CT Protocol Case Studies: Safety and Image Quality

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Purpose & Learning Objectives

- **Review FDA recommendations for CT scanning of electronic medical devices**
  - Provide an example of institutional policy for scanning electronic devices
- **Review case studies of artifacts related to devices or patient physiology**
  - Metallic implants
  - Bariatric imaging
  - Motion artifact

FDA Guidance on CT of Electronic Medical Devices

- **2008 – FDA issues first public health notification about CT interference with electronic medical devices**
- **Reported adverse events due to device failure during radiation exposure**
- **Applies to:**
  - Cardiac implantable electronic devices (CIED)
  - Neurostimulators
  - Insulin pumps

https://www.fda.gov/radiation-emitting-products/electromagnetic-compatibility-emc/interference-between-ct-and-electronic-medical-devices

FDA Guidance on CT of Electronic Medical Devices

What can happen:

Cardiac Implantable Electronic Devices:

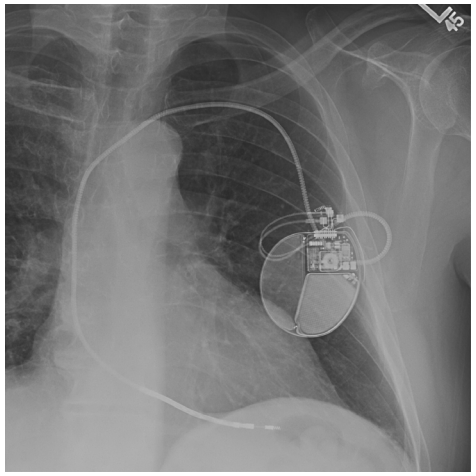
- Improper pacing
- Heart palpitations
- Device restart required or device failure
- Recorded data corruption

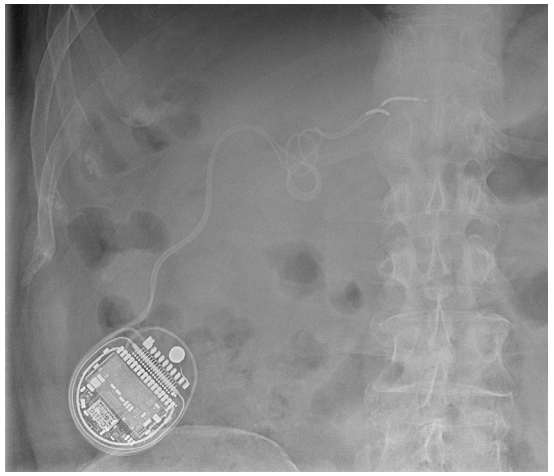
Neurostimulators

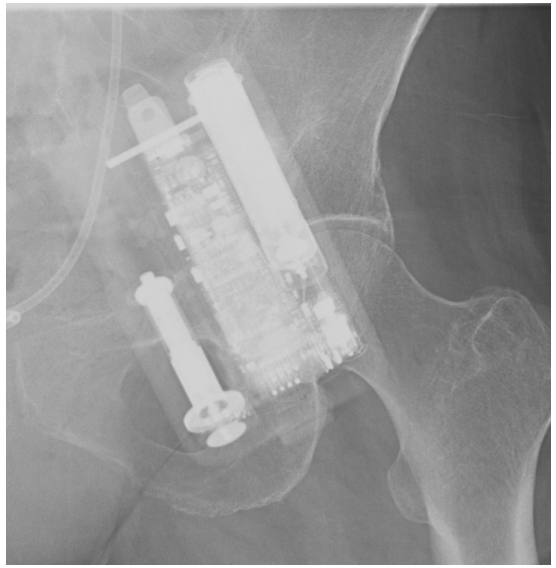
- Involuntary movement
- Shocks, pain, discomfort, tingling or burning sensation
- Device turning on or off during/immediately after CT

Insulin Pumps/Continuous Glucose Monitors

- Failure to deliver proper insulin amount
  - Hypoglycemia leading to dizziness, fainting, and seizures
  - Hyperglycemia leading to ketoacidosis



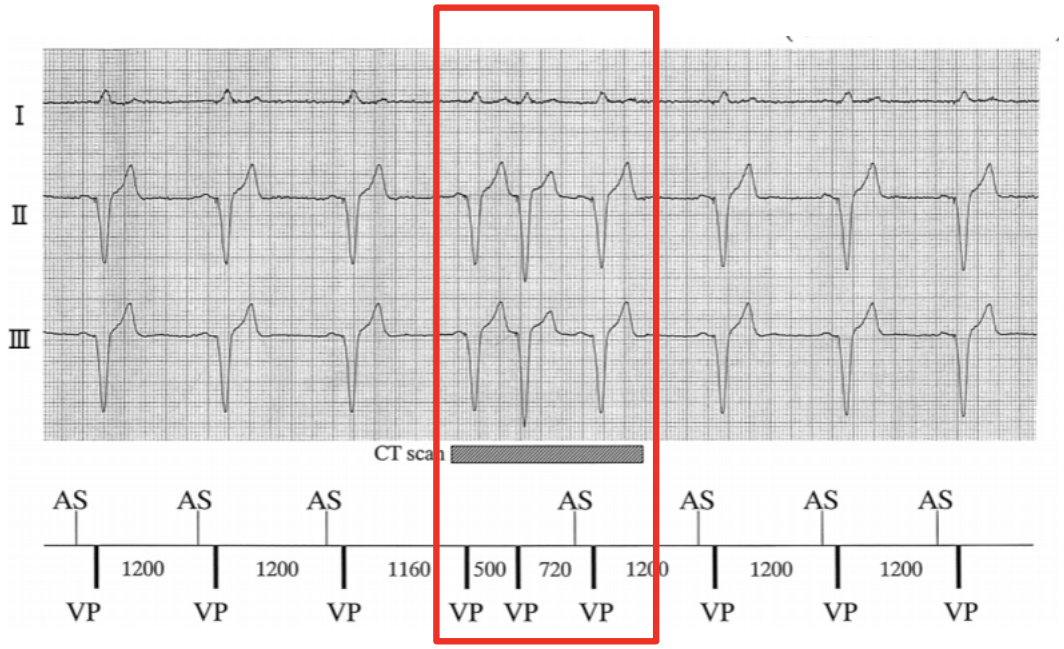




Case reports in the literature

CIED

- Pacing or recording anomalies have been documented by Yamaji et al (2006), McCollough et al (2007), Oda et al (2008), and Porres et al (2009)
  - Oversensing in 20/21 devices during high dose exams and 17/20 at typical dose (McCollough, Zhang et al. 2007)
- Hussain et al (2014) published a 10-year retrospective review of 516 CT scans that directly exposed CIED
  - No deaths, bradycardia or tachycardia requiring intervention, unplanned hospital admission, or incorrect defibrillation reported

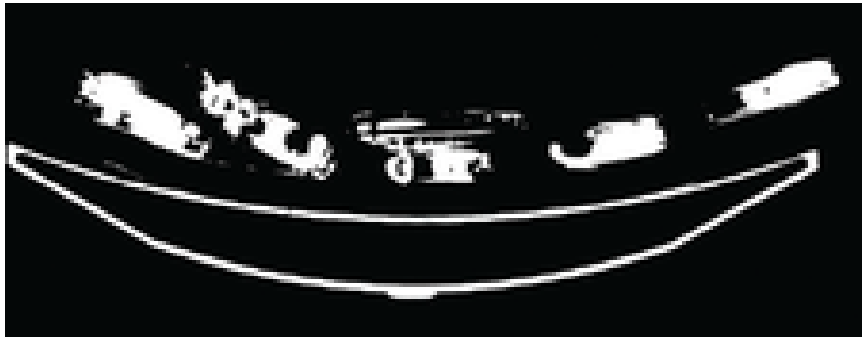


(Yamaji, Imai et al. 2006)

Case reports in the literature

Insulin Pumps

- Magdaleno et al (2018), and Whicher et al (2017) scanned insulin pumps
- Scan setup did not mimic clinical use
- Repeated scanning
- No severe alarms or malfunction attributed to CT
- One device demonstrated screen dimming



Neurostimulators

- No studies available
- Many can be turned off during scanning if patient is not dependent on device

Top: Whicher et al. *Practical Diabetes* (2017)
Bottom: Magdaleno et al. *J Diabetes Sci Tech* (2018)

Severe events are incredibly rare! CT is often safer than MRI for electronic implants!

Patients: Physicians recommend CT scans for medical reasons. **The probability of an adverse event is extremely low.**

Healthcare providers: The presence of the devices mentioned above should NOT preclude the performance of an appropriate, medically indicated CT scan. The probability of an adverse event being caused by exposing these devices to CT irradiation is extremely low, and it is greatly outweighed by the clinical benefit of a medically indicated CT examination.

When tested, all effects on implanted electronic devices have been <u>transient</u> and only occur during <u>direct exposure</u> from CT

https://www.fda.gov/radiation-emitting-products/electromagnetic-compatibility-emc/interference-between-ct-and-electronic-medical-devices

Implantable and External Electronic Device Policy

- **Applicable to exams with direct radiation exposure >3 seconds to common electronic medical devices**
  - Coronary Artery Screening, Cardiac Tumor, Thoracic Aorta, CT Perfusion, 4D or Average CT for PET/CT, CT Fluoroscopy
- **Device must be:**
  1. Moved out of the scan region
  2. Turned off during scanning
  3. If unable to be moved or turned off, radiologist or other health care provider will obtain signed, informed consent from the patient
- **Responsibilities:**
  - Nurse and technologist must ensure policy followed when patients are identified
  - Radiologist must obtain signed informed consent and adjust protocol choice
  - Imaging physics consults and advises policy

Case #1: Hip Implant

Metal Artifact due to Hip Implants

Patient had bilateral hip implants with severe beam hardening and photon starvation

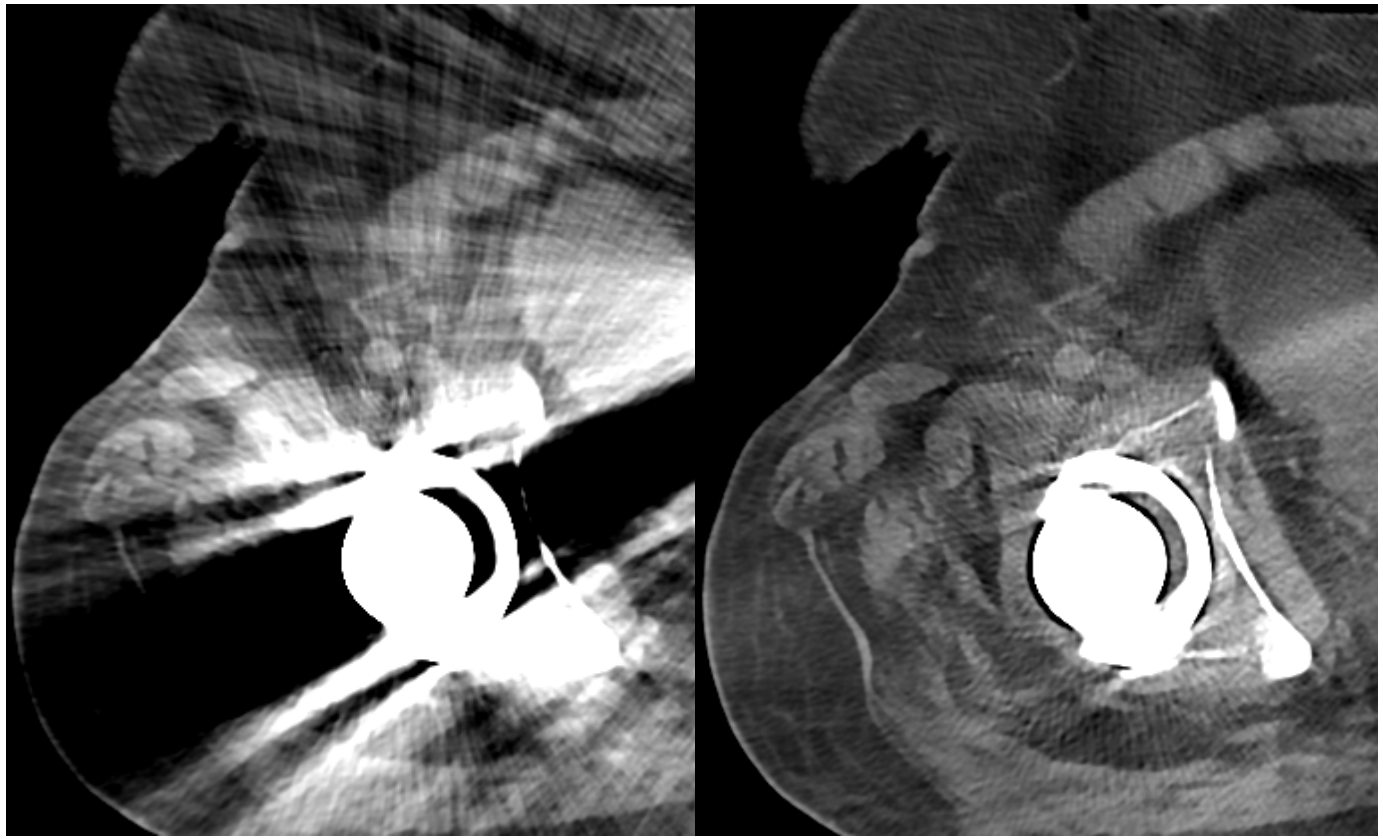
- Metal artifact reduction algorithm applied
- MAR segments corrupted sinogram data and interpolates data to reduce streaking

Other techniques to improve image quality:

- Increase kVp
- Increase mAs to reduce photon starvation
- Perform DECT with monoenergetic imaging (with or without MAR)

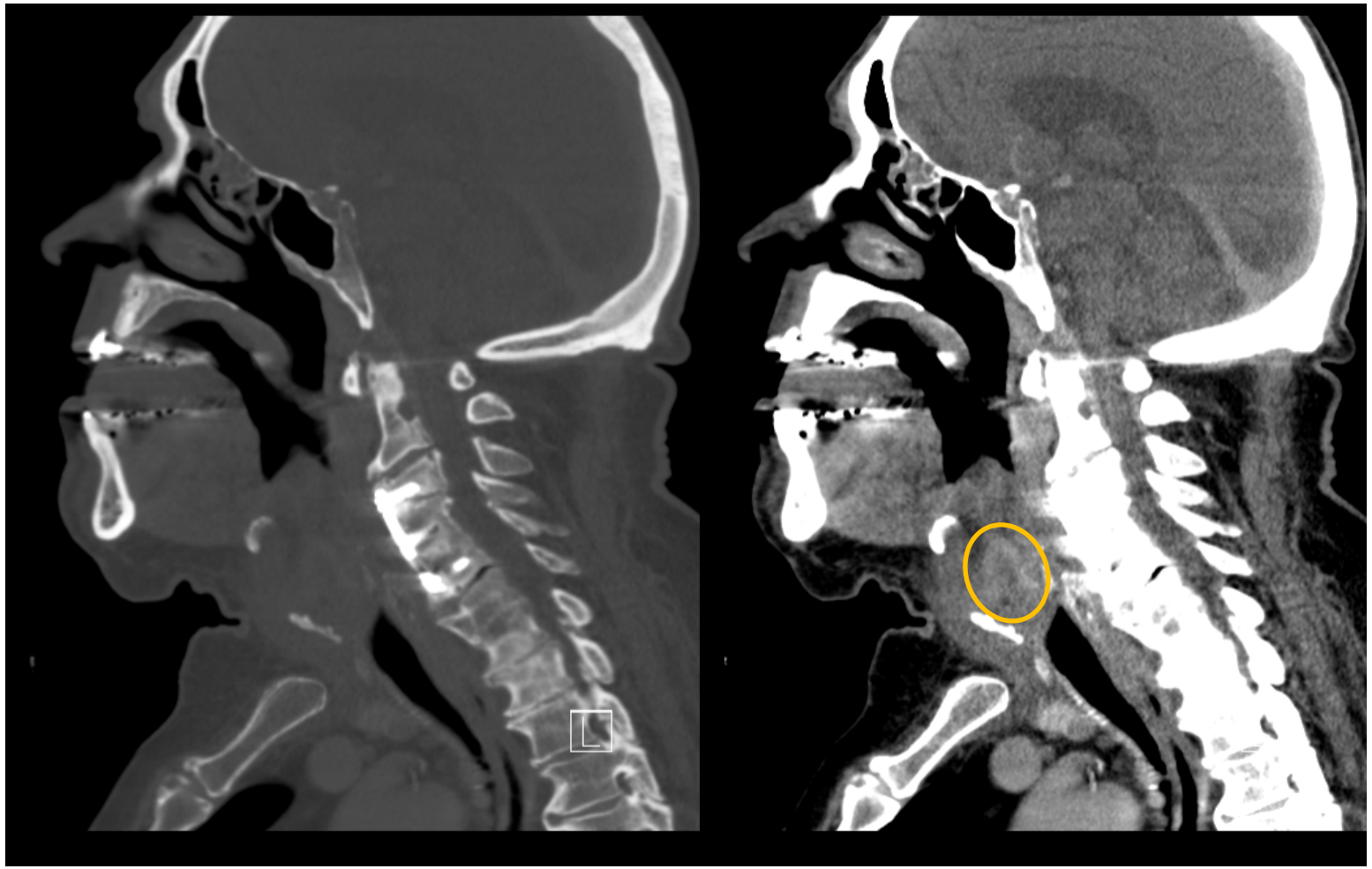
Without iMAR

With iMAR



Case #2: Neck Exam with Cervical Fixation

Cervical Spine Hardware



Laryngeal carcinoma in patient with cervical spine fixation/hardware

- Dental artifact accounted for with gantry angulation

Primary mass visible on sagittal reformats, but beam hardening near spine reduces image quality

Cervical Spine Hardware

Cervical spine hardware impeded visualization of adjacent soft tissue structures

- Photon starvation and beam hardening

Patient received a DECT for radiation therapy treatment planning

- Virtual monoenergetic imaging reduces beam hardening near the hardware
- Metal artifact reduction in addition to monoenergetic imaging may further improve image quality
- Low keV images can improve image contrast, while high keV settings can reduce artifact

DECT useful if MAR is unavailable or insufficient

120 kVp
26.2 mGy $CTDI_{vol}$

DECT 140 keV
24.2 mGy $CTDI_{vol}$

Case #3: Bariatric Abdominal Imaging

Liver metastases

Bariatric Imaging

Reduced image quality due to beam hardening, high noise

- Tube output limited, resulting in high noise
- Some protocols may cap the mAs to reduce dose, further reducing image quality in large patients

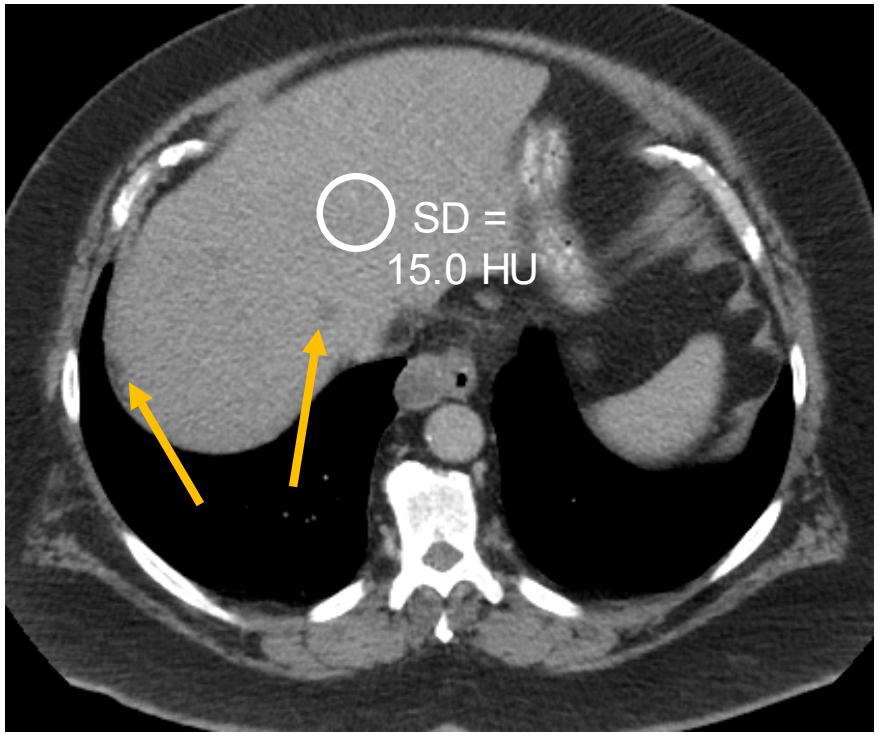
Methods to improve image quality:

- Increase mA and rotation time and/or reduce pitch
  - Increases dose and slows scan
  - Higher risk of motion
  - Utilize dual-source CT to increase scanner output
- Increase kVp
  - Reduces image contrast
- Use iterative or deep learning reconstruction methods
  - Effectively reduces image noise

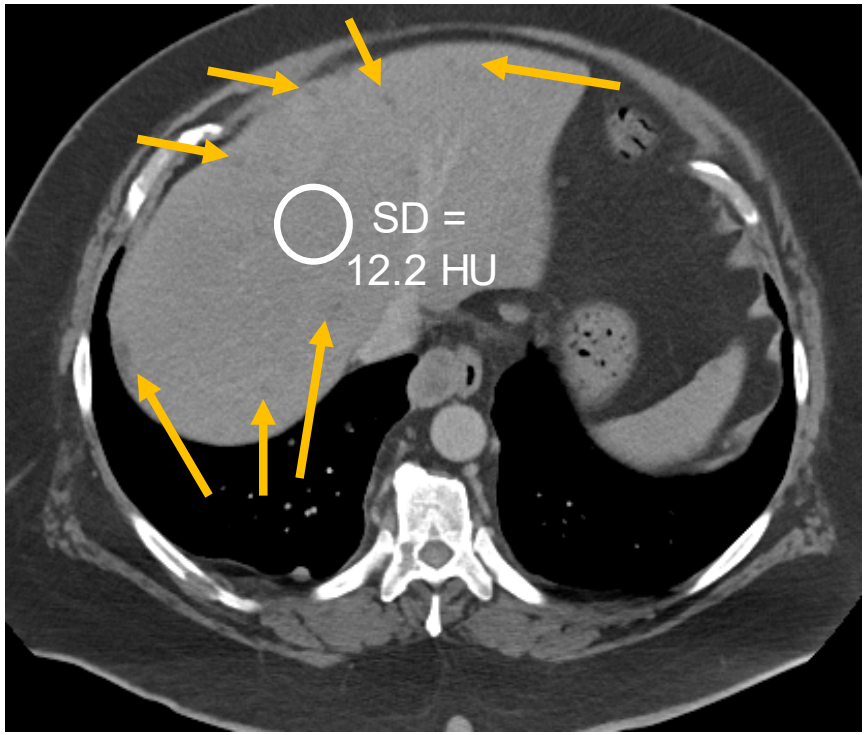
Goal is a diagnostic quality exam to minimize repeats

Bariatric Imaging Example

120 kVp, 600 mA, 0.5 sec, 0.8 pitch
5 mm image thickness
20 mGy CTDIvol
Soft Reconstruction Kernel (FC18)

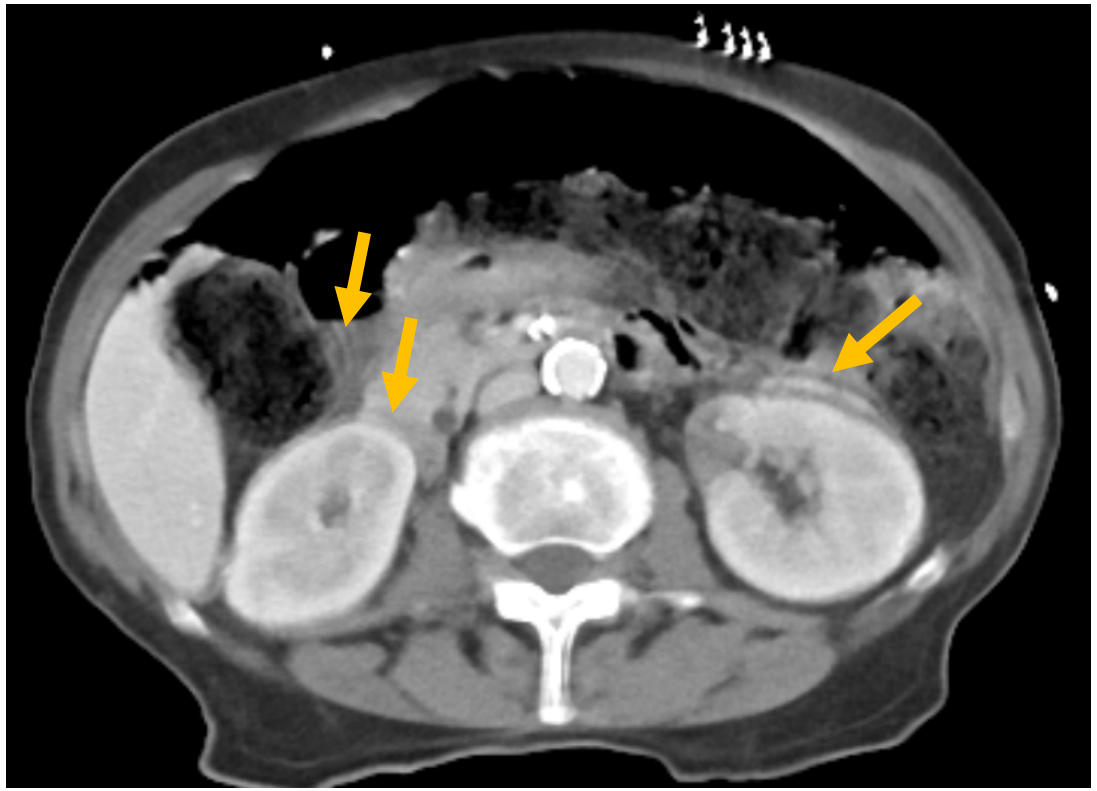


MDACC Dual-source:
120 kVp, 1166 mA, 0.5 sec, 0.7 pitch
3 mm image thickness
69 mGy CTDIvol
Medium Recon Kernel with IR (I40f/Strength 2)



Cases #4 & 5: Motion Artifacts

Motion Artifacts



Patient motion causes blurring of tissue boundaries, double images, and potentially long streaks

- Patient had severe lung disease and could not maintain breath hold
- Rotation Time = 0.5 s; Pitch = 0.6

Artifact severity depends on extent and speed of motion

- Faster scanning
  - Reduce scan range where possible
  - Reduce rotation time and increase pitch
  - Utilize flash mode on dual-source systems
  - Improves breath hold compliance
- Appropriate use of immobilization and sedation
- Gated studies

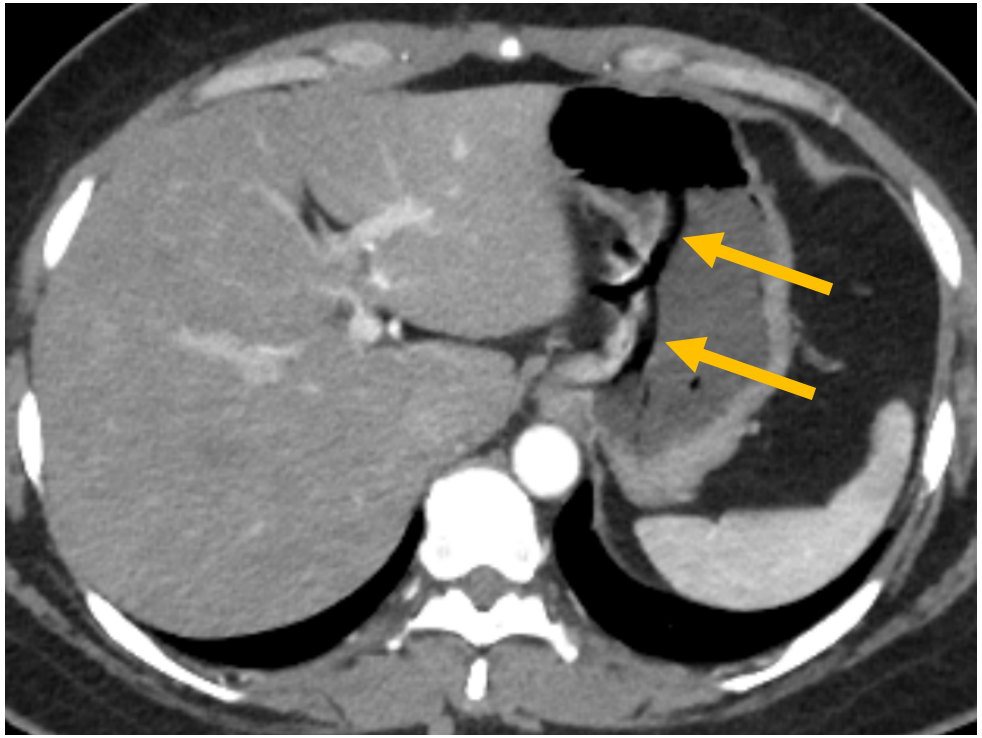
Motion Artifacts

Motion of gas within the patient causes unique artifacts

- Curvilinear hypointense artifacts extending from air bubbles in gastrointestinal tract
- Results from involuntary motion
- Reconstruction assumes that bubble is stationary

For a constant bubble velocity, faster scanning results in arcs of smaller radius

- Liu et al. *AJR* (2008)
- Simulations and phantom experiments demonstrate artifact
- Motion is fast and unpredictable
  - Antispasmodic drugs prior to scan could reduce, but are more common for long exams such as MR



Take-home Messages

1. **Electronic medical devices may be scanned safely with CT**
   a) Adverse events are very rare and are more likely in exams with high dose rate and long exposure times
   b) Transient effects may occur during direct exposure
   c) Institutional policy may recommend temporary removal of devices that are not implanted, such as insulin pumps and glucose monitors
2. **Challenging examinations due to patient physiology or implants can be optimized with appropriate protocol adjustments**
   a) Metallic artifacts may be reduced with metal artifact reduction or dual-energy CT
   b) Bariatric imaging often requires higher dose, iterative reconstruction, and potentially higher kVp to reduce image noise
   c) Motion artifacts may present in different ways, including organ blurring, streaking, double images, or curvilinear gas bubble artifacts

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