CT-guided interventions

Concept of Computed Tomography (CT)
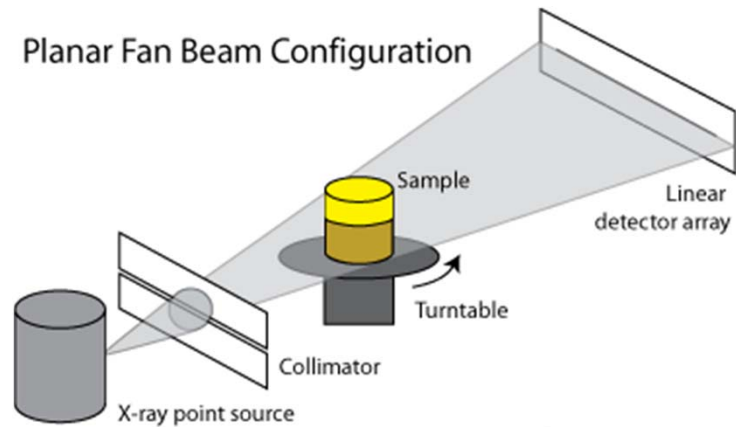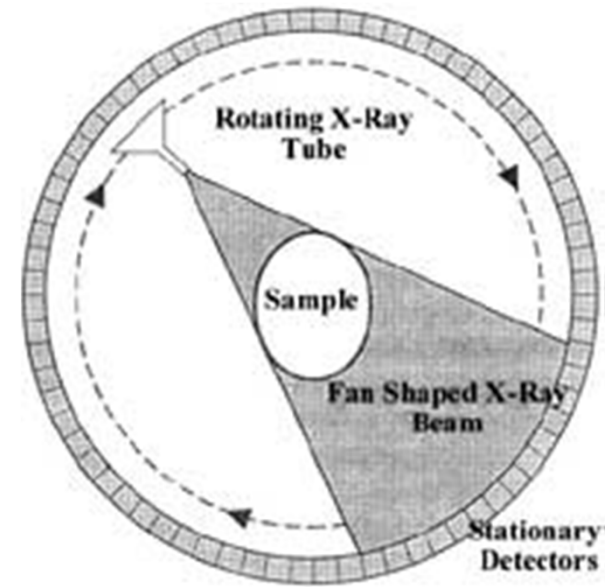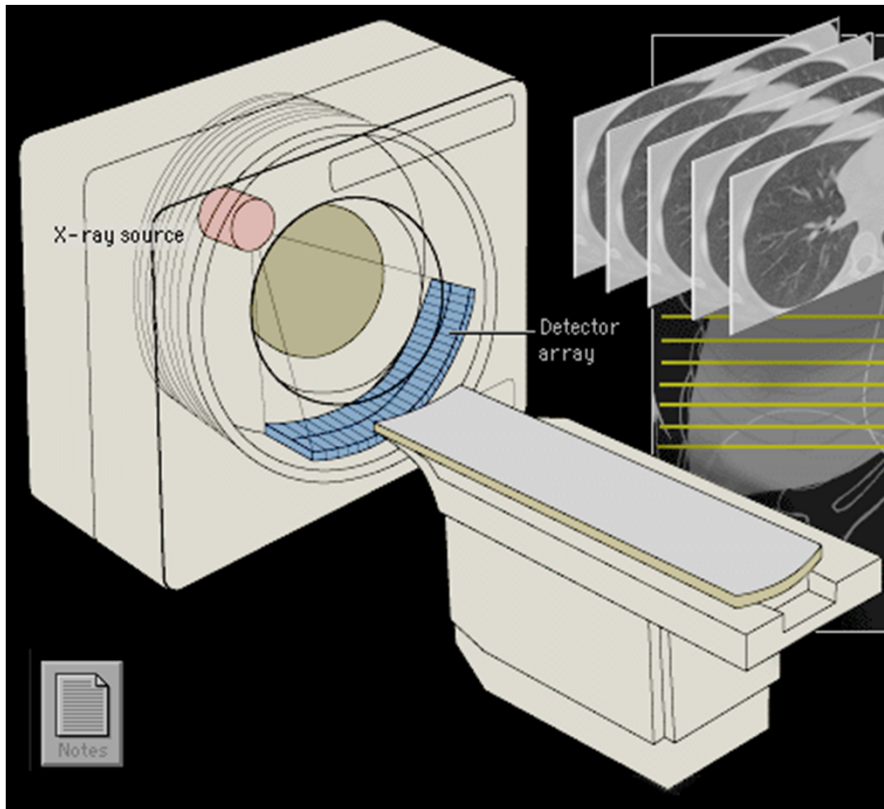
CT scanners (examples)

Modern spiral & multi-slice CT

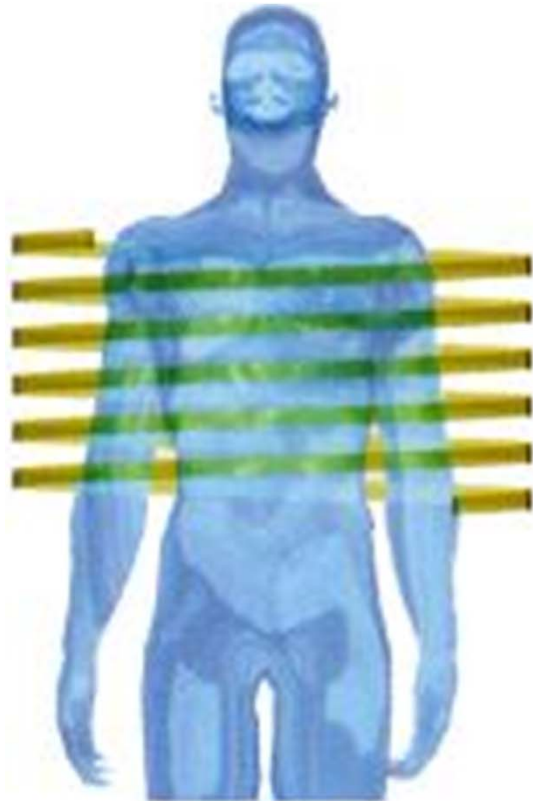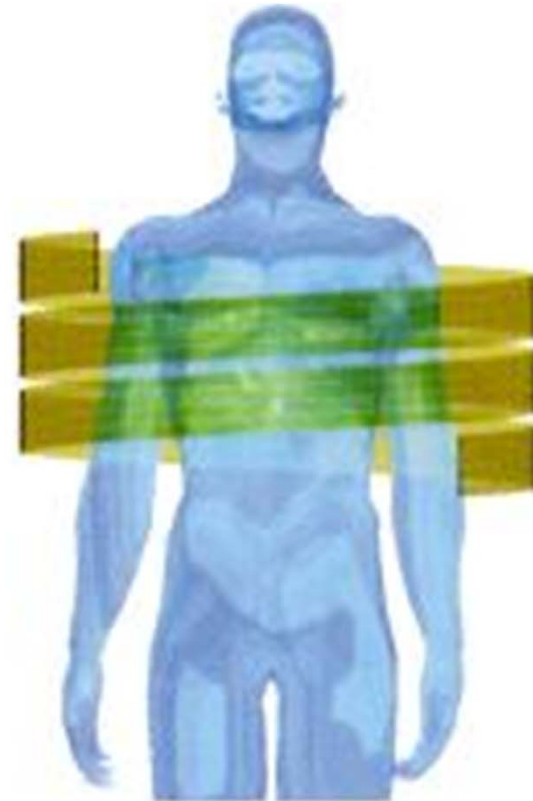SINGLE SLICE SPIRAL   MULTISLICE SPIRAL

Spiral path with 4,8,16,32,64, 128, 256 rows
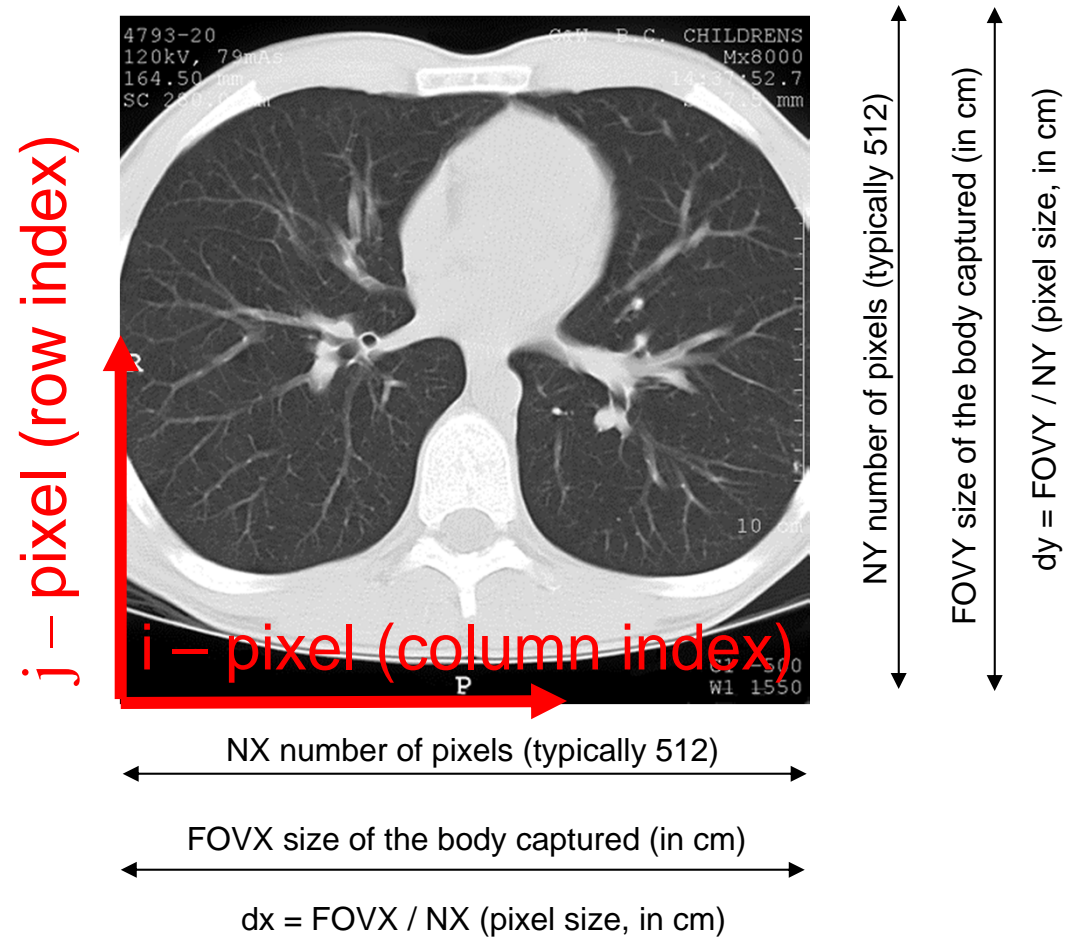
Scan Examples: http://www.radiology.uiowa.edu/3d/

Examples to CT imaging

Navigation in a CT Slice

j – pixel (row index)

i – pixel (column index)

NY number of pixels (typically 512)

FOVY size of the body captured (in cm)

dy = FOVY / NY (pixel size, in cm)

NX number of pixels (typically 512)

FOVX size of the body captured (in cm)

dx = FOVX / NX (pixel size, in cm)
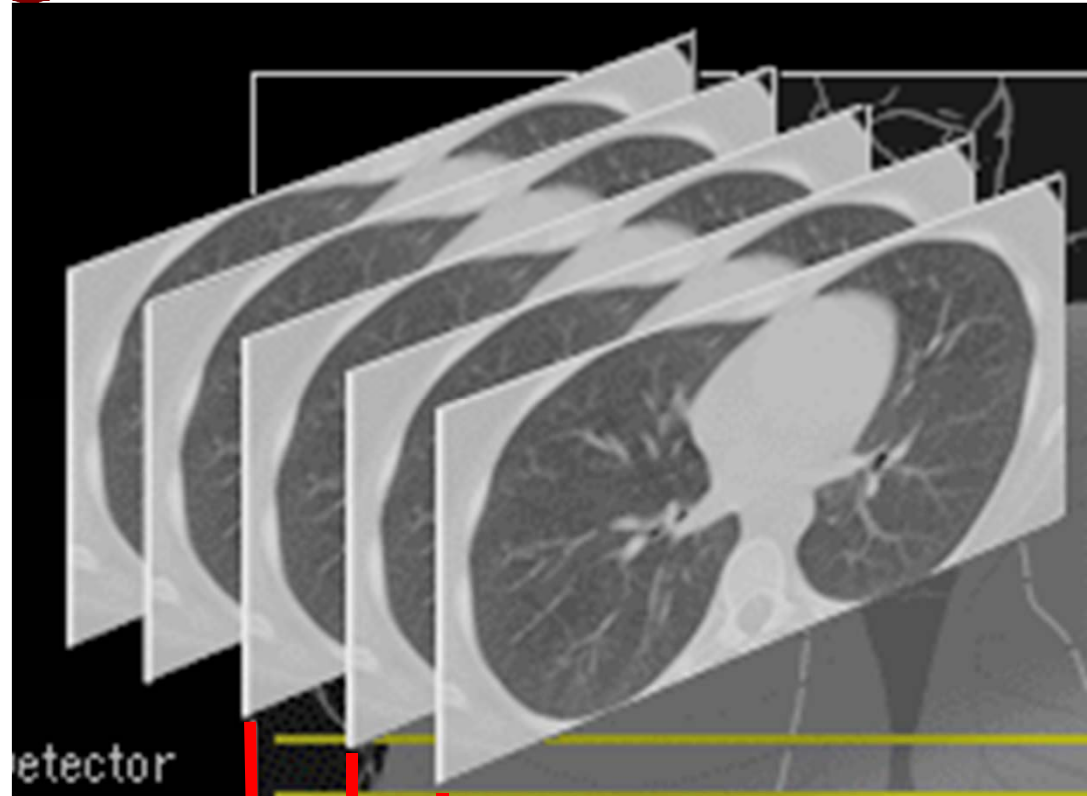
Navigation between CT slices
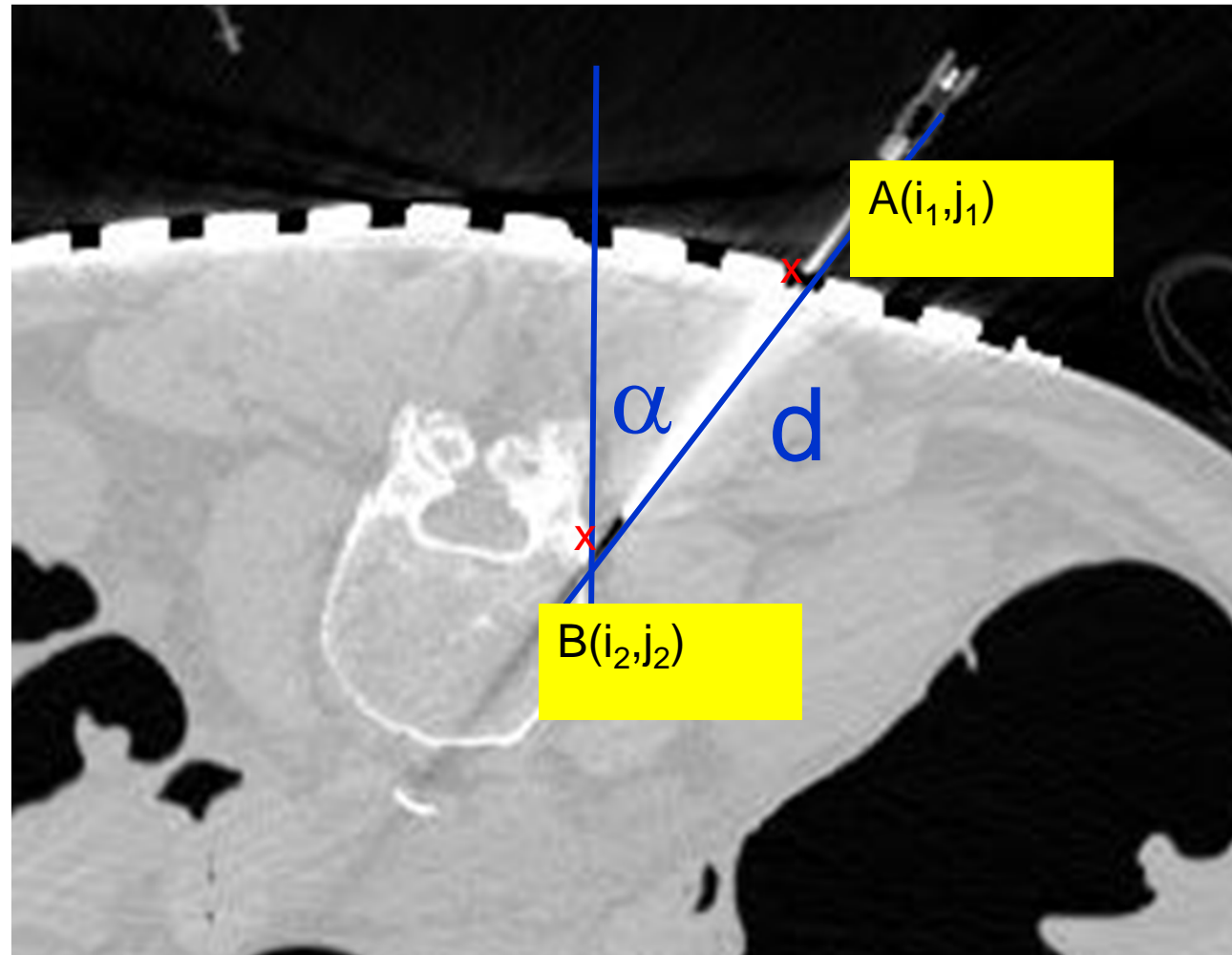

2   1   0   k -- slice index

th = slice thickness (cm or mm)

Calculate needle angle (α) and depth (d)

Conversion between pixel and metric coordinates in CT imaging
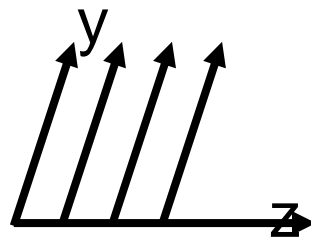
$$P(xyz) = P(i*dx, j*dy, k*th)$$

Where:

dx = FOVX / NX
dy = FOVY / NY

FOVX, FOVY, NX, NY, th are
usually printed on the CT image

Tilted CT gantry

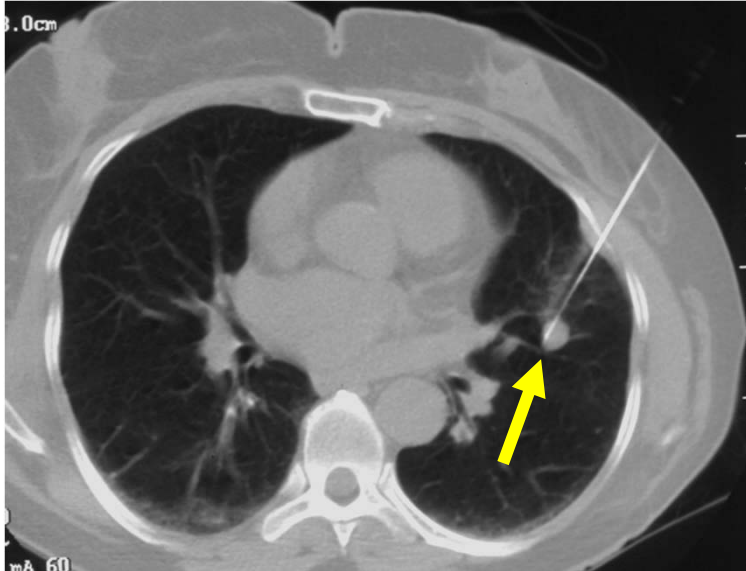No longer a Cartesian coordinate system

Computed Tomography

- Widely available
- Reasonable cost
- Broad insurance coverage
- Excellent hard tissue
- Reasonable soft tissue

ϑ

- 2D by nature
- Limited angles
- X-ray dose
- Access to patient
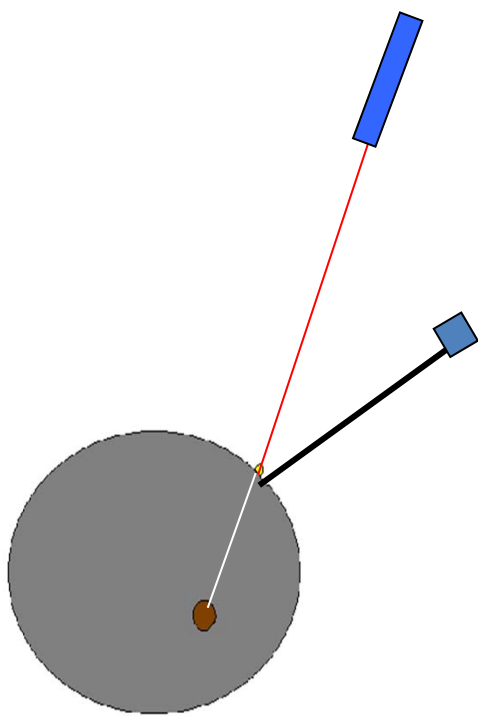
Λ

The needle placement challenge

- **To navigate a needle to a certain point within the body that corresponds to the same point in a CT-image**
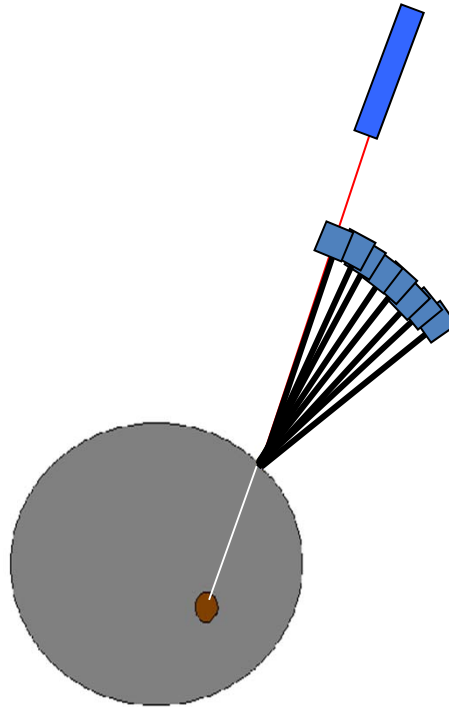
Needle insertion as a 5-DOF problem
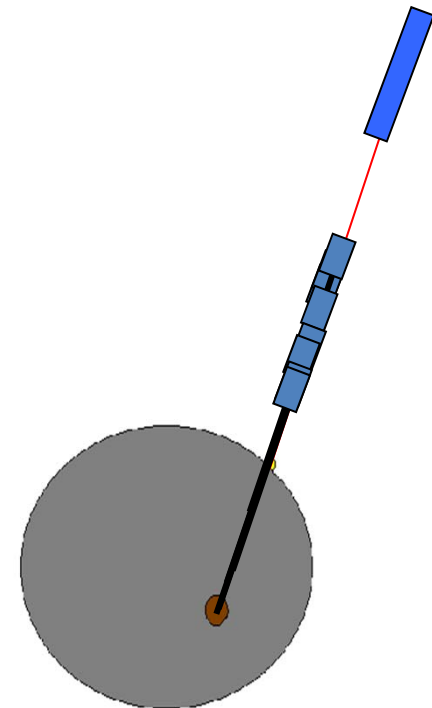
Decoupled motion

3-DOF
Cartesian

Safe but feasible

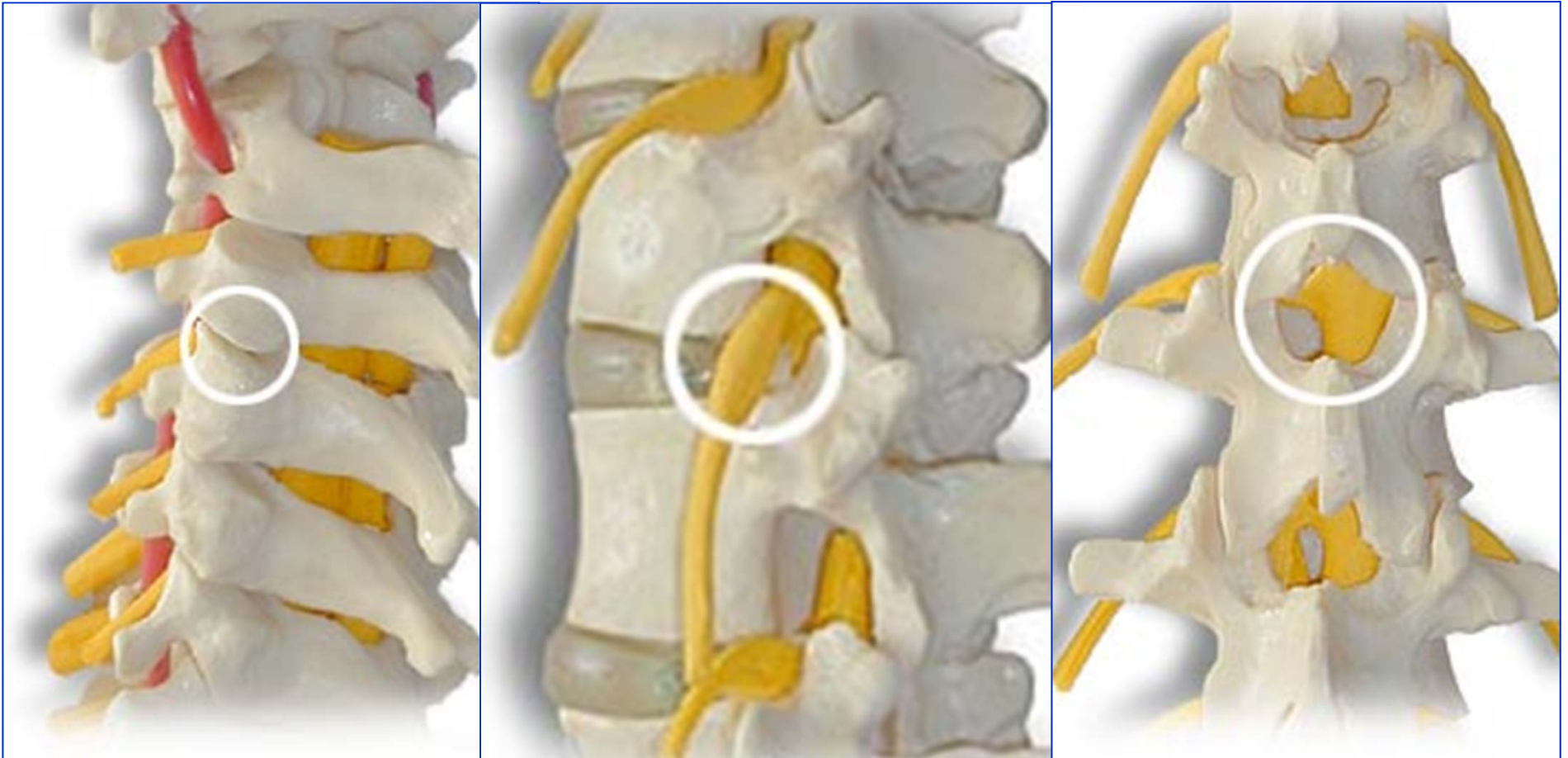2-DOF pivoting

Must be very
accurate

1-DOF or
2 -DOF insertion

Assumes no bending and
accurate depth

Example: spinal pain management

Targeted areas in facet joint injection (left), nerve block (middle), and epidural space injection (right). All figures show the lumbar spine. Facet joint injections and nerve blocks are also frequently performed on the thoracic and cervical spine.

Key Clinical Issues

- Accuracy
  - Longevity of pain relief
  - Collateral damage
  - Pain during procedure
  - Acceptable ~1mm
  - Access/accuracy challenges in 10% of cases for good surgeons
- Time
  - Time = Money
  - High volume / high throughput procedure
  - Good surgeons ~10 min, others may be 45 min
- Toxic radiation
  - Primarily concern is physician & staff
  - Typical fluoro times:
    - Good surgeons ~5 sec total beam time
    - Others may be 30+ sec total beam time

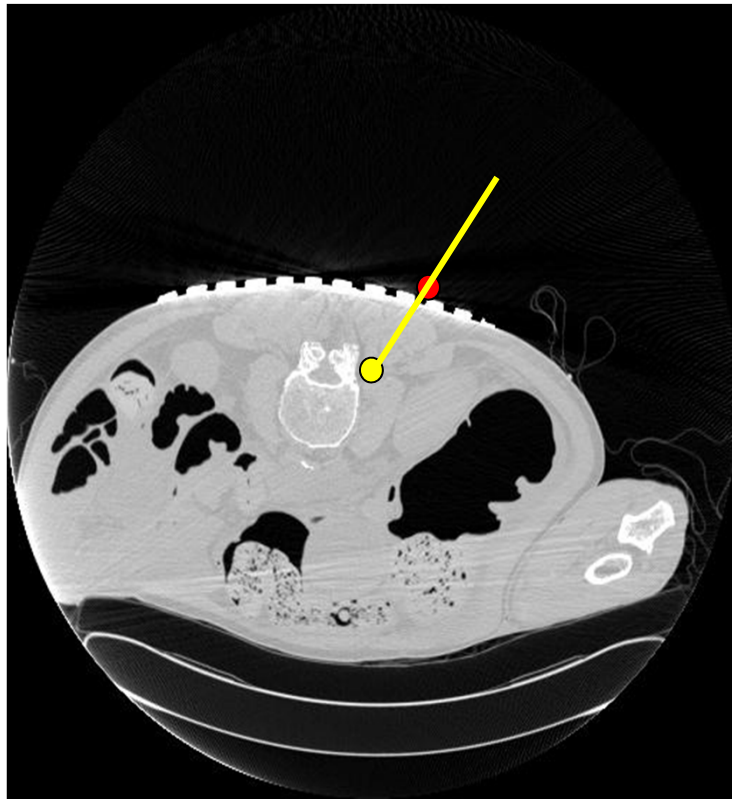# Mark the plane of interest with fiducial strip
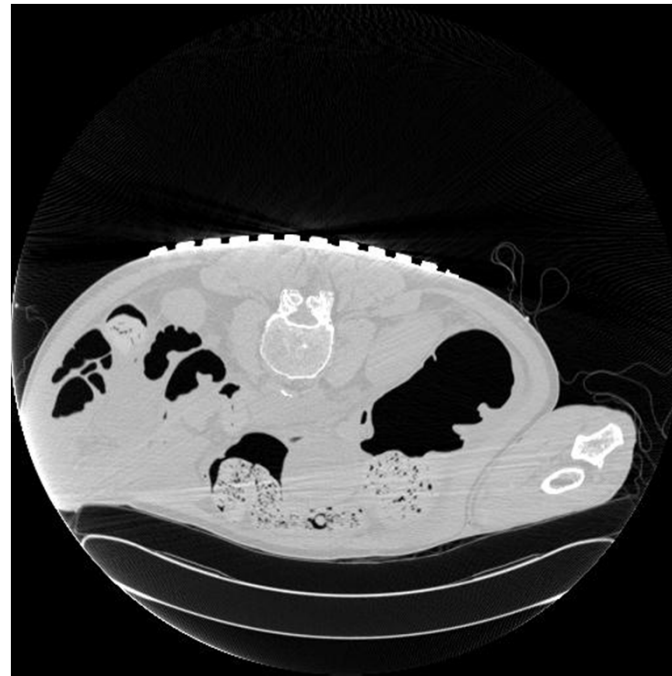
Scanner laser
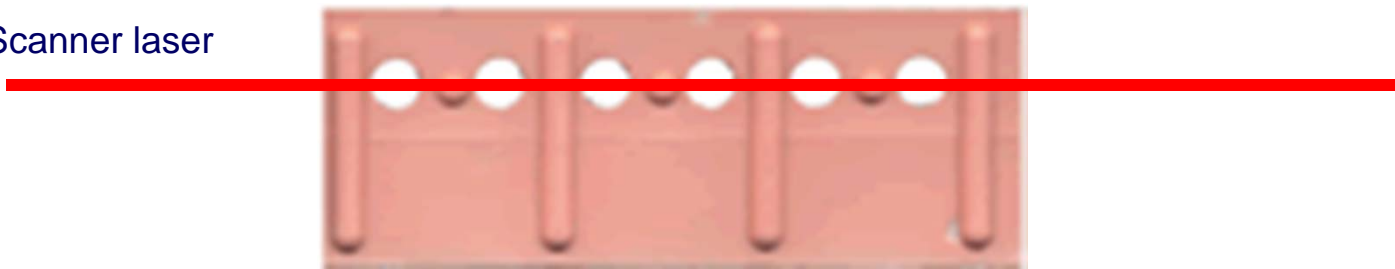
Entry point based on fiducial

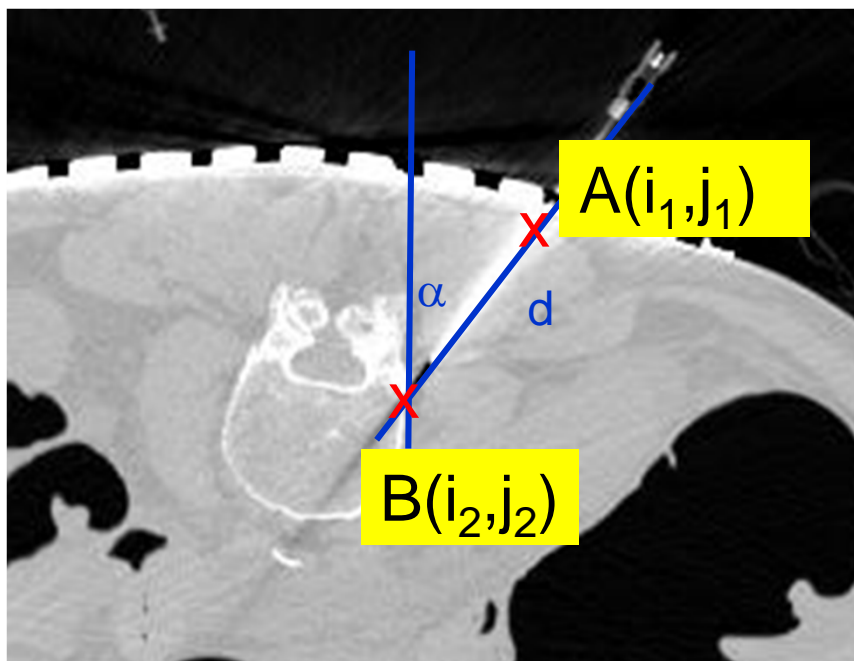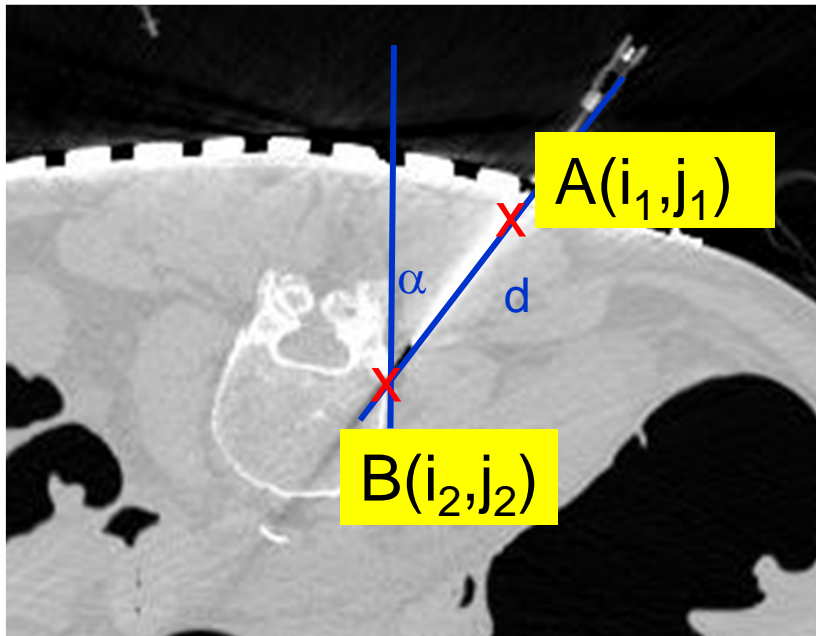Laboratory for Percutaneous Surgery (The Perk Lab) – Copyright © Queen's University, 2014

Workflow for CT-guided injection

1. Put patient in the scanner
2. Palpate vertebra
3. Take thin volume scan
4. Select slice of interest
5. Affix fiducial strip
6. Take single slice
7. Pick target and entry
8. Determine angle and depth
9. Identify entry on skin
10. Touch needle to entry point
11. Maintain insertion angle
12. Keep needle in laser plane
13. Judge current insertion depth
14. *Insert contrast (if need to)*
15. Push patient back to scan plane
16. Take confirmation CT
17. Pull out patient
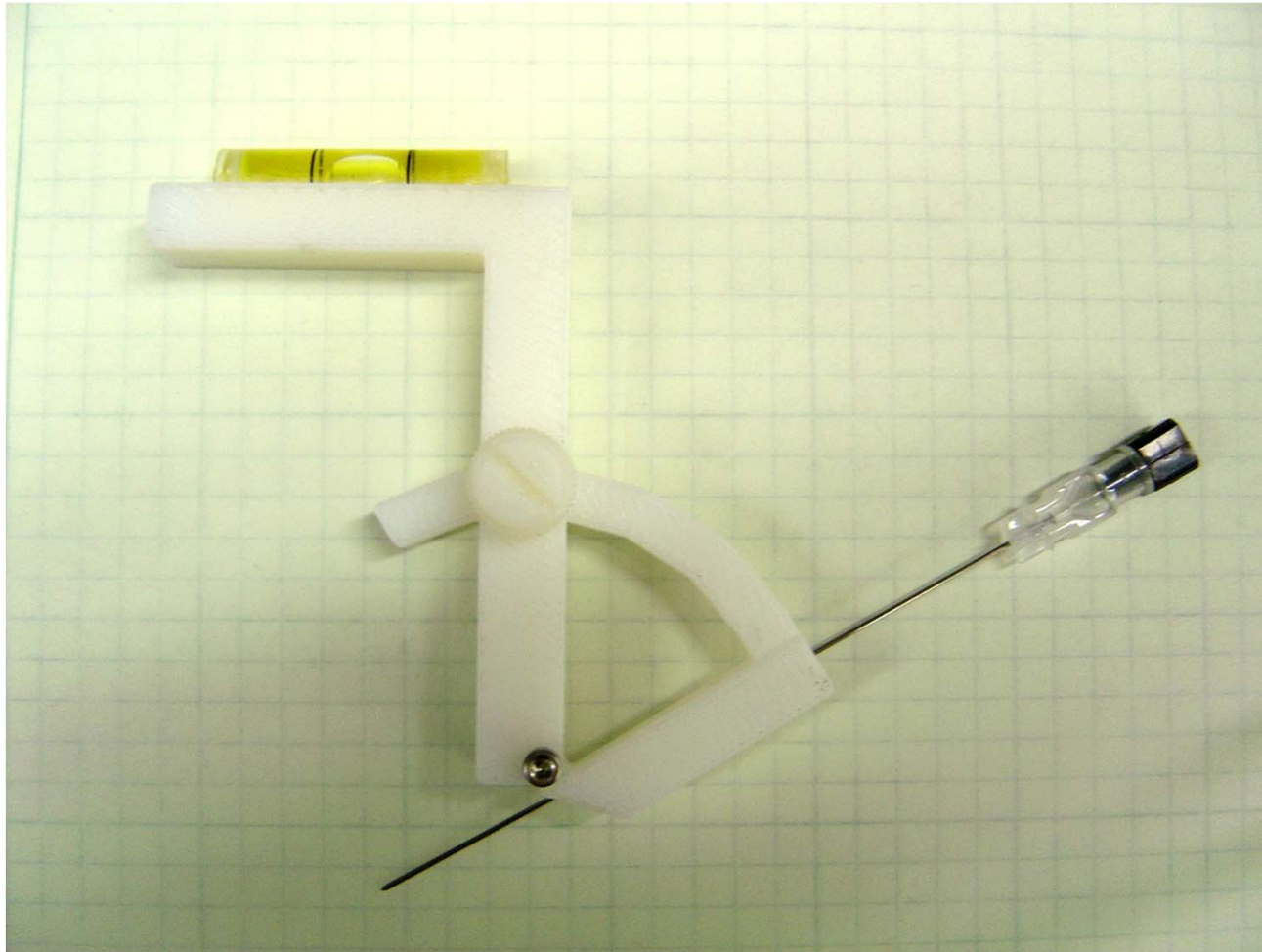18. Inject therapeutic agent

The challenge

- Transfer entry, angle and depth onto the patient
- Control all 3-DOF simultaneously during insertion

Handheld Needle Guide

Bubble level + protractor

Fichtinger, et al.

Handheld Needle Guide

Bubble level + protractor

Fichtinger, et al.

Handheld Needle Guide

Bubble level + protractor

Fichtinger, et al.

CT-Mounted Laser Overlay

Fichtinger, et al.

CT-Mounted Laser Overlay

Fichtinger, et al.

SimpliCT device by NeoRad

NeoRad.com

Image overlay
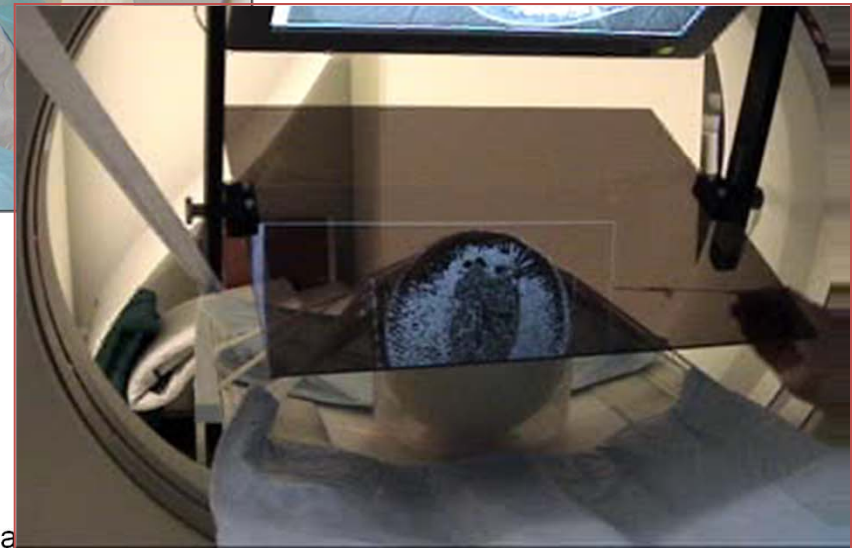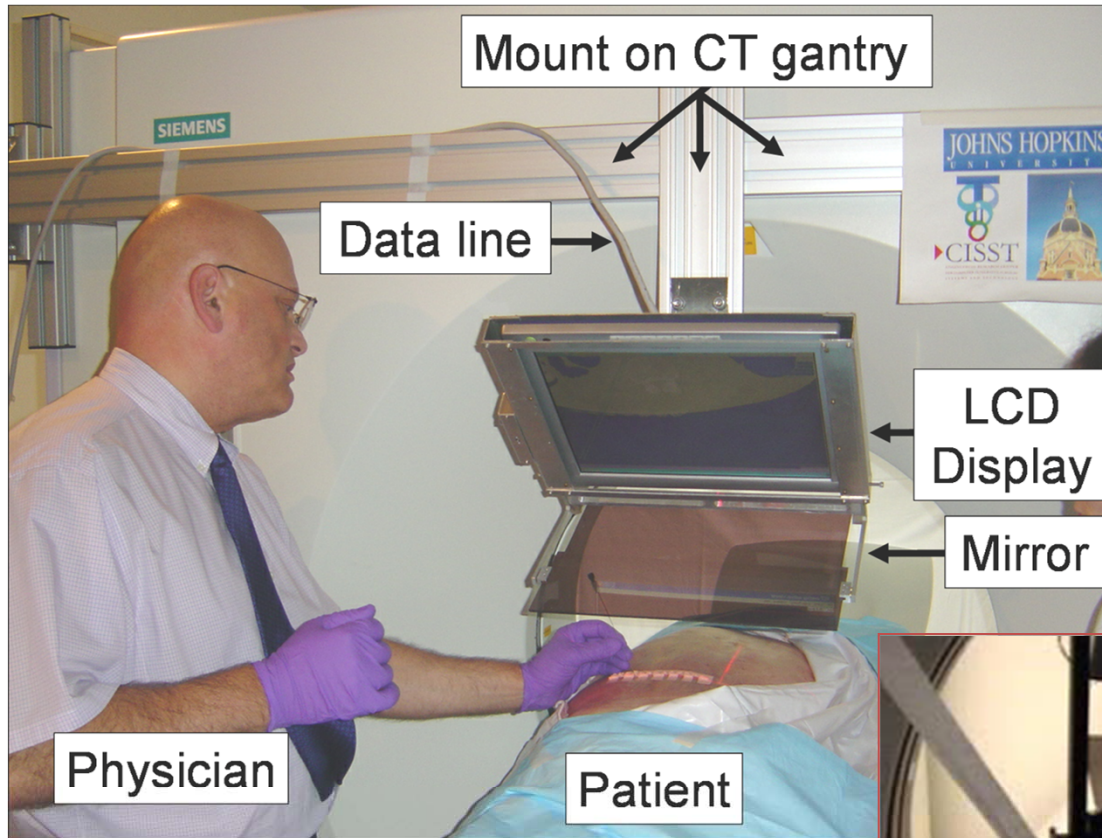
Fichtinger, et al
Laboratory for Percutaneous Surgery (The Perk Lab), copyright Queen's University

The Picker/Marconi/Philips/Immersion "Pinpoint" device
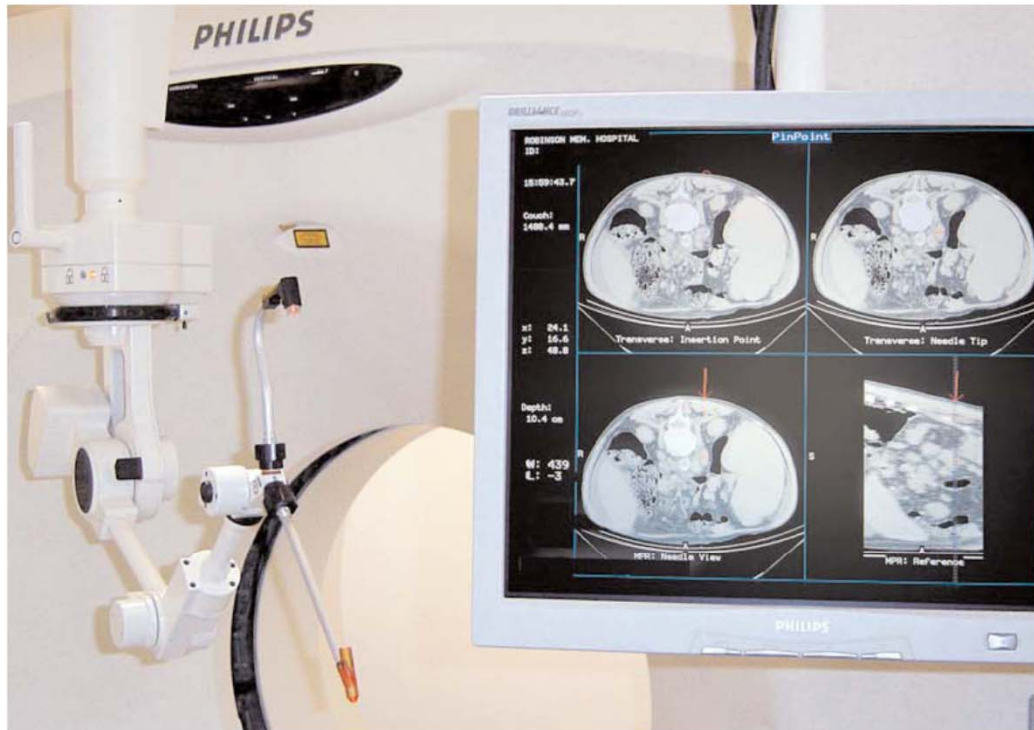
Robot-assisted prostate biopsy

Fichtinger, et al.

3-DOF decoupled robot

7-DOF passive arm

Needle

Locking arm

Joysticks and safety switches

2-DOF RCM

1-DOF needle injector

Amplifier box

Table side robot mount
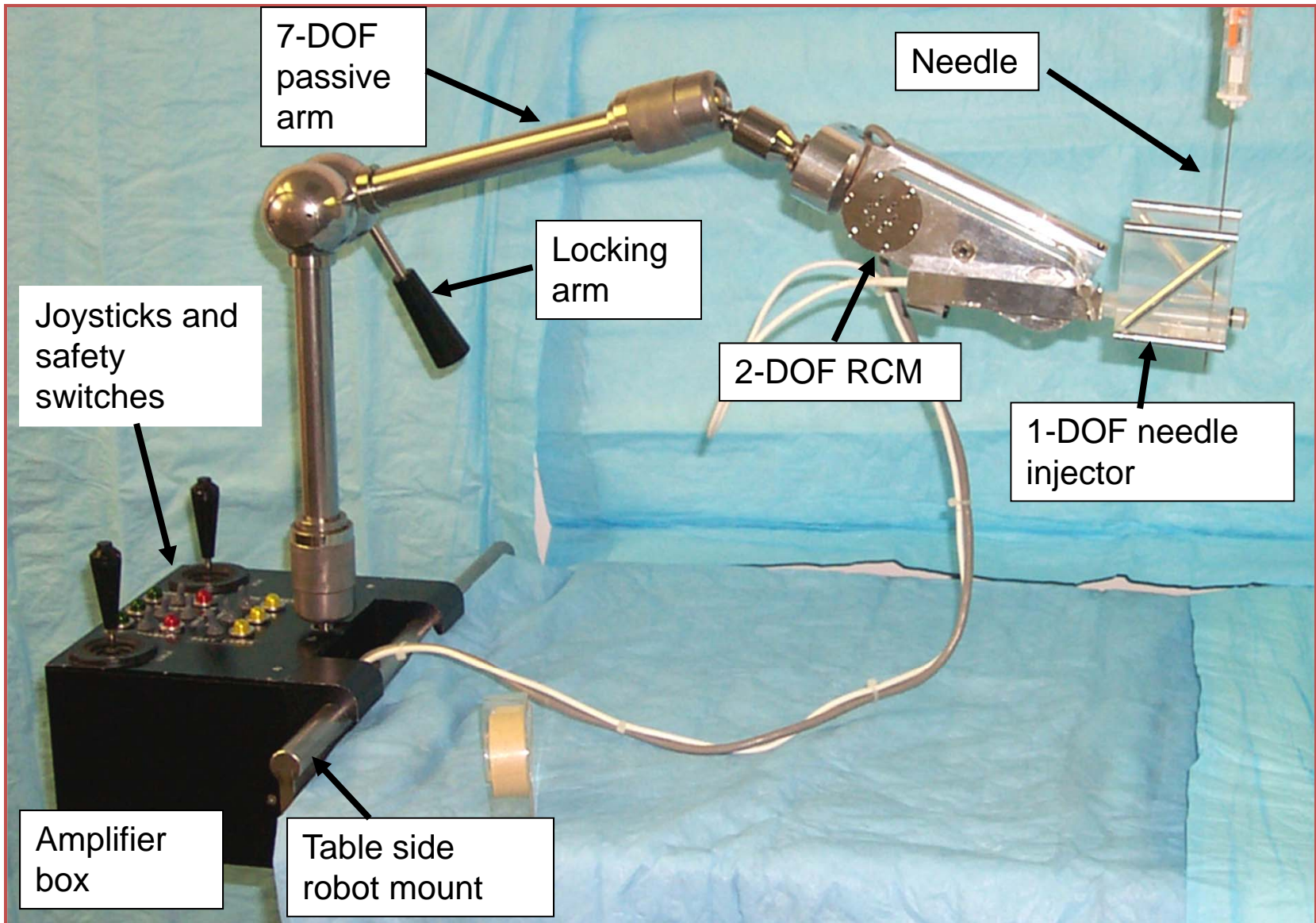
Target & entry planning

Fichtinger, et al.
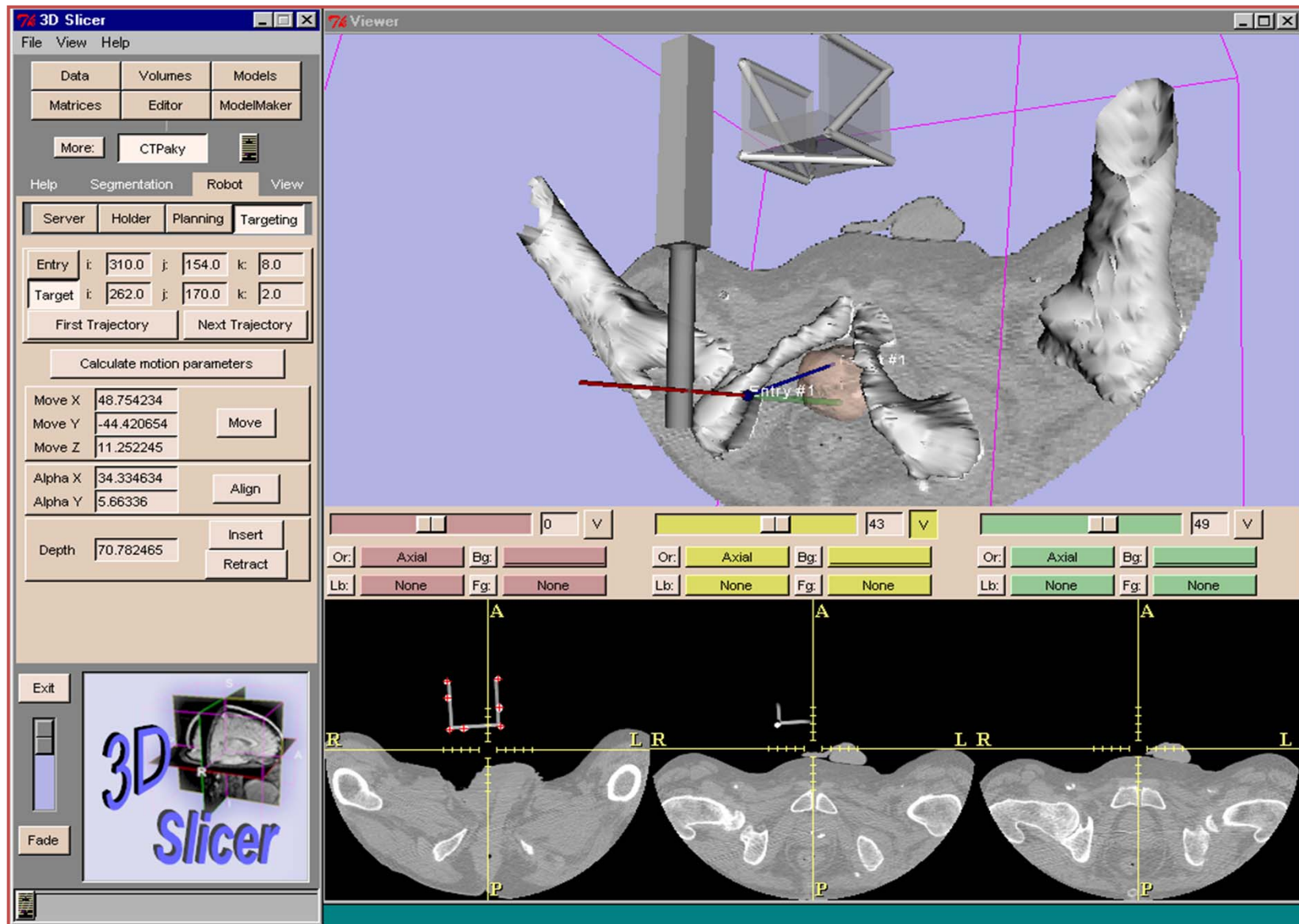
Robotic kidney biopsy

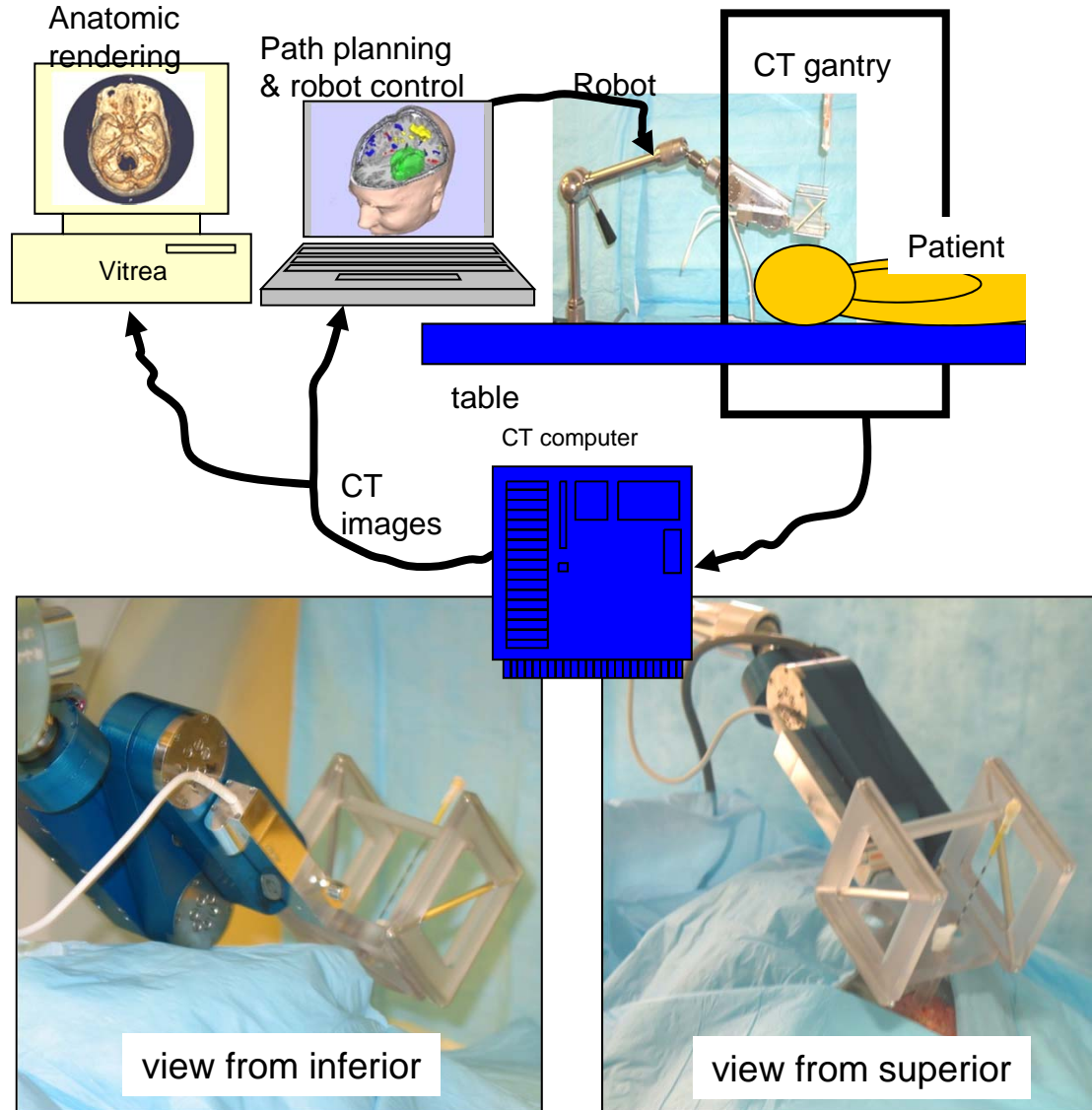Robot registered to CT from a single image using stereotactic frame on the end-effector

MOVIE

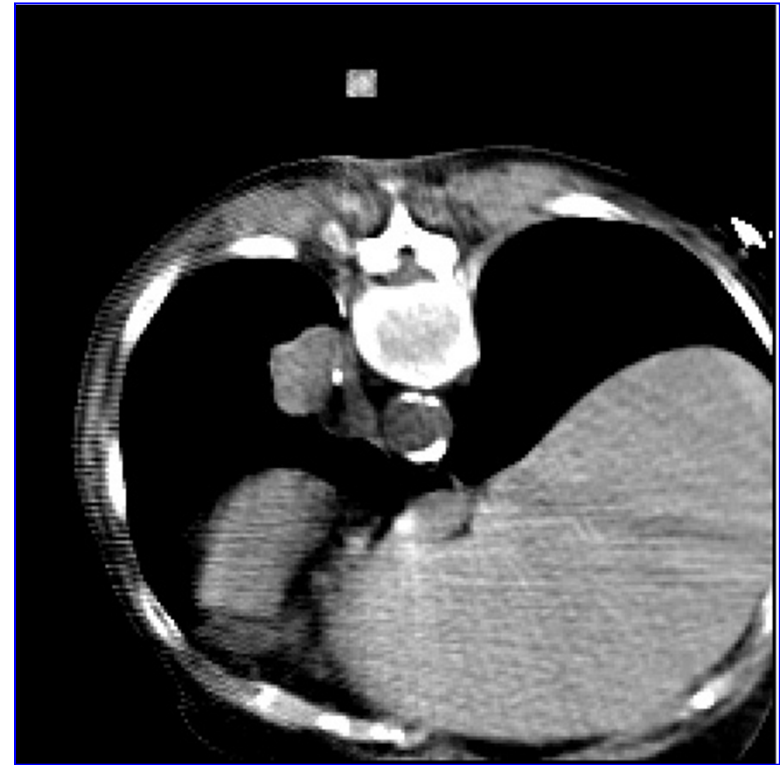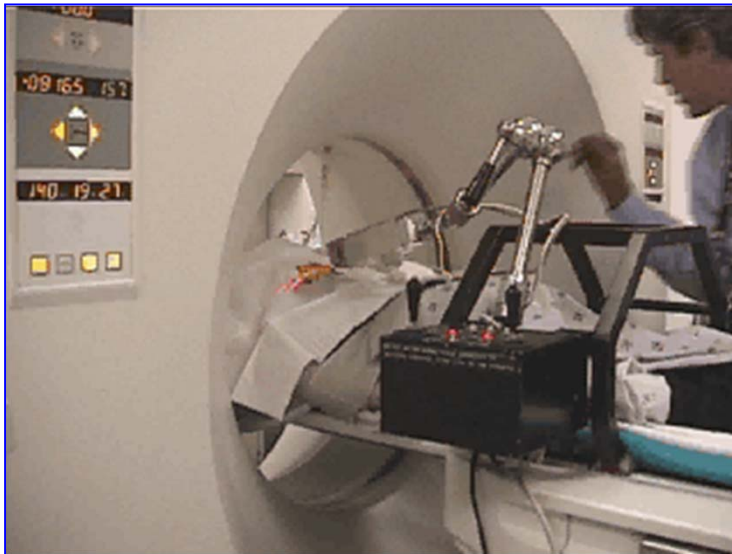Credit: D. Stoianovici, L. Kavoussi, A. Patriciu, S. Solomon (JHU Bayview)

Robot assisted ICH removal

Anatomic rendering

Path planning & robot control

Robot

CT gantry

Vitrea

Patient

table

CT images

CT computer

view from inferior

view from superior

Fichtinger, et al.

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UNIVERSITY

Robotic lung biopsy

Robot registered to CT using the scanner's alignment laser

MOVIE

Credit: D. Stoianovici, L. Kavoussi, A. Patriciu, S. Solomon, JHU Bayview and G. Fichtinger, ERC

Robotic spine biopsy

Fichtinger, et al.

Robotic lung biopsy w/ motion compensation

3D CT Volume

CT Fluoroscopy
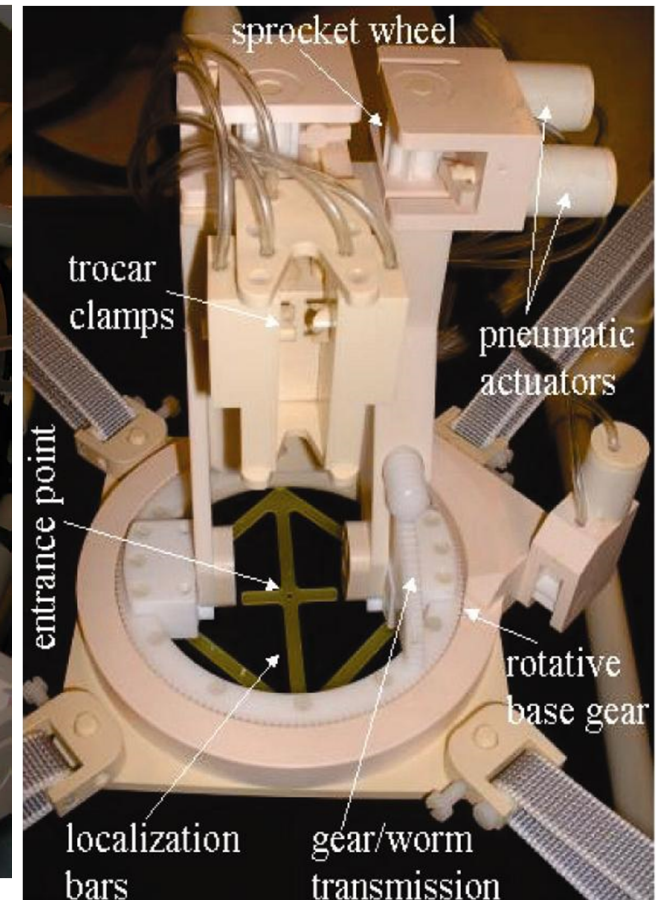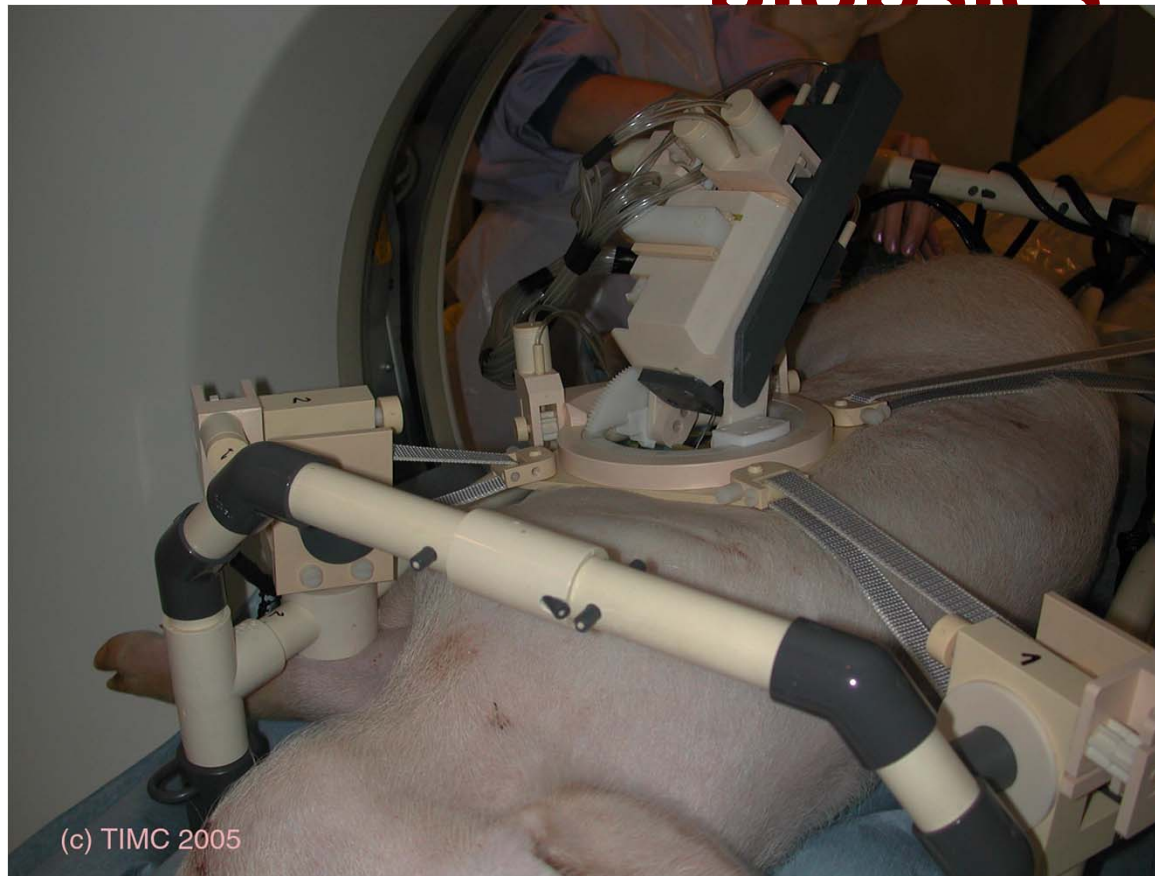
Frame Grabber
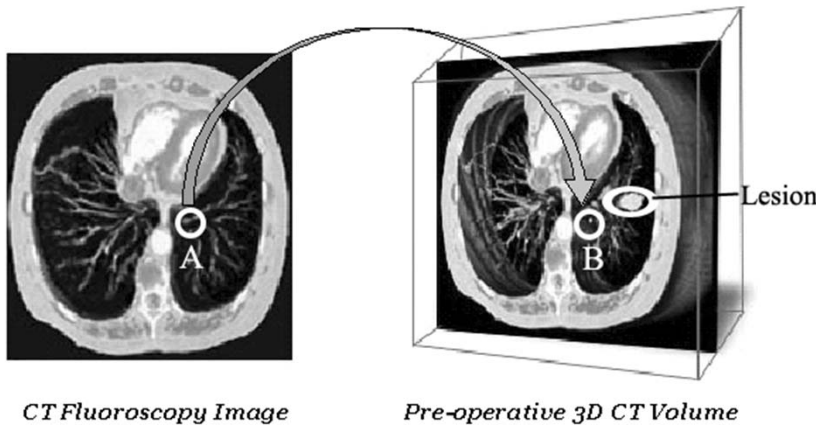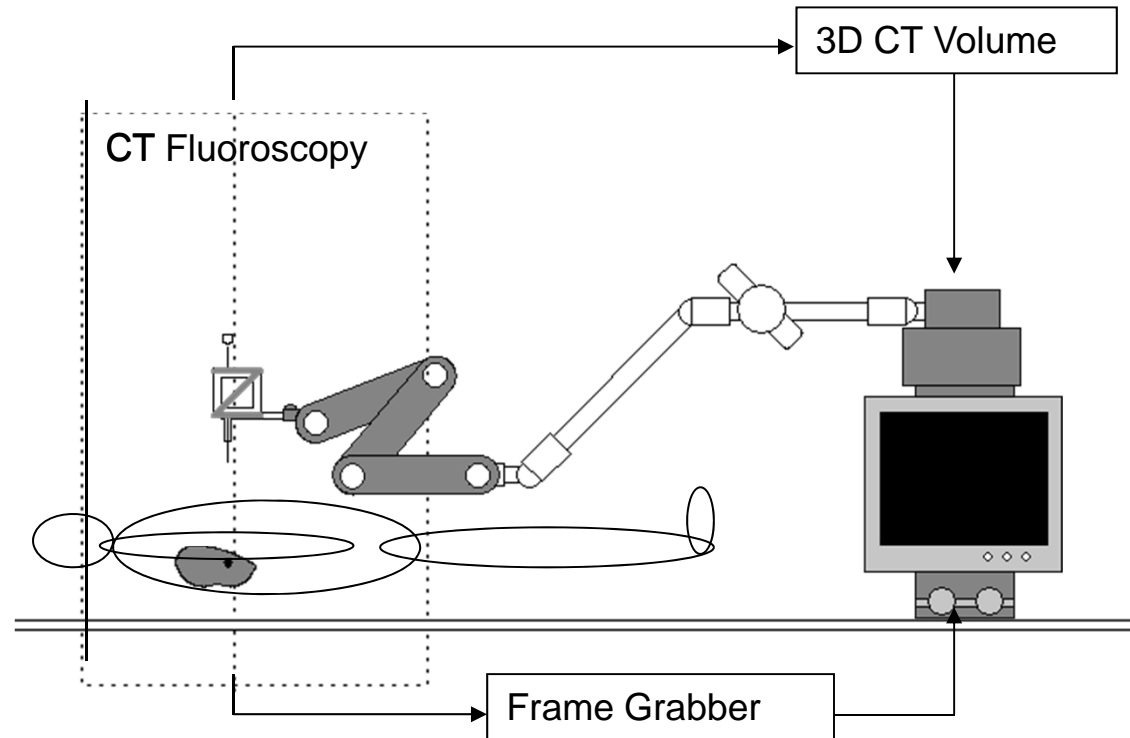
Register real-time CTF to CT
Then compensate with robot

Lesion

CT Fluoroscopy Image

Pre-operative 3D CT Volume

Fichtinger, et al.

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Patient mounted robot for biopsies

(c) TIMC 2005

sprocket wheel

trocar clamps

pneumatic actuators

entrance point

rotative base gear

localization bars

gear/worm transmission

- **CT/MR compatible**
- **No trajectory limitation**

- Embedded localization
- Pneumatic actuation
- Accuracy <1.5mm

Troccaz, et al.