Department of Radiology
UNIVERSITY OF WISCONSIN
SCHOOL OF MEDICINE AND PUBLIC HEALTH

UW IMAGE-GUIDED INTERVENTIONS LAB

# A Comprehensive Guide to Interventional CT: Technology, Workflow, and Dose Considerations

**Martin Wagner, PhD**

Slides partially courtesy of **Timothy Szczykutowicz**

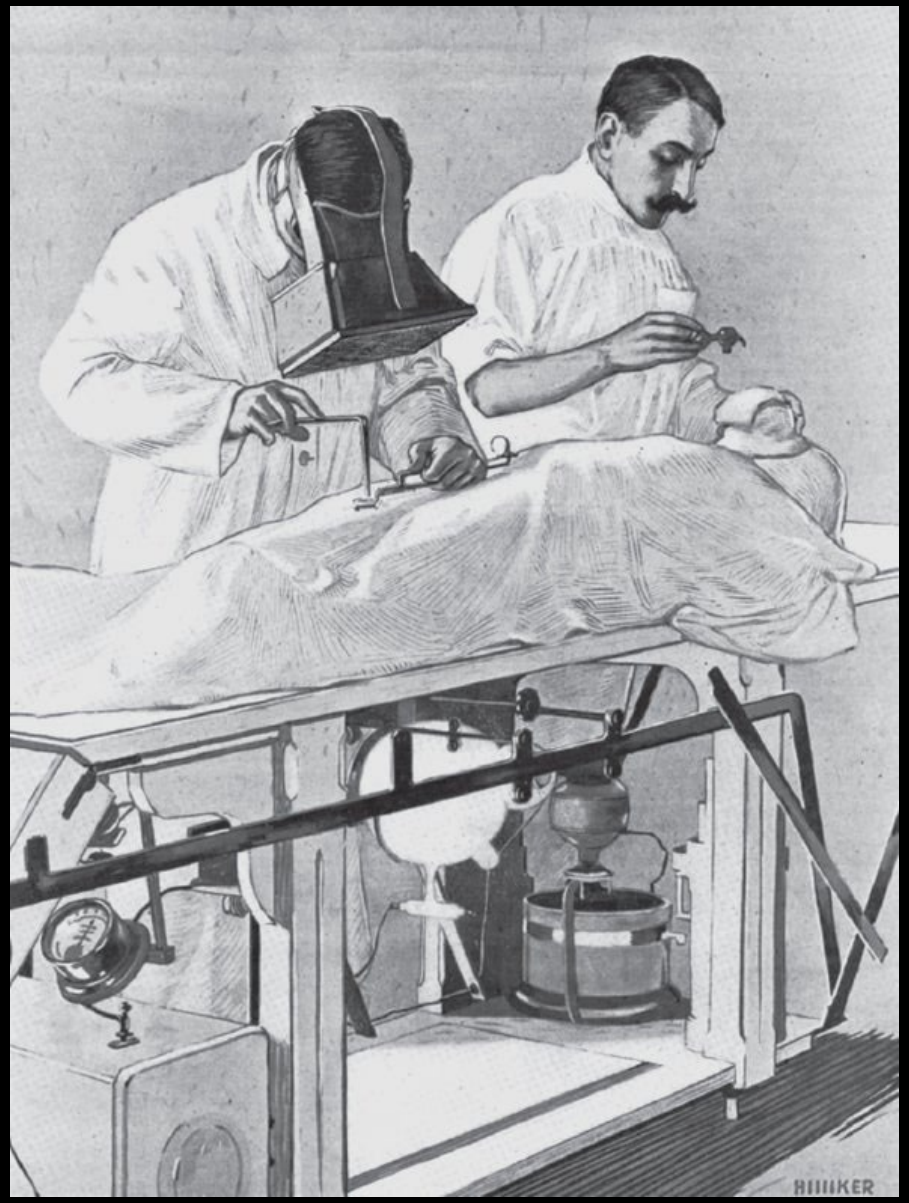
# Disclosures

- Consultant for HistoSonics Inc.
- Sponsored research agreements with
  - Siemens Healthineers
  - Canon Medical
  - HistoSonics Inc.

# Outline

1. **What is Interventional CT?**
2. High level scheduling considerations
3. Scanner Options Overview
4. Interventional CT Specific Options
5. Dose
6. Advanced Device Guidance
7. Ongoing Research

# History

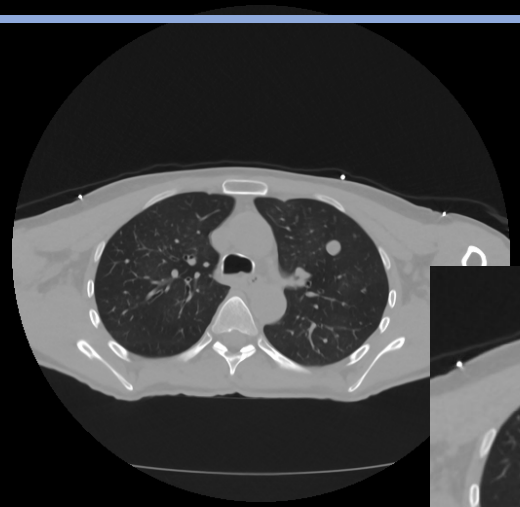


**1916:** Surgery performed with the help of x-rays. Credit: Scientific American Supplement, VOL. LXXXI, NO. 2110; June 10, 1916

# Interventional CT Guidance Overview

Some prior imaging where we identify the need for a biopsy or ablation/treatment intervention

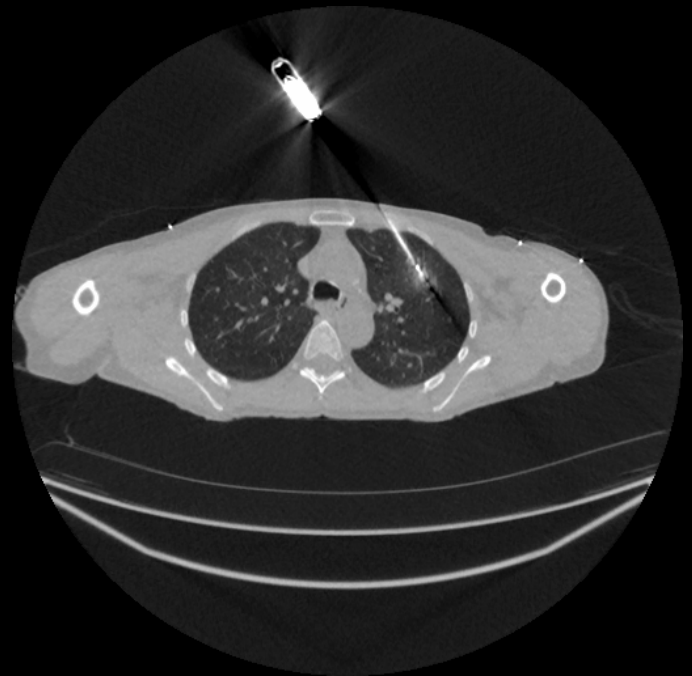
Procedural imaging



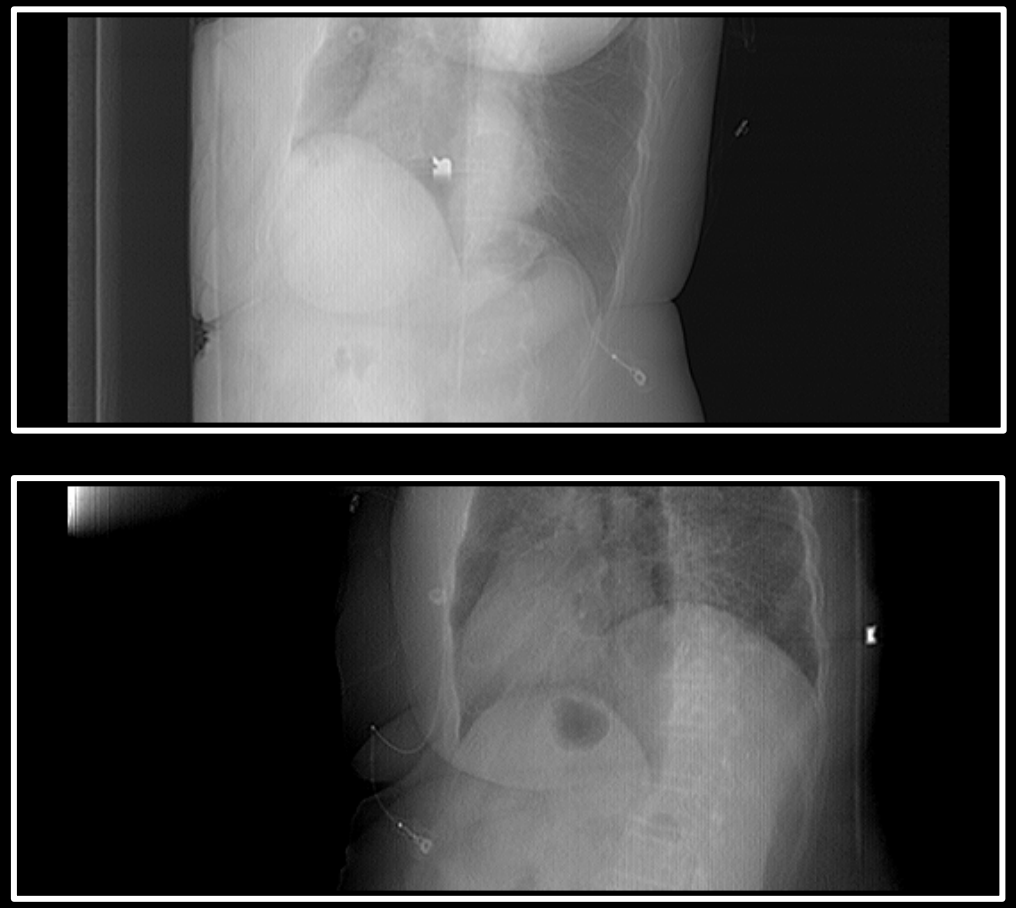
Day of planning


Trajectory planning

Imaging to make sure device is heading towards target, imaging to ensure device hits target



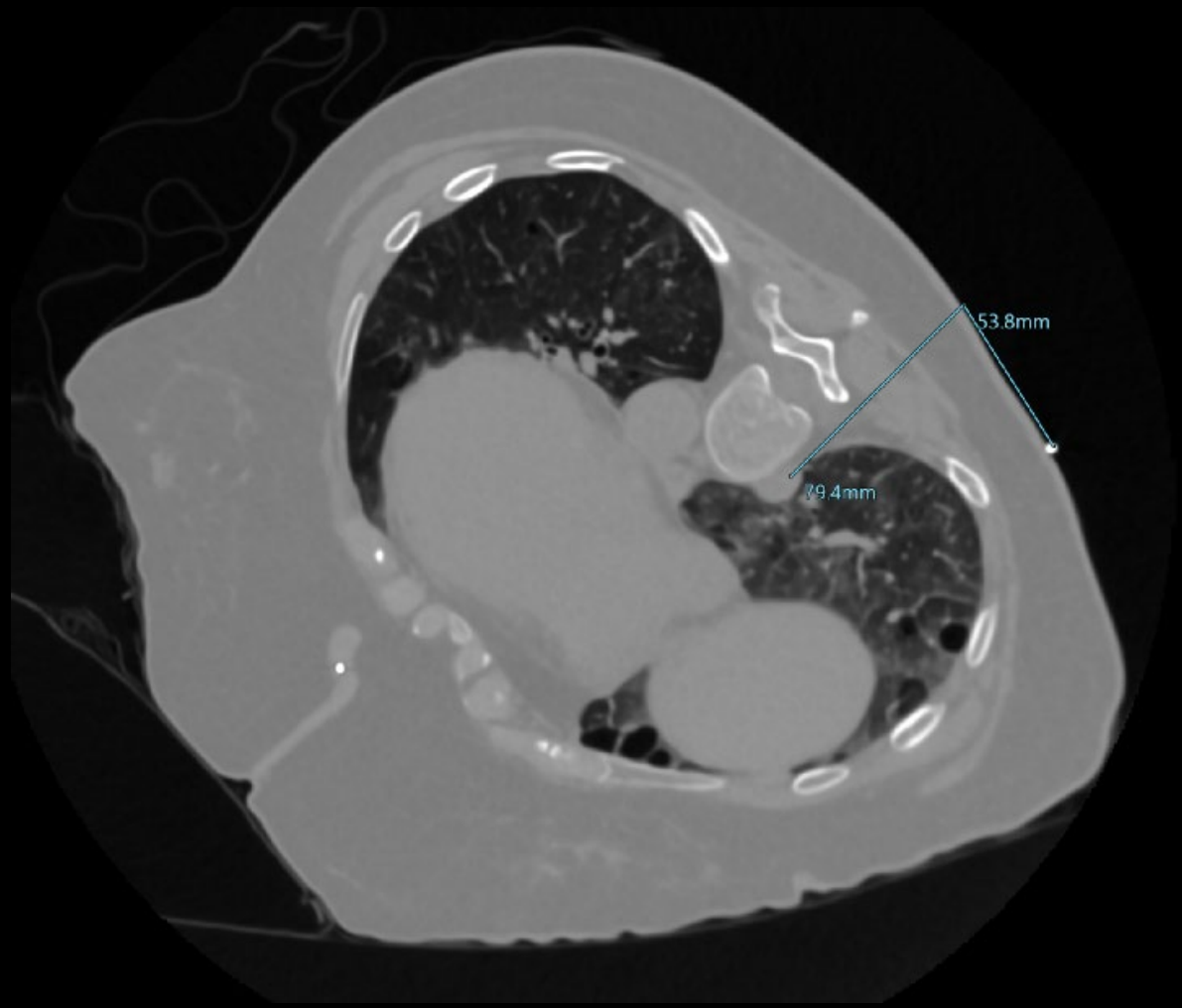
# Overview of an interventional CT procedure



1. Scout patient like we do in dx imaging

2. Plan and acquire a “planning volume” i.e., a “regular helical CT” as is done in dx imaging

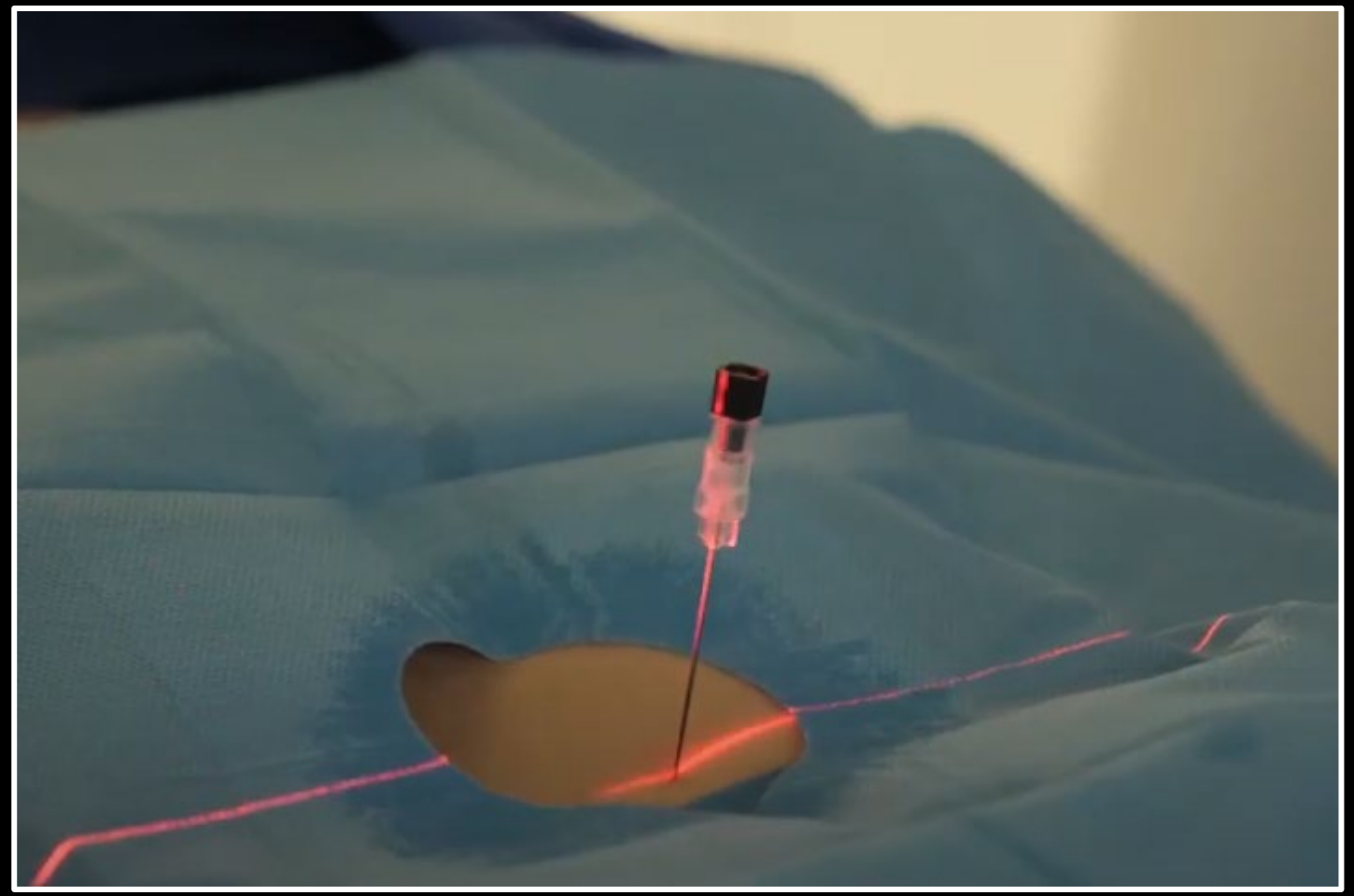
# Overview of an interventional CT procedure



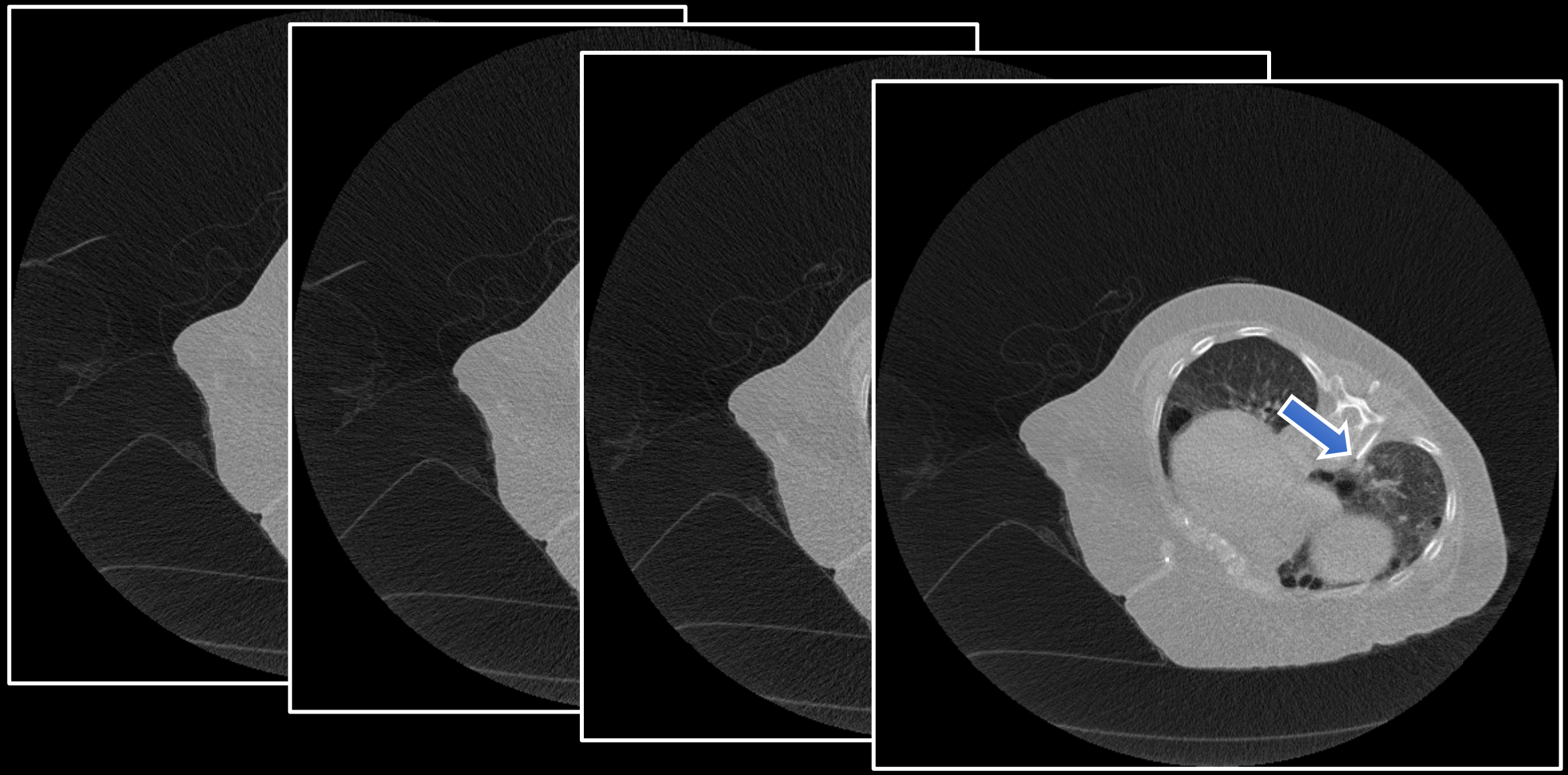

3. Interventional physician reviews planning volume and picks target slice locations and plans trajectory

# Overview of an interventional CT procedure

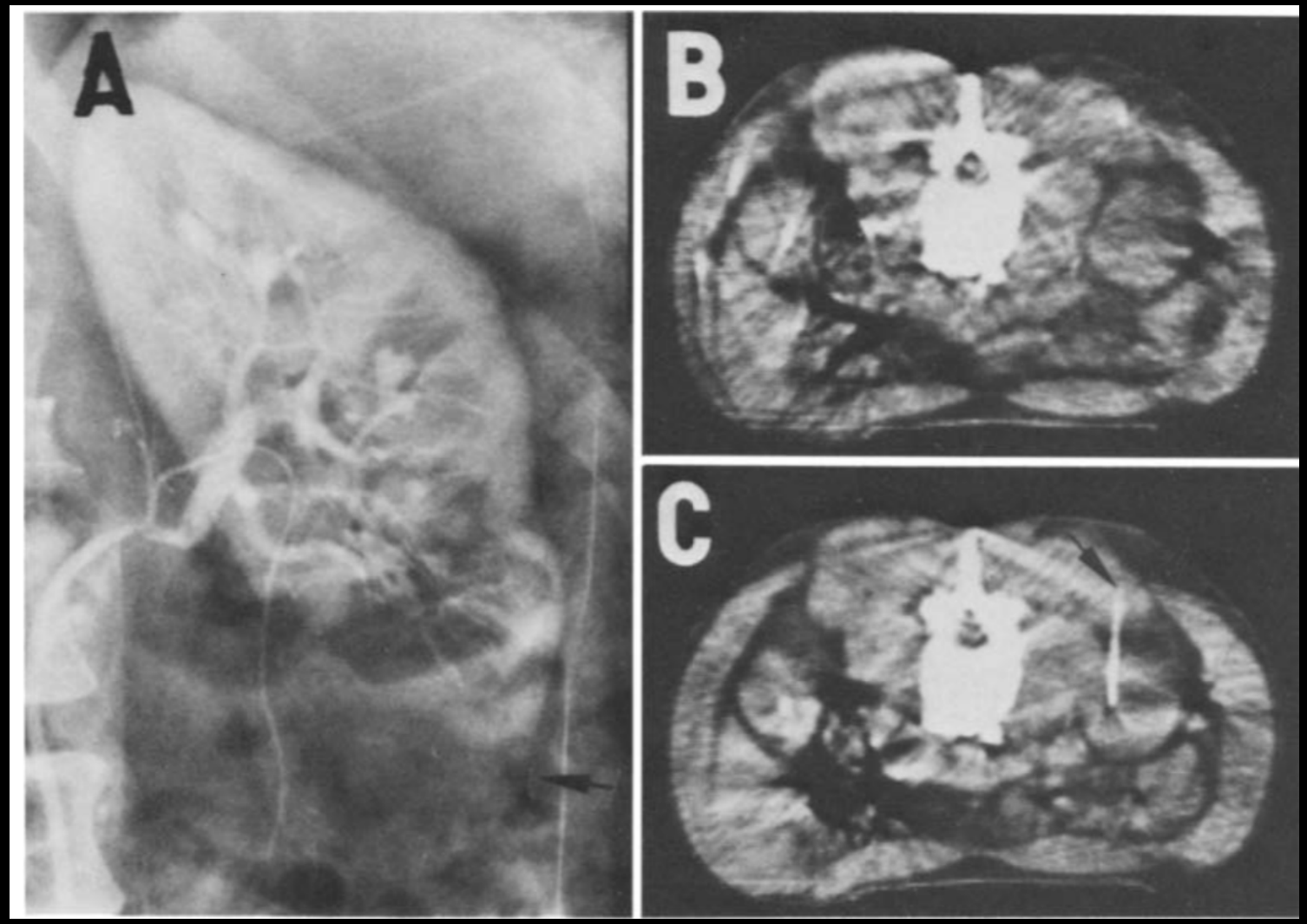

4. Interventional physician performs initial puncture and aligns needle with the planned trajectory

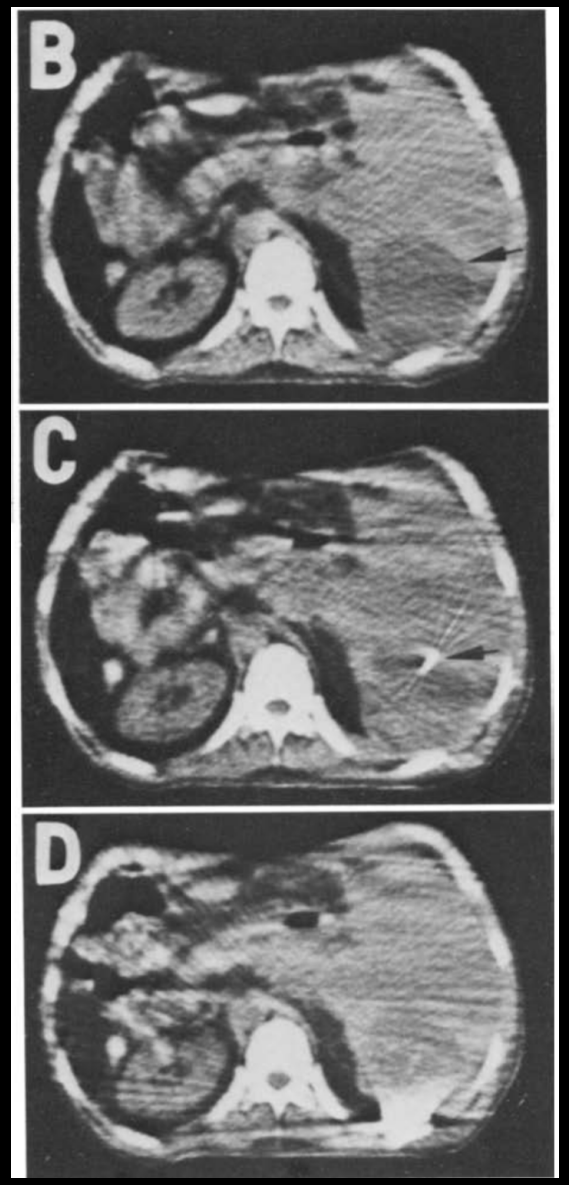


# Overview of an interventional CT procedure



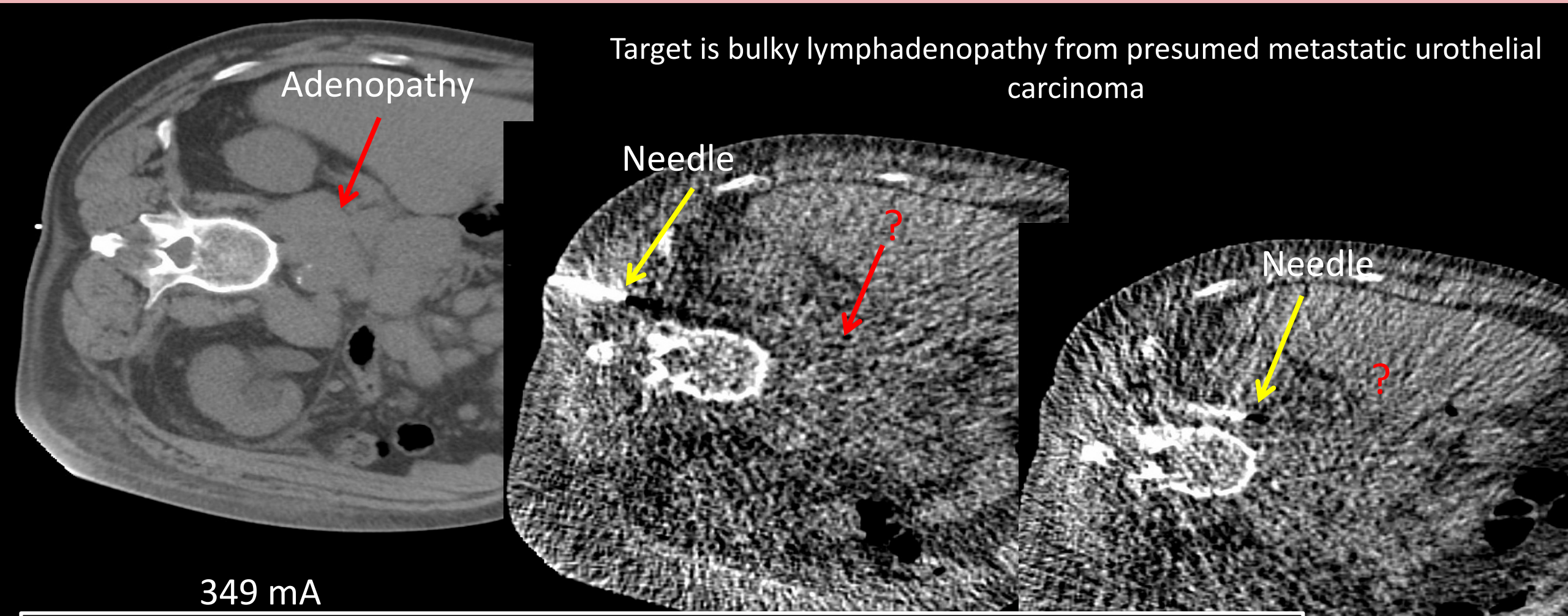
# Haaga Method




Haaga J, Alfidi R, Radiology 1976;118

# CT Fluoroscopy: Image Quality




CTF images are so noisy and artifact laden, one often cannot see the target!

# Percutaneous Biopsies

## Percutaneous biopsy in the abdomen and pelvis: a step-by-step approach

George A. Carberry,[1,2] Meghan G. Lubner,[1] Shane A. Wells,[1]

[1]University of Wisconsin School of Medicine and Public Health, Madison, WI, USA
[2]Department of Radiology, University of Wisconsin School of Medicine and Public Health, Highland Ave., Madison, WI 53792-3252, USA

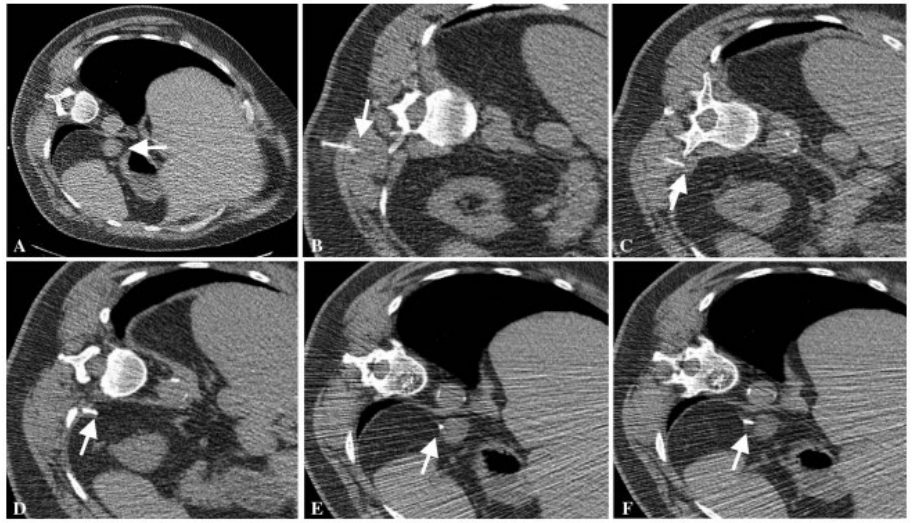
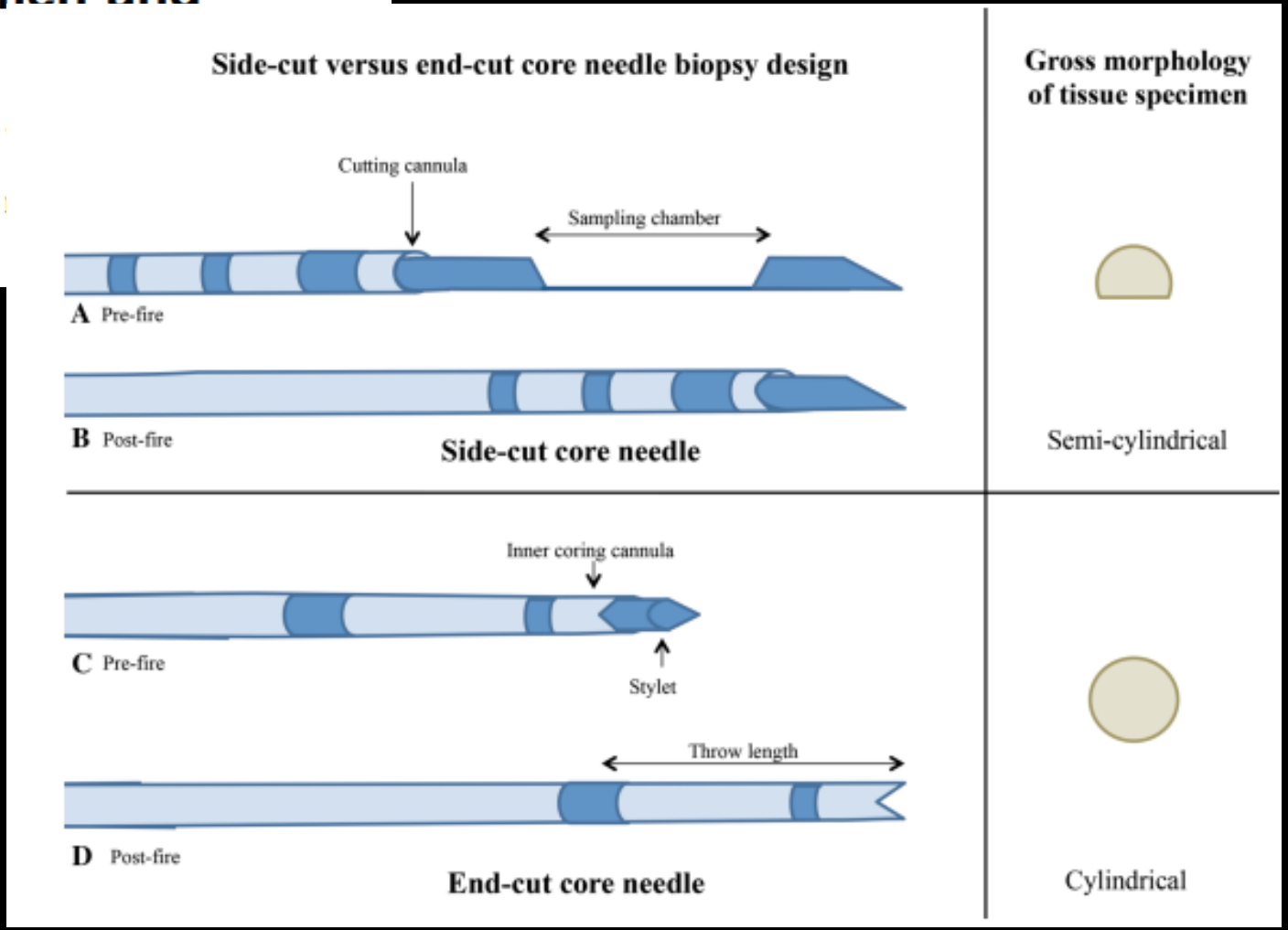
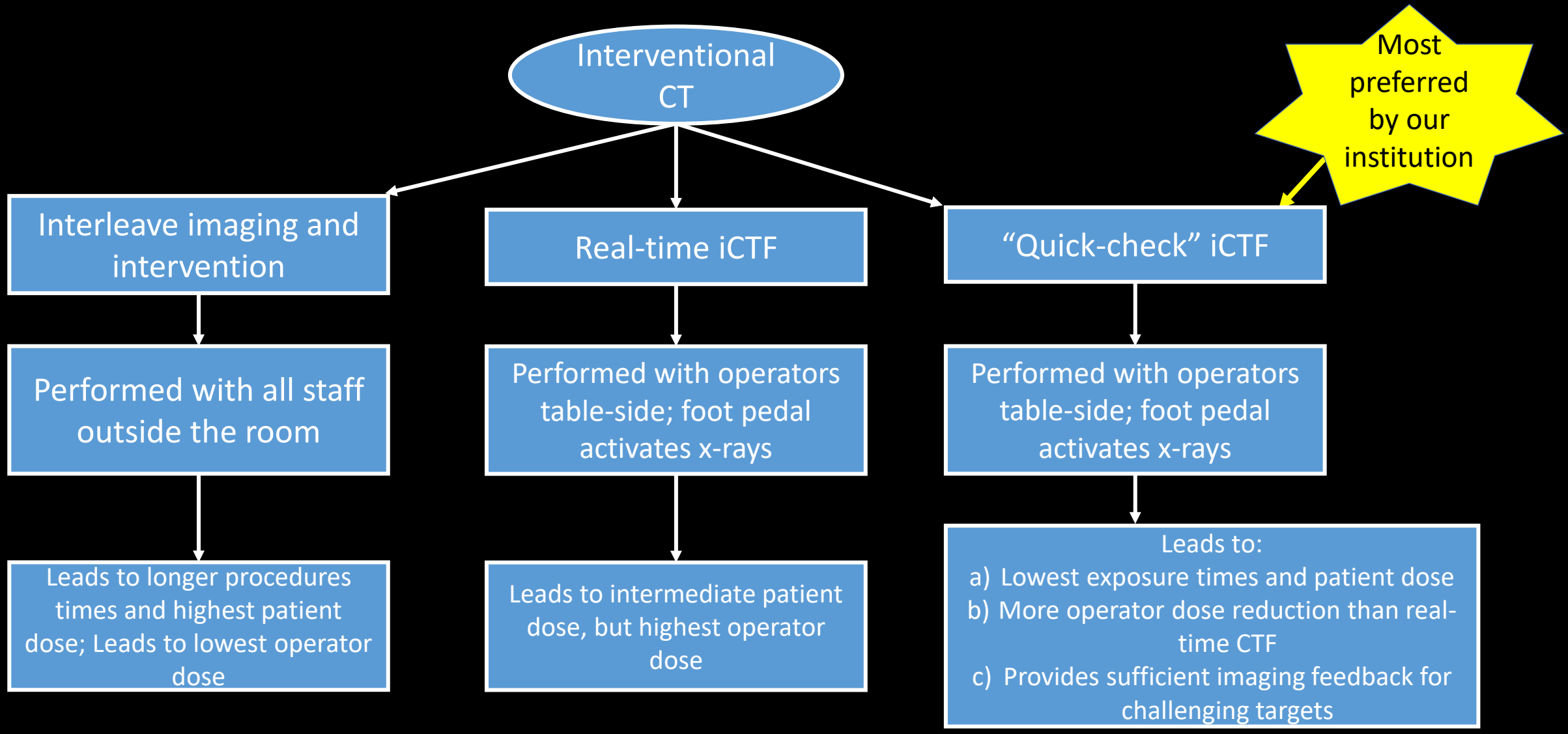



**Fig. 7.** Use of the "dead reckoning" technique to safely biopsy an indeterminate adrenal nodule. Transverse unenhanced pre-procedure CT image (**A**) demonstrates lung in the projected needle path to the left adrenal nodule (*arrow*) despite left lateral decubitus positioning of the patient. An axial slice several centimeters caudal to the lesion (**B**) was selected for needle entry (*arrow* needle tip). Sequential CT fluoroscopic images (**C**–**F**) demonstrate progressive advancement of the needle in the cephalad direction, keeping only the tip of the needle (*arrow*) in the axial plane with the CT table adjustments. Image (**F**) demonstrates the needle tip in the target lesion without traversing the lung. This can be a very technically challenging biopsy method.



# Overview of interventional CT practices



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# Interventional CT…more people, more room prep, longer exams, longer room turn over.

**Interventional CT**

- Usually 1-2 CT techs, 1-2 radiologists, 1-2 people for sedation/anesthesia, 1 nurse, 1 sonographer.
- Supplies for interventional device, supplies for EM navigation, contrast supplies, lines, sterile trays, way more PPE than dx imaging on everyone.

**Diagnostic CT**

- A single CT tech and linens. ~40% of the time→ contrast injector consumables.

# Scheduling

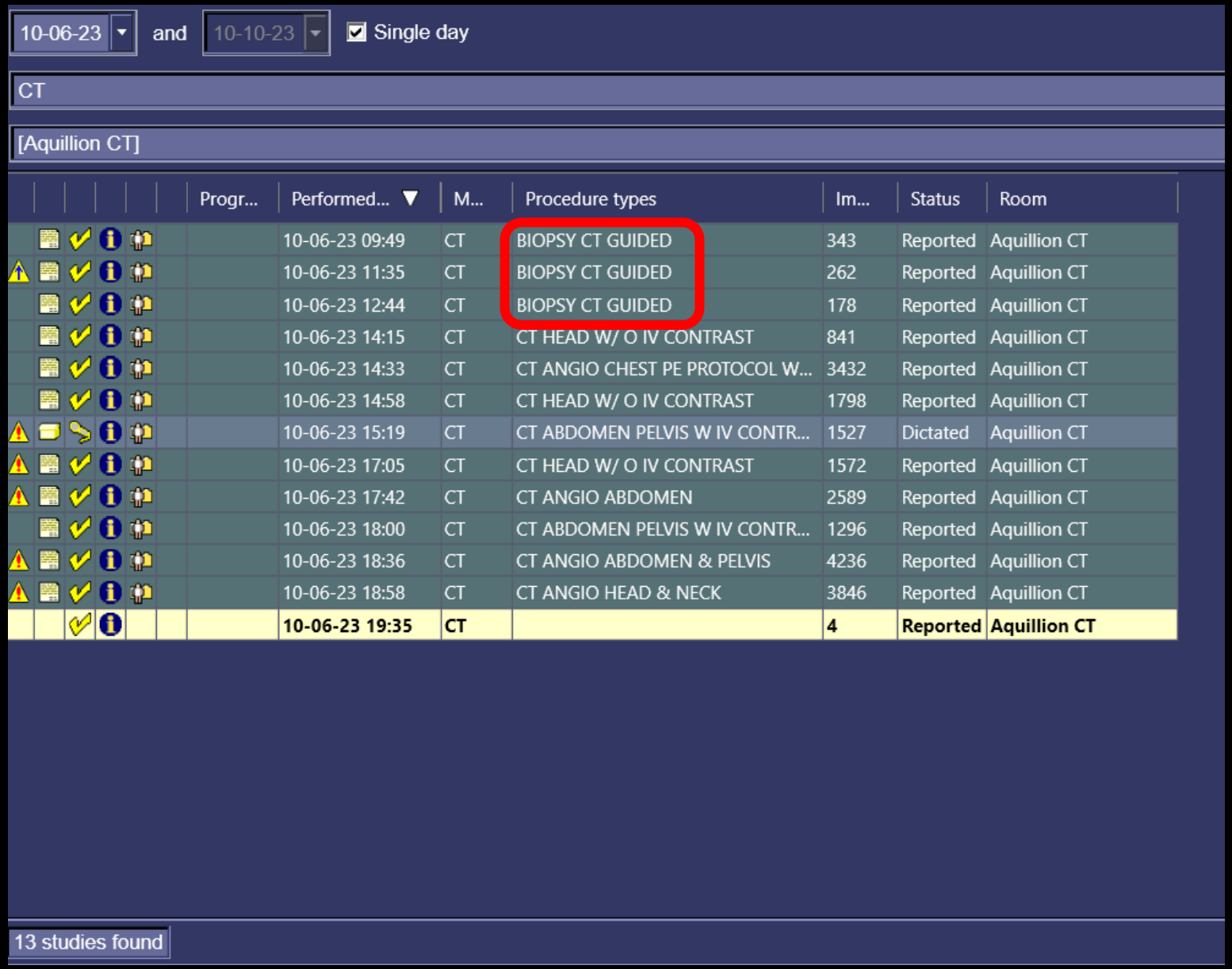
1 CT scanner, doing dx studies during the day, some after hours use as needed


| Progr... | Performed on | M... | Procedure types | Im... | Status | Room |
|---|---|---|---|---|---|---|
| | 10-03-23 21:35 | CT | CT ANGIO CHEST PE PROTOCOL... | 2173 | Reported | Aquillion CT |
| | 10-03-23 21:09 | CT | CT ANGIO CHEST PE PROTOCOL W... | 2216 | Reported | Aquillion CT |
| | 10-03-23 17:48 | CT | CT ABDOMEN PELVIS W IV CONTR... | 1463 | Reported | Aquillion CT |
| | 10-03-23 23:24 | CT | | 5 | Reported | Aquillion CT |
| | 10-03-23 09:21 | CT | CT NECK W IV CONTRAST | 2503 | Reported | Aquillion CT |
| | 10-03-23 09:00 | CT | CT HEAD W/ O IV CONTRAST | 893 | Reported | Aquillion CT |
| | 10-03-23 22:05 | CT | CT ANGIO CHEST PE PROTOCOL W... | 2015 | Reported | Aquillion CT |
| | 10-03-23 15:23 | CT | CT CHEST W/ O IV CONTRAST W/C... | 3144 | Reported | Aquillion CT |
| | 10-03-23 20:41 | CT | CT ABDOMEN PELVIS W IV CONTR... | 1475 | Reported | Aquillion CT |
| | 10-03-23 19:01 | CT | CT NECK W IV CONTRAST | 2848 | Reported | Aquillion CT |
| | 10-03-23 10:10 | CT | CT CERVICAL SPINE W/ O IV CONT... | 1422 | Reported | Aquillion CT |
| | 10-03-23 10:07 | CT | CT HEAD W/ O IV CONTRAST | 1524 | Reported | Aquillion CT |
| | 10-03-23 10:55 | CT | CT ABDOMEN PELVIS W IV CONTR... | 1697 | Reported | Aquillion CT |
| | 10-03-23 10:51 | CT | CT CHEST W/ O IV CONTRAST W/C... | 2690 | Reported | Aquillion CT |
| | 10-03-23 10:46 | CT | CT SINUS W/ O IV CONTRAST | 1272 | Reported | Aquillion CT |
| | 10-03-23 16:36 | CT | STROKE CODE-CT ANGIO HEAD NE... | 4949 | Reported | Aquillion CT |
| | 10-03-23 12:00 | CT | CT SINUS W/ O IV CONTRAST | 1224 | Reported | Aquillion CT |
| | 10-03-23 15:56 | CT | CT ANGIO CHEST PE PROTOCOL W... | 2862 | Reported | Aquillion CT |
| | 10-03-23 19:35 | CT | CT TRAUMA ABDOMEN PELVIS W I... | 1650 | Reported | Aquillion CT |
| | 10-03-23 13:41 | CT | CT ABDOMEN PELVIS W IV CONTR... | 1631 | Reported | Aquillion CT |
| | 10-03-23 20:11 | CT | CT ANGIO CHEST PE PROTOCOL W... | 2386 | Reported | Aquillion CT |
| | 10-03-23 18:15 | CT | CT ABDOMEN PELVIS W IV CONTR... | 1394 | Reported | Aquillion CT |

# Scheduling

1 CT scanner, AM biopsy, afternoon dx

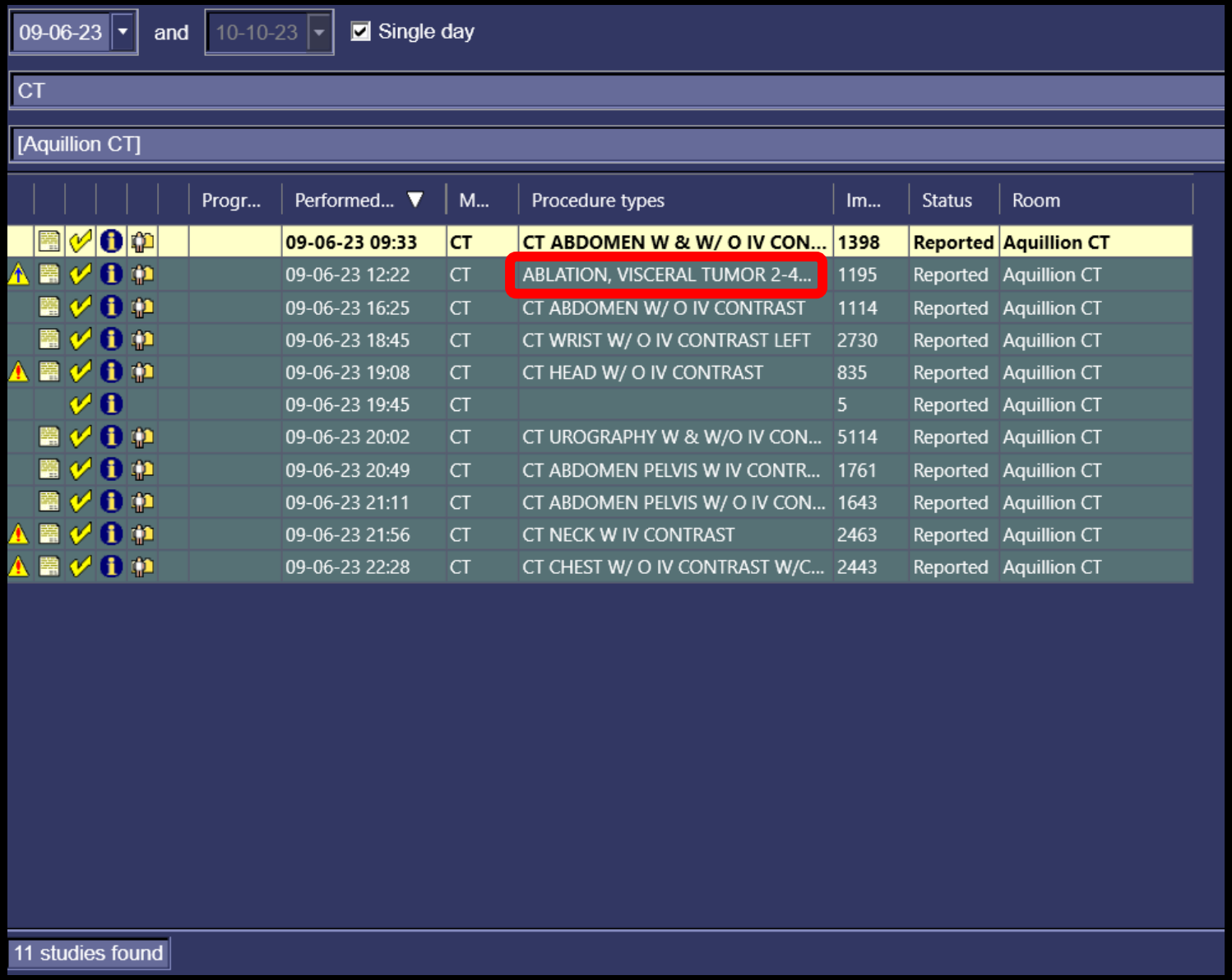
28 exams to 13



# Scheduling

1 CT scanner,
1 ~4 hour ablation block

28 exams to 11



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# Scanner Features

CT Task Legend:
Green = CTF
Yellow = Diagnostics
Orange = Both

Work spearheaded at Wisconsin by Jonathan Troville, PhD
(presented at RSNA 2023 as an educational exhibit
*"Purchasing decisions for an interventional CT program")*

## Highly Preferred

1) Wide Bore Access
2) Visualization Planes Along Needle
3) Gantry Ergonomics
4) In-Room Control
5) Gantry Tilt
6) Extended Table Option
7) Cardiac Gating
8) Neuro Perfusion

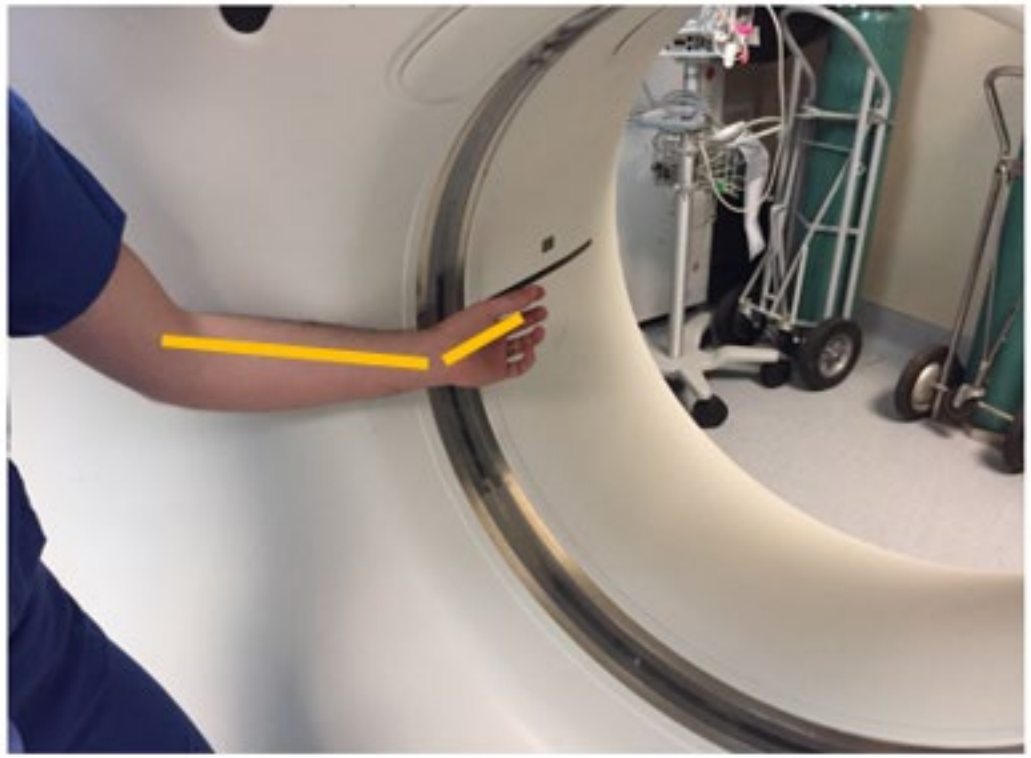
## Preferred

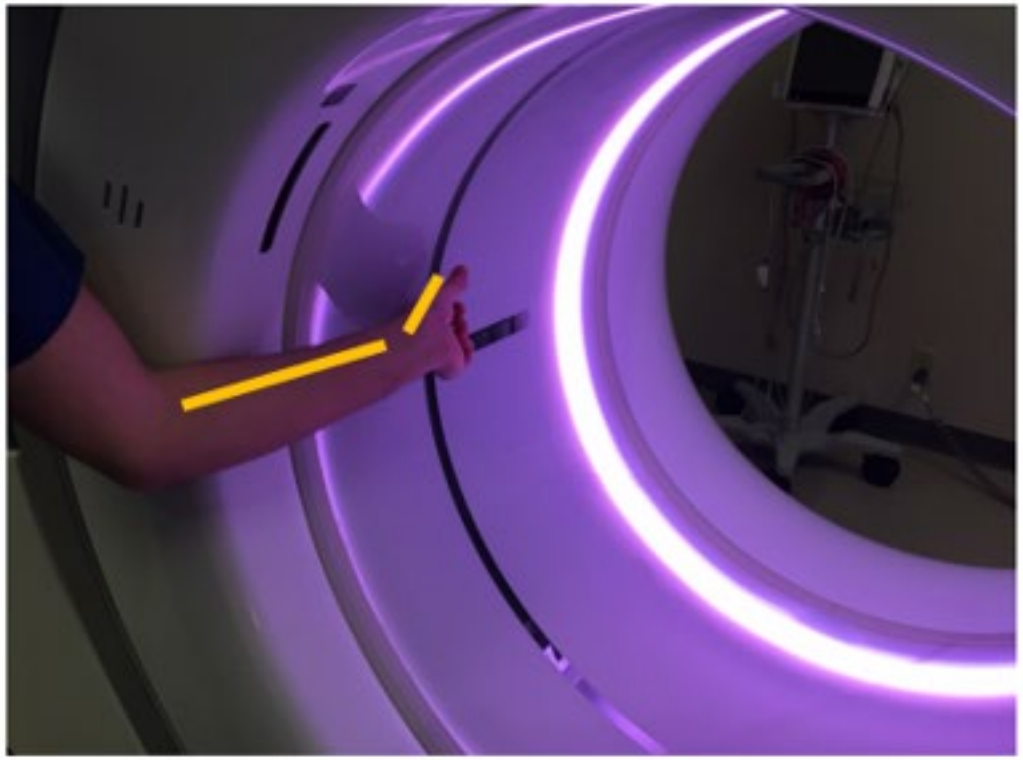
1) Prior Image Fusion
2) Needle Tracking/Trajectory Prediction
3) Bariatric Table
4) Tube Power Rating
5) Metal Artifact Reduction

## Useful

1) Large Z-Axis Coverage
2) Dual Energy

# Gantry Ergonomics





# Wide Bore Access

**We need at least enough room for device to fit!**

Typical interventional “wide bore” CT scanners have openings 78-80 cm
Typical diagnostic scanner has a bore size of ~70 cm

# Wide Bore Access

a) Physicians require ample space around patient for easy access to treatment sites and to manipulate devices without interference from CT gantry
b) Treatment of larger patients

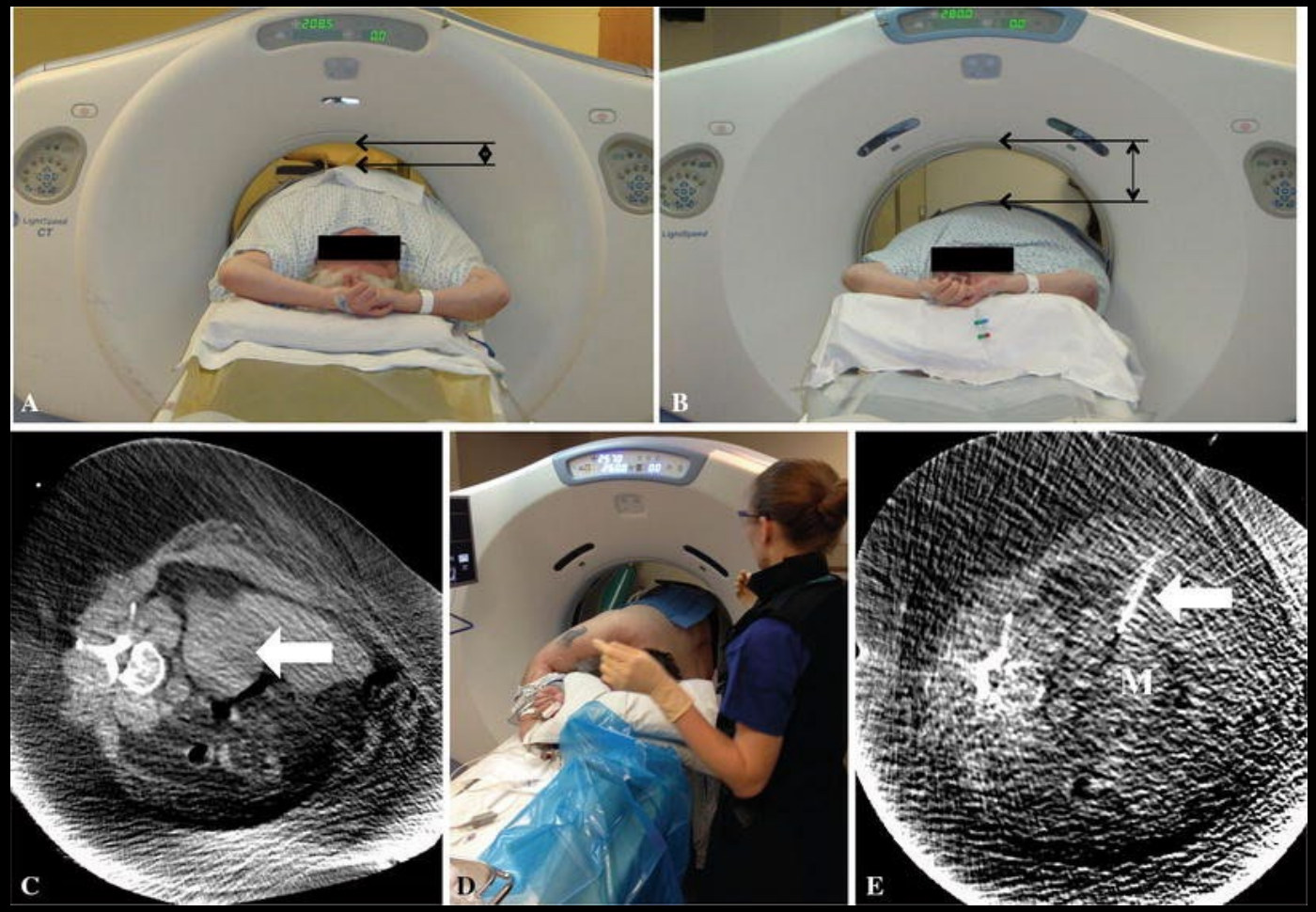



***Figure obtained from:*** *Carberry, G. A., Lubner, M. G., Wells, S. A., & Hinshaw, J. L. (2016). Percutaneous biopsy in the abdomen and pelvis: a step-by-step approach. Abdominal Radiology, 41, 720-742.*

# In Room Controls

a) Table-side controls can shorten procedure times and simplify the process of needle guidance (i.e., not leaving the room to acquire an image to then adjust the needle or rely on the physician to communicate acquisition and image display instructions to a technologist).

***Figure Acquired From:*** *Troville, J., Wagner, M., Stratchko, L., Toia, G.V., Lubner, M.G., Lee, F.T., & Szczykutowicz, T.P. (2023). Purchasing Decisions for an Interventional CT Program. Radiology Management, v45 n3, 23-29.*

# Gantry Tilt

Szczykutowicz, Timothy. *The CT Handbook: Optimizing Protocols for Today's Feature-rich Scanners*. Medical Physics Publishing, 2020

# Gantry Tilt

Gantry tilt is really one of the game changing options for head and neck diagnostic imaging to mitigate metal artifacts.

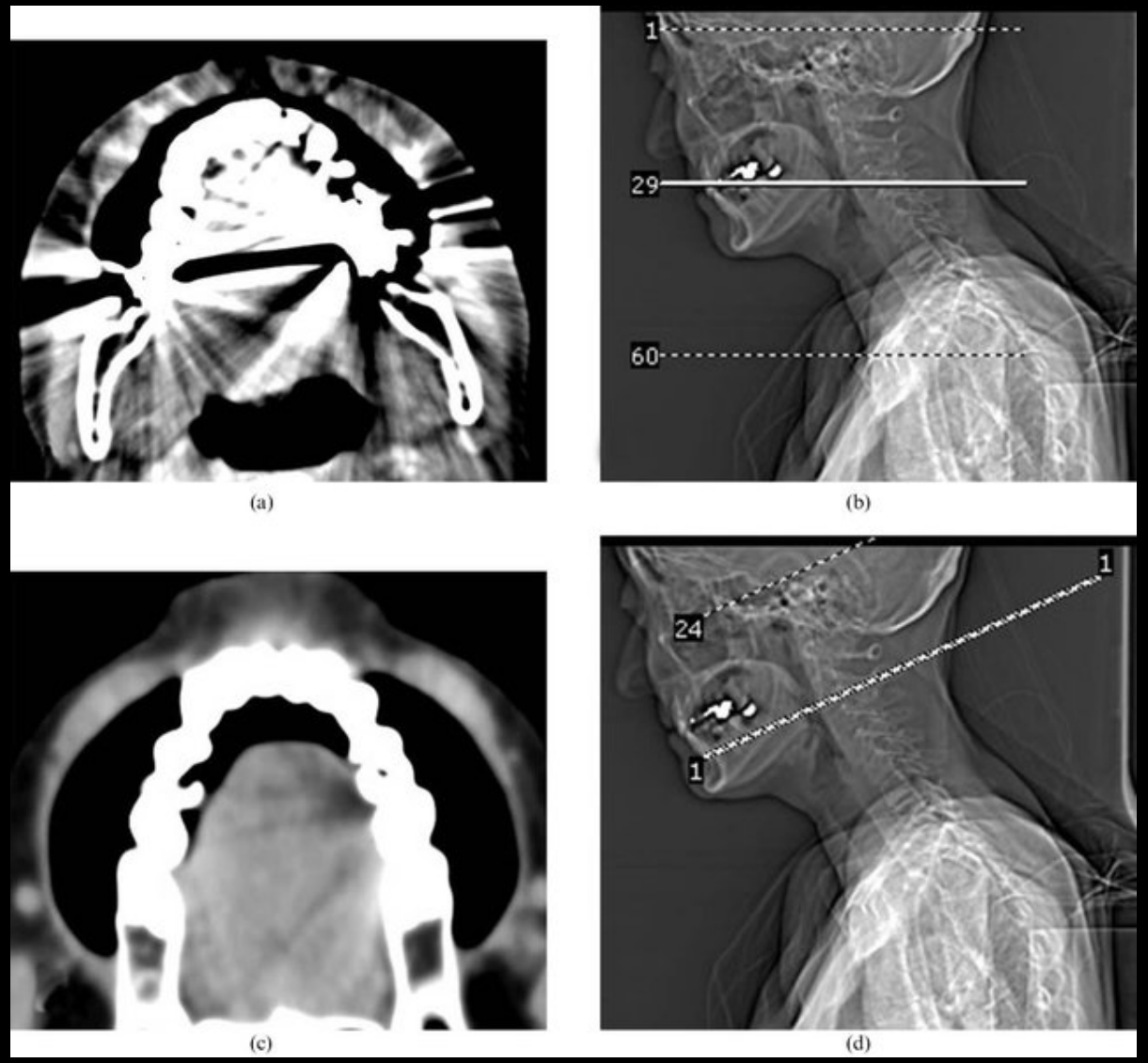
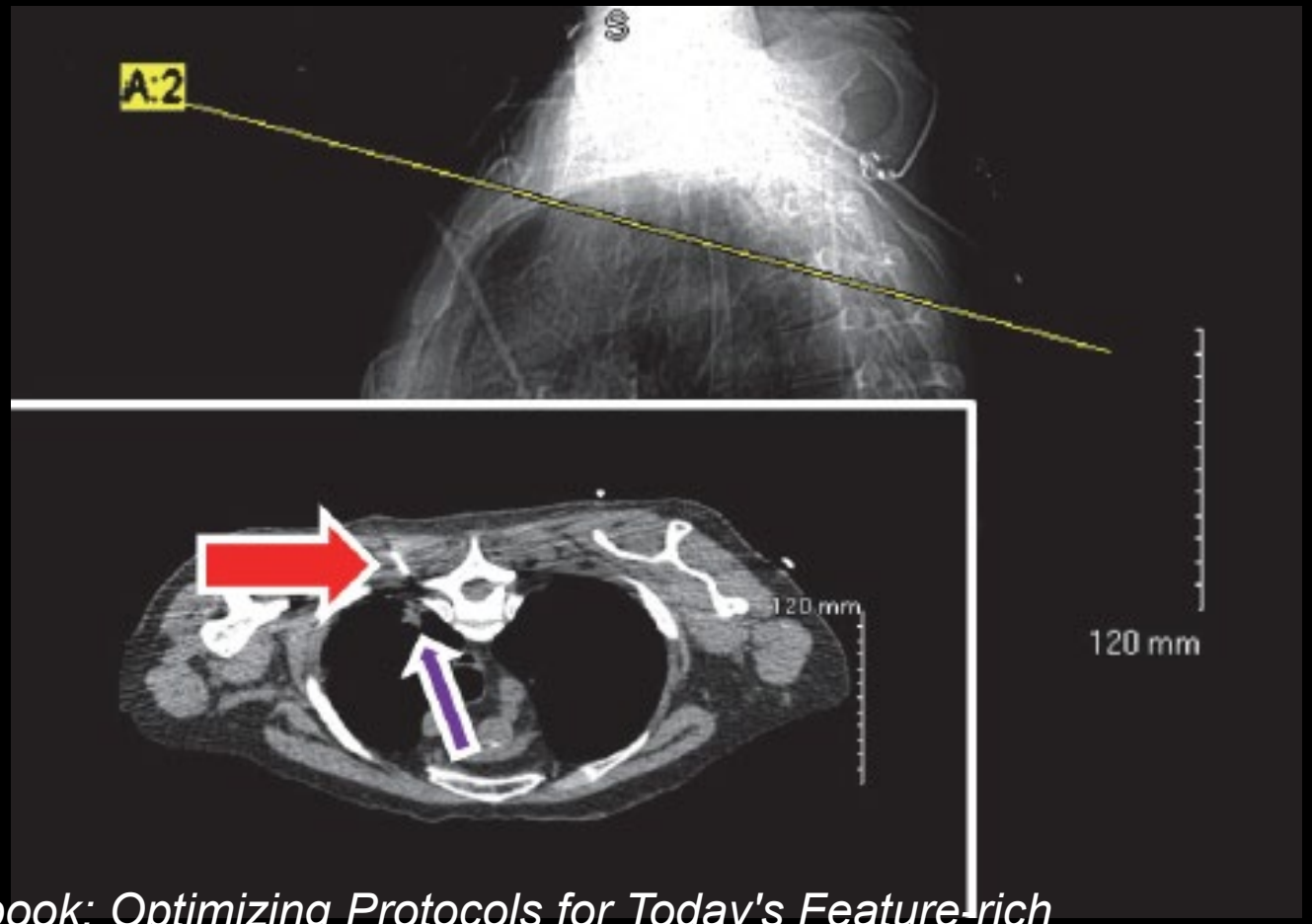



***Figure Acquired From:*** *Law, C. P., Chandra, R. V., Hoang, J. K., & Phal, P. M. (2011). Imaging the oral cavity: key concepts for the radiologist. The British Journal of Radiology, 84(1006), 944-957.*

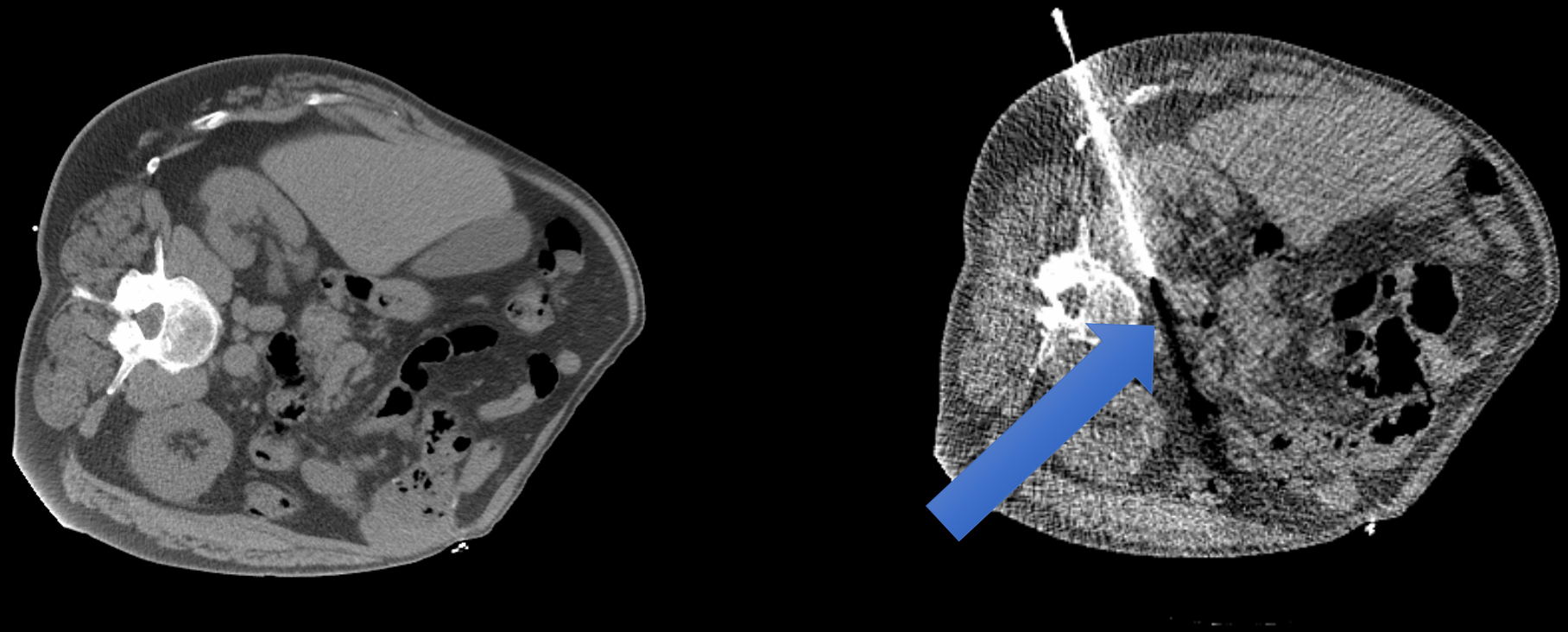
# Gantry Tilt

In interventional CT, gantry tilt is used to puncture the lung at a ~90-degree angle, or to allow for better patient access (around the CT gantry)



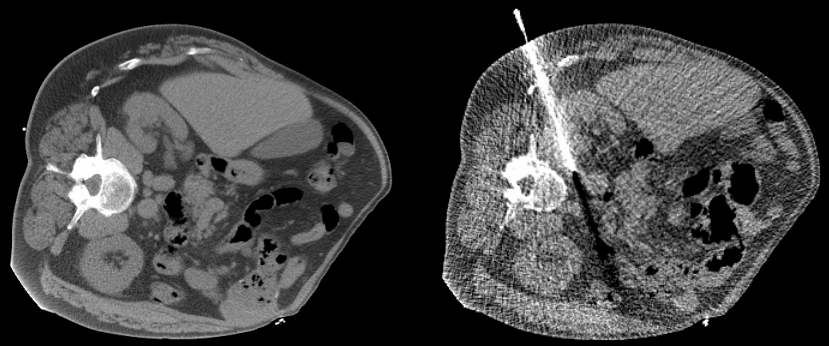

Szczykutowicz, Timothy. *The CT Handbook: Optimizing Protocols for Today's Feature-rich Scanners*. Medical Physics Publishing, 2020

# Metal Artifact Reduction



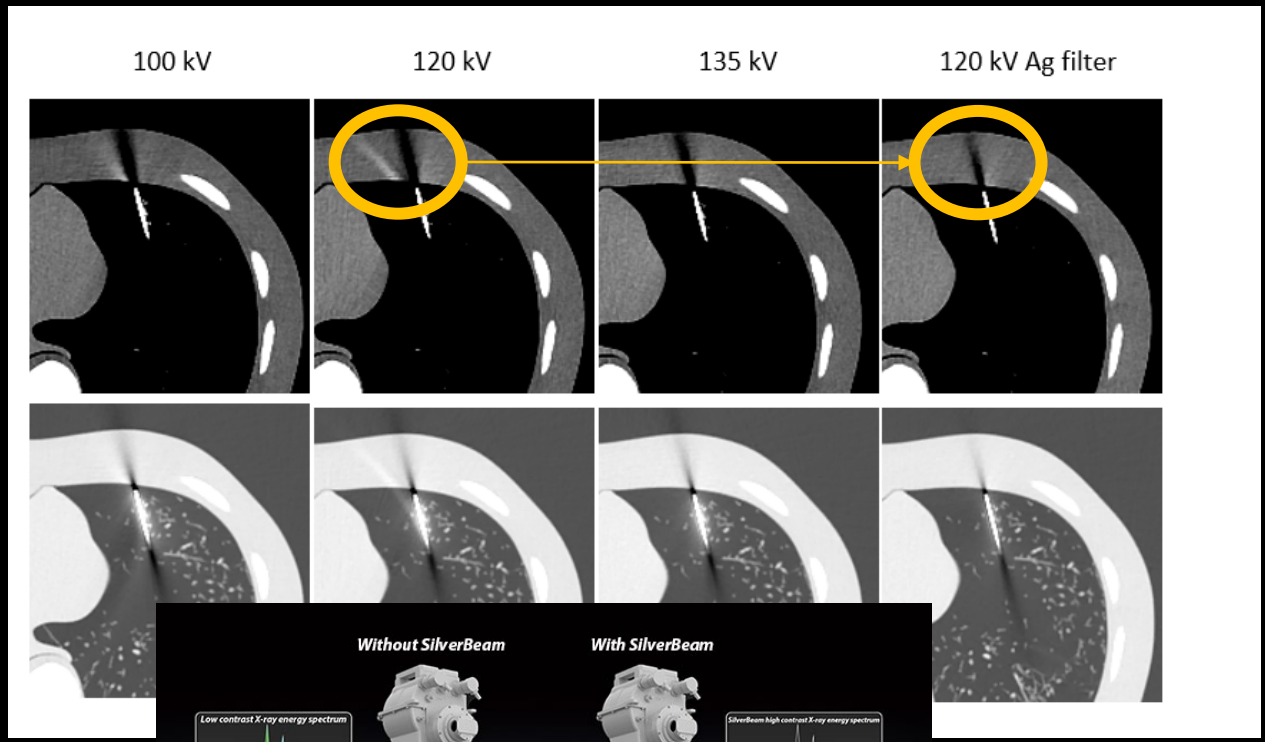
Metal artifacts in interventional CT literally put blinders on the physician in the exact spot they most need to see

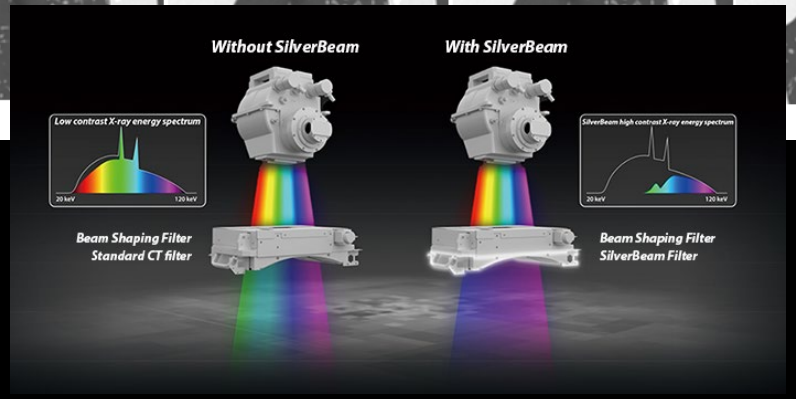
# Metal Artifact Reduction



Interventional CT needs to have near real time imaging, MAR algorithms are too slow for this.

Currently no vendors offer MAR algorithms in interventional CT modes. Canon does offer Ag beam filtration, which does partially reduce metal artifacts.




**Title:** Needle artifact reduction during interventional CT procedures using a silver filter

**Authors:** Carlos A. Reynoso-Mejia PhD[1], Jonathan Troville[2] PhD, Martin G. Wagner PhD[2], Bernice Hoppel PhD[3], Fred T. Lee Jr. MD[1,2,4], Timothy P. Szczykutowicz PhD[1,2,5]

University of Wisconsin – Madison, Departments of Radiology[1], Medical Physics[2], Urology[4], and Biomedical Engineering[5]

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Keywords: Interventional CT, CT artifact, CT filter

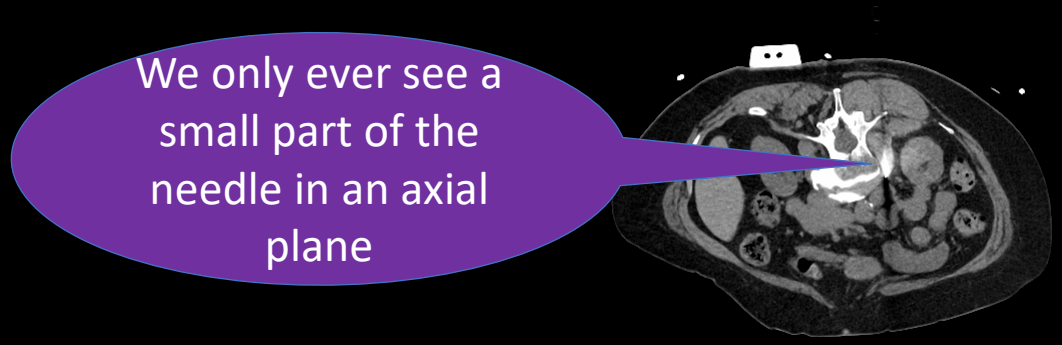
# Visualization Planes Along Needle

Data in CT is only acquired in the axial scanner plane

Devices can be inserted into the patient at planes other than the scanner's axial plane

Needle is inserted along scanner's axial plane


Needle is not inserted along scanner's axial plane



# Visualization Planes Along Needle

A CT scanner can allow the user to manually, or automatically create oblique reformatted views which are aligned to the axis of the needle. This lets the physics see “in front of” the needle.

# Visualization Planes Along Needle

These images were all taken at the same time, I am just scrolling through slices. See how difficult it is to see the trajectory of the needle when it is not aligned with the imaging plane!

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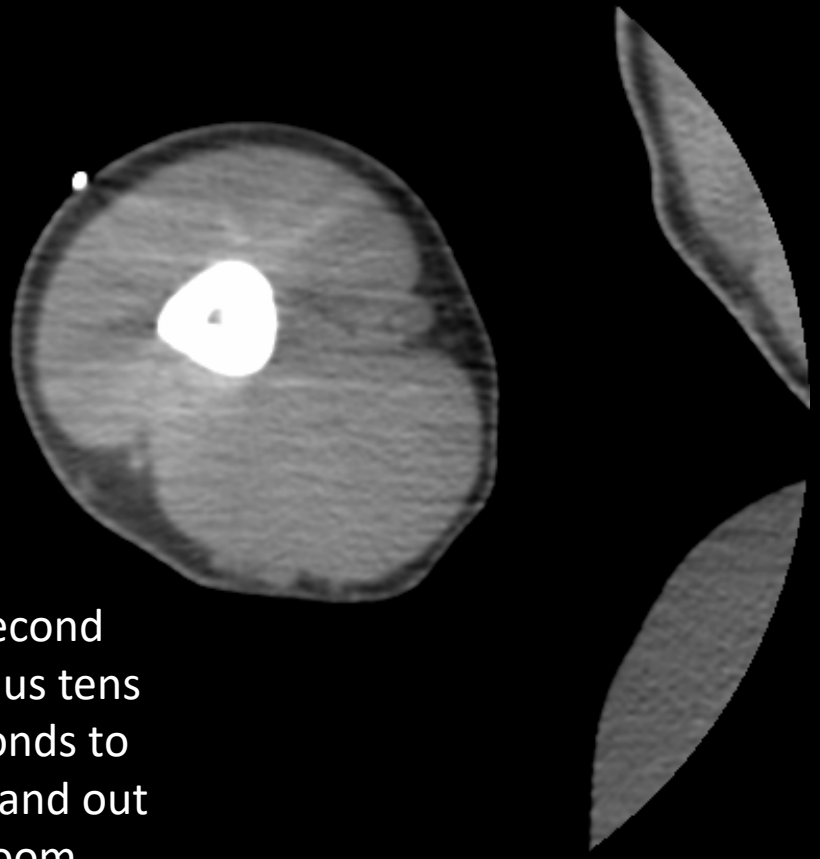
# Fluoroscopy Options

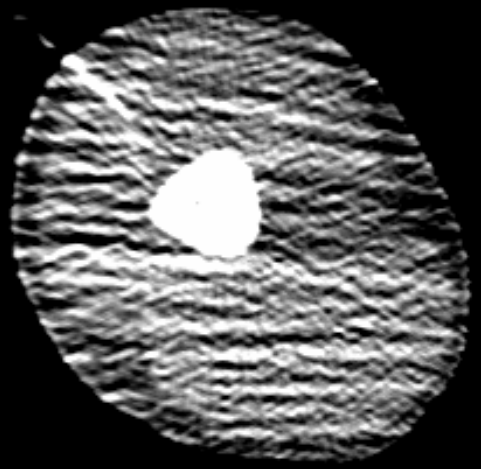
Interventional imaging should not use **diagnostic doses**! The walk in and out of the room and use of a dx protocol to localize interventional devices is decades old workflow (Haaga 1976 Radiology).

# Interventional Imaging Dose

68 mGy

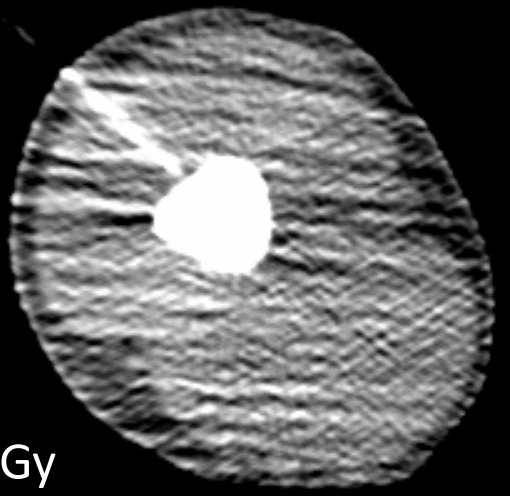


3.6 second scan, plus tens of seconds to walk in and out of room



1.59 mGy

0.5 second scans



3.19 mGy

# Fluoroscopy Concepts

- Increases in dose rate increase physician scatter
  - I.E., generating more x-rays allows more scattering
- Increases in collimated beam area increase scatter
  - I.E., the large the patient volume irradiated, the more scattered x-rays
- Scatter is always higher where x-rays enter the patient
  - True for c-arms AND Computed Tomography

Journal of Vascular and Interventional Radiology
Volume 32, Issue 3, March 2021, Pages 439-446

Laboratory Investigation

## CT Fluoroscopy for Image-Guided Procedures: Physician Radiation Dose During Full-Rotation and Partial-Angle CT Scanning

Emily A. Knott BS [a], Sean D. Rose PhD [b], Martin G. Wagner PhD [b], Fred T. Lee Jr. MD [a], Jeff Radtke MS [b], Daniel R. Anderson MS [b], Annie M. Zlevor BA [a], Meghan G. Lubner MD [a], J. Louis Hinshaw MD [a], Timothy P. Szczykutowicz PhD [a, b, c]

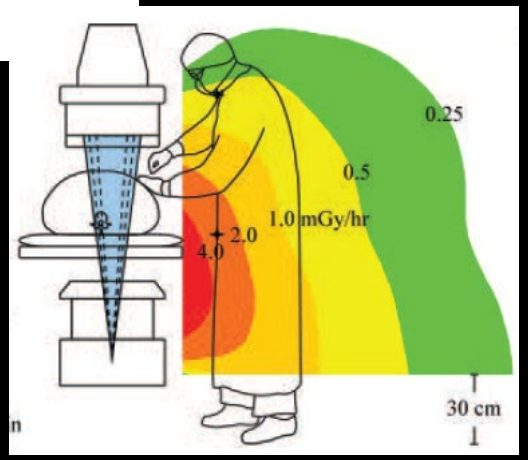
RSNA Education Exhibits

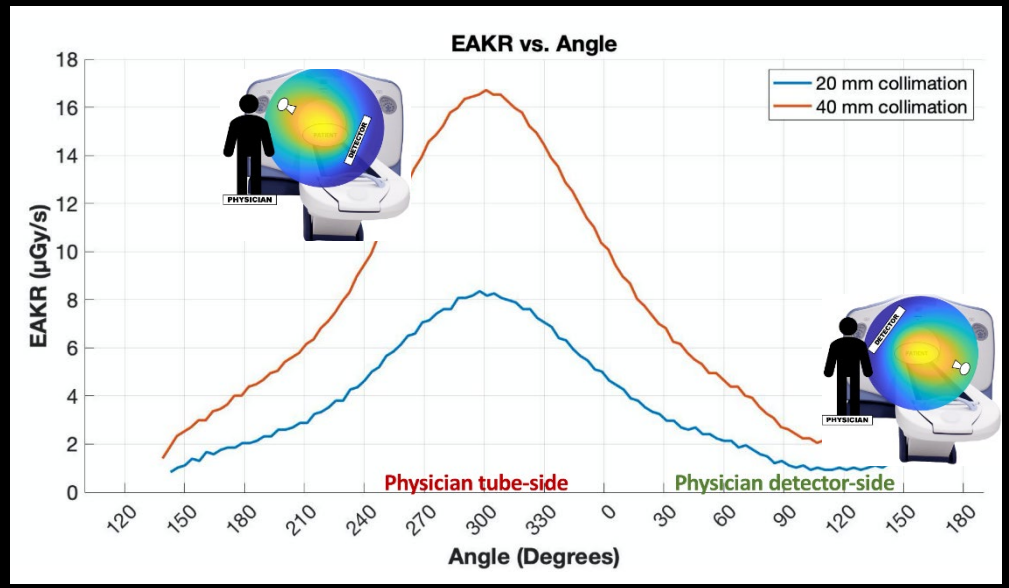
## An Investigation of Operator Exposure in Interventional Radiology

Beth A. Schueler, Thomas J. Vrieze, Haraldur Bjarnason, Anthony W. Stanson

Author Affiliations

**Published Online:** Sep 1 2006 | https://doi.org/10.1148/rg.265055127



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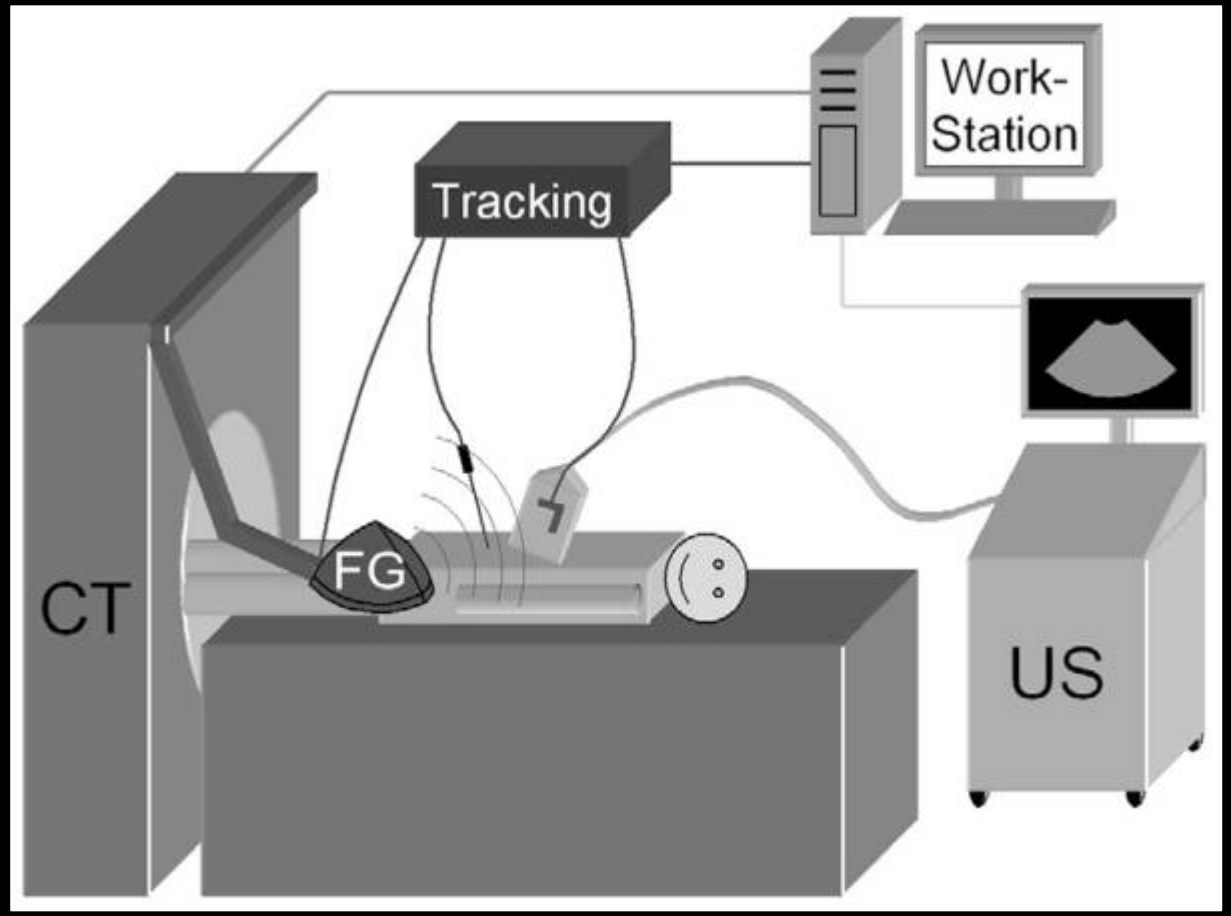
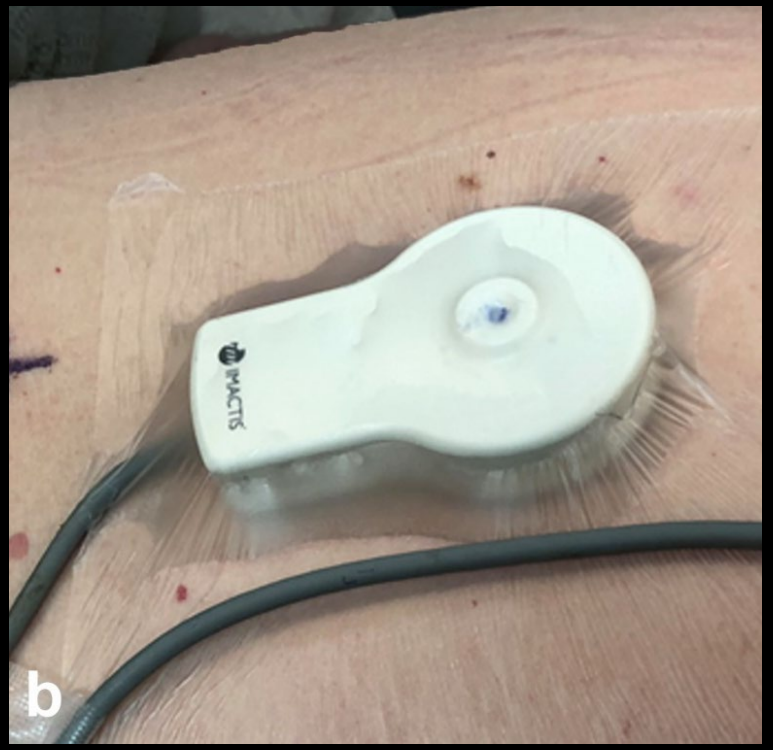
# Advanced Guidance: EM Tracking



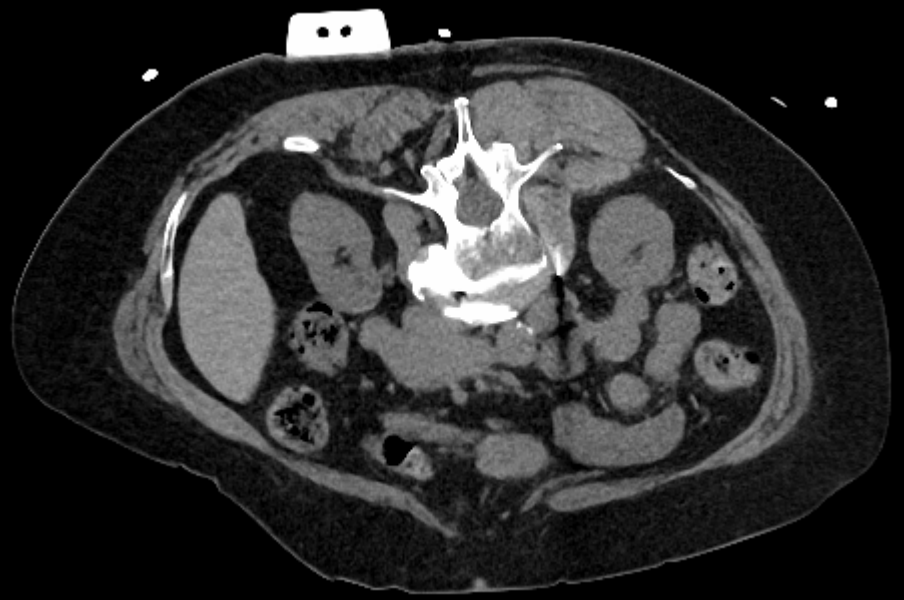

Krücker, J., Xu, S., Glossop, N., Viswanathan, A., Borgert, J., Schulz, H., Wood, B.J., 2007. J. Vasc. Interv. Radiol. JVIR 18, 1141–1150.

# Advanced Guidance: EM Tracking

Zlevor, A.M et al., 2023. J. Vasc. Interv. Radiol. 34, 910–918.



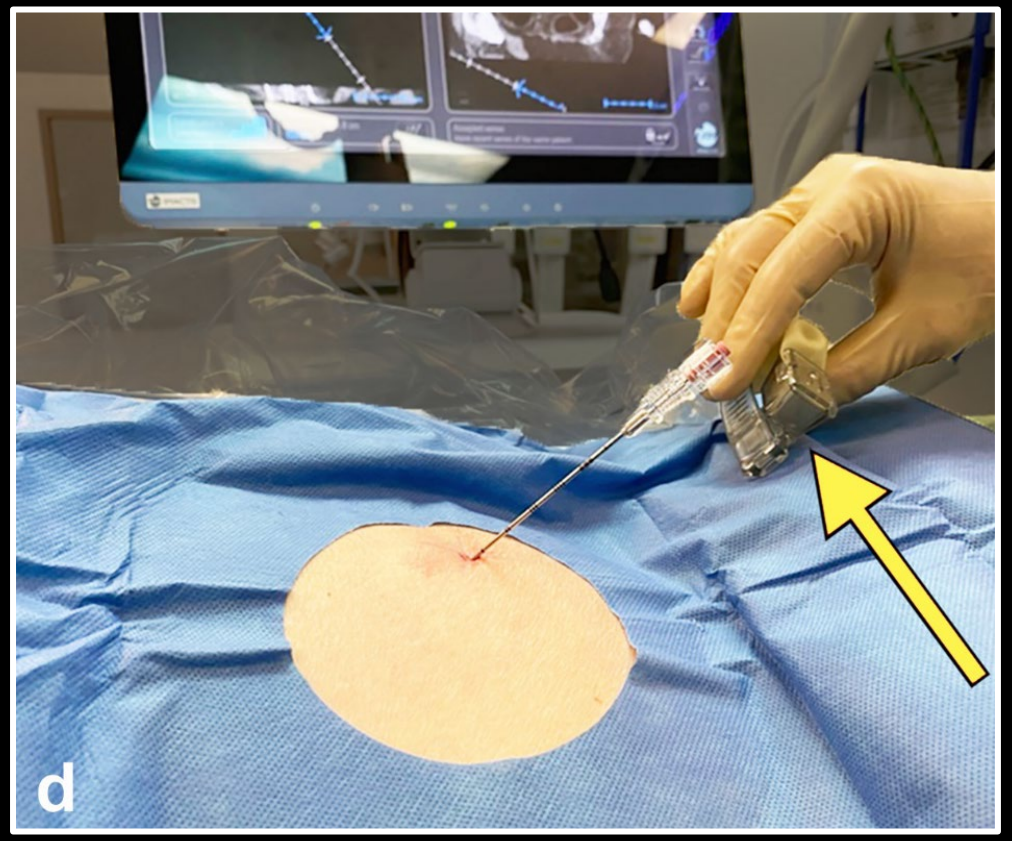

1. EM field generator is attached to patient skin



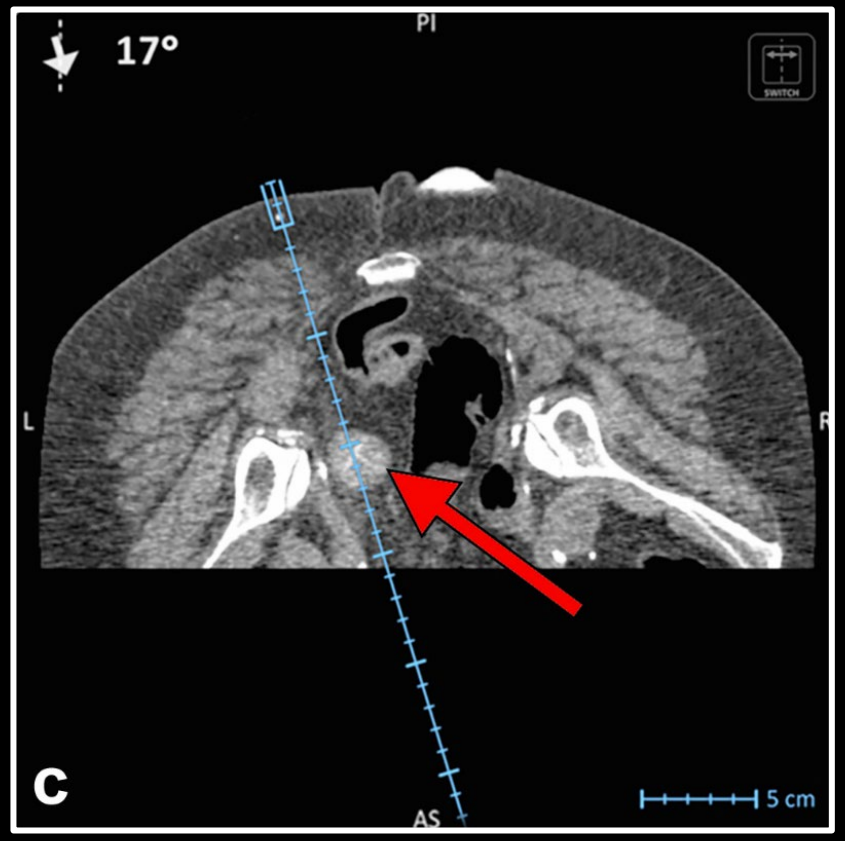
2. CT scan of patient and EM field generator registers the system to CT

# Advanced Guidance: EM Tracking

Zlevor, A.M et al., 2023. J. Vasc. Interv. Radiol. 34, 910–918.

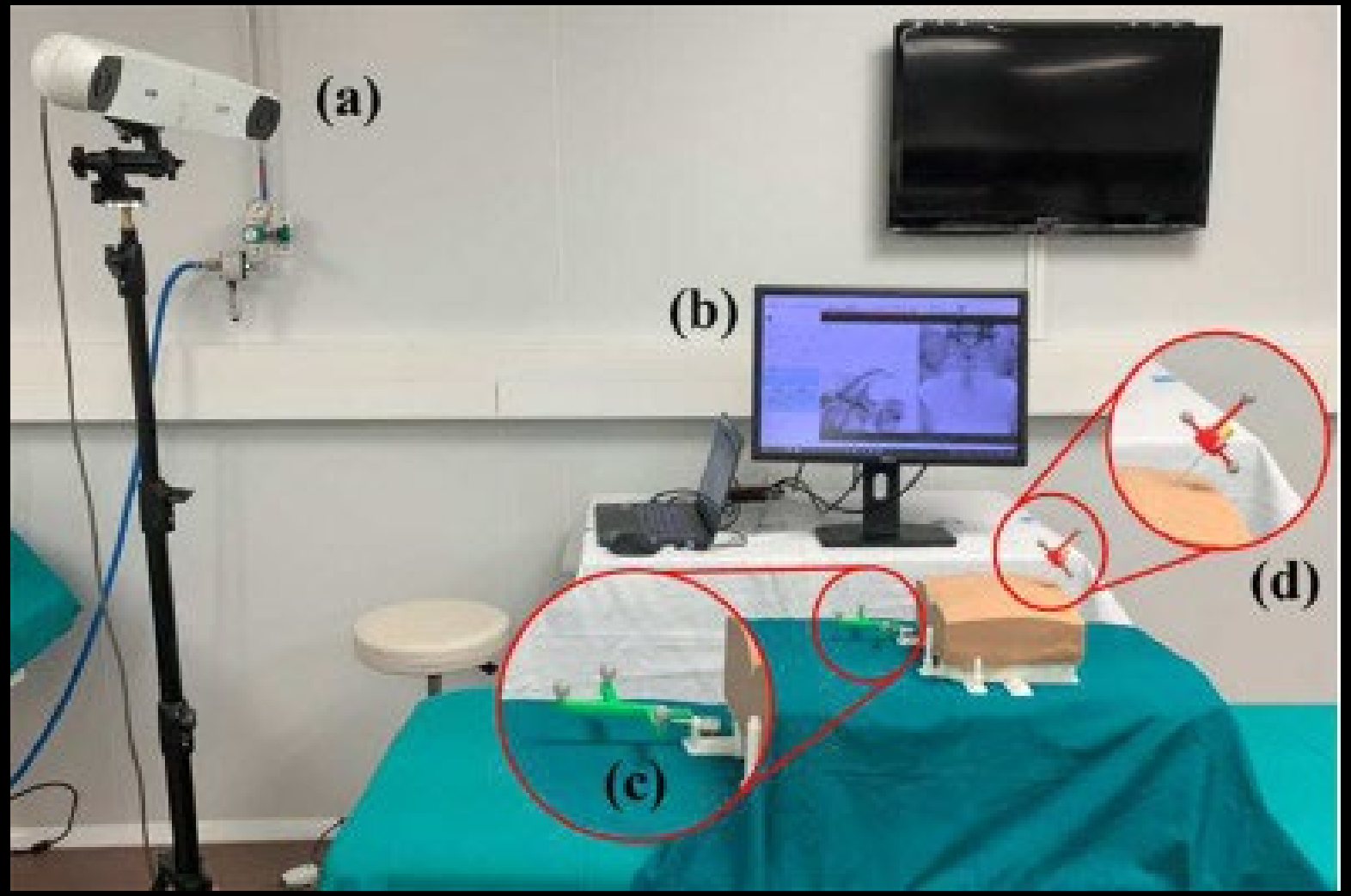



3. EM sensor attached to the needle holder provides real-time needle position




4. Virtual needle position and trajectory is superimposed on CT

# Optical Tracking




Moreta-Martínez, R., Rubio-Pérez, I., García-Sevilla, M., García-Elcano, L., Pascau, J., 2022. Comput. Methods Programs Biomed. 224, 106991.

# Robotic Needle Guidance

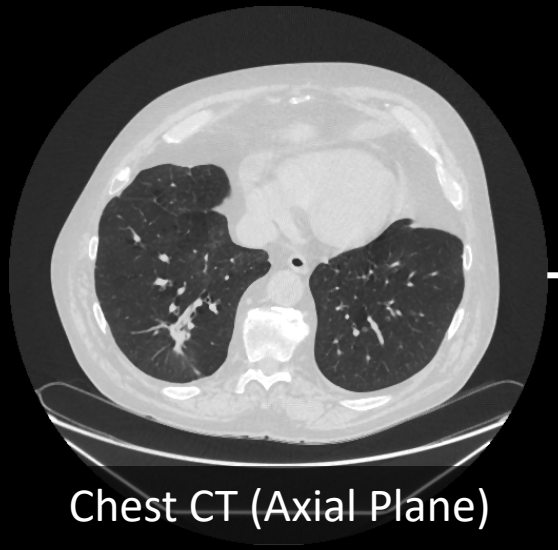
Ben-David, E., Shochat, M., Roth, I., Nissenbaum, I., Sosna, J., Goldberg, S.N., 2018. J. Vasc. Interv. Radiol. JVIR 29, 1440–1446.


Scharll, Y., Mitteregger, A., Laimer, G., Schwabl, C., Schullian, P., Bale, R., 2022. J. Clin. Med. 11, 3746.

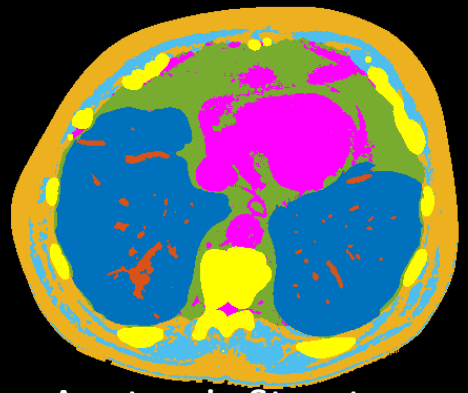
# Outline

1. What is Interventional CT?
2. High level scheduling considerations
3. Scanner Options Overview
4. Interventional CT Specific Options
5. Dose
6. Advanced Device Guidance
7. **Ongoing Research**

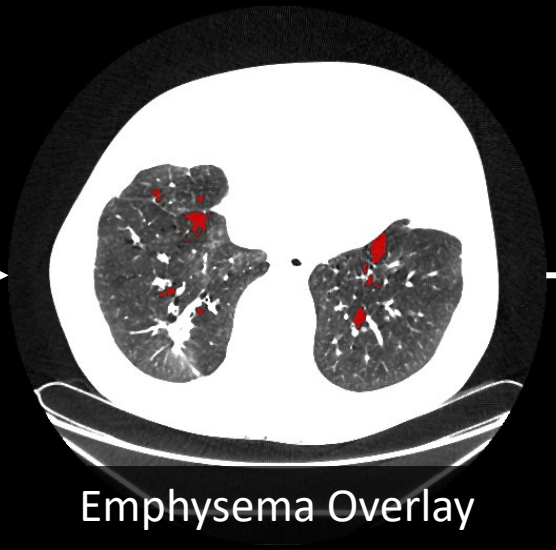
# Algorithm Overview



Chest CT (Axial Plane)

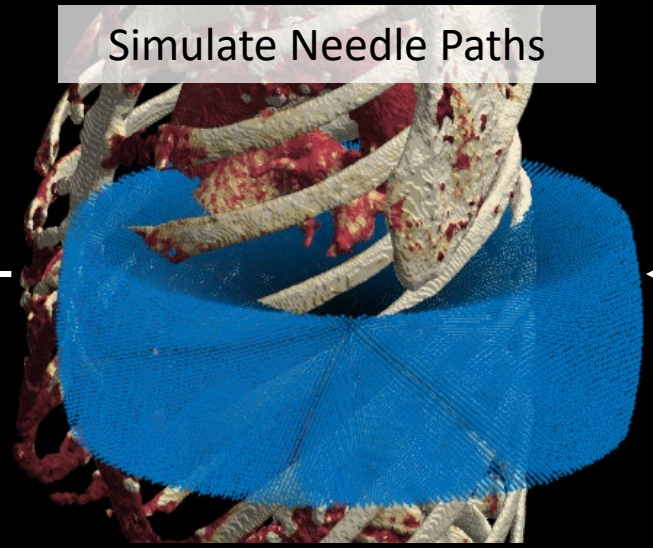


Anatomic Structure Segmentation

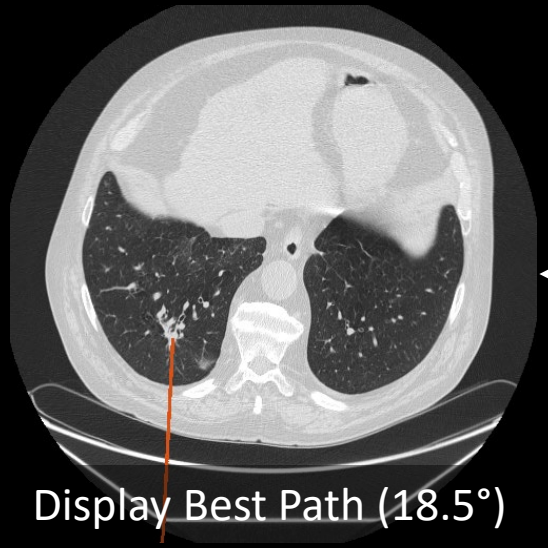


Emphysema Overlay

Simulate Needle Paths



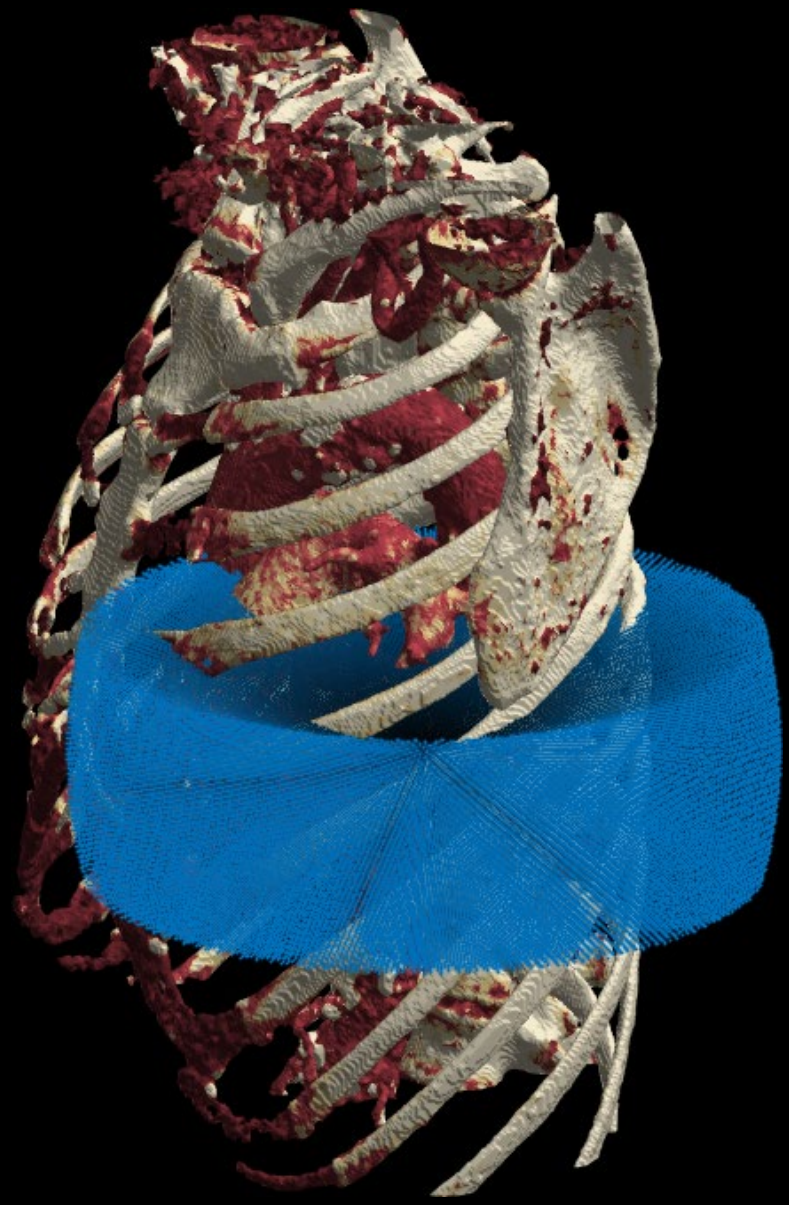
Path evaluation based on traversed tissue and pre-written rules



Display Best Path (18.5°)

# Needle Path Simulation

- An artificial intelligence (AI) algorithm can consider many pathways (50,000) out of plane
- Segmentation determines which tissues are traversed
- Calculates “risk” based on a pre-written set of rules to suggest the safest pathway



# Scoring System

| Category | Structure or organ | Metric | Weight | Minimum ranking |
|---|---|---|---|---|
| Path is crossing critical structures or organs (yes = 1, no = 0) | Heart/aorta | Yes/no | Infinity | 5 |
| | Large vessels or airways | Radius ≥ 1.5 mm | 1 | 3 |
| | Other organs | Yes/no | 3 | 4 |
| | Fissure | Yes/no | 0.6 | 4 |
| | Emphysematous bleb | Radius ≥ 2 mm | 0.8 | 4 |
| | Ribs or bone | Yes/no | 3 | 4 |
| | Spine | Yes/no | Infinity | 5 |
| Path is close to critical organs | Heart | (10 mm to minimum distance)/10 mm | 0.8 | NA |
| | Large vessels or airways | (10 mm to minimum distance)/10 mm | 0.8 | NA |
| Trajectory angle | Angle (±90°) to axial plane | Abs (angle/90) | 0.05 | NA |
| | Angle (0°–90°) to pleural surface | (90 − angle)/90 | 0.25 | 3 if metric > 0.7 |
| Length of needle path | Path length (mm) through lung tissue (at least 1 cm) | Maximum (0 [10 mm − length]/10 mm) | 0.5 | NA |
| | Total path length (mm) through tissue | Maximum (0 [length−60 mm]/40 mm) | 1 | 3 if metric > 100 |
| | Path length through minor vessels or airways | 0.5 × length | 1 | NA |

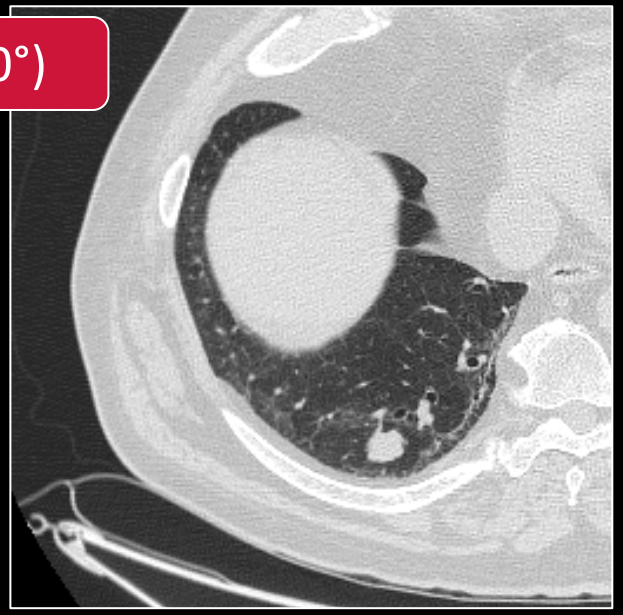
- Rules-based approach
- Based on physician feedback
- Weights can be manually adjusted or “learned” over time

[1] **M. A. Kisting** *et al.*, *J Vasc Interv Radiol*, Nov. 2023, doi: 10.1016/j.jvir.2023.11.016.

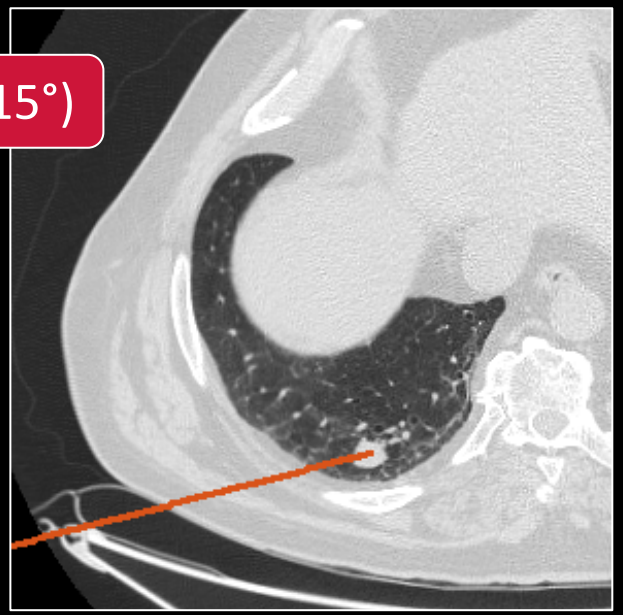
# Results Overview

- 140 pathways generated for 28 patients
  - Mean age = 68.4 ± 9.2, 12 female, 16 male
  - 64% (18/28) had a history of emphysema
- Computer and physician ratings identical in 57.9% (81/140)
- All 28 of the “best” pathways were rated by physicians as ideal or near ideal
  - Mean gantry tilt of 9.1° ± 6.7° for 28 “best”

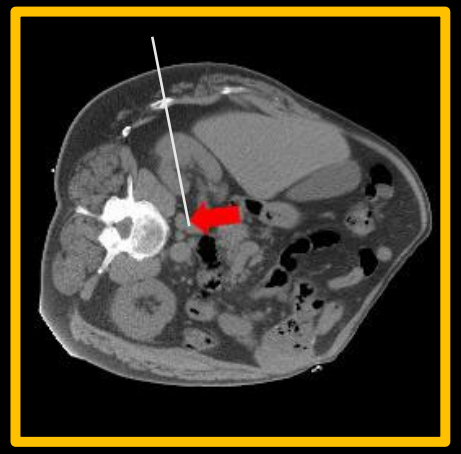
Axial Plane (0°)



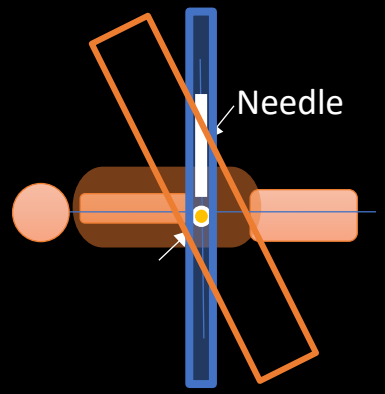
Best Path Plane (15°)



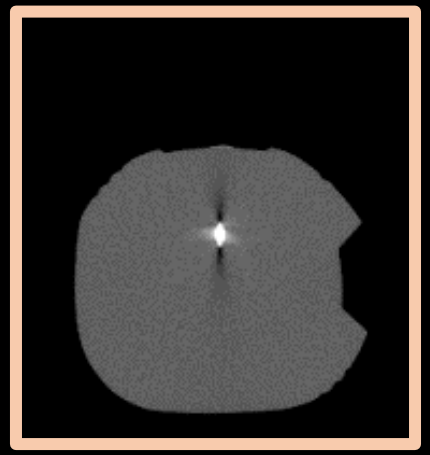
# Needle-ART Method Overview



1. Plan needle trajectory

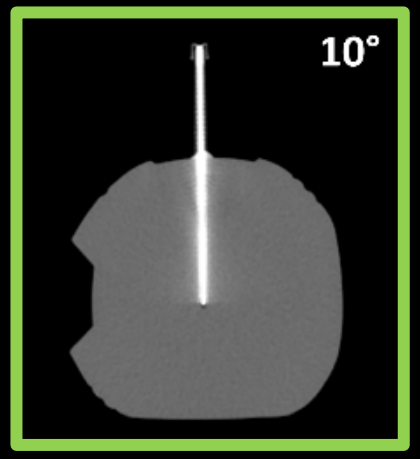



2. Place / update needle and tilt gantry



3. Acquire axial scan with gantry tilt

4. Automatic Segmentation of Needle Centerline

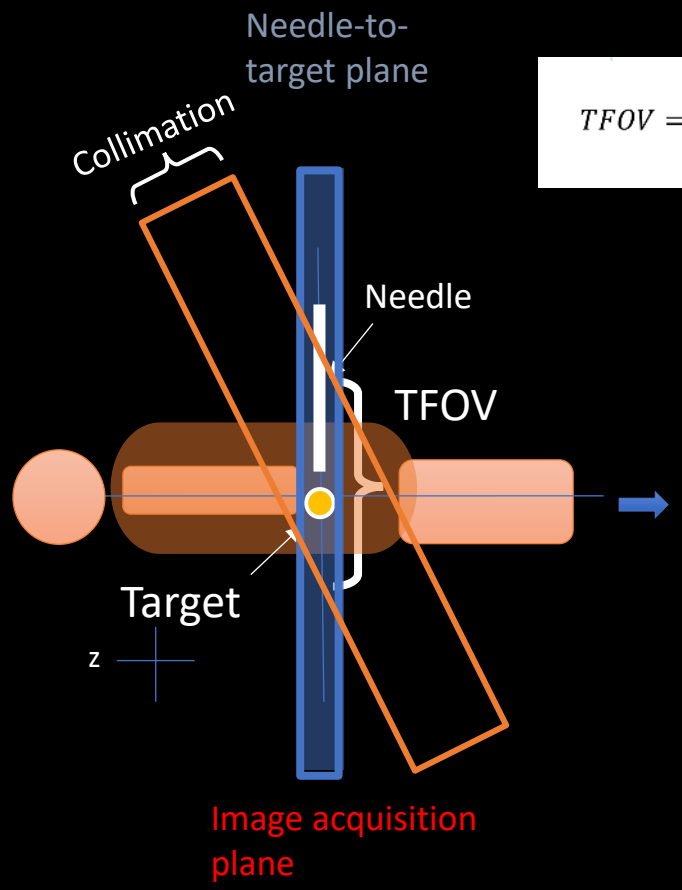



5. Reformat image to needle plane

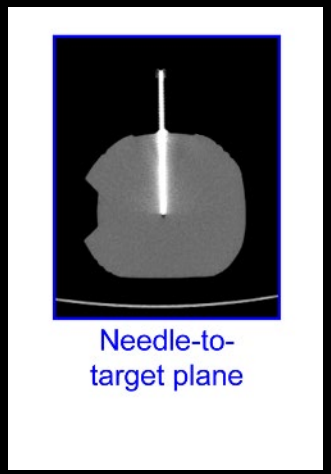
# Needle-ART

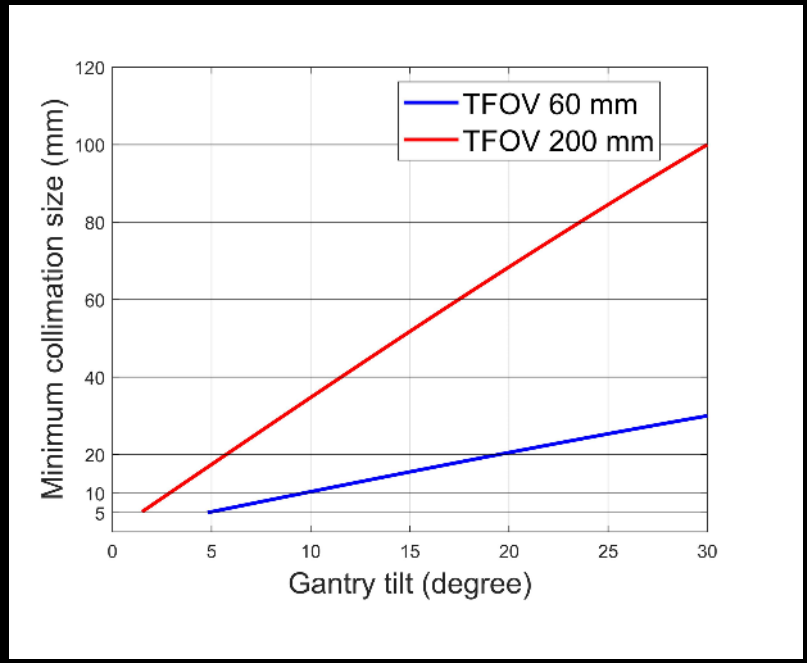
TFOV ↑ Collimation size ↑

TFOV ↓ Gantry tilt ↑



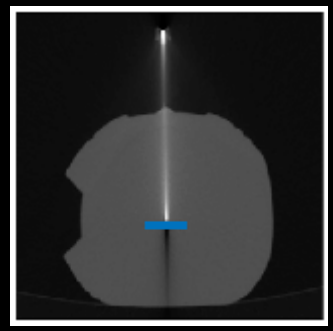

$$TFOV = \frac{collimation\ size}{\sin(gantry\ tilt\ angle)}$$



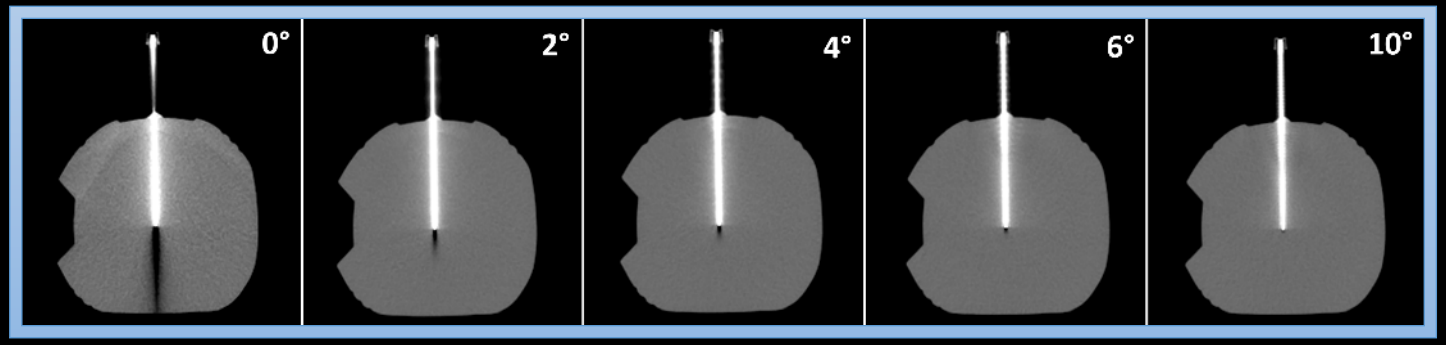
# Results

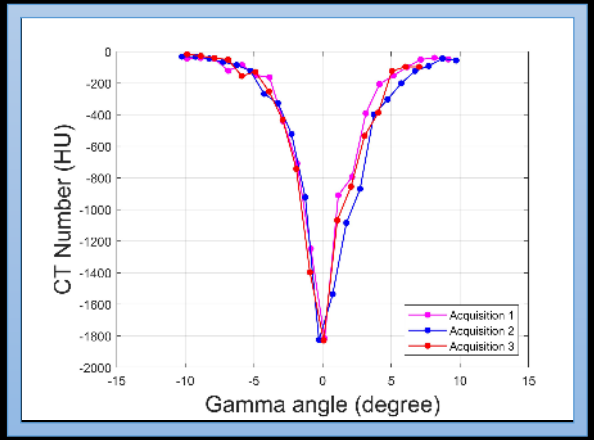
Perpendicular profile to the trajectory artifact



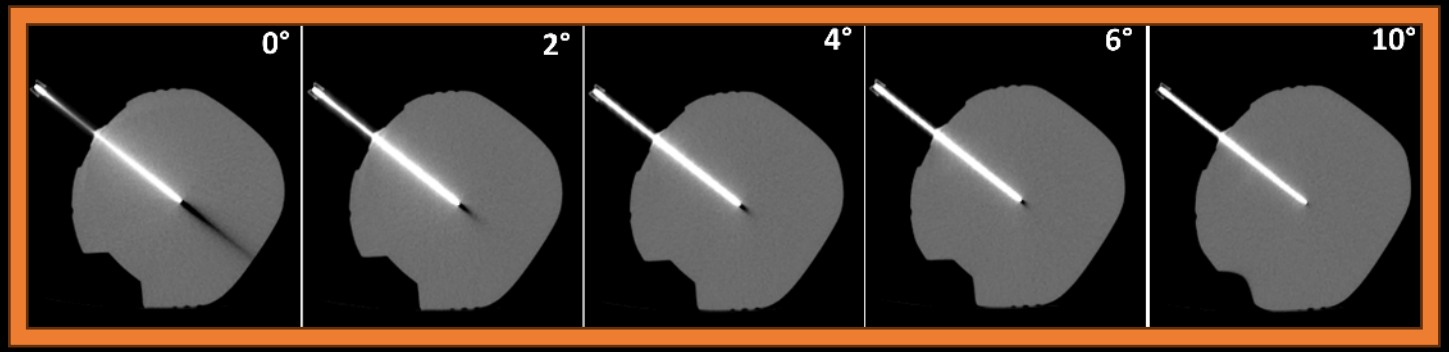
## Water gallon phantom

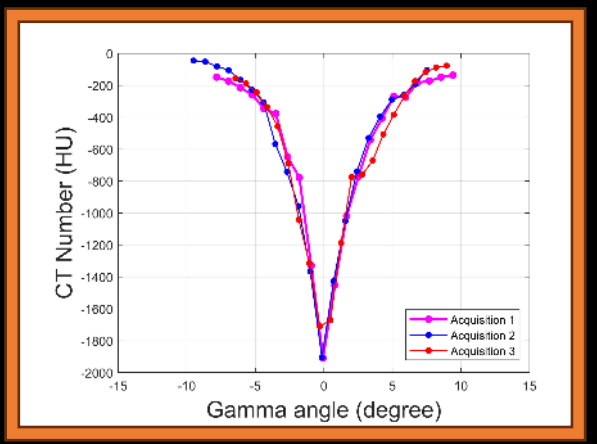
0° →




45° →



# Thank You