Technology for Adaptive MR Guided Brachytherapy

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- Patents submitted for IP related to actively tracked stylets
- Sequences and devices do not have regulatory clearance

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Educational Goals

- Review justification of MR for brachytherapy
- Review different means of incorporating MR imaging into brachytherapy
- Discuss technology that facilitates MR guided brachytherapy

Outline

- Brachytherapy
  - Implant evaluation
  - Image based
  - Image guided
  - Adaptive
  - Role of MR
- MR based brachytherapy
- MR guided brachytherapy
- Applications of microcoils in brachytherapy

Ferenc Jolesz (1946-2014)

Brachytherapy

- Sites
  - Breast
  - Skin
  - Prostate
  - GYN
    - Cylinder
    - T&O
    - Interstitial

Applicator Based Brachytherapy

- Cylinder
  - Rx to surface (depth)
  - Plan determined by diameter and length
- Mammosite
  - Rx: 1cm from surface
- Postimplant dose evaluation
  - Dose calculation based on source
- Plan determined without anatomic information imaging provides information about source or applicator

Image Based Brachytherapy

- Imaging timing
  - After placement
  - Before dose
- Image provides
  - Applicator geometry
  - Anatomy
- Dose planning incorporated anatomic (image based) dose goals/constraints

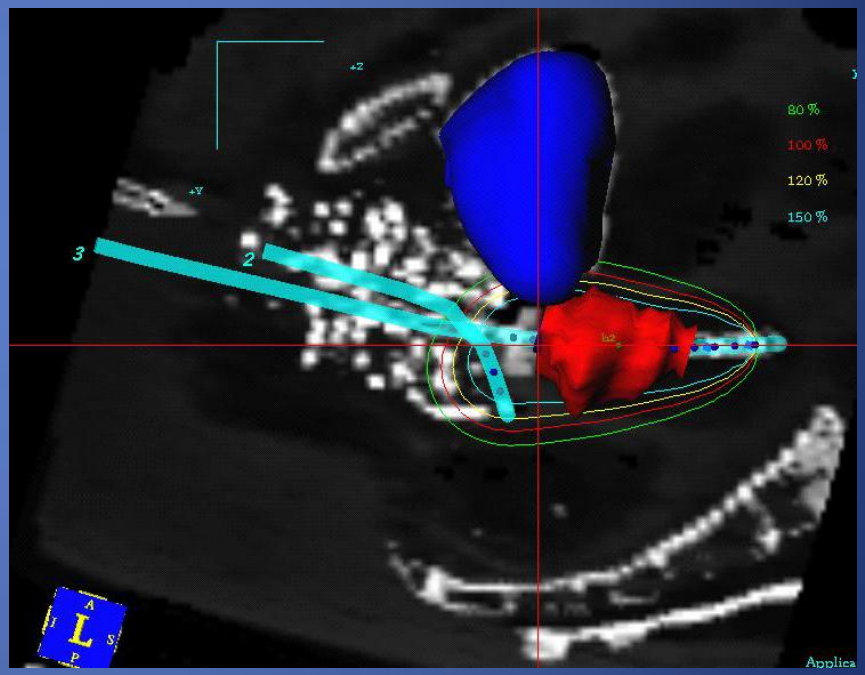
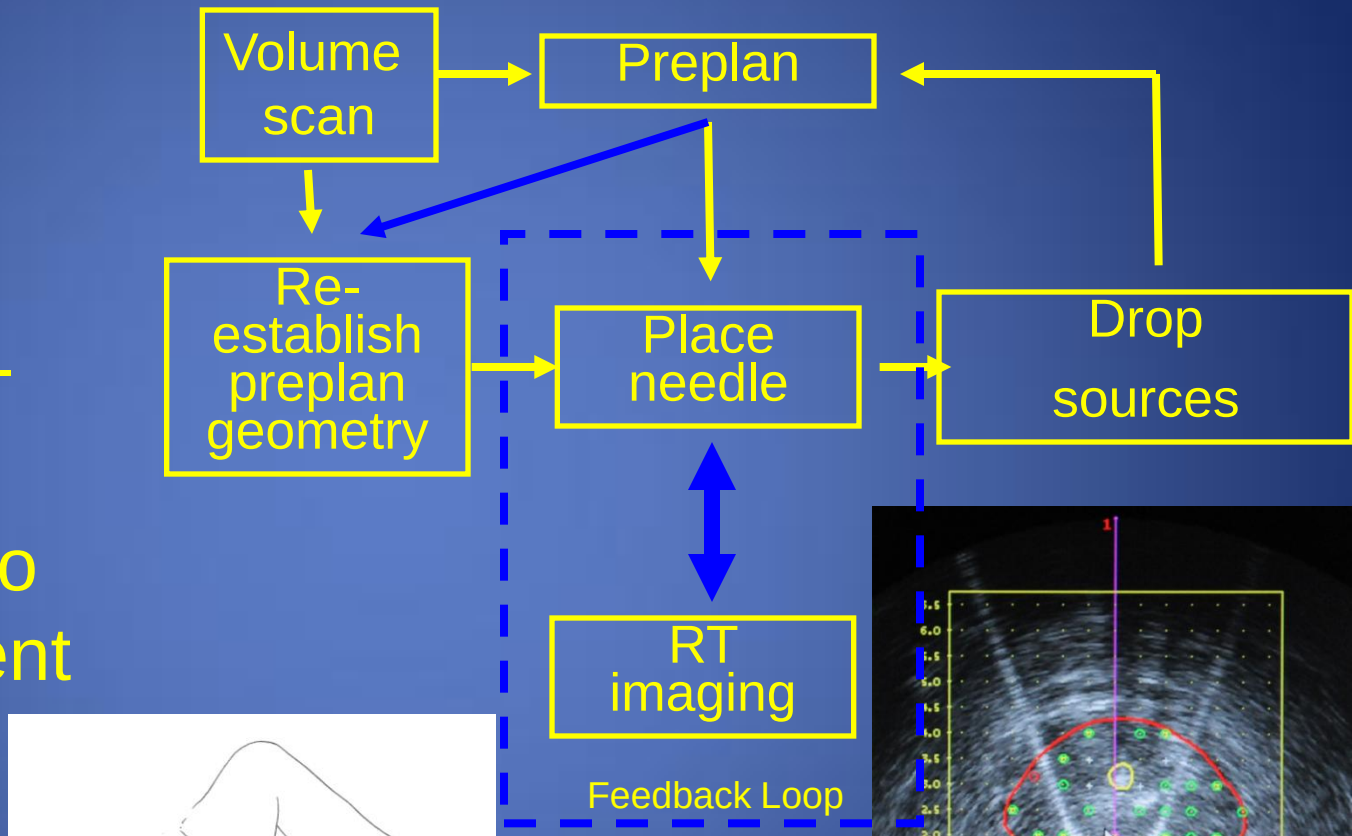
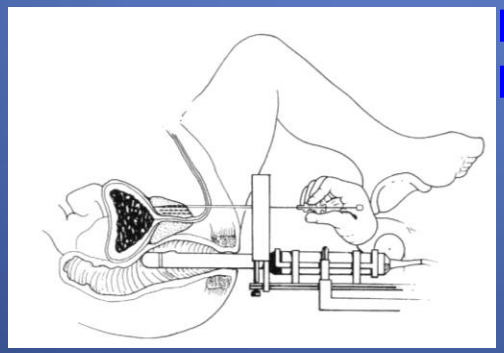


Image Guided Brachytherapy

- Incorporates image based brachytherapy (volume study-preplan)
- Uses images to guide placement of applicator (needles)

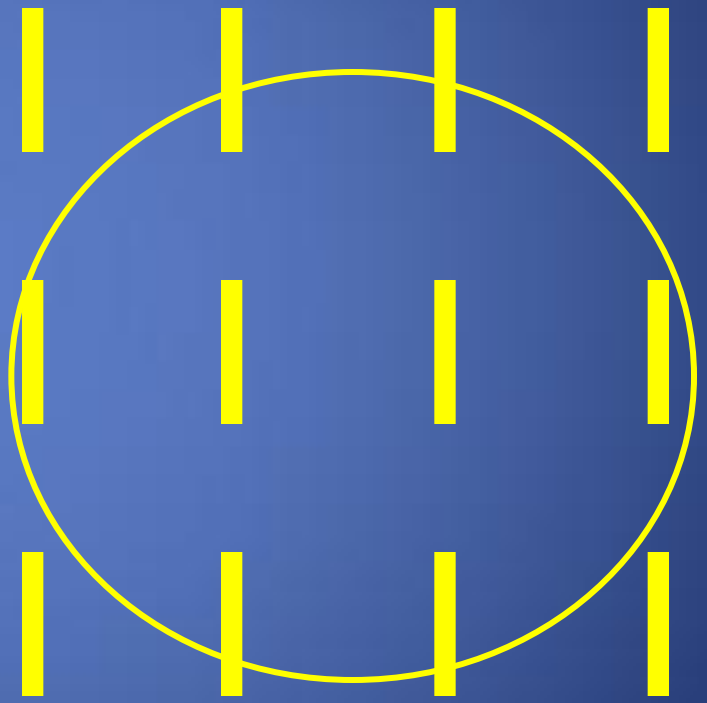




Nag: Principles of Brachytherapy

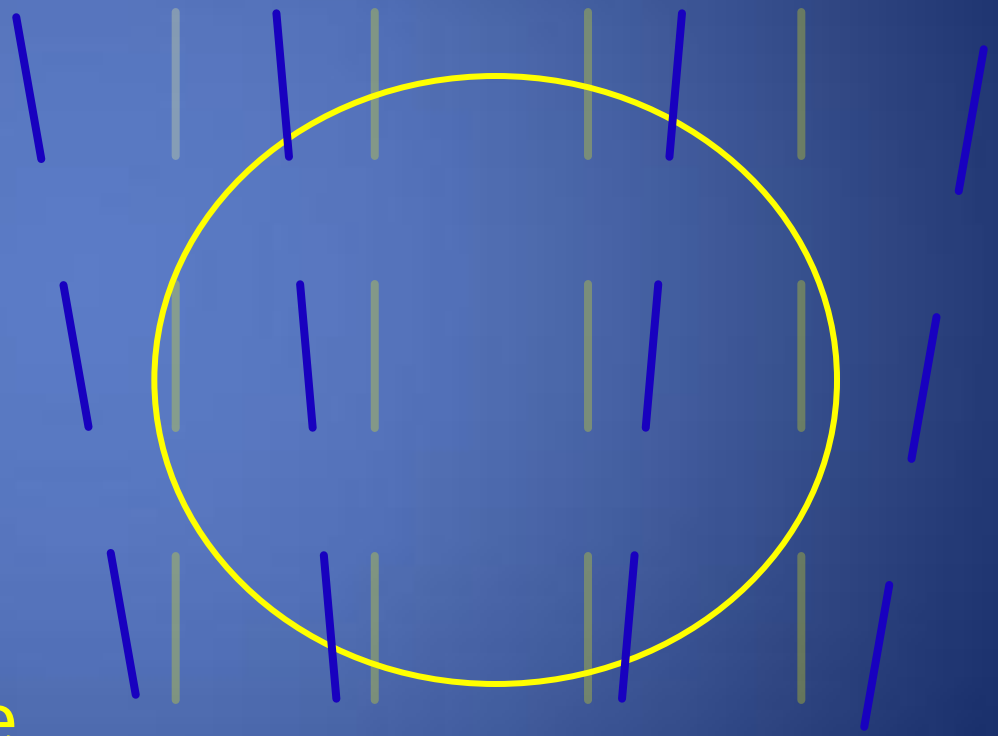
Adaptive Brachytherapy
(Dosimetry Guided Brachytherapy)

- Image guided
- Treatment planning in procedure room
  - planning
  - image based applicator updates
- Dosimetric feedback
- Update plan throughout procedure



Adaptive Brachytherapy
(Dosimetry Guided Brachytherapy)

- Image guided
- TPS in procedure room
  - planning
  - image based applicator updates
- Dosimetric feedback
- Update plan throughout procedure

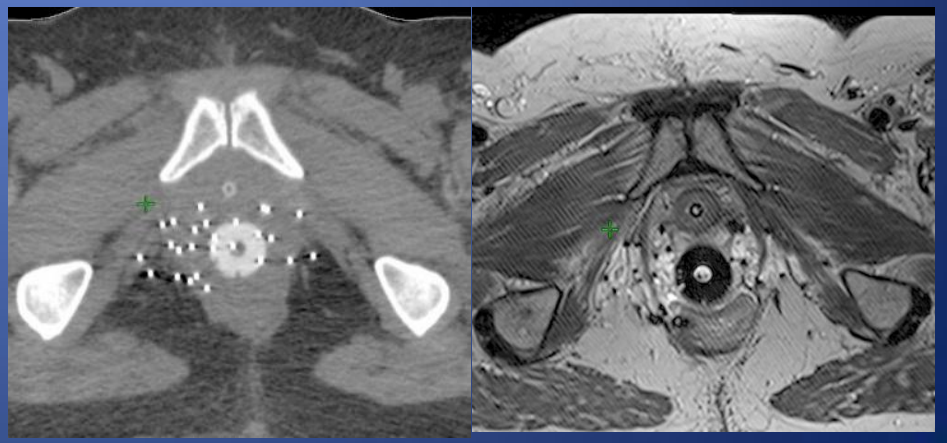


Adaptive Brachytherapy
(Dosimetry Guided Brachytherapy)

- Image guided
- TPS in procedure room
  - planning
  - image based applicator updates
- Dosimetric feedback
- Update plan throughout procedure

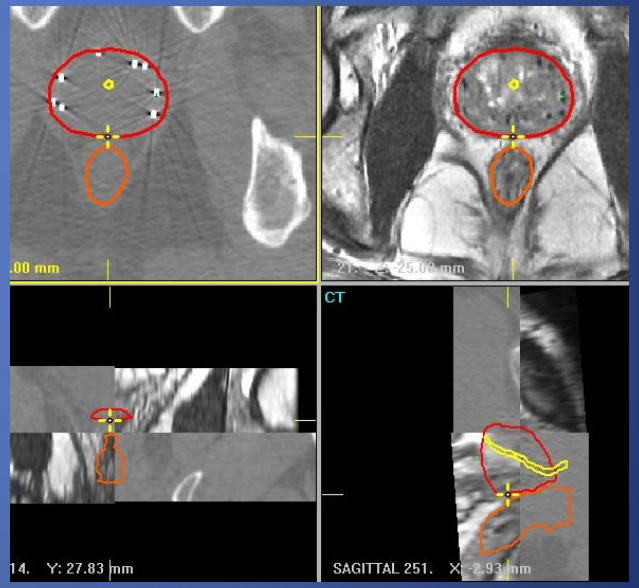
Why MR for Brachytherapy?

- Pelvis
  - CT anatomy
  - MR anatomy
- GEC-ESTRO guidelines for target definition



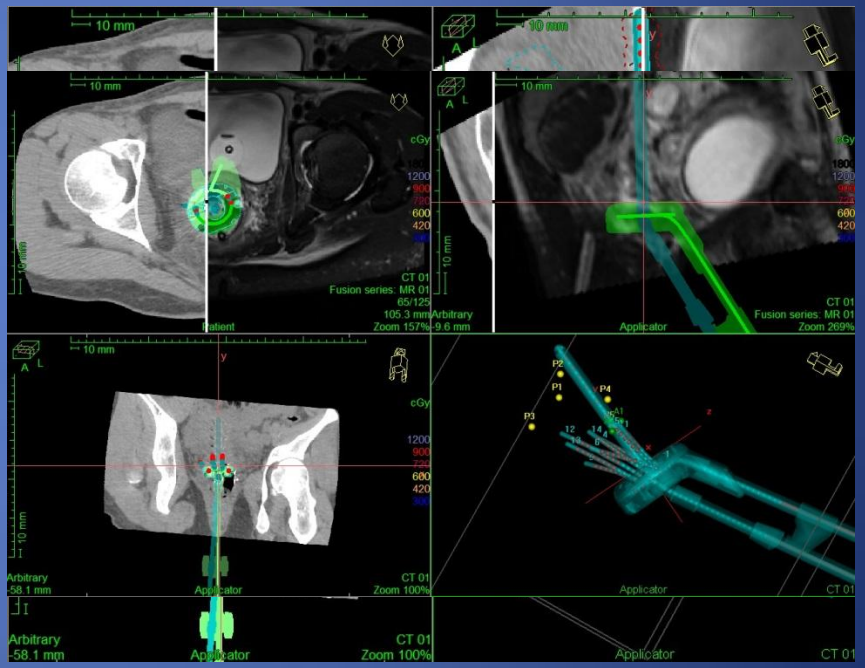
MR Dose Evaluation

- MR
  - T2 anatomy
  - T1 sources (ambituity)
- CT
  - Sources
- Sources provide registration landmarks
- Fusion allows dose evaluation to MR based anatomy



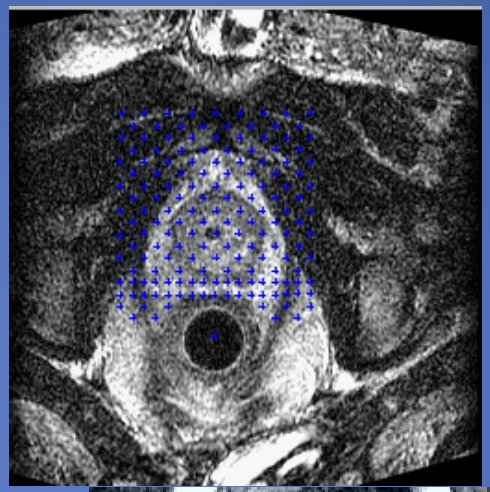
MR Based Brachytherapy

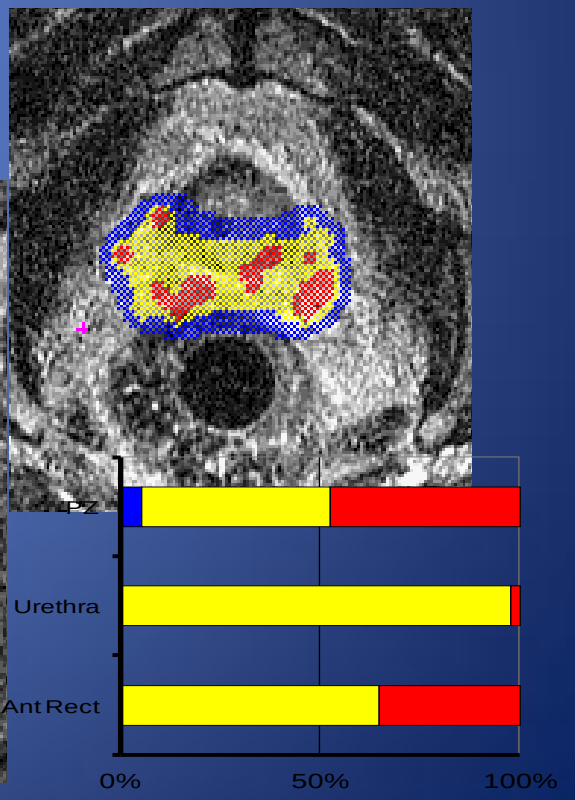
- Applicators
  - MR safe
  - MR compatible
- Applicator can facilitate registration
- Model based applicator digitization helpful
- Needles identification challenging



MR Adaptive Prostate Brachytherapy

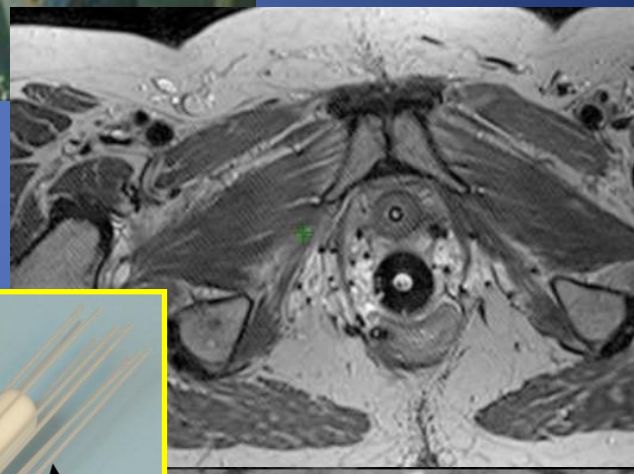
- TPS
  - Incorporate needle information
  - Efficient feedback
  - Passive needle identification (few needles at a time)
- Technology
  - MR compatible needle
  - Template registration
  - Survey meter
  - Pulse sequences
    - T2 anatomy
    - T1 devices
- Passive tracking

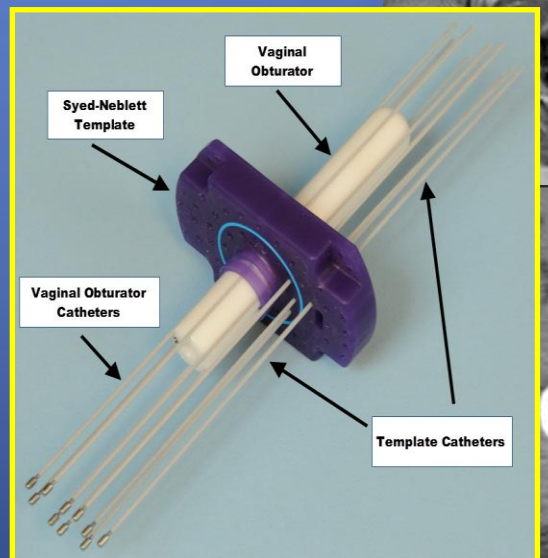


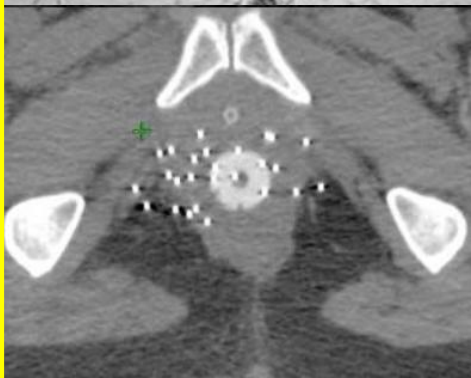


GYN Interstitial HDR Brachytherapy (Passive Tracking)

- Trajectory planning
- Needle placement
  - scanner control
  - tracking out of plane
- Needle digitization
  - time consuming
  - subject to ambiguities
  - rely on post-implant CT







Device Tracking in MR

Passive Tracking

Device is visualized within images

3D: Slow

2D: Only in-plane part of device visible

MR Sequences optimized for device

Active Tracking

Device emits or receives a tracking signal

3D, Fast, High res

Unambiguous tracking

- ❑ Special device
- ❑ Integration with imaging system

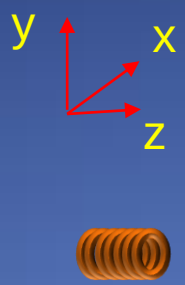
- Magnetic field tracking
- MR Tracking

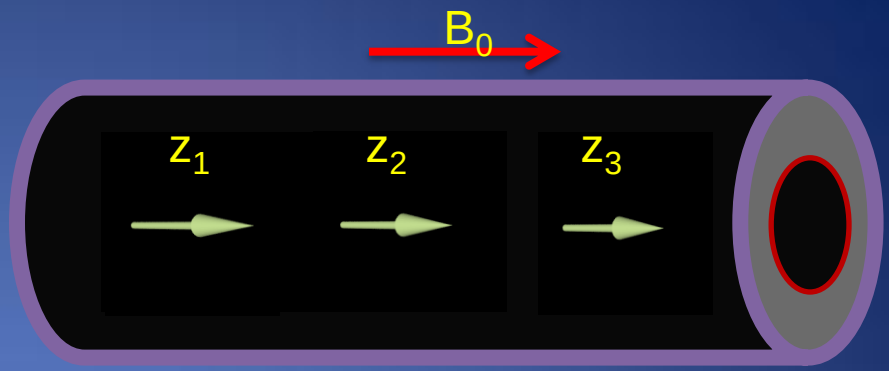
MR Tracking

Simple MR Tracking Sequence

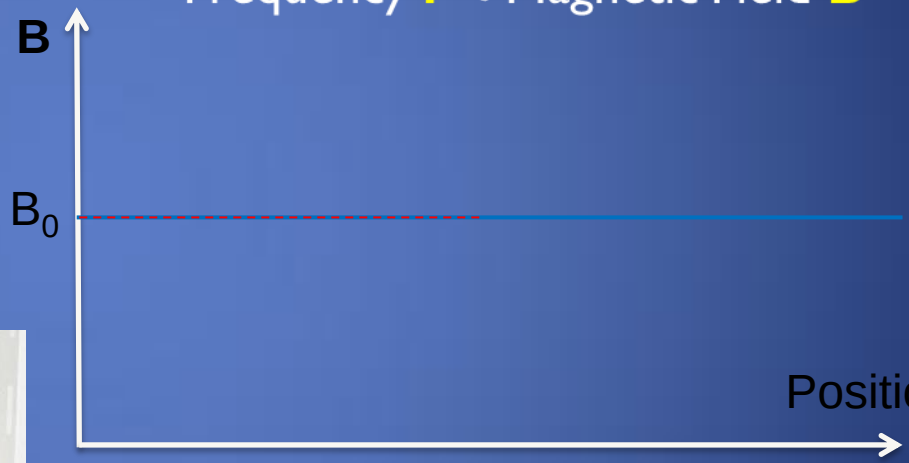
RF pulse

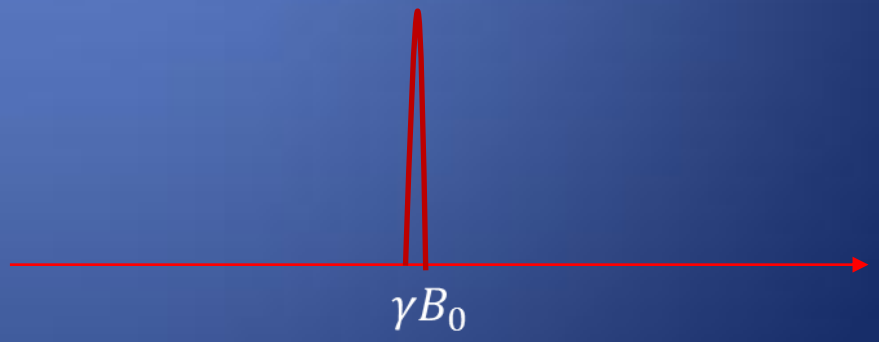
Acquisition



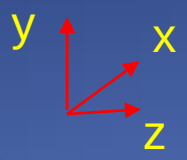


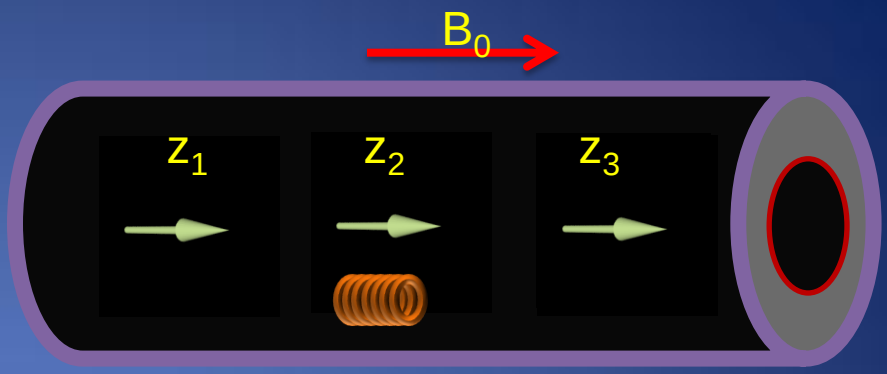
Frequency **f** ∝ Magnetic Field **B**



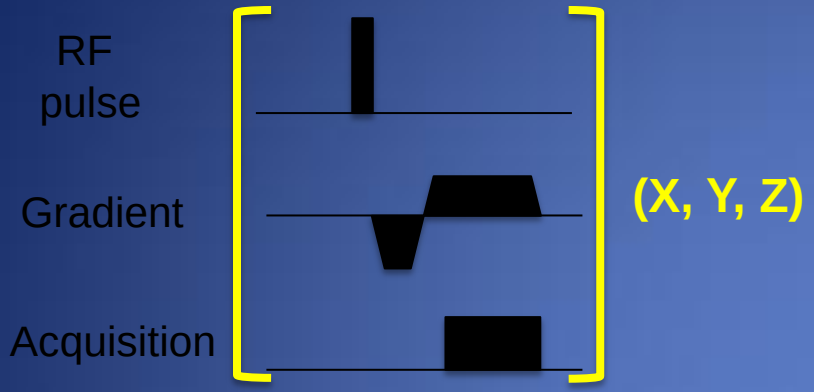


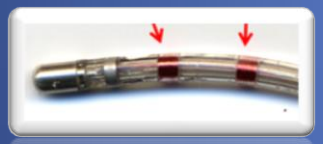
MR Tracking





Simple MR Tracking Sequence



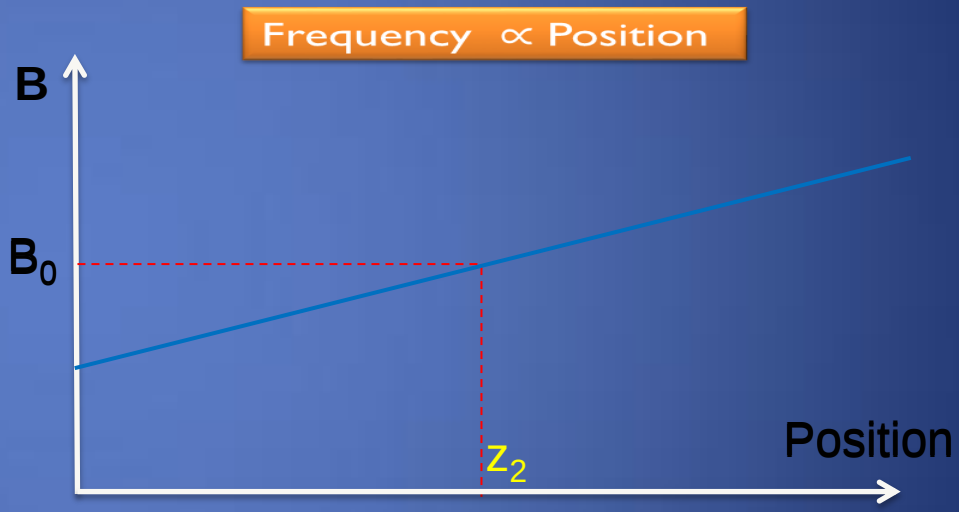


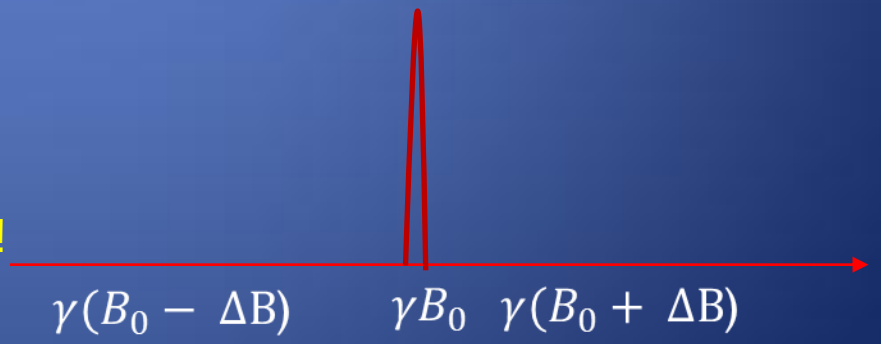
Microcoil

Limited Sensitivity Profile

$$\Delta z = \frac{\Delta f}{\gamma G_z}$$

Same coordinate system as MR images!





SAMS Question

Active tracking with micro-coils measures position by:

8%

A. Sampling the spatially uniform magnetic field to determine spatial location

7%

B. An RFID chip embedded on a non-magnetic stylet

78%

C. Sampling spatially varying magnetic fields (gradients) superimposed on the static field to determine location

2%

D. An active radiologist to measure location of MR artifacts on ultrafast 3D volume scans

5%

E. Change in T2 weighted time constant resulting from the presence of 0.1 g of ferromagnetic material embedded in the coil.

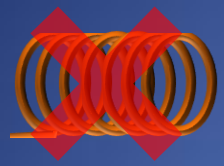
Active tracking with micro-coils measures position by:

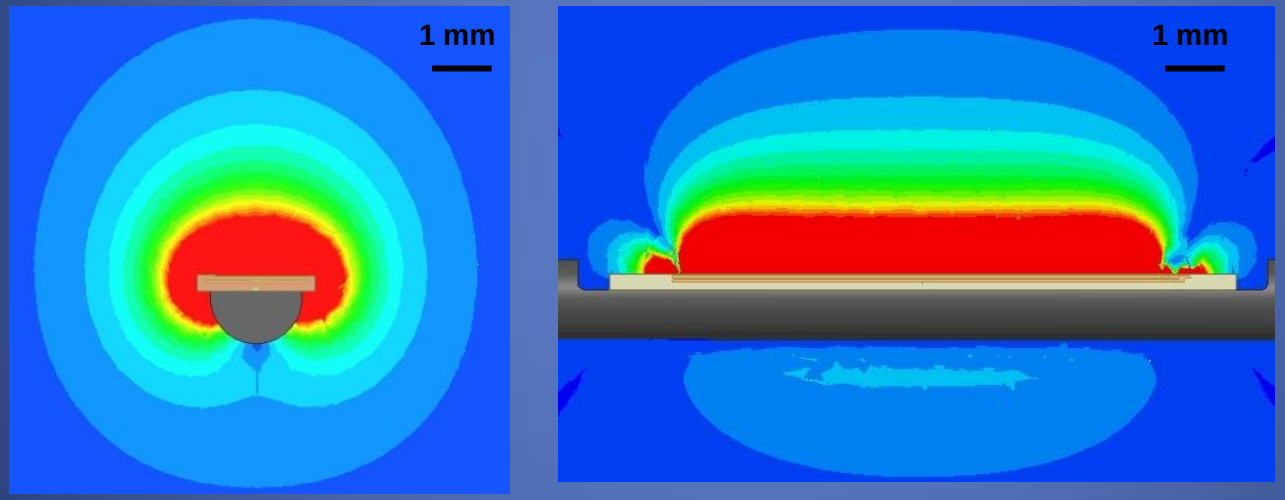
C: Sampling spatially varying magnetic fields (gradients) superimposed on the static field to determine location.

Reference: 3 Dumoulin et al. Magn Reson Med 1993; 29:411-15, Slides 17-19

Active Tracking on Metal I -- Coil Design

EM simulation of different coil geometries on metallic surface

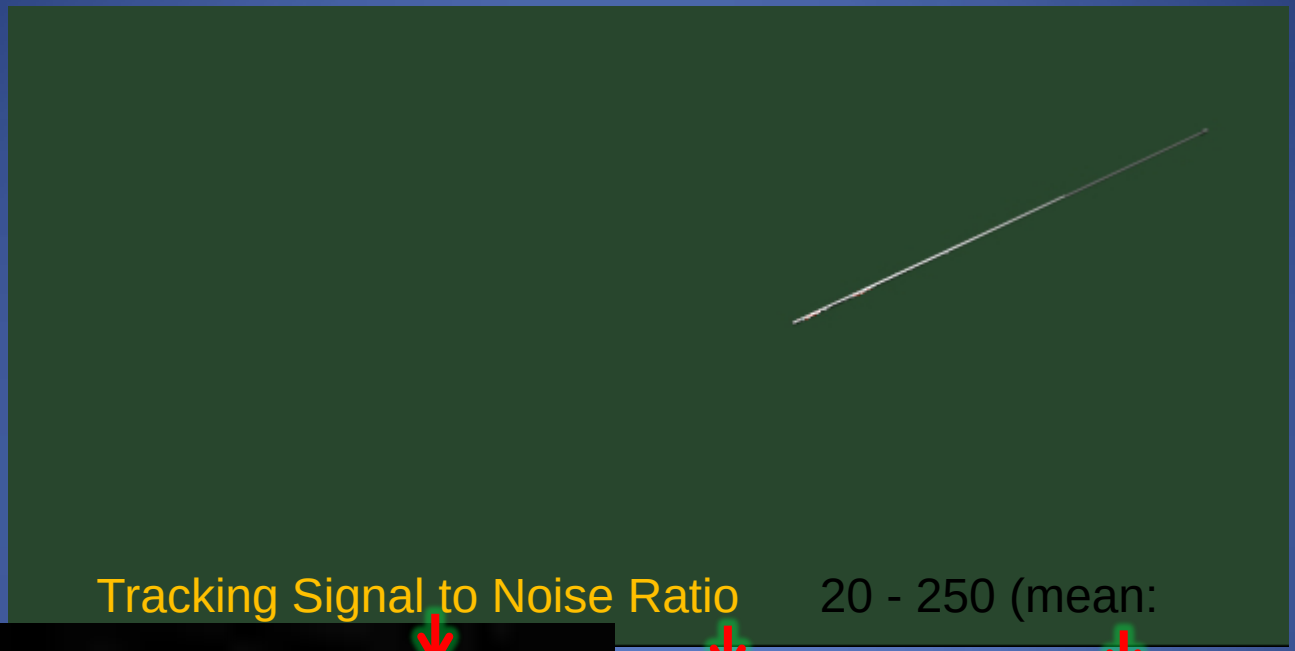




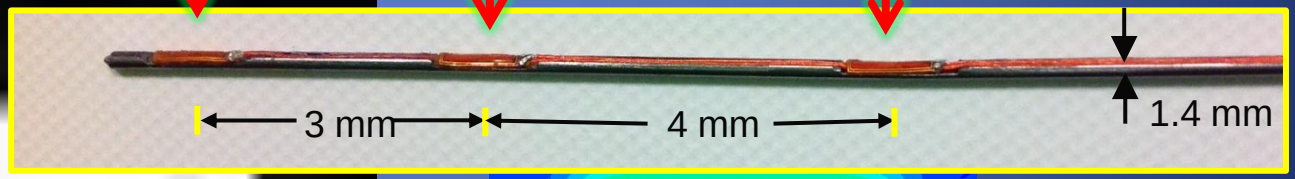
Electromagnetic simulation of B_1^- field

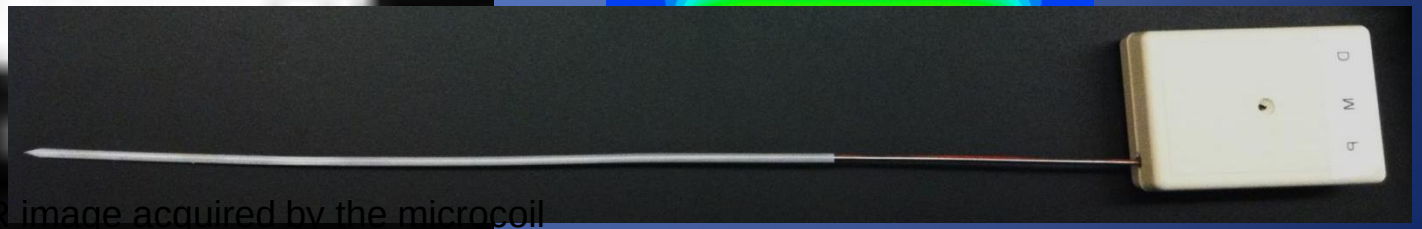
Active Tracking on Metal II -- Construction of active device

multi-layered printed circuit coil



Tracking Signal to Noise Ratio 20 - 250 (mean: 160)





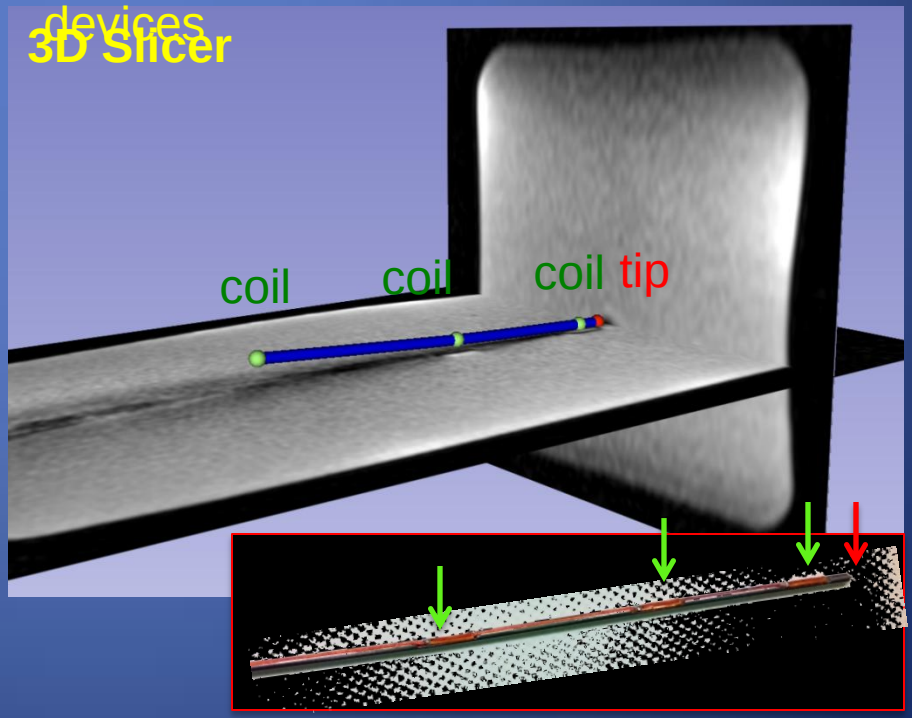
Sagittal MR image acquired by the microcoil

Active MR Tracking on Metal

- High Spatial Resolution 0.6 × 0.6 × 0.6 mm^3 Accuracy ~ 0.5 mm (static)
- High Temporal Resolution 40 updates/sec (N = 1)
- Heating < 0.6 °C increase for a 15-min scan (3.3 W/kg)

- Visualization Interface
  - Real-time needle display
  - Overlaid on 3D image

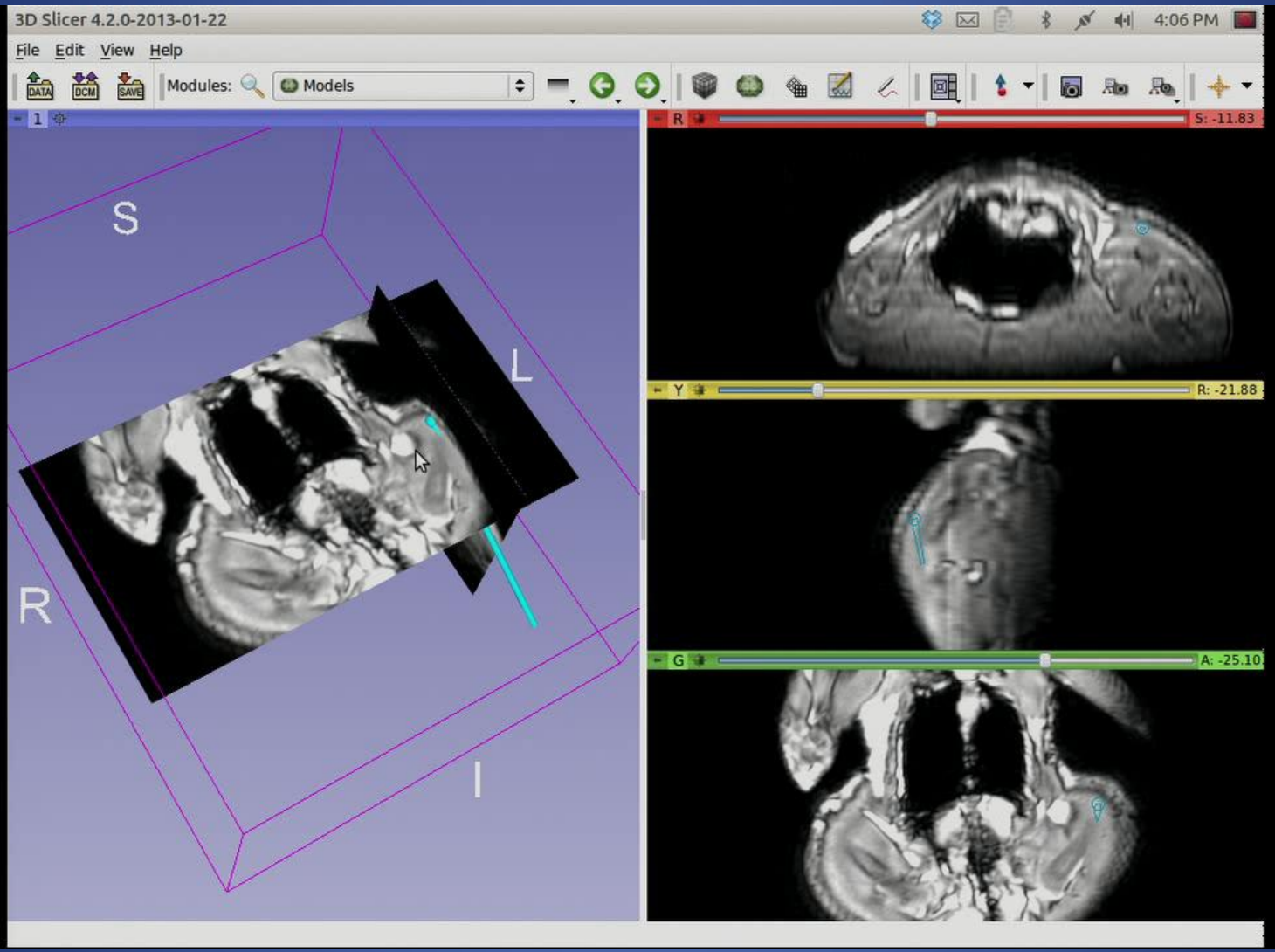
Active track the shaft of metallic devices



Applications of Active Tracking

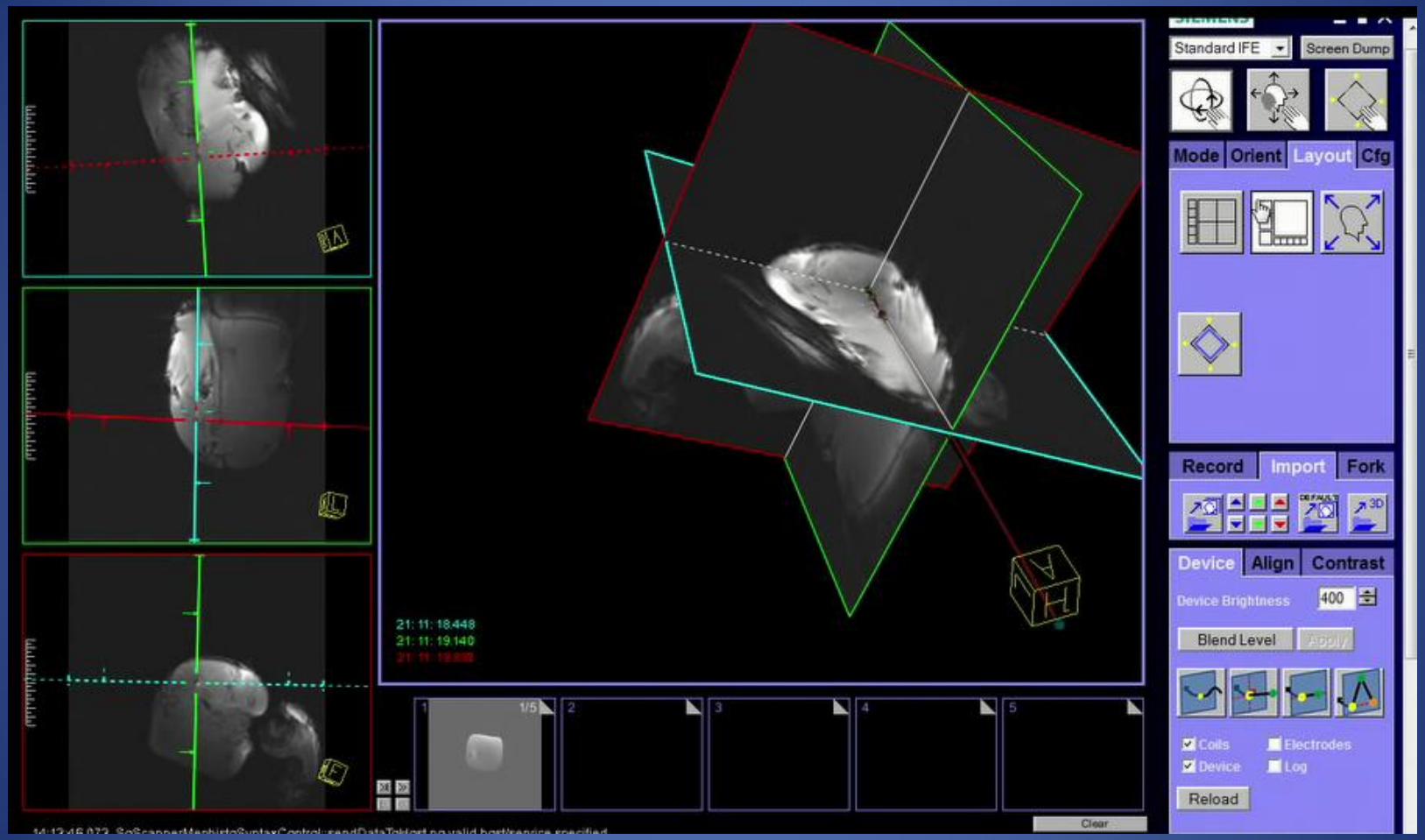
- Trajectory planning: projecting needle path through imaging volume based on tracked position and orientation
- Needle placement: Identifying needle of interest, controlling scanner to image at needle tip
- Adaptive planning: reconstruct catheters in seconds, adjust treatment plan

Projected trajectories in imaging volume:animal model



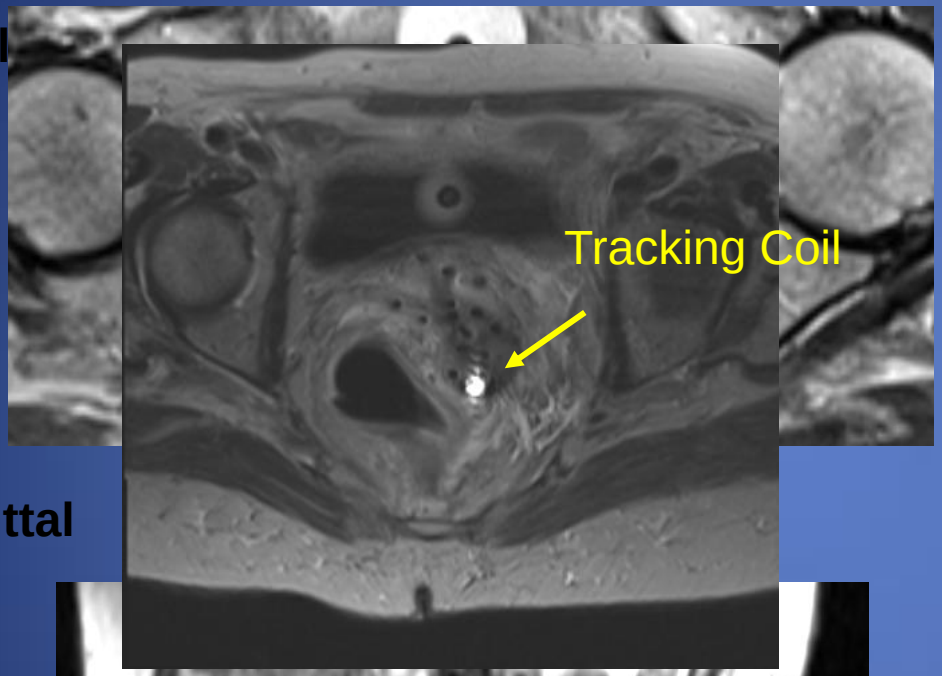
Real-time Imaging with Tracking for Needle Placement

Real-time Imaging with Tracking for Needle Placement



Catheter Visualization and Scanner Control Human Study

Axial



Sagittal

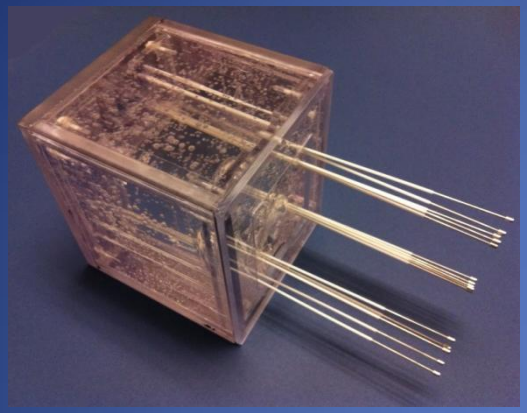
Axial MR Image (Body Array + Tracking Coil)

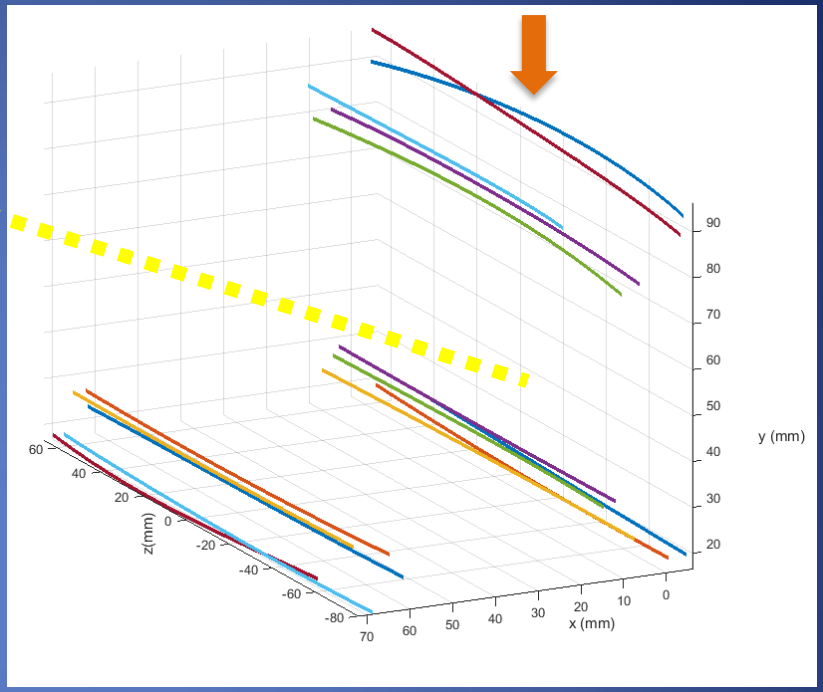
Tracking SNR:
18 – 130 (mean 100)

Needle placement in a 84 y/o woman with recurrent uterine adenocarcinoma

Catheter Trajectory Reconstruction by MR Tracking

Phantom Study



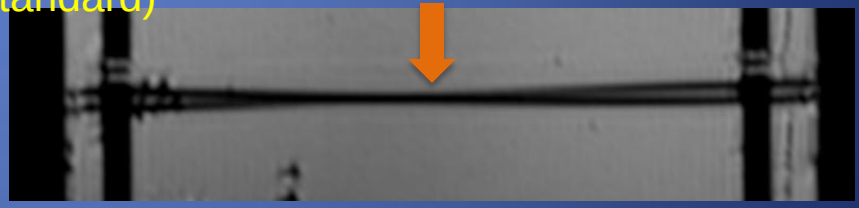


Fifteen needles: 9 parallel + 3 pairs crossed
Through two templates with 5 mm grid of holes

A. MR-image based needle digitization (clinical standard)

B. Active Tracking during stylet pull-out

3D distance: 1.1 ± 0.9 mm

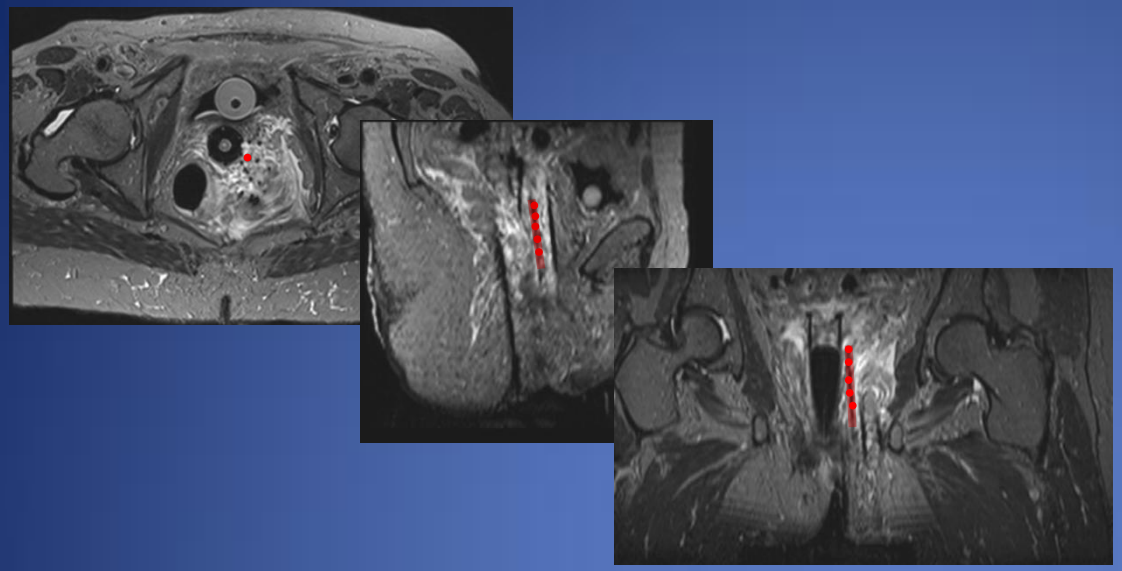


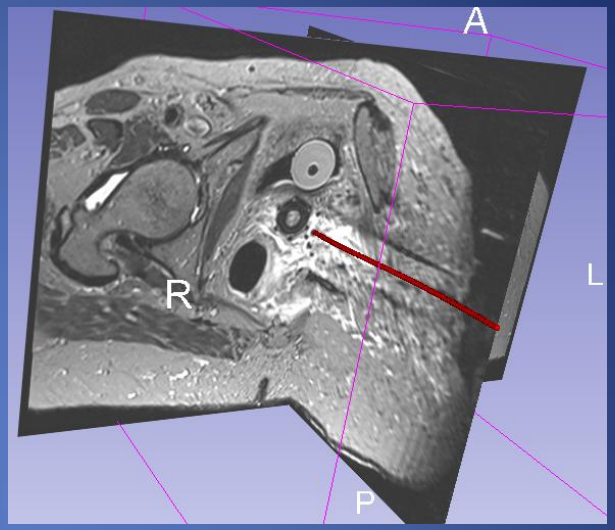
3D MP-RAGE, resolution: 0.5 × 0.5 × 1 mm^3

Two bent needles

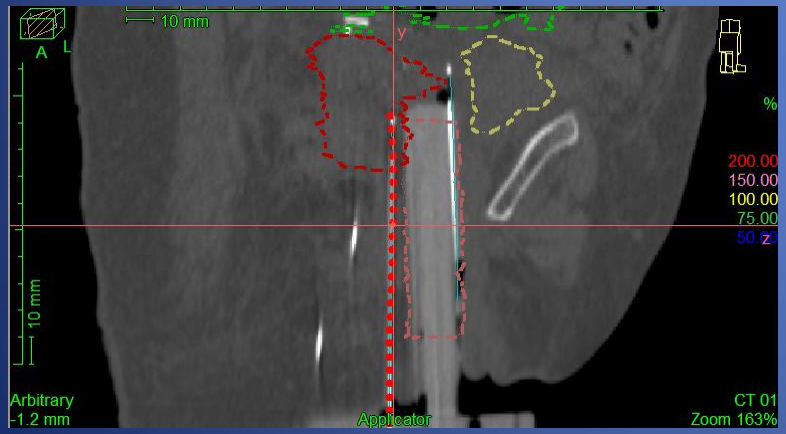
Two crossed needles

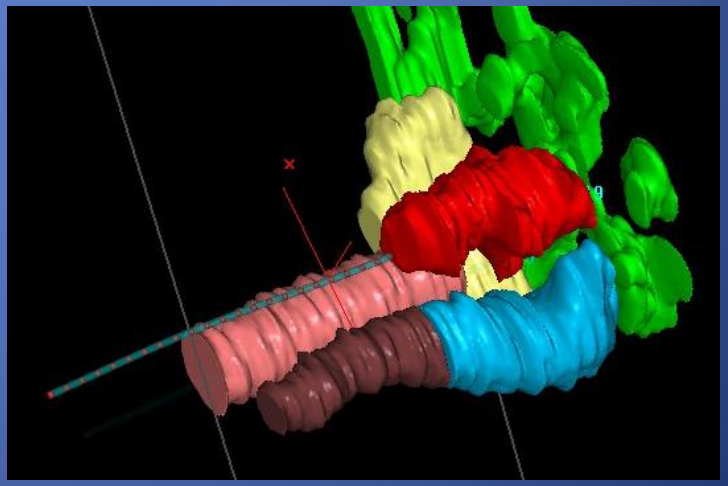
Catheter Trajectory Reconstruction by MR Tracking





Compared to CT

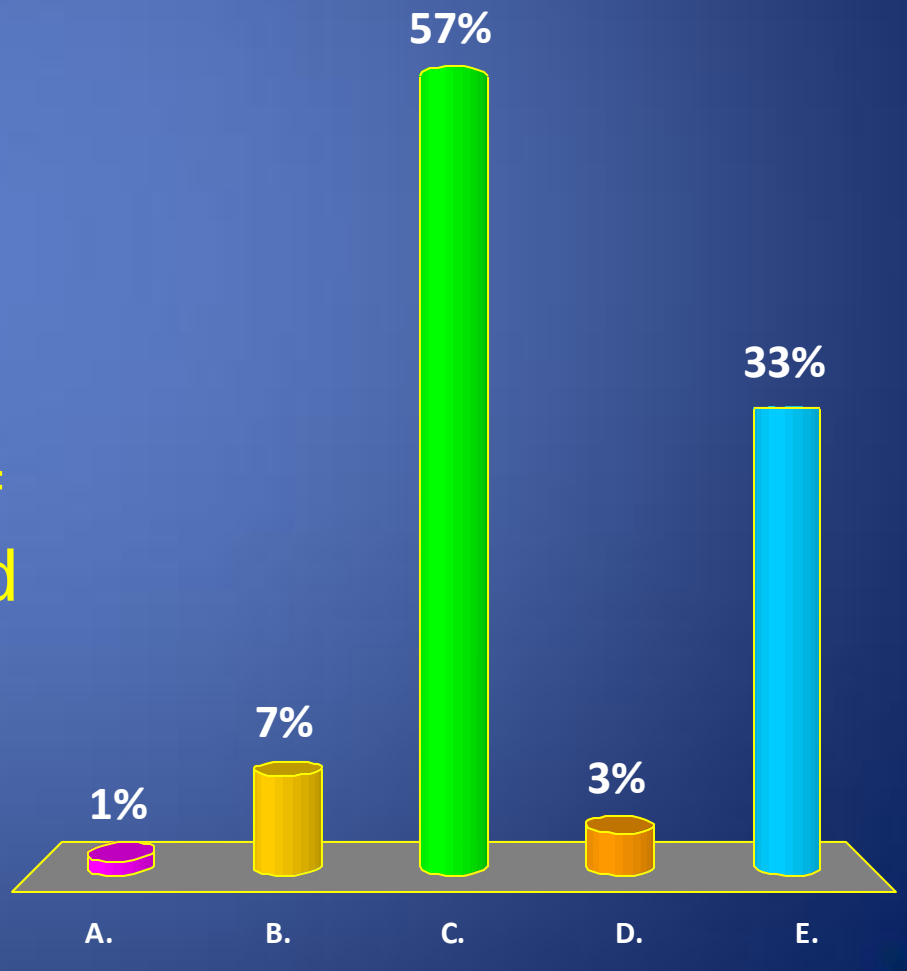




SAMS Question

Active tracking can facilitate MR guided brachytherapy implants by providing the following functions except:

A. Control of MR scan plane
B. Efficient measurement of catheter location
C. Absolute measurement of tissue oxygenation
D. Projection/extrapolation of catheter trajectories based into MR volume
E. Both A and D



Active tracking can facilitate MR guided brachytherapy implants by providing the following functions except:

C: Absolute measurement of tissue oxygenation

Brachytherapy does not require information about oxygenation, while all other functions are mentioned in slides 25-31

Conclusions

- MR imaging is the modality of choice for pelvic imaging
- MR compatible applicators devices are readily available
- MR imaging can be incorporated in brachytherapy over a wide range of complexity and resource demands
- Many on-going efforts to facilitate MR brachytherapy
  - Transfer tables
  - Robotics
  - Tracking devices
  - Pulse sequences