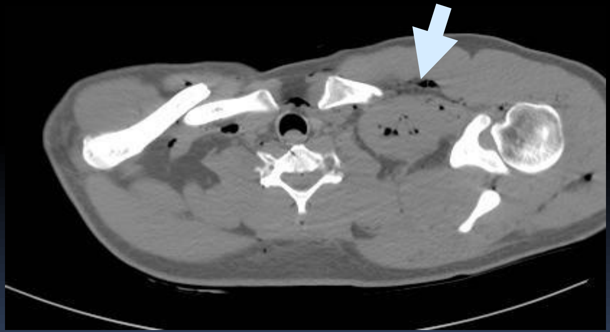




Family opposed to autopsy

Same Case: Herniation of mediastinal and abdominal organs

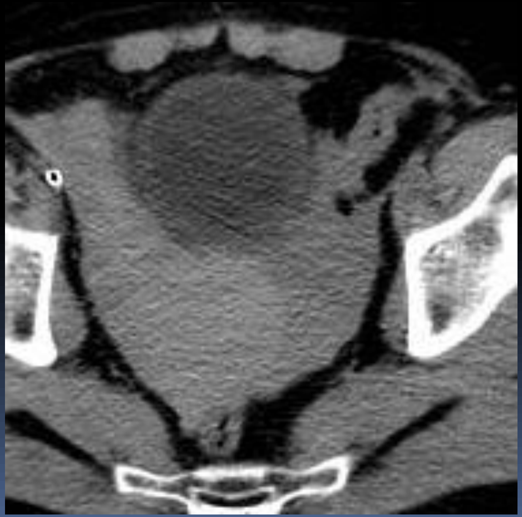




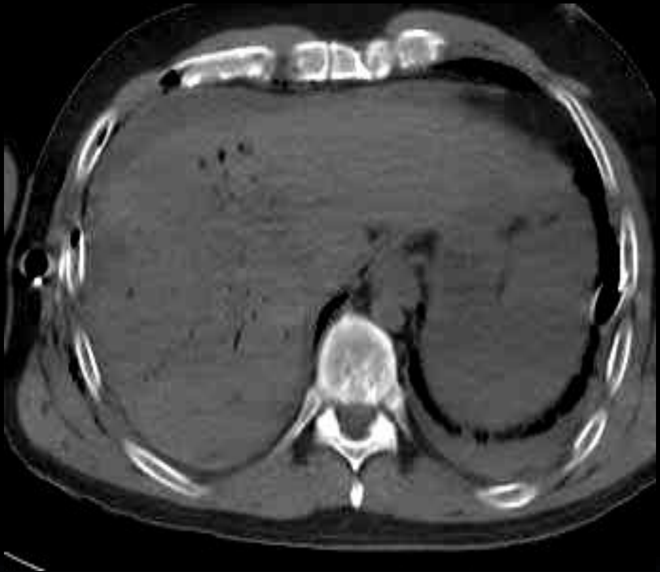
Case 6: Driver in High Speed MVC

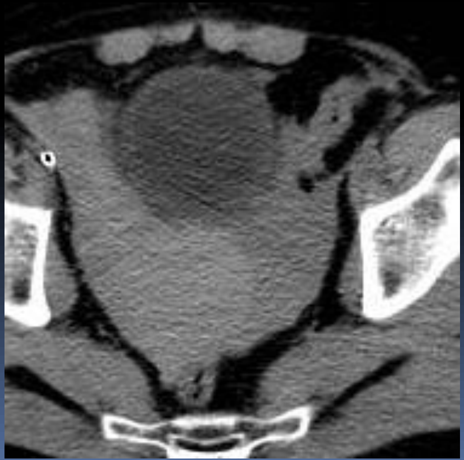
CT showed big hemoperitoneum and abnormal liver with distorted gas pattern

* Extent of liver injury and source of bleeding not seen unless PMCT Angiogram performed



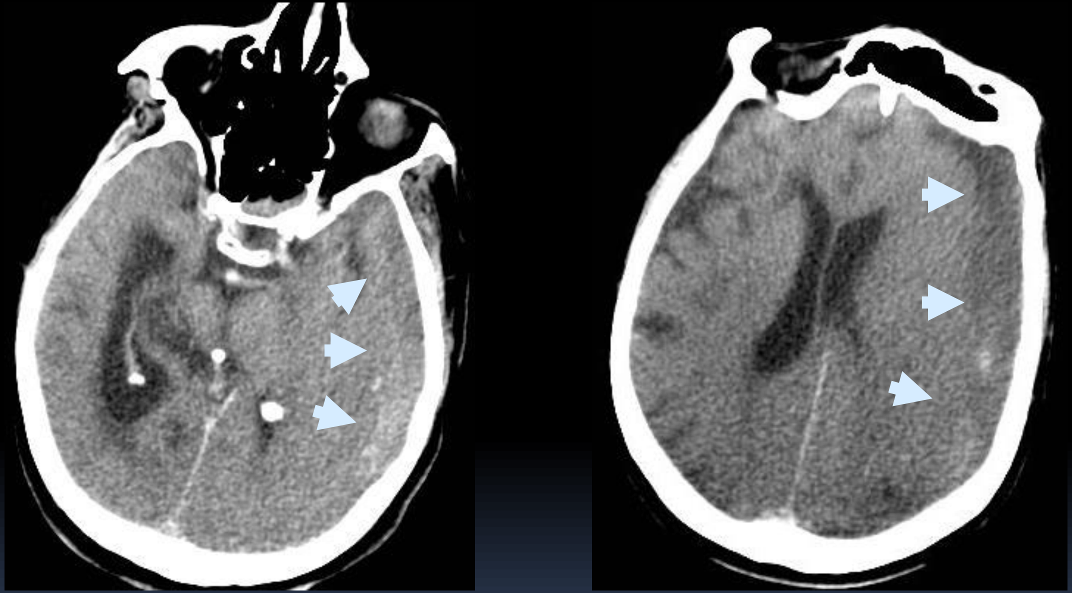
Same case: CT and Autopsy comparison





Case 7: Undetermined Death of Elder following Accident in Nursing Home

Death determined on PMCT as due to subdural hematoma (arrows)



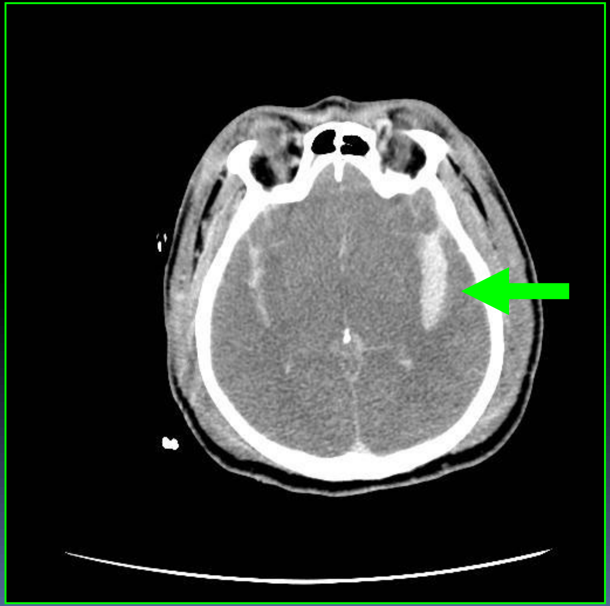
Autopsy not performed due to religious objections

Case 8: Suspected Traumatic Death

Driver in roll-over MVC – CT showed subarachnoid bleeding++ and some scalp contusions – NO MAJOR INJURIES

CT diagnosis of likely aneurysm bleed confirmed at autopsy – Likely lost consciousness before accident

Not actual event



Weaknesses of PMCT versus Traditional Autopsy ?

- Common ***false-negative*** findings at CT include:
  - Laceration of aorta and other vessels - can see bleeding but not source
  - Non-displaced fractures or dislocations
  - Soft tissue and organ injuries, especially if small or subtle

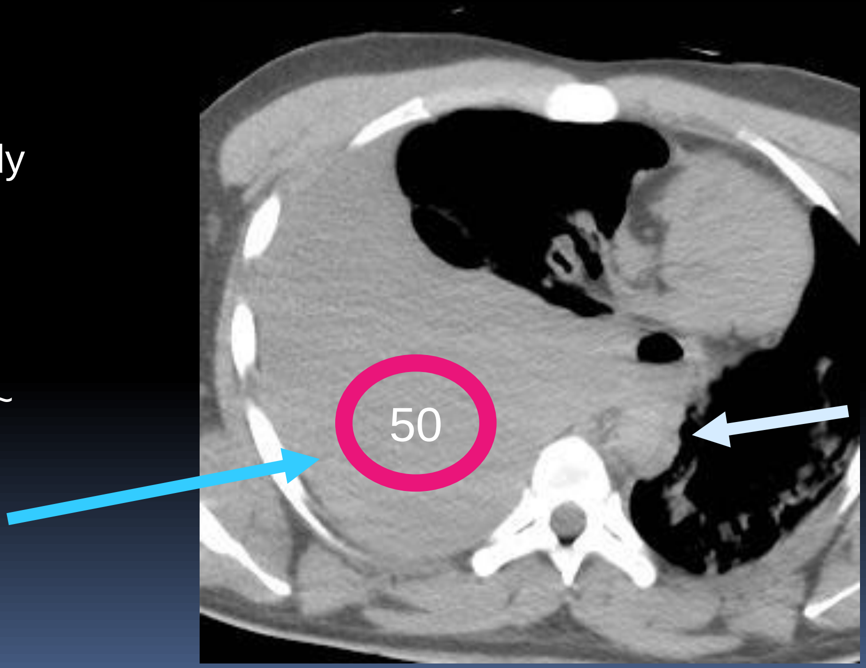
- Common ***false-negative*** findings at Autopsy:
  - Spinal fractures/dislocation
  - Air embolism
  - Pneumothorax

Example of False-negative findings at CT:

Fatal large Hemothorax from laceration of ascending aorta not seen on CT

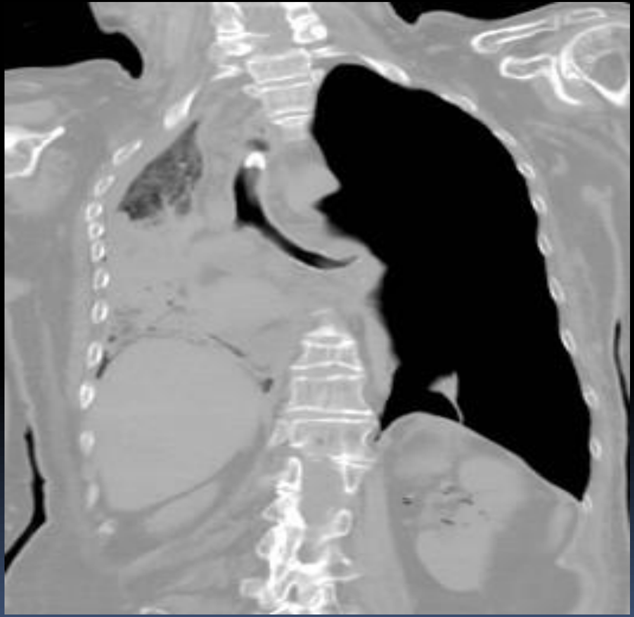
Limitation of non-enhanced study (no contrast dye used)

Attenuation (Density) measurement of pleural fluid is ~ 50 Hounsfield units = blood



Example of False-negative findings at Autopsy:

Tension Pneumothorax in Chronic Lung Disease



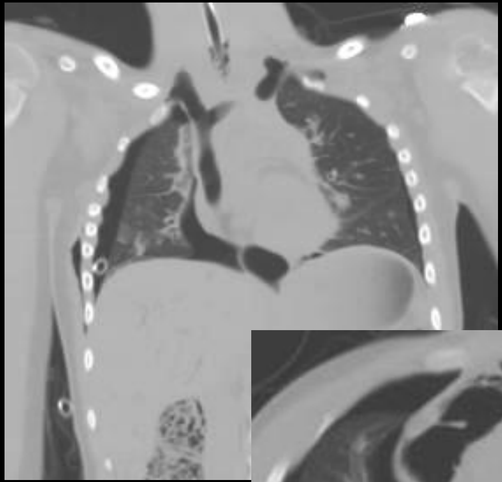
Example of False-negative findings at Autopsy:

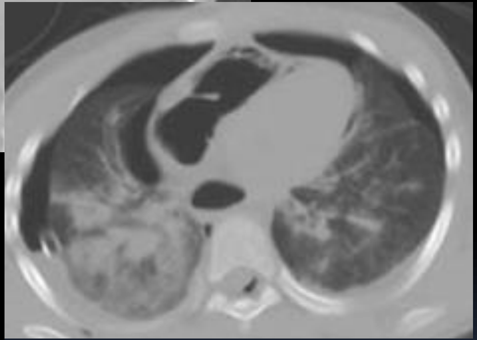
Air Embolism

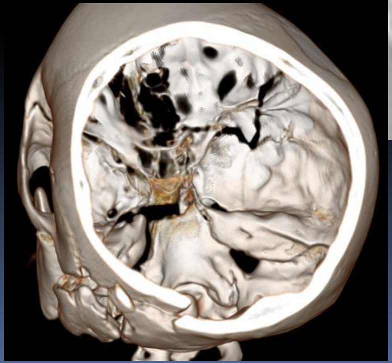
Seen in association with major skull base or thoracic fractures or ballistic/knife injuries to major vessels

Contribution to death not well understood but importance may be underestimated

Need special techniques to identify at autopsy – more easily seen at CT







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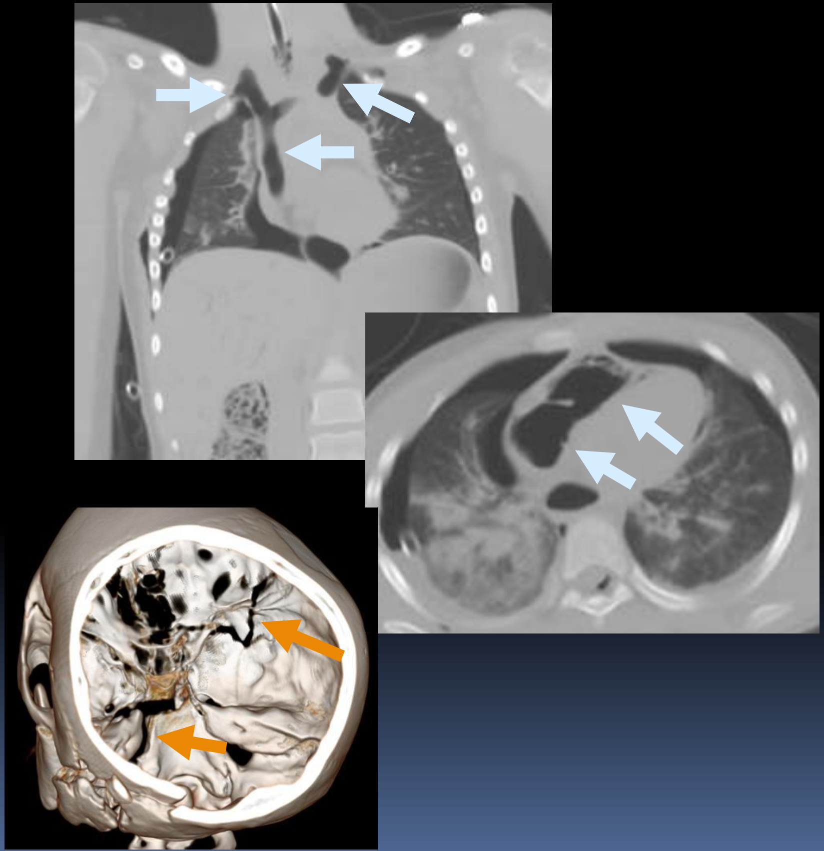
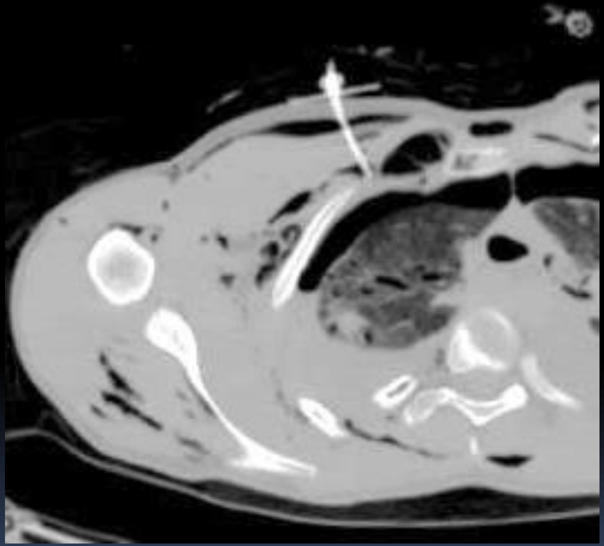


Post-Resuscitation Devices at PMCT

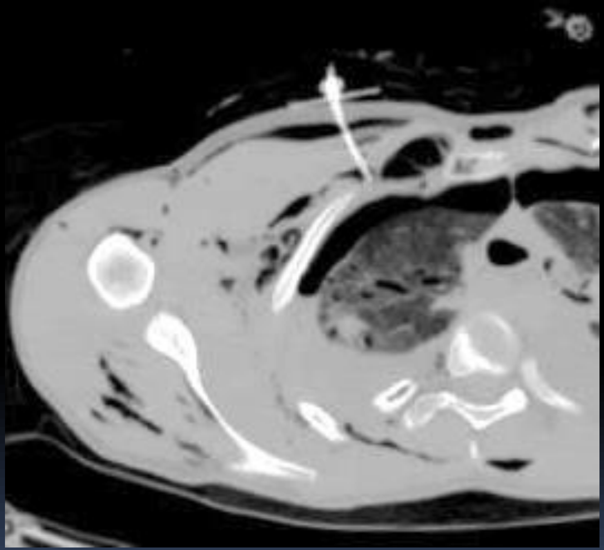
- Usually left in place after unsuccessful attempted resuscitation
- Noted at traditional Autopsy but correct/incorrect position not described – not a QA process
  - Catheters/tubes may have migrated from original location
  - Typically placed emergently
  - Often placed under difficult conditions
    - In the field/at night
  - Children especially challenging
    - Intubation problems
    - Venous access

Bilateral Hemo-Pneumothorax

Attempted chest drainage with venous catheters



Fatal outcome likely related to large amount of bleeding from aortic rupture also



Attempted chest drainage with venous catheters

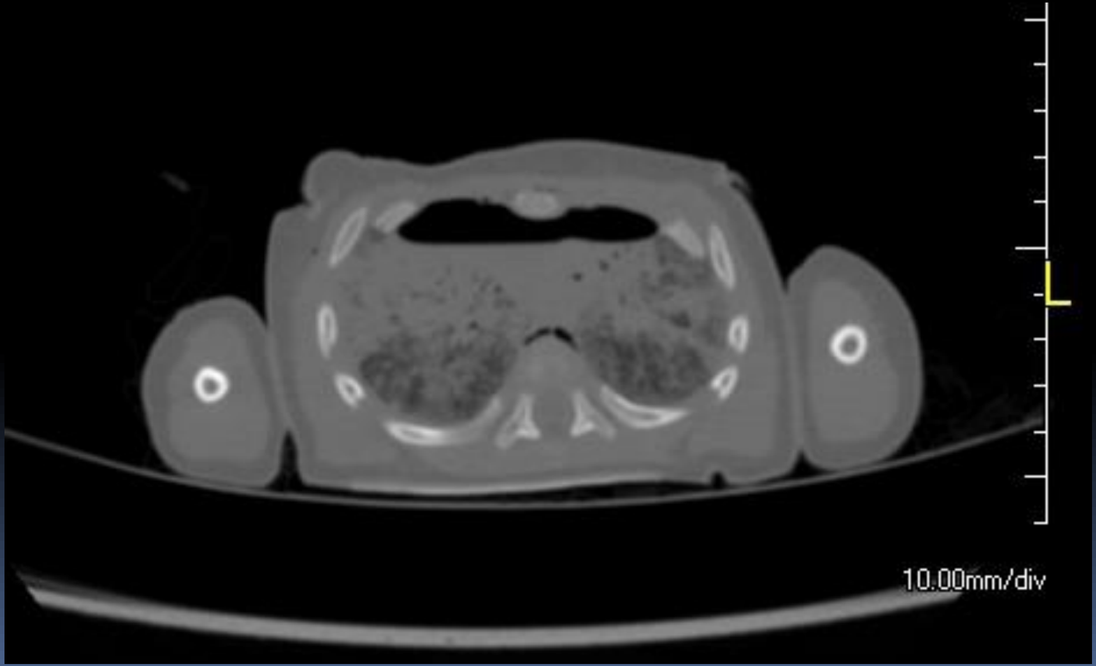
- Venous catheters used for emergency chest drains need to be longer

- People getting larger !
  - Obesity - at every age
  - Larger muscles in healthy younger males
    - noted in military deaths in Iraq

Not everyone has got this message yet…

Over-aggressive attempted resuscitation of an infant - SUDI case

Bilateral rib fractures, lung contusions and pneumothorax



Conclusions

- Early experience suggests that virtual autopsy using a whole body CT scan shows promise as a sensitive tool for detection of major injuries and cause of death, especially after ***accidental blunt trauma***
- Potential to replace or enable limited, focused autopsy in such cases
- Potential to provide feedback on CPR techniques
- In ***non-accidental traumatic death***, CT can be a valuable adjunct to mandatory autopsy for detection of injuries and ballistics
  - May shorten autopsy time
  - Provides better record of injuries than traditional radiographs – now used in court

Suspected Elder Abuse

Utility of Whole-Body Computed Tomography Imaging in Postmortem Detection of Elder Abuse and Neglect: Comparison with and Potential Substitution for Standard Autopsy

U.S. National Institute of Justice

Office of Justice Programs Grant: 2007-DN-BX-0007

https://www.ncjrs.gov/pdffiles1/nij/grants/237613.pdf

Introduction

Elder abuse (EA) contributing to death is a crime that is currently considered difficult to exclude without a full conventional autopsy, even where allegations of abuse are questionable

or are limited to nonphysical issues

Purpose

We investigated the potential for use of whole-body post mortem CT (PMCT) as a triage tool to determine the need for conventional autopsy based on detection of injuries suggestive of physical abuse and/or evidence suggestive of neglect

METHODS AND MATERIALS

- 58 decedents (14 M, 44 F; mean age 76 years, range 52-93 years) had PMCT and subsequent conventional Autopsy by state medical examiners within 24 hours of death
  - in all cases allegations of EA had been made by family members, caregivers or physicians

- Sensitivity of PMCT for injuries suspicious for abuse, evidence of potential neglect, and other major findings were determined with Autopsy as the standard of reference

METHODS AND MATERIALS

- Injuries considered suspicious for abuse:
  - Unsuspected or unreported injuries, especially in bedridden decedents or in presence of malnutrition and dehydration
  - Fractures
    - of differing ages
    - of long bones and ribs
    - of atypical type (e.g., spiral fracture of the humerus suggesting inflicted injury rather than a fall)
  - Injuries in locations unlikely to be the result of a fall or self inflicted
  - Cranial trauma – scalp, subdural and other intracranial hematomas
  - Evidence for abdominal organ injuries, or intra-abdominal hemorrhage
- Evidence of potential neglect
  - Decubitus sacral or ischial tuberosity ulcers, especially if deep

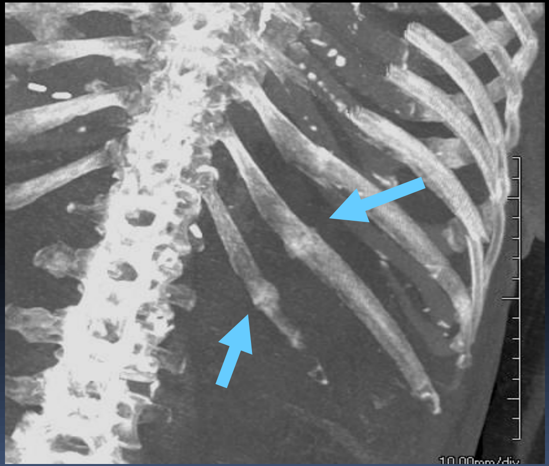
RESULTS – Elder Abuse

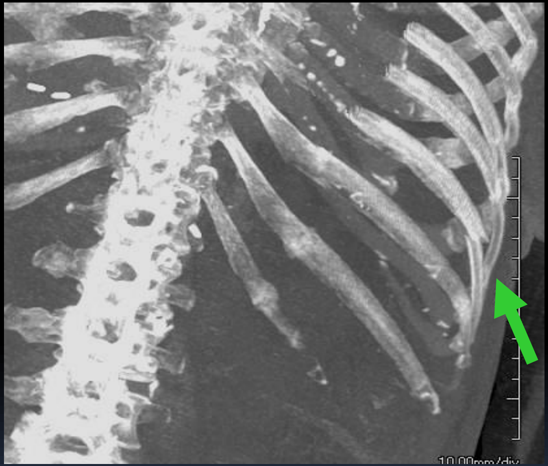
- PMCT and Autopsy were concordant in the exclusion of evidence suspicious for elder abuse in 57/58 cases

- PMCT and Autopsy were concordant in the detection of evidence suspicious for elder abuse in 1/58 cases
    - Both investigations demonstrated multiple previously unreported new and old rib fractures of varying age in this single case

Multiple undocumented new and old rib fractures suspicious for elder abuse

Old Fractures





New Fracture

RESULTS - Fractures

- PMCT noted acute bilateral upper rib fractures in 20/21 decedents who had attempted cardiac resuscitation (CPR)
  - These injuries were undetected at Autopsy in almost half of such cases (11/21)

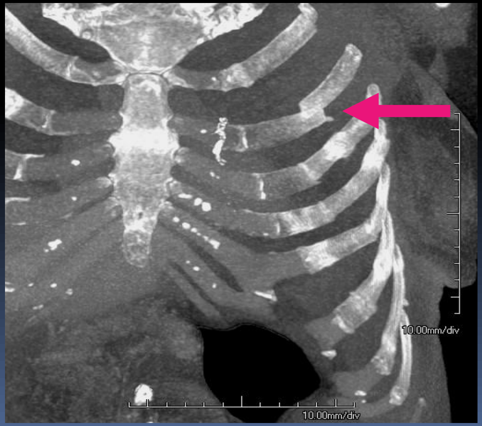
- PMCT noted other fractures typical for accidental trauma

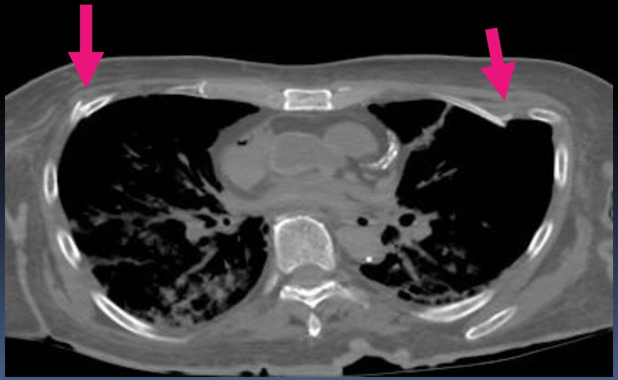
  in 5/58 cases
  - These injuries were undetected at Autopsy in 4/5 cases

- Post mortem PMCT failed to detect 2 fractures identified on autopsy

RESULTS: Rib Fractures

- Multiple acute rib fractures seen in 20/21 cases on PMCT
  - Multiple bilateral, upper, anterior locations in all cases
  - All cases associated with attempted Cardio Pulmonary Resuscitation
  - Likely related to brittle, osteopenic bone

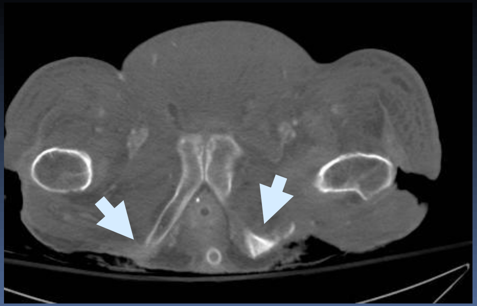




RESULTS: Decubitus Ulcers

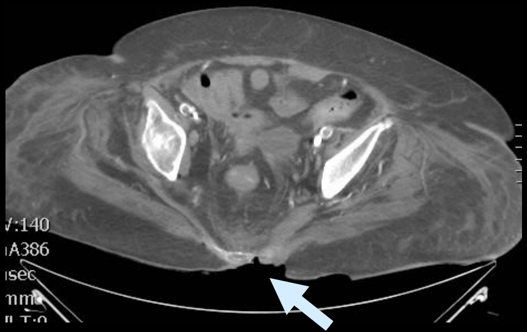
- PMCT identified decubitus ulcers in only 8/17 cases noted at Autopsy
  - Missed *superficial grade 1-2* decubitus ulcers in 9 cases

- PMCT identified *deep grade 4* decubitus ulcers /deep abscesses/septic discitis in 3 cases missed at Autopsy

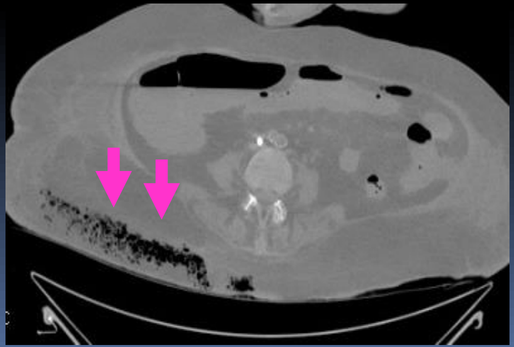


Stage 4 deep ischial ulcers involving bone not detected on autopsy

Discordant Findings between PMCT and Autopsy



Deep decubitus ulcer of sacrum



Large subcutaneous abscess at L3 level

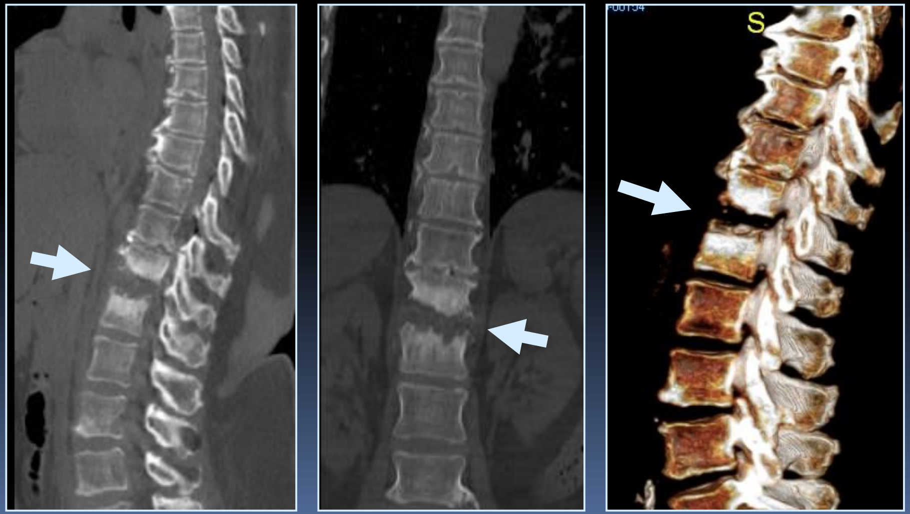
Cause of Death:
Septicemia of unknown cause

No evidence for Abuse

Subcutaneous abscess not detected on autopsy

Discordant Findings between PMCT and Autopsy

Unsuspected Infectious Discitis of T12-L1



Cause of Death:

Septicemia of unknown cause

No evidence for Abuse

Infectious discitis not detected on autopsy

RESULTS

Cause of Death:

- Determined by PMCT in 24/58 (41%) cases
- Determined by Autopsy in 58/58 (100%) cases

» Major Causes of death determined as

Cardiovascular	29
Chest infection	8
Accidental Head Injury/Neurologic	5
Septicemia	4
Pulmonary embolism	3
Accidental medication overdose	2
Other	6
suspected elder abuse case	1

(Ketoacidosis + multiple co-morbidities)

Discussion

Cause of Death:

- As expected, PMCT was not reliable for detection of cardiovascular and many other natural causes of death
  - Important to emphasize limitations of PMCT in this respect

- Conventional Autopsy included Toxicology, External Examination, Death Scene investigation and Medical Record review and determined the cause of death in all cases

Discussion

STUDY LIMITATIONS

- This study is limited by the low number of positive cases – only a single positive case was identified in this series of 58 decedents
- The low % of positive cases may reflect limited awareness for elder abuse among family members, caregivers, and the healthcare system in general, and subsequent failure to refer suspicious cases
- Alternatively, this study may support a view that many cases are referred to the medical examiner with allegations of abuse that are related to non-physical issues, medication problems or general unhappiness with care facilities among next-of-kin

Conclusions

- PMCT appears reliable for the detection or exclusion of skeletal injuries suspicious for elder abuse and may be used (in correlation with history and external examination) to determine the need for Autopsy where allegations or suspicion of abuse are raised
  - *Further research in a larger cohort including more positive cases would be helpful to confirm*

- Deep decubitus ulcers suggestive of neglect are more accurately detected and characterized at PMCT than at Autopsy
  - Superficial ulcers are better seen on external examination

Conclusions

- In this group PMCT was not reliable for determination of cause of death
- 32 of 58 cases had a diagnosis of cardiovascular death

Clinical Relevance

- PMCT may be used as a triage tool to help the medical examiner determine the need for conventional autopsy when allegations of elder abuse are made

- Acute upper anterior bilateral rib fractures were noted in all decedents who underwent full CPR, and are likely related to osteoporosis
  - *This information is of value for Emergency Room staff and may influence both CPR techniques and decisions to perform CPR in the elderly*

Thank you for your attention !

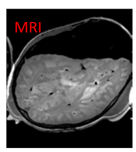
Postmortem Magnetic Resonance Imaging in Medicolegal Death Investigation

Natalie Adolphi, Ph.D. and Matthew Cain, M.D.

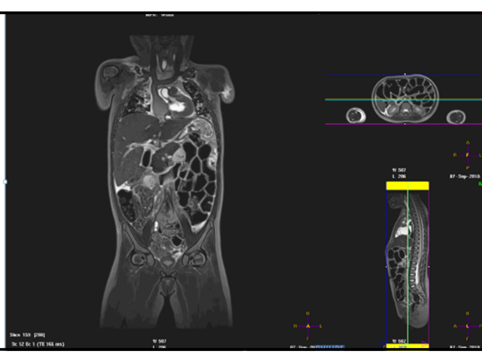
Office of the Medical Investigator
University of New Mexico
School of Medicine

CT is really useful – why bother with MRI?

- Superior soft tissue detail
  - Complements excellent bony detail of CT or x-ray
  - Good contrast even from badly decomposed tissue
- Particularly good for imaging…
  - Fetuses and infants
  - Complex soft tissue structures (*e.g.,* brain, heart)
  - Soft tissue injury (*e.g.,* adipose, nerve)
- Not practical for every case
  - CT ~15 mins   MRI ~30 mins to 2+ hours



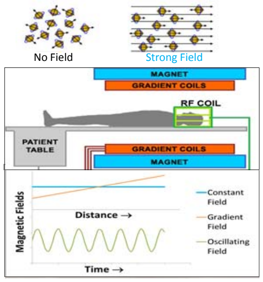
Coronal View



Axial View

Sagittal View

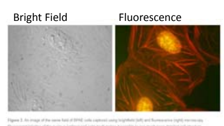
How does Magnetic Resonance Imaging work?

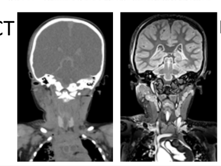


- Hydrogen nuclei (*e.g.,* in water molecules) are weak magnets
- MRI utilizes 3 **magnetic fields** to align, perturb, and spatially localize hydrogen nuclei to produce a voltage signal
- Image is *computed* from raw signal

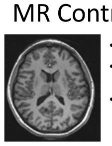
Why is soft tissue discrimination better with MRI?

- In CT, x-rays either pass through tissue or are attenuated
  - The signal comes from the x-ray tube
  - Analogous to bright field microscopy
  - Denser tissues attenuate x-rays more
- In MRI, hydrogen nuclei absorb energy and *emit their own signal*
  - The signal comes from hydrogen in tissue
  - Analogous to fluorescence microscopy
  - Hydrogen signal depends sensitively on several properties of the local environment, **not just density**



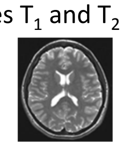


MR Contrast: Tissue Relaxation Times T_1 and T_2

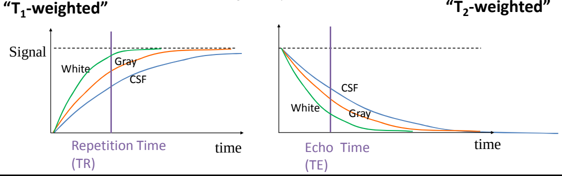


"T_1-weighted"

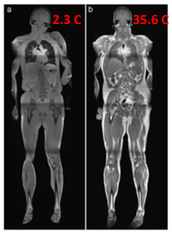
- Most soft tissues have around the same hydrogen density
- MR contrast depends mostly on the *time-dependence* of the hydrogen signal
- Different tissues have different relaxation times
  - T1 characterizes signal growth
  - T2 characterizes signal decay



"T_2-weighted"



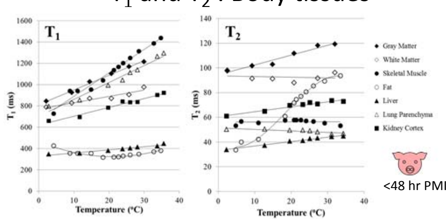
Why do PMMR Research?



From: Ruder et al. The influence of body temperature on image contrast in post mortem MRI. *Eur J Radiol.* 2012 Jun;81(6):1366-70.

- *Clinical* MR image acquisition protocols are optimized for *warm, well-oxygenated* subjects
- Temperature varies post-mortem and affects relaxation of MR signal
- MR acquisition protocols can be optimized specifically for the PM setting

T_1 and T_2 : Body tissues



<48 hr PMI

- T1: increases with temp for most tissues; weak temp-dependence for liver, fat
- T2: weak temp-dependence for most tissues; but Fat T2 significantly decreases at low temp

Clinical vs. PMMR Comparison

Clinical	Post-mortem
• **Motion** is a challenge – may require gating and/or may reduce image quality	• **No motion**
• **Contrast agents** administered IV or orally	• **PM subjects require external pump** to deliver contrast – many T_1-w protocols will not be useful
• **Body temperature is constant** – tissue contrast is predictable	• **Body temperature varies** – requires optimization
• Hospital throughput, patient comfort/compliance, and need for diagnosis in emergent situations limit exam time	• Forensic case load, needs/expectations of decedents' families and law enforcement limit exam time

Other Considerations for PMMR

- Safety
  - CT or Radiography survey to screen for potentially magnetic objects – prior to MRI
    - Ferrous objects (*e.g.*, drill bits)
    - Possibly ferrous (*e.g.*, possible steel jacket)
    - Actual magnets
    - Screening not needed for fetal demise/still birth
  - MR-safe (non-magnetic) gurney is required
- MR scanning is generally more time consuming than CT

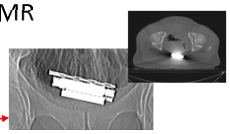
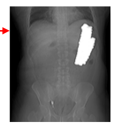
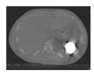
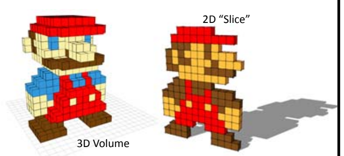
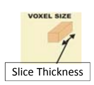
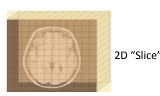




Image Data

- Voxels are volume elements
  - "Pixels" are picture elements
- The size of the voxel sets the image resolution
- Volume elements can be longer in one direction
  - 1 mm x 1 mm x 5 mm
  - Suitable for 2D display
- Volume elements can be cubes (isotropic)
  - 1 mm x 1 mm x 1 mm
  - More flexible (allows display of different planes or 3D rendering)

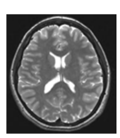






OMI PMMR

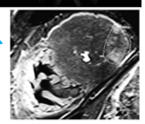
- Early application of PMMR at OMI
  - Typically use T2 weighted imaging
    - Fairly quick whole body scans ~30 minutes
    - Excellent detail of soft tissue
    - Contrast is relatively independent of temperature
- Scans typically of infants
  - Useful for brains and hearts
  - Can show soft tissue injuries
- Not for every case, and not every sequence on these select cases - multiple contrasts can lead to > 2 hrs scan



T_2-weighted Brain

PMMR is good for finding fluid

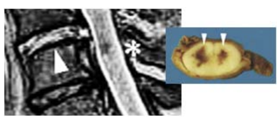
- T2-w PMMR identifies "pathological fluid accumulation"
  - Edema due to blunt force trauma (contusions of neck and forearms)
  - Focal necrosis + peri-focal edema in Myocardial Infarction*
  - Note: T2 is generally less temperature-sensitive

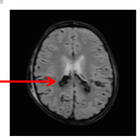


*Ruder, Thali and Hatch, *Br J Radiol* 2014:87:20130567

PMMR detection of hemorrhage

- Spinal cord injury without fracture in an adult*
- Intraventricular hemorrhage due to non-accidental trauma

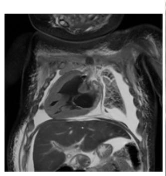


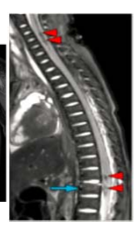


*T. Okuda, et al., A case of fatal cervical discoligamentous hyperextension injury without fracture: Correlation of postmortem imaging and autopsy findings, *Forensic Sci. Int.* (2012)

A Well-Established PMMR Application: Fetal and Infant Imaging

- MR well-suited for imaging complex soft tissues using small FOV
  - In utero or ex situ
- Detection of congenital anomalies, injuries
- Protocols and several systematic studies published by Thayyil, Arthurs et al. (Great Ormond Street Hospital, London)

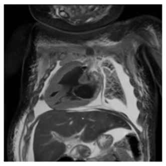




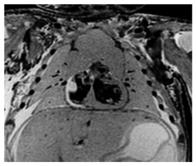
*Thayyil S, et al.; MARIAS collaborative group. Post-mortem MRI versus conventional autopsy in fetuses and children: a prospective validation study. *Lancet.* 2013 Jul 20;382(9888):223-33.

Left: Dextrocardia and structural anomalies of heart
Right: *Cervical and lumbar spinal cord injuries (non-accidental trauma)

Scanning Method Makes a Difference

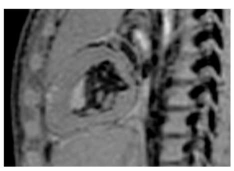


Individual 2D scans of long and short Axes, 4 chamber views – time consuming, no MPR

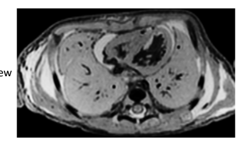


3D Isotropic view – 0.7 x 0.7 x 0.7 mm resolution on a heart that is 3.2 cm across
~30 to 40 min scan with MPR option

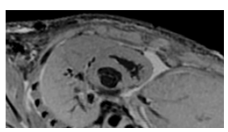
MPR – Multiplanar reformatting



Sagittal view



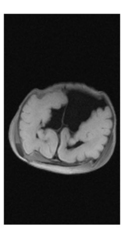
Axial view



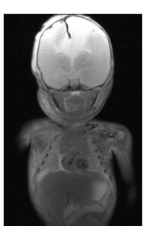
Oblique view

Multiple views from a single 3D volume image

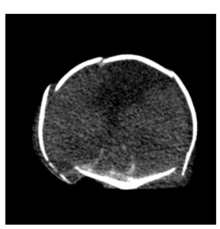
Brain Cysts



MRI - FLAIR



T2 weighted

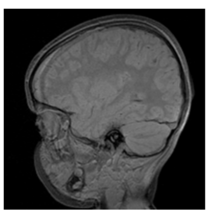


CT – brain window

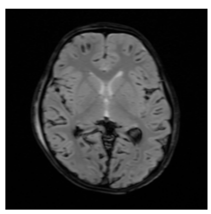
Multiple contrasts

- Multiple contrasts are possible with PMMR
  - Discuss with neuroradiologist about desired sequences
- Useful for brain imaging
  - Not just T2, but T1, FLAIR, hemo sequences
- These are often temperature dependent and resolution can be affected if not accounted for.
- Examples: ->

2 year old suspected child abuse

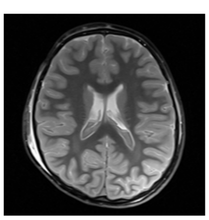


FLASH – T1



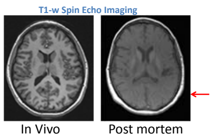
Hemo sequence

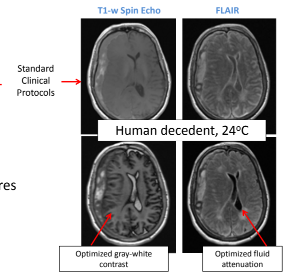
Contrasts continued



Ax-destir (FOV 180)

PMMR Brain Imaging





- T1 difference between gray and white matter is reduced at lower temperatures encountered in PM setting
- PM contrast can be improved with adjustments to protocols

Interpretation

- OMI pathologists are trained for CT and have limited experience with MRI – primarily T2 weighted images
- The scans are performed:
  - Permanent record of detailed information for interpretation
  - Contact radiology
    - This typically involves a specialist that can interpret these special images
    - Different than CT – your local radiologist may need to contact his/her neuroradiology colleague

Take Home Points

- 3D imaging is useful in the ME context
- MRI enables superior soft tissue discrimination, relative to CT, due to fundamental differences in signal generation
- PMMR is particularly good for examining complex soft tissue anatomy, detecting pathological fluid accumulations and hemorrhage, and imaging fetuses and infants
- PMMR requires additional optimization, due to the greater variability of subject temperature in the PM setting

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