Laboratory for Percutaneous Surgery

Prostate Brachytherapy

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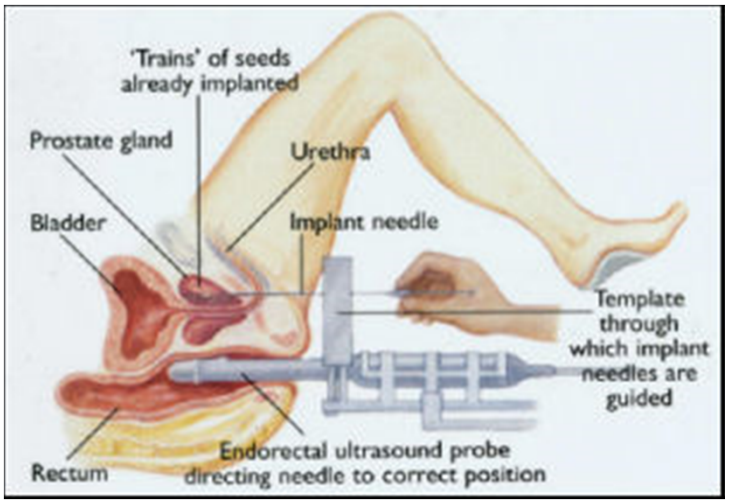
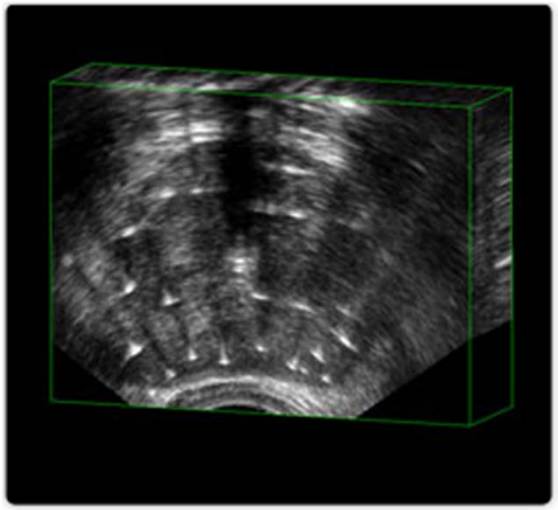
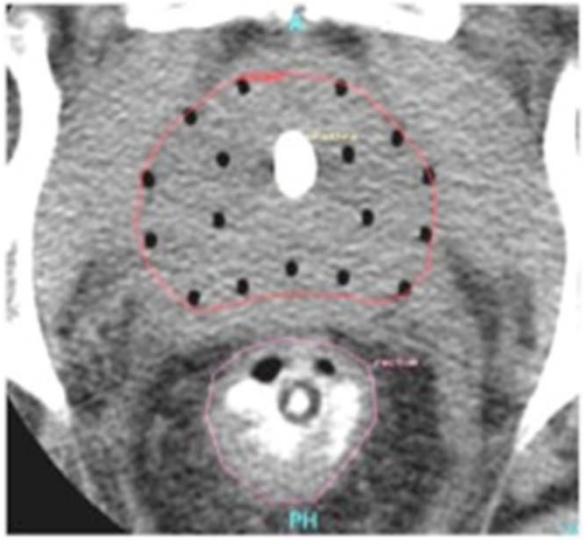
Queen's University

HDR brachytherapy – TRUS imaging

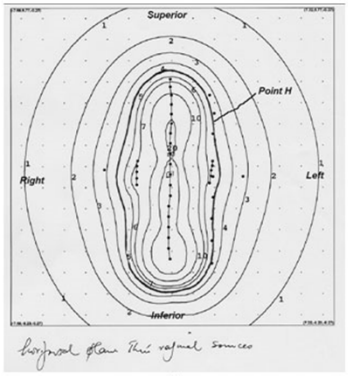




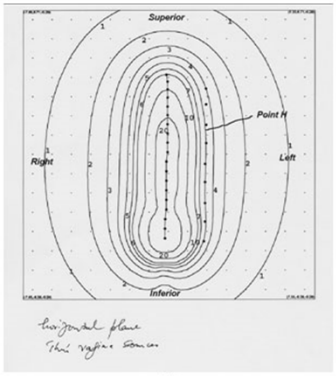
HDR – CT/X-ray imaging



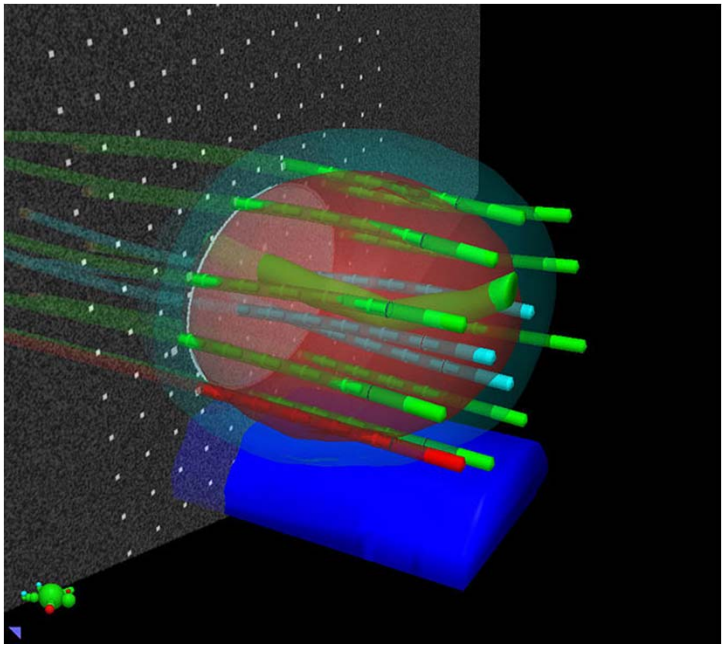
HDR – Dose planning

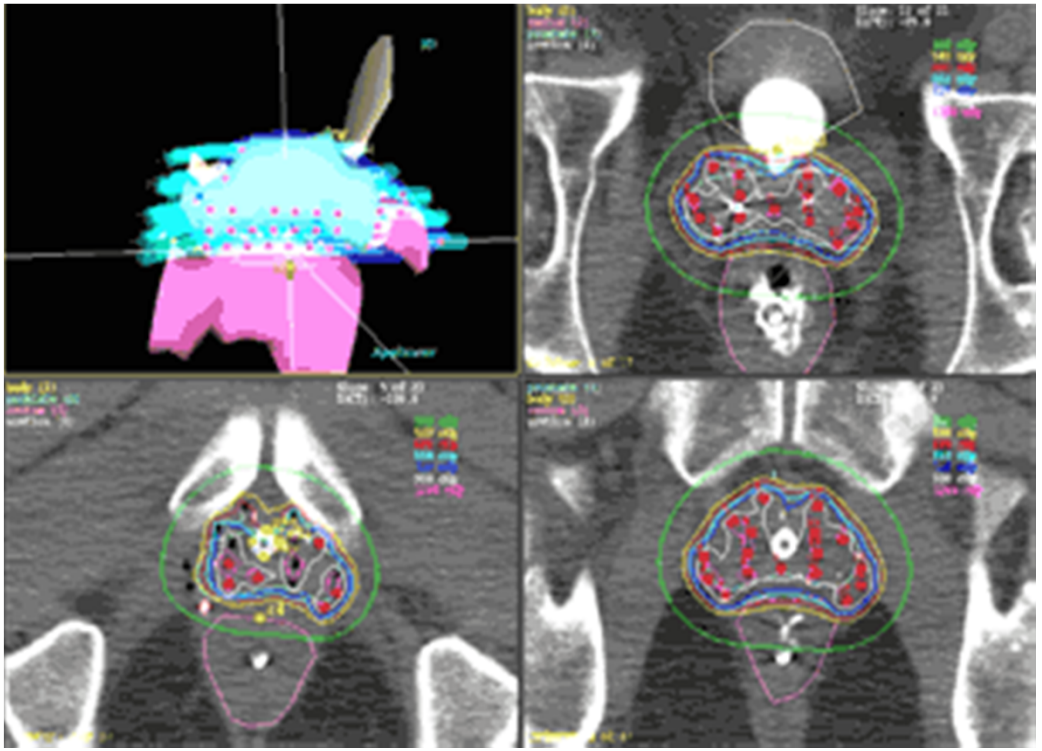


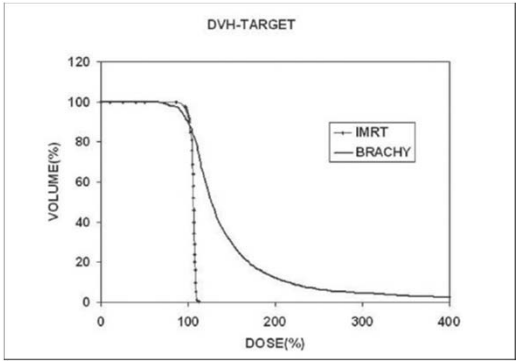
(a)



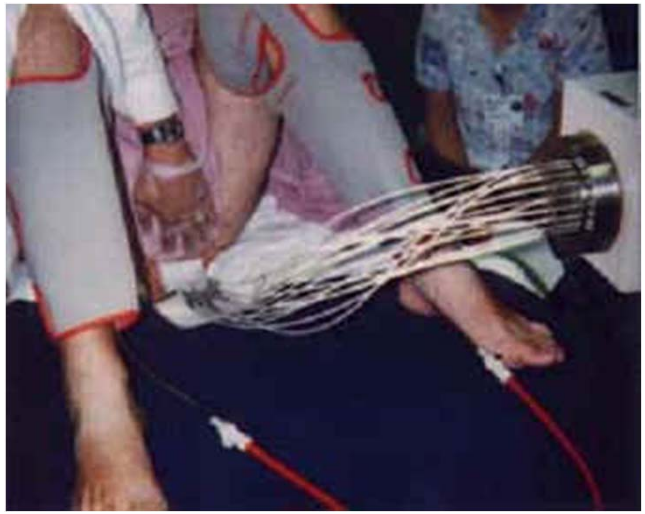
(b)



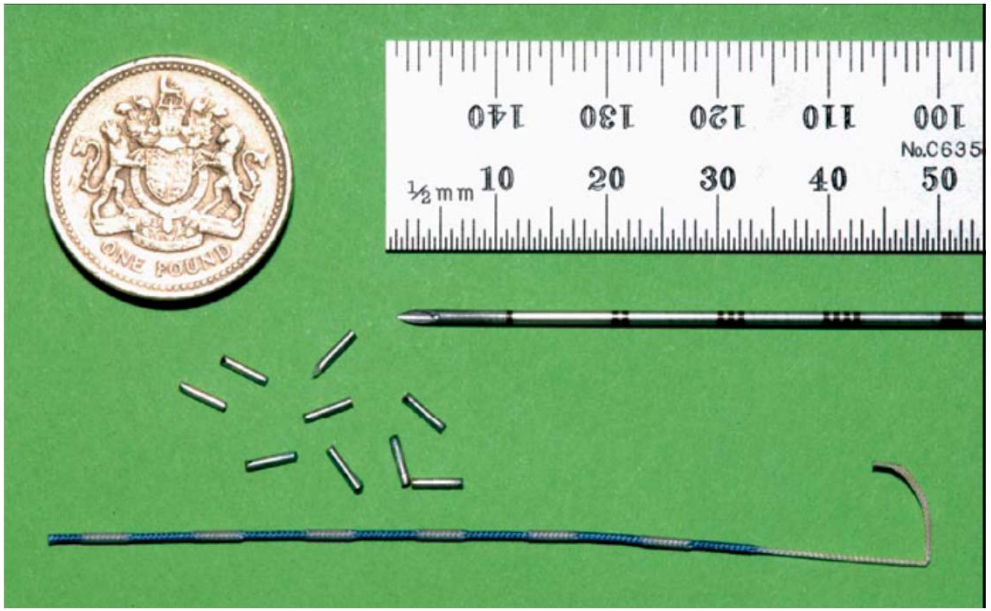




HDR – dose delivery



Low dose rate (LDR) brachytherapy



The seeds are tiny canisters of Titanium (4.5mm long by 0.8mm diameter) which contain the radioactive isotope Iodine-125 (T2=60 days) or Palladium-103 (T2=17 days.)

Typical cased source

- **I-125 – 60d T2**
- **Pa-103 – 17d T2**

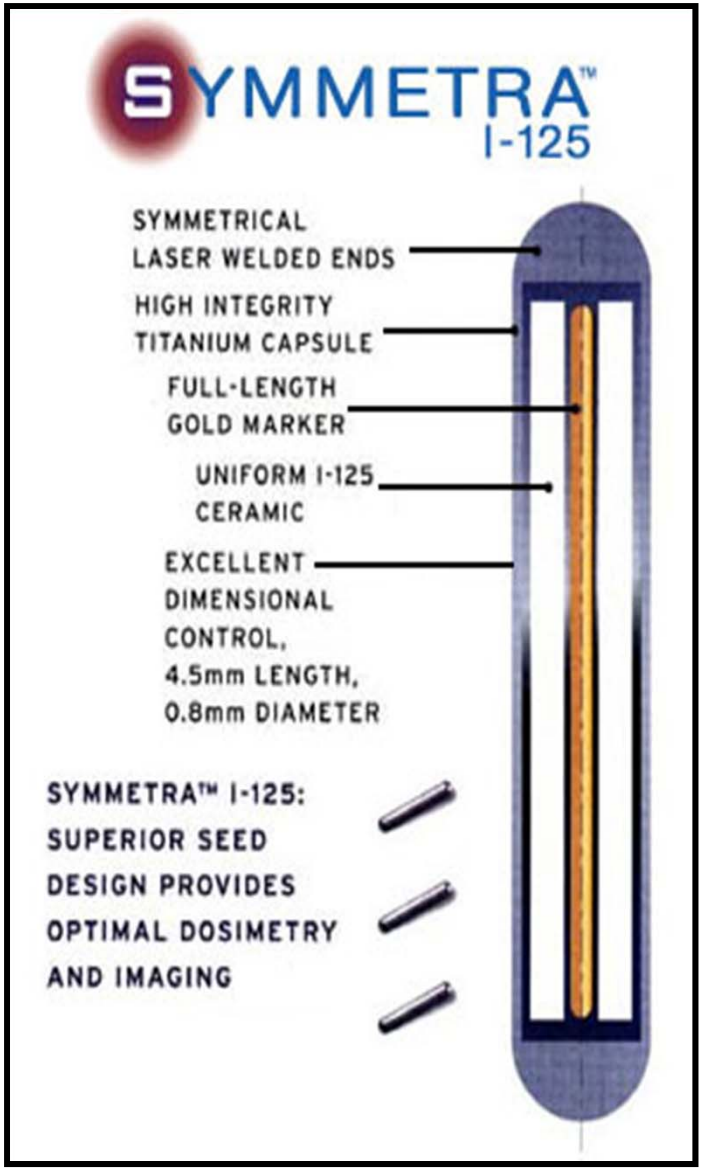
•IoGold™ I-125 brachytherapy sources

•welded titanium capsule

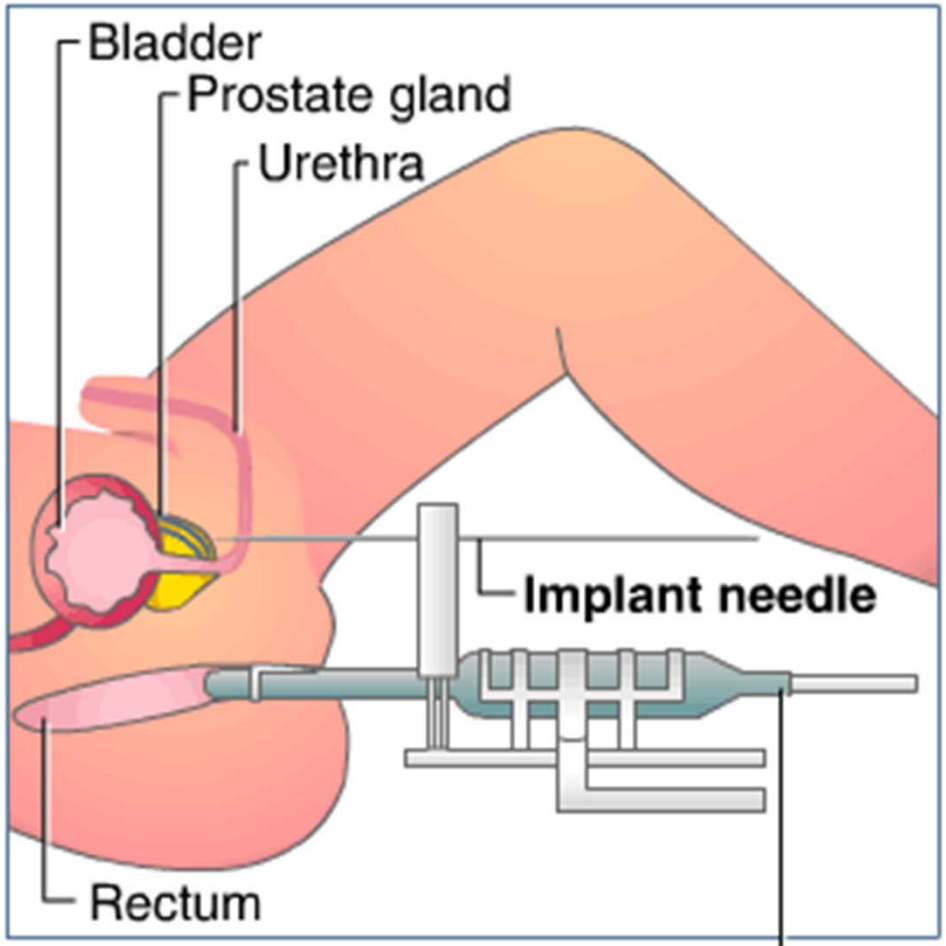
•I-125 absorbed onto four resin beads

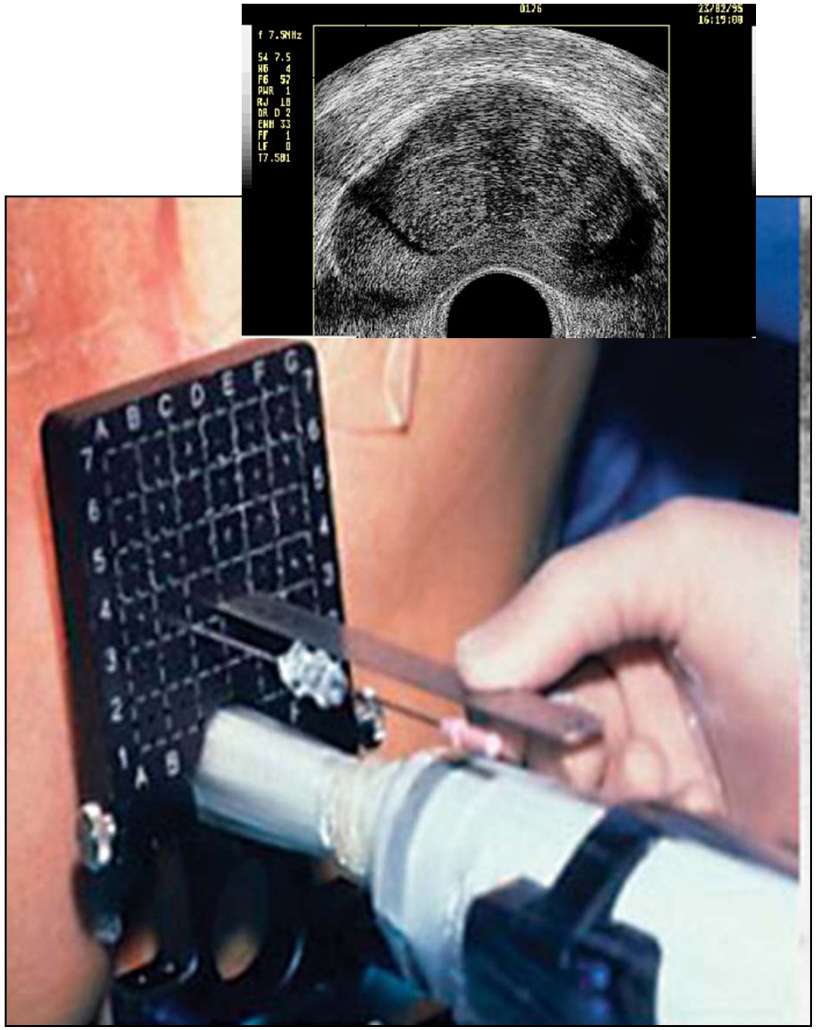
• two inactive gold beads serving as x-ray markers identifying source location and orientation.

•supplied non-sterile when shipped



Low dose rate brachytherapy



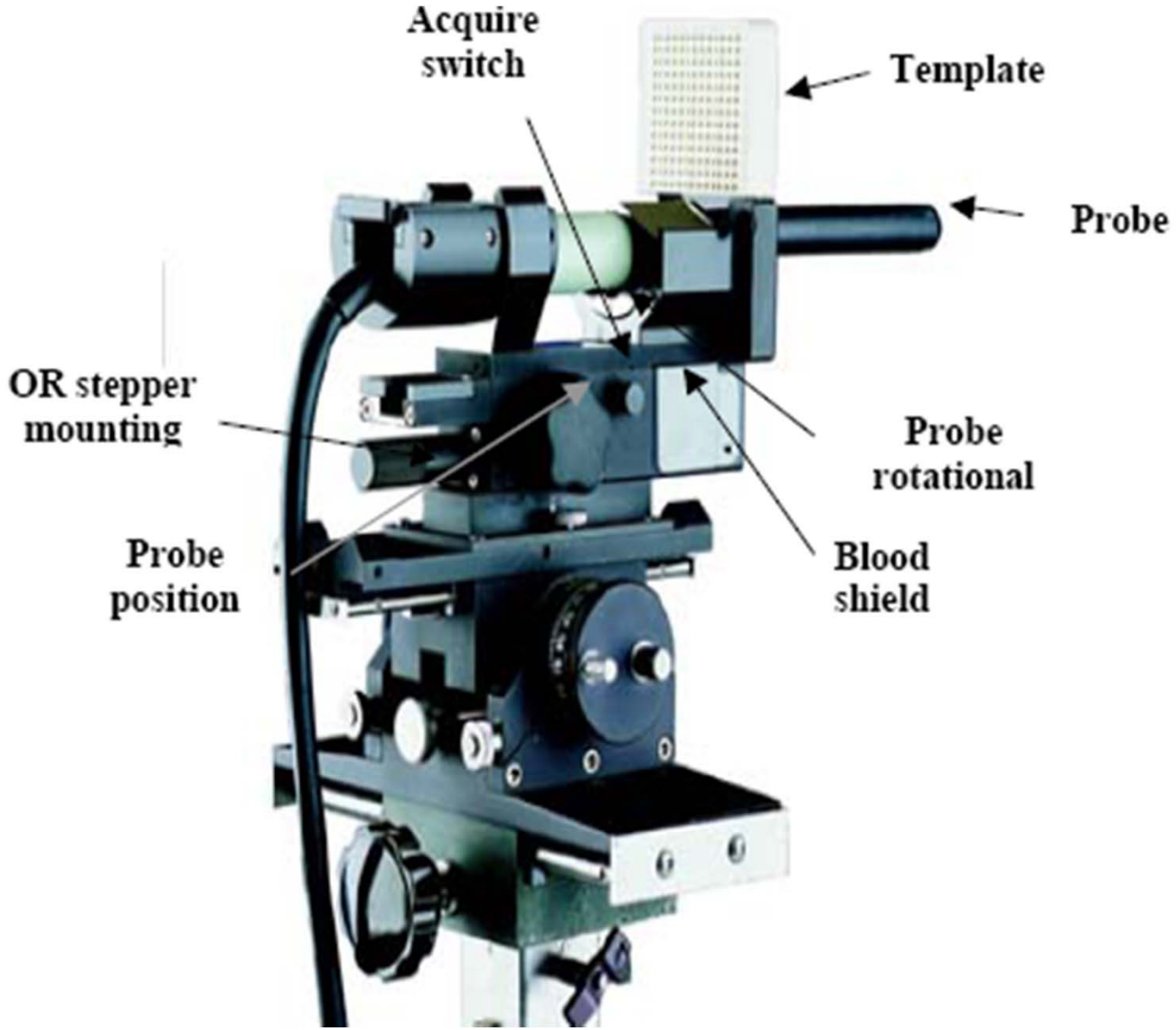


LDR brachytherapy workflow

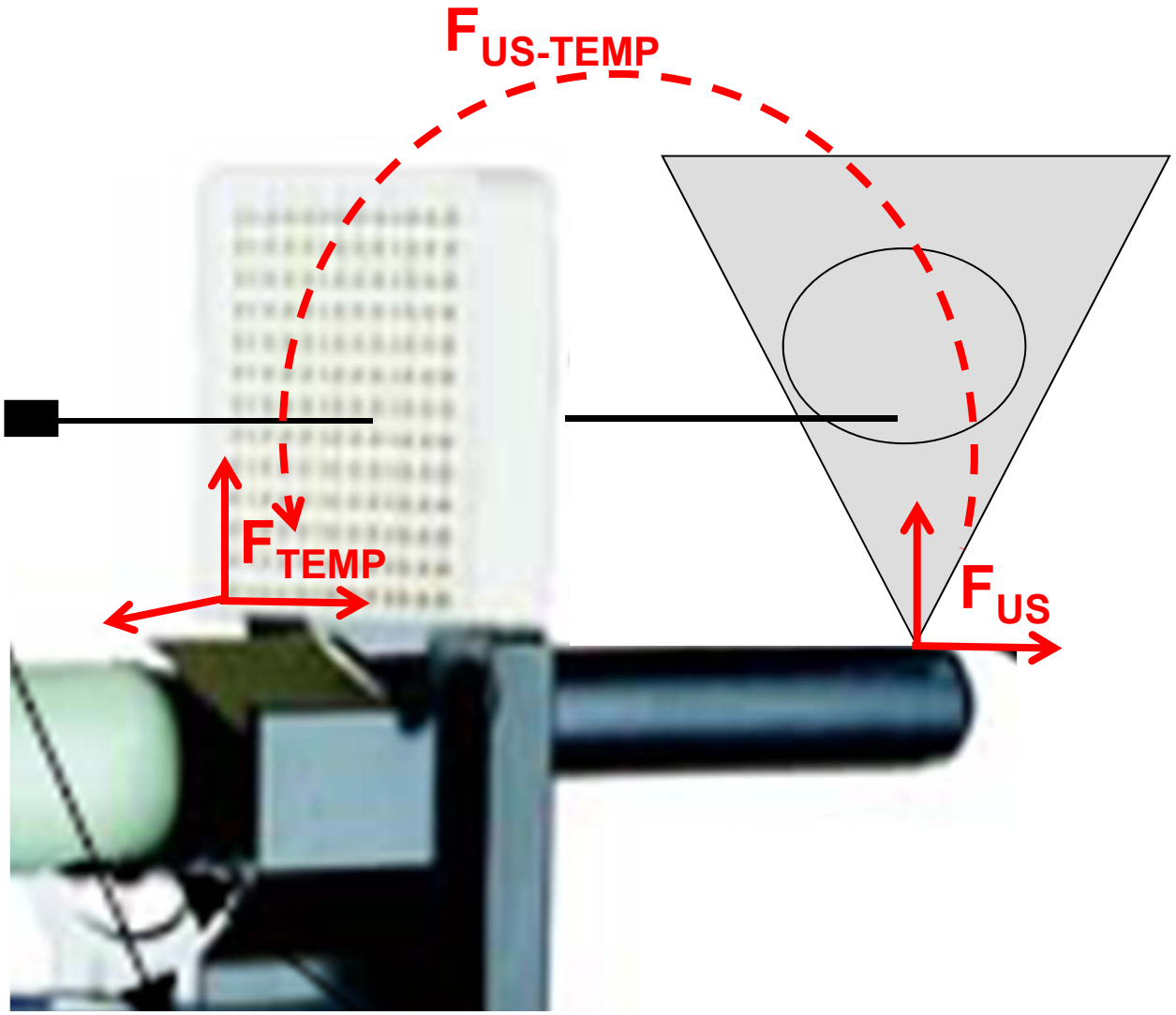
- System Calibration
- Planning*
  - Volume study for seed ordering
  - Implant planning
- Implantation
- Post-OP dose assessment

* w/ computerized Treatment Planning System or TPS)

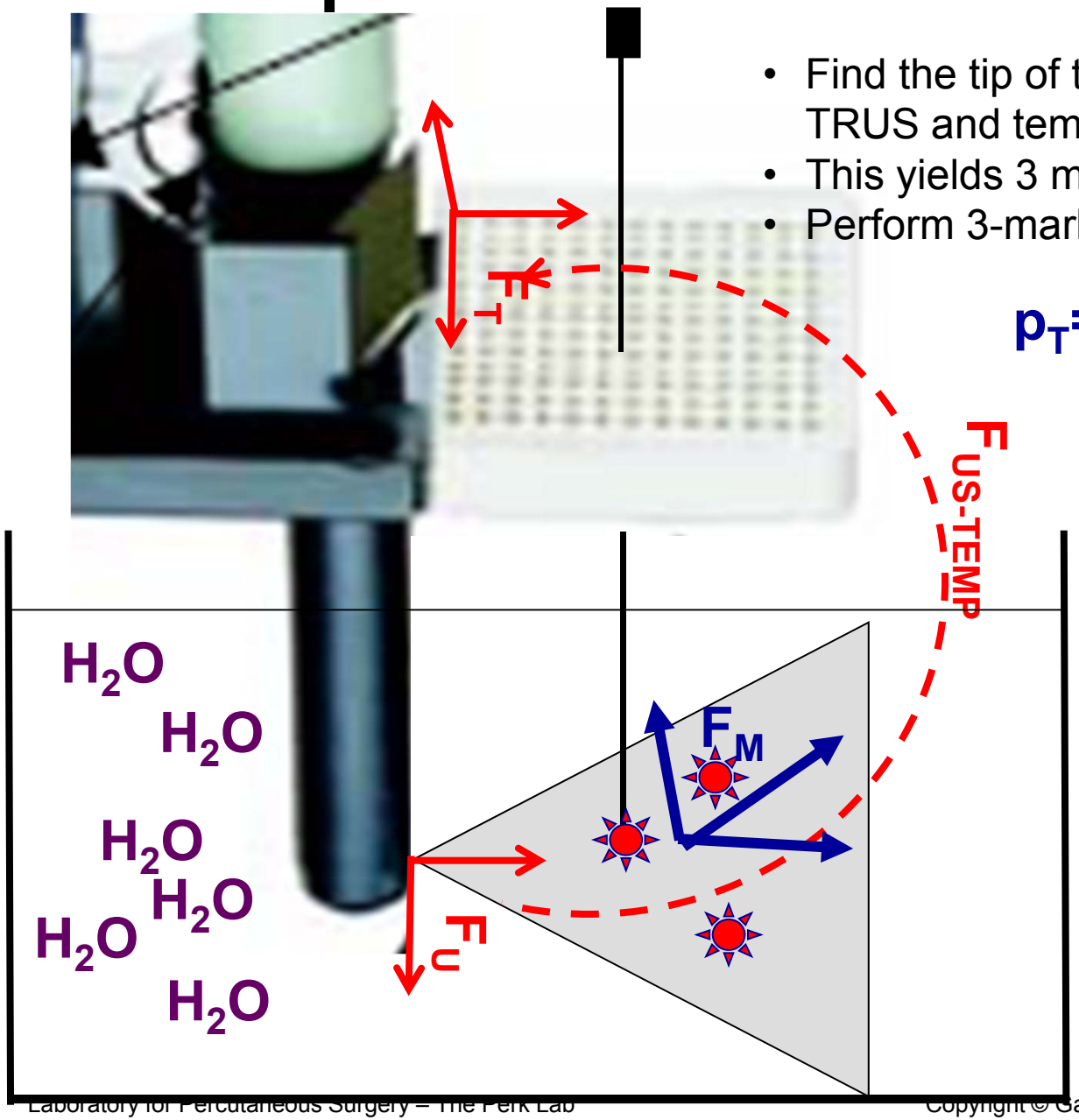
The delivery hardware



Template – TRUS calibration



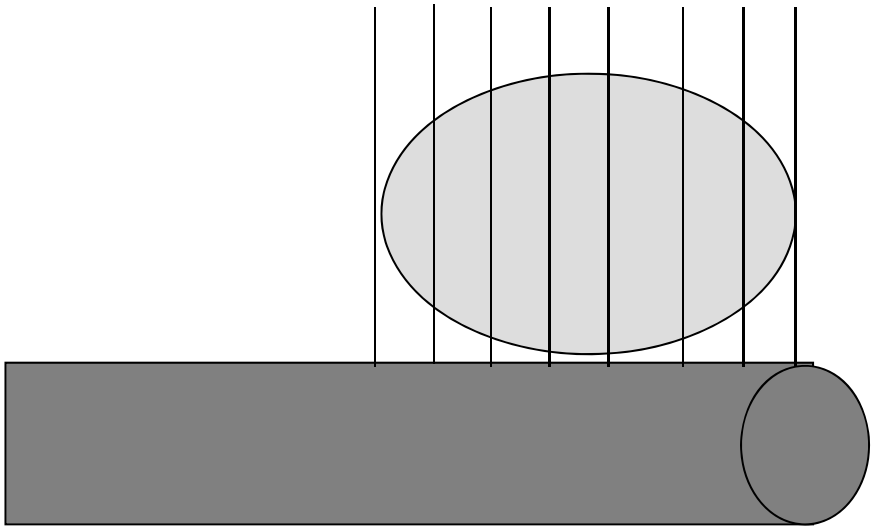
Template –TRUS calibration

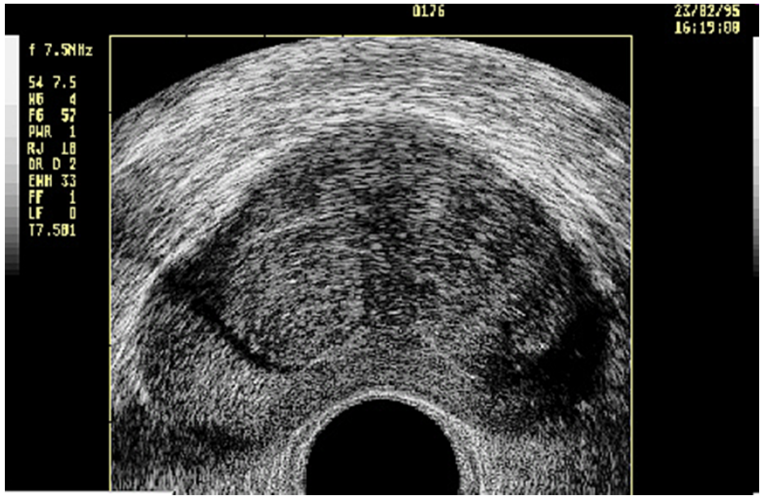


- Find the tip of three needles in both TRUS and template frames
- This yields 3 markers…
- Perform 3-marker registration

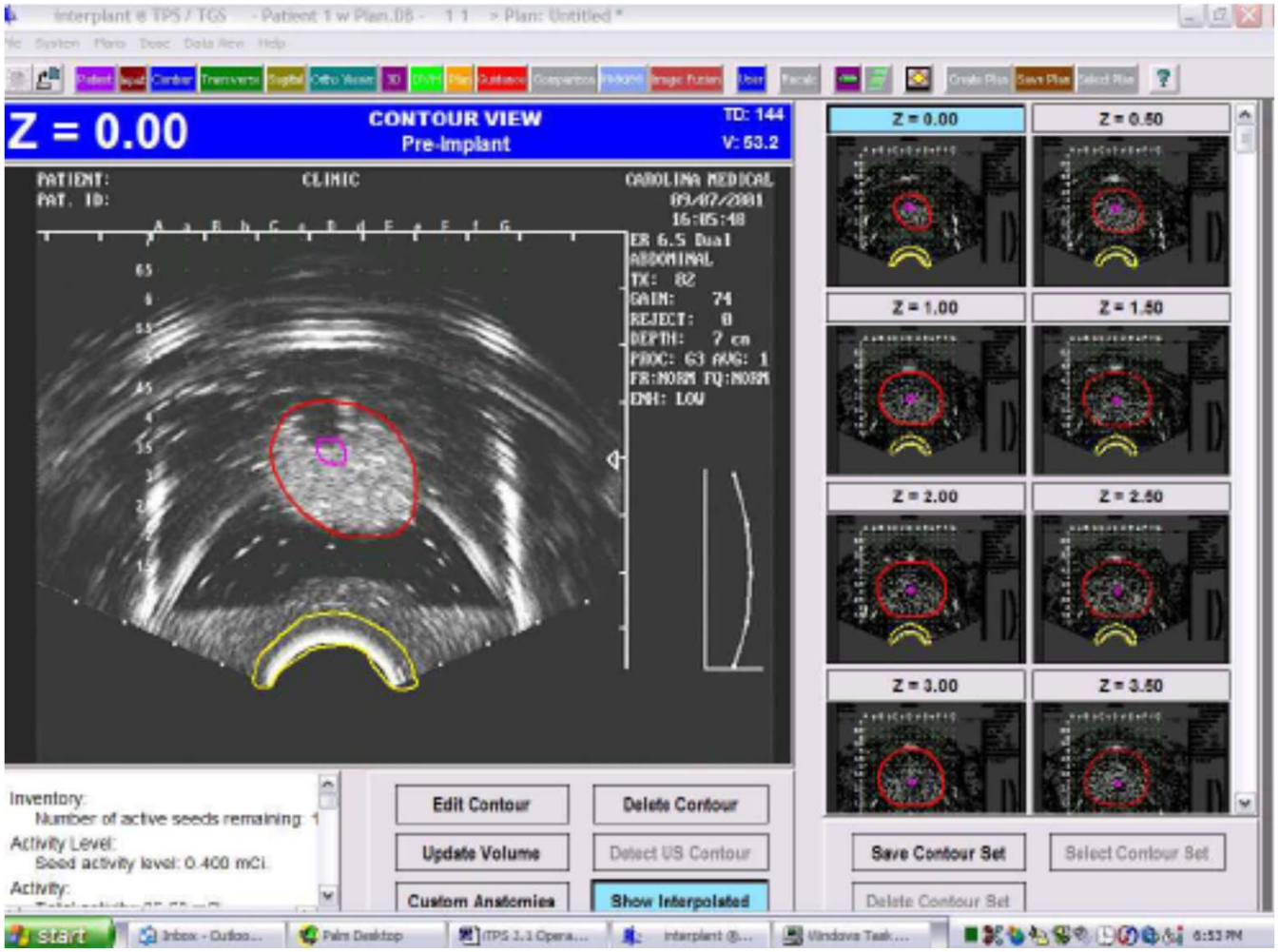
$$p_T = (F_{TM} F_{UT})_U p$$

TRUS Imaging





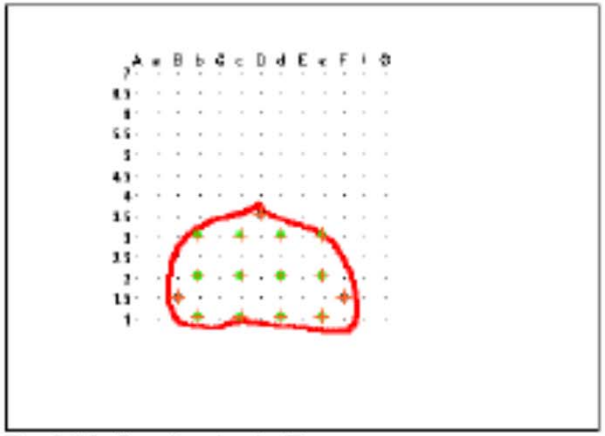
TPS – contouring



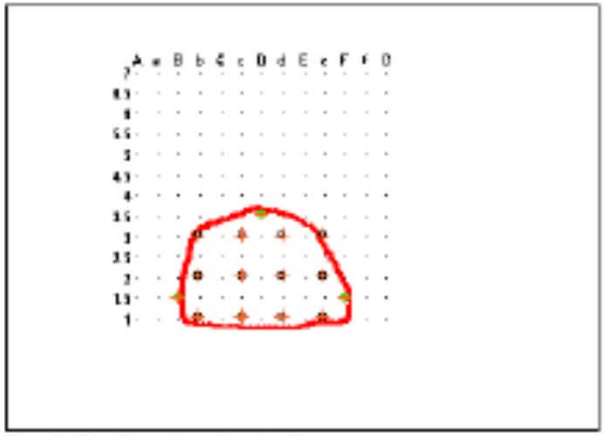
Seed loading pattern

4.6.3.1 Modified Uniform Example

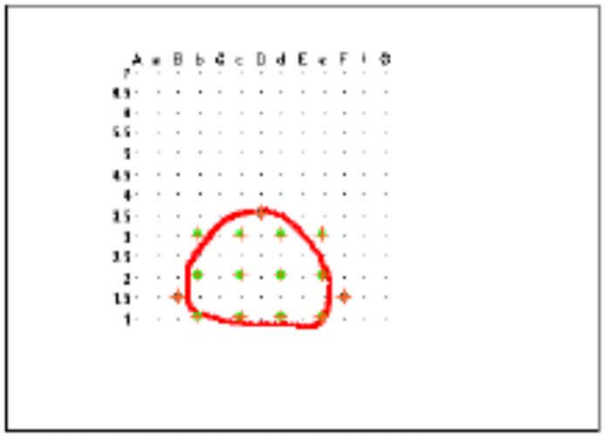
Transverse Images



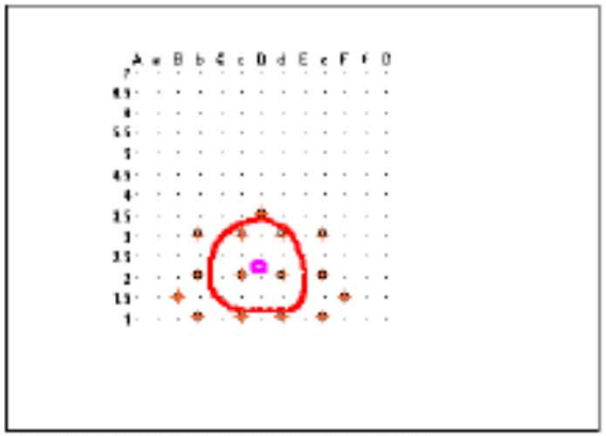
Z = 2.00 Pre-Implant : Transverse



Z = 2.50 Pre-Implant : Transverse



Z = 3.00 Pre-Implant : Transverse

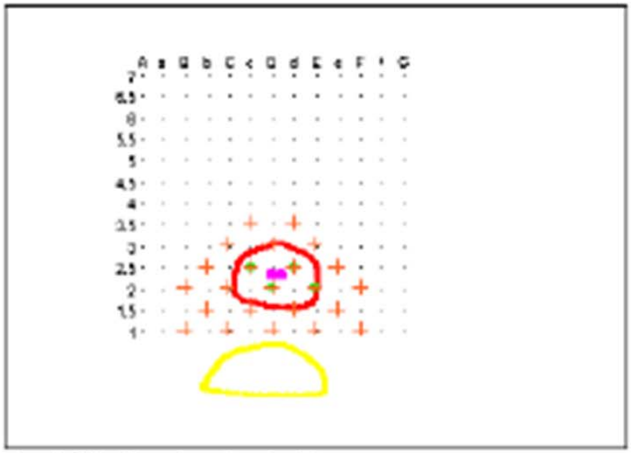


Z = 3.50 Pre-Implant : Transverse

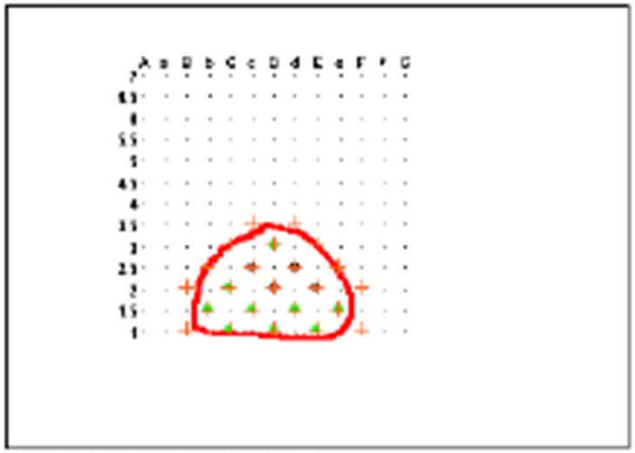
Seed loading pattern

4.6.3.2 2D Alternating Pattern Example

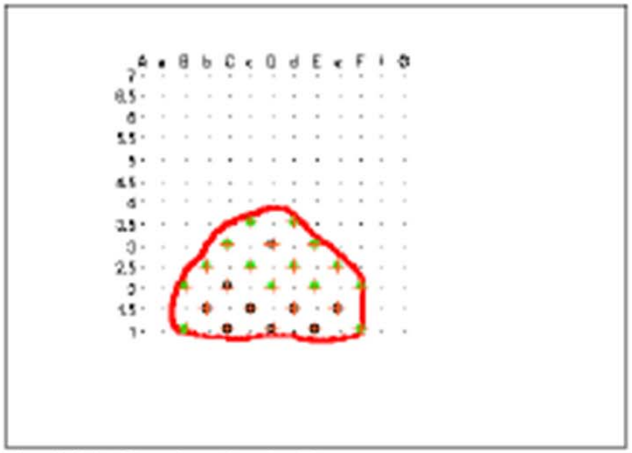
Transverse Images



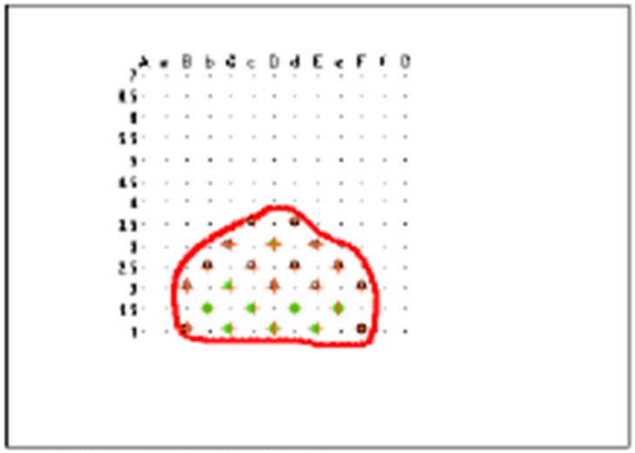
Z = 0.00 Pre-Implant : Transverse



Z = 0.50 Pre-Implant : Transverse



Z = 1.00 Pre-Implant : Transverse

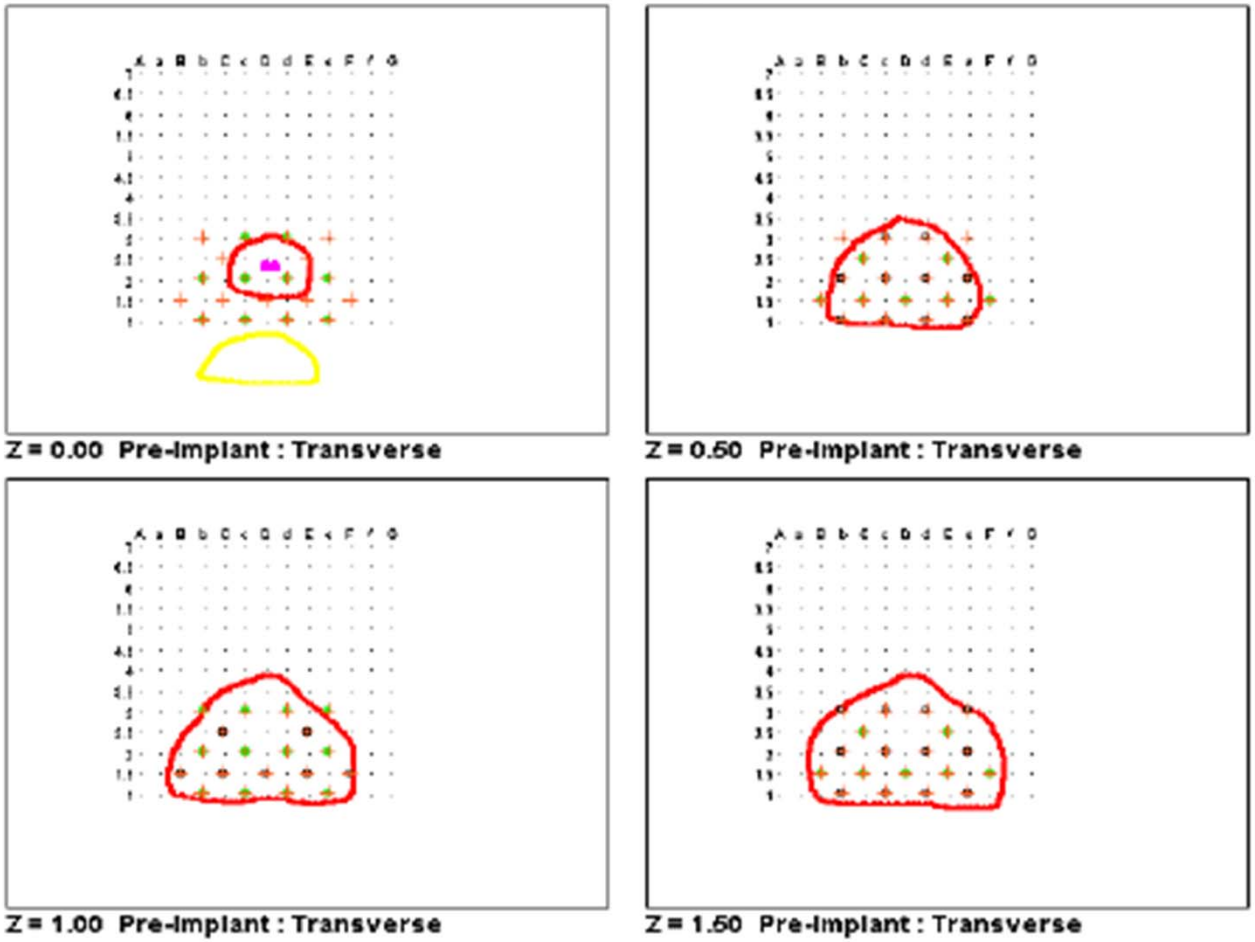


Z = 1.50 Pre-Implant : Transverse

Seed loading pattern

4.6.3.3 3D Alternating Pattern Example

Transverse Images



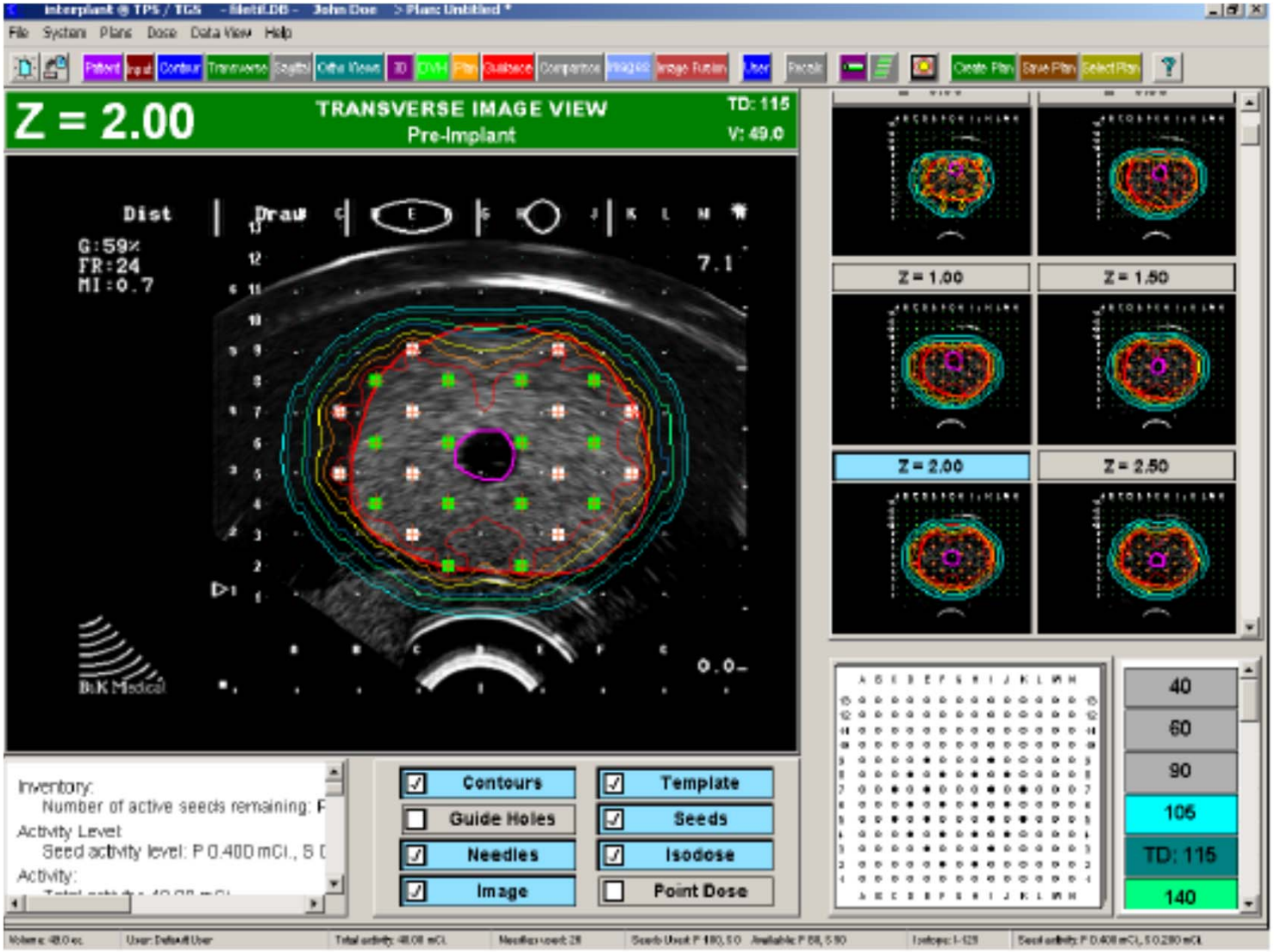
Z = 0.00 Pre-Implant : Transverse

Z = 0.50 Pre-Implant : Transverse

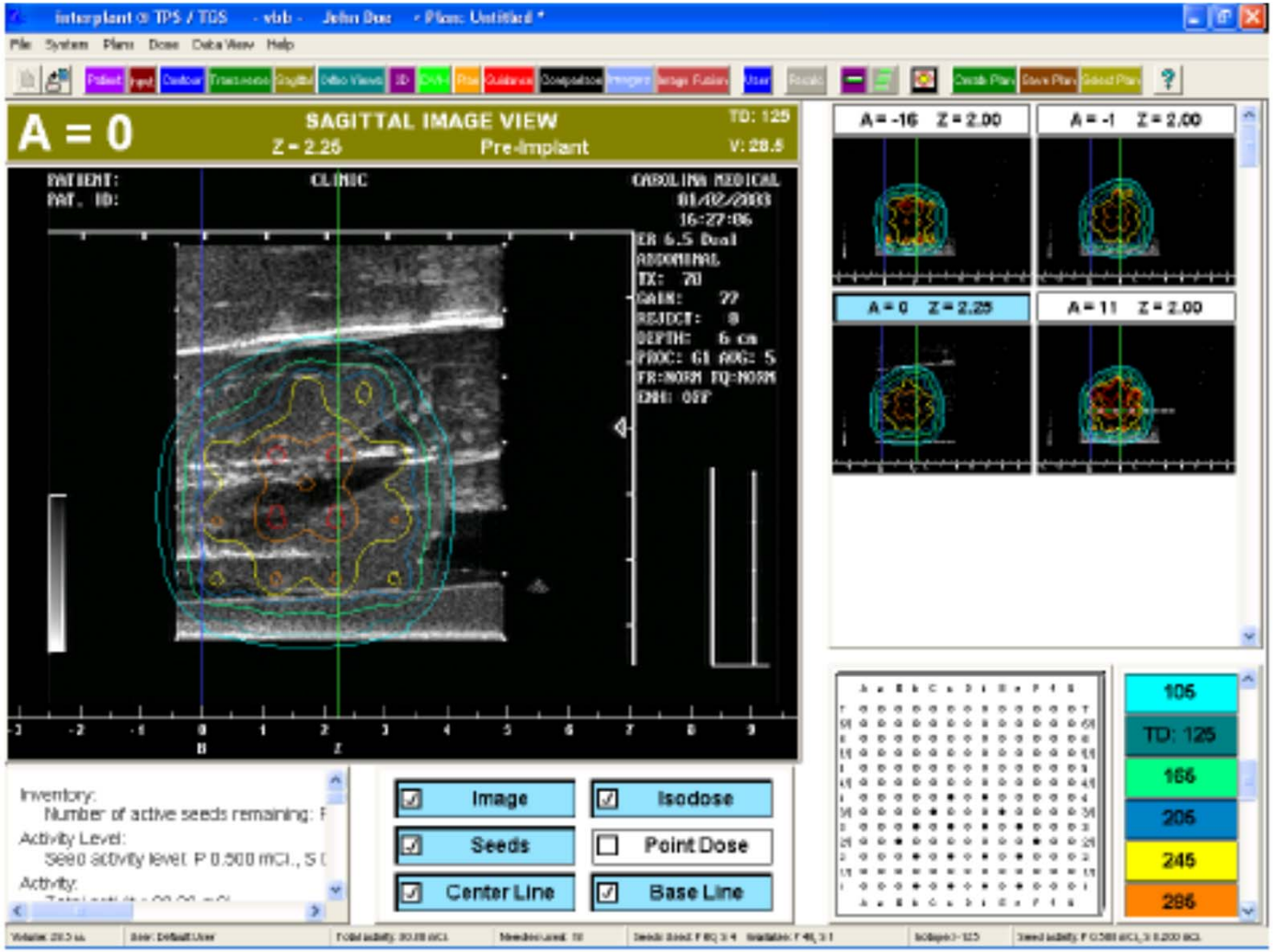
Z = 1.00 Pre-Implant : Transverse

Z = 1.50 Pre-Implant : Transverse

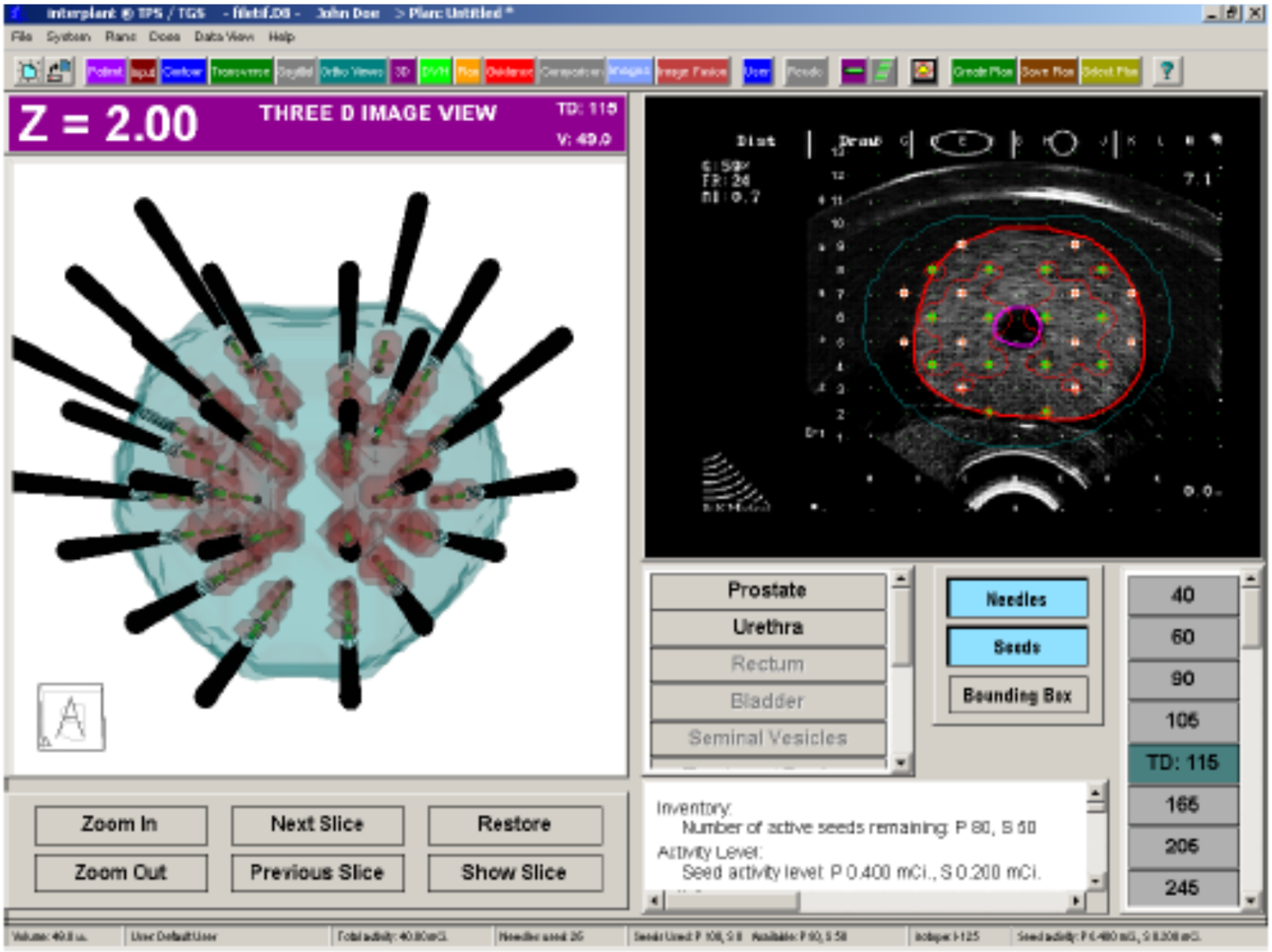
TPS – dose planning



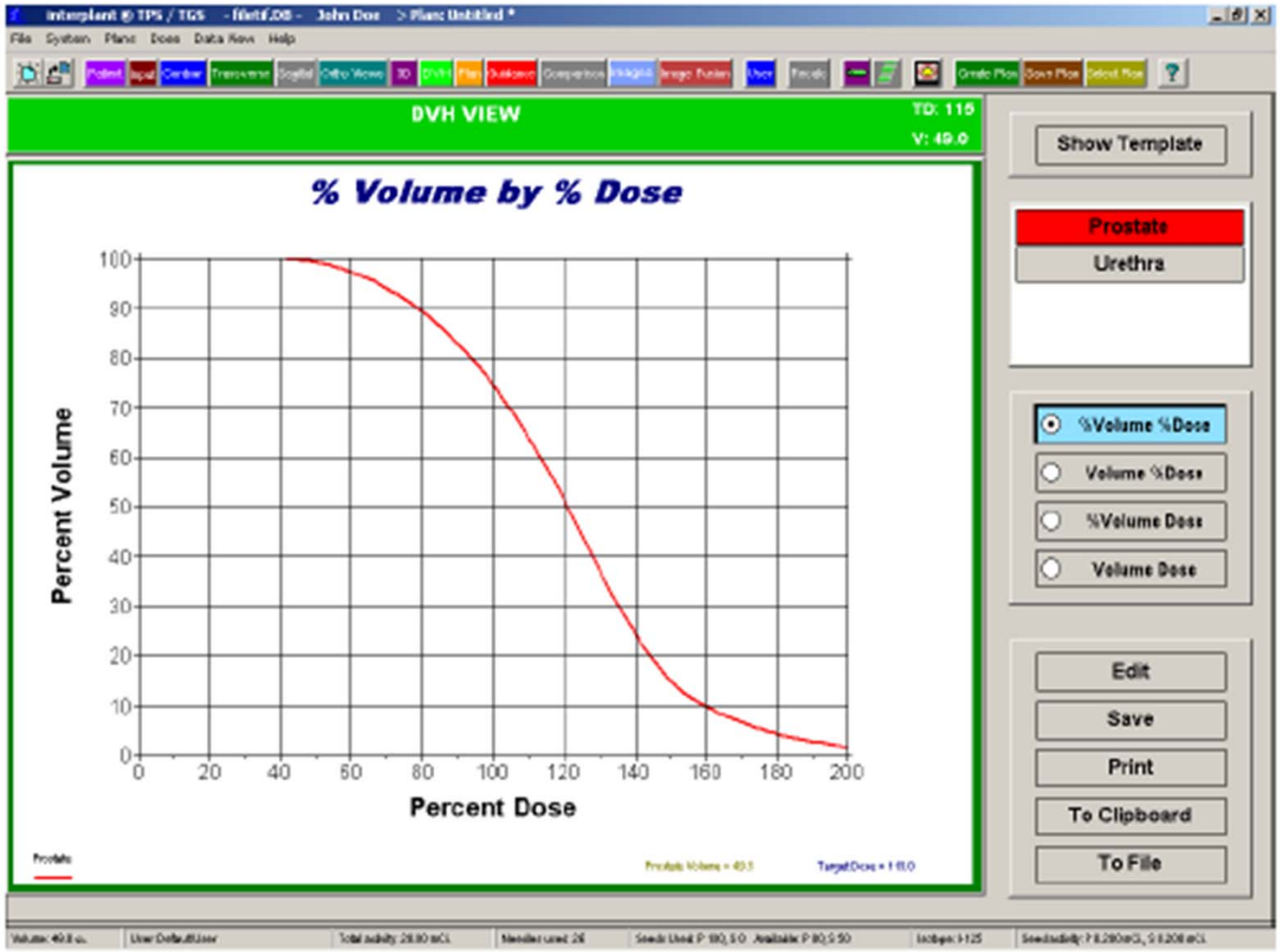
TPS – dose planning



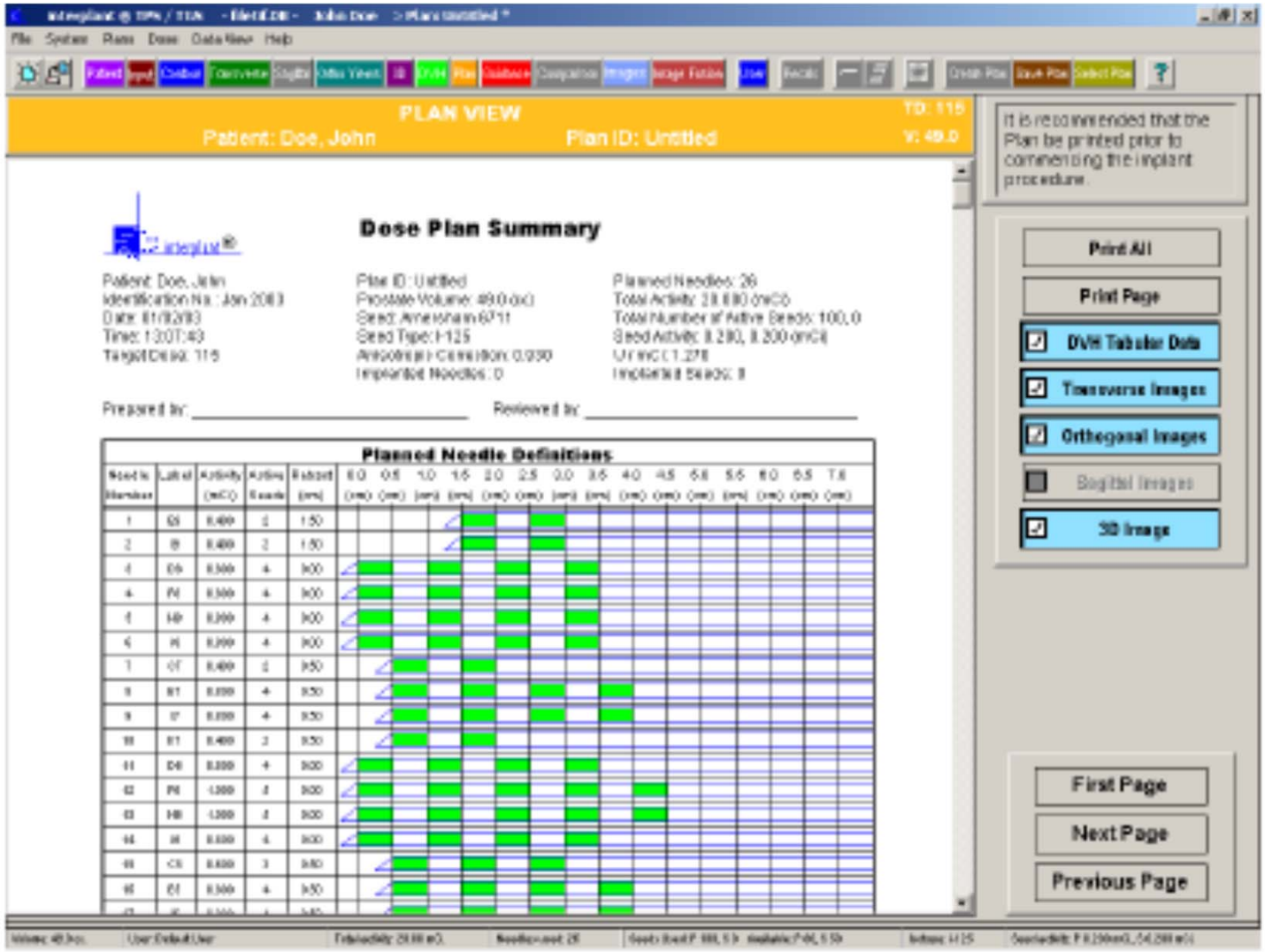
TPS – needle view



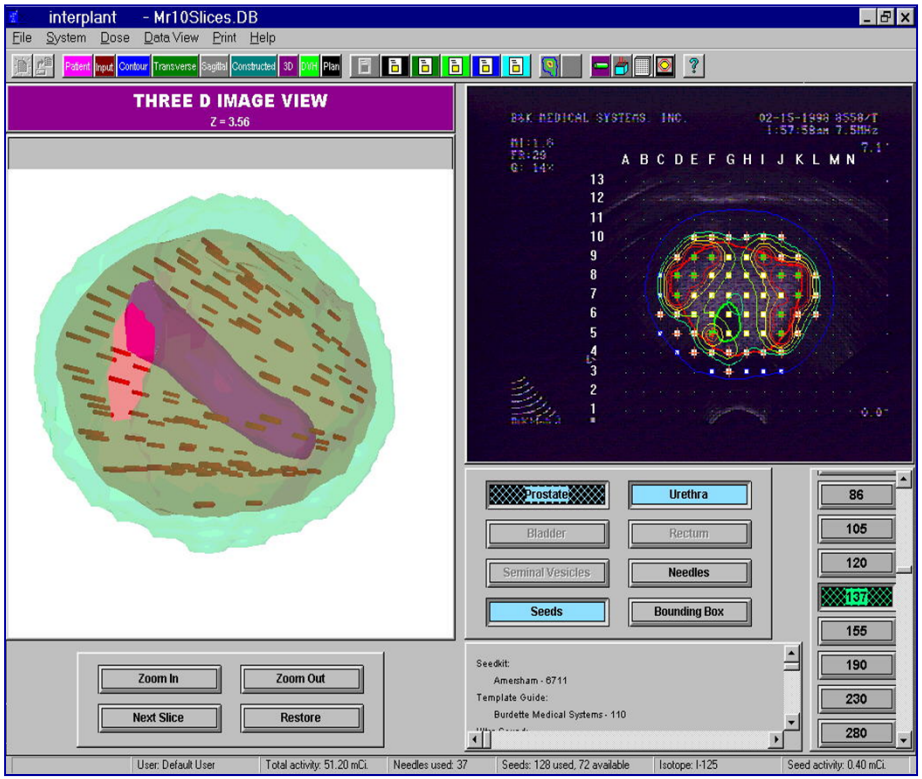
TPS – dose volume histogram (DVH)

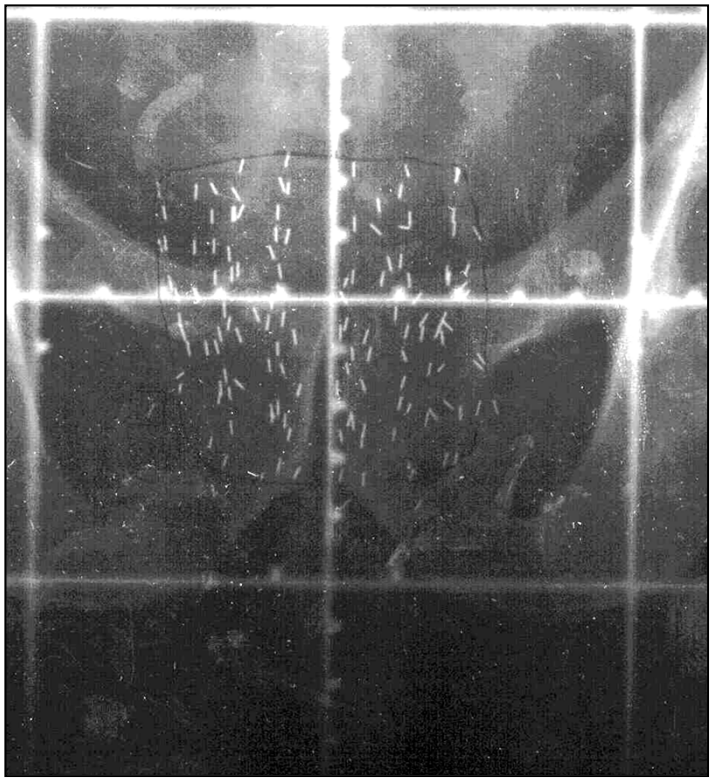


TPS – dose plan summary



Plan versus actual implant



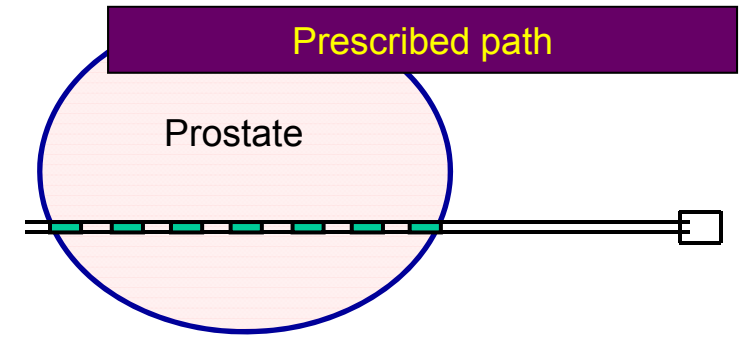


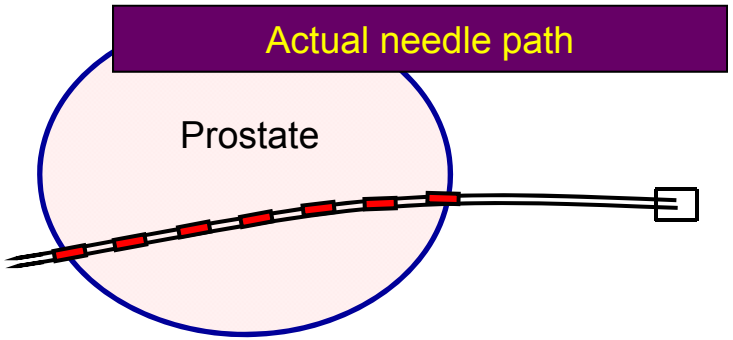
Implants ***NEVER*** turn out to be what was planned

- System miscalibration
- Organ motion & deformation
- Needle bending
- Edema

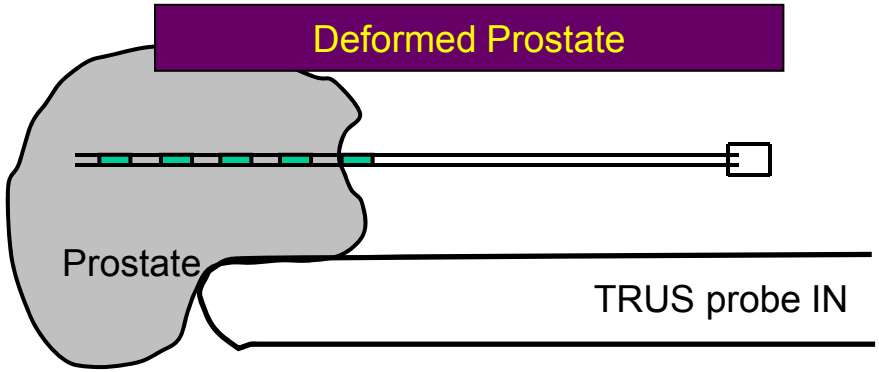
Why seeds get misplaced?

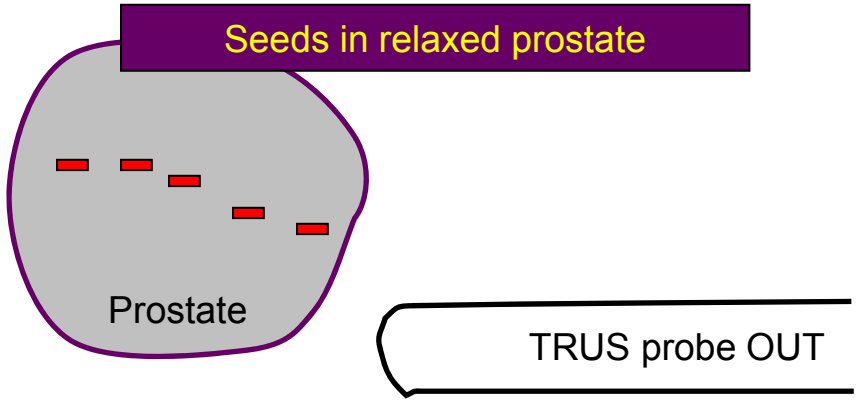
(1) Needle Deflection





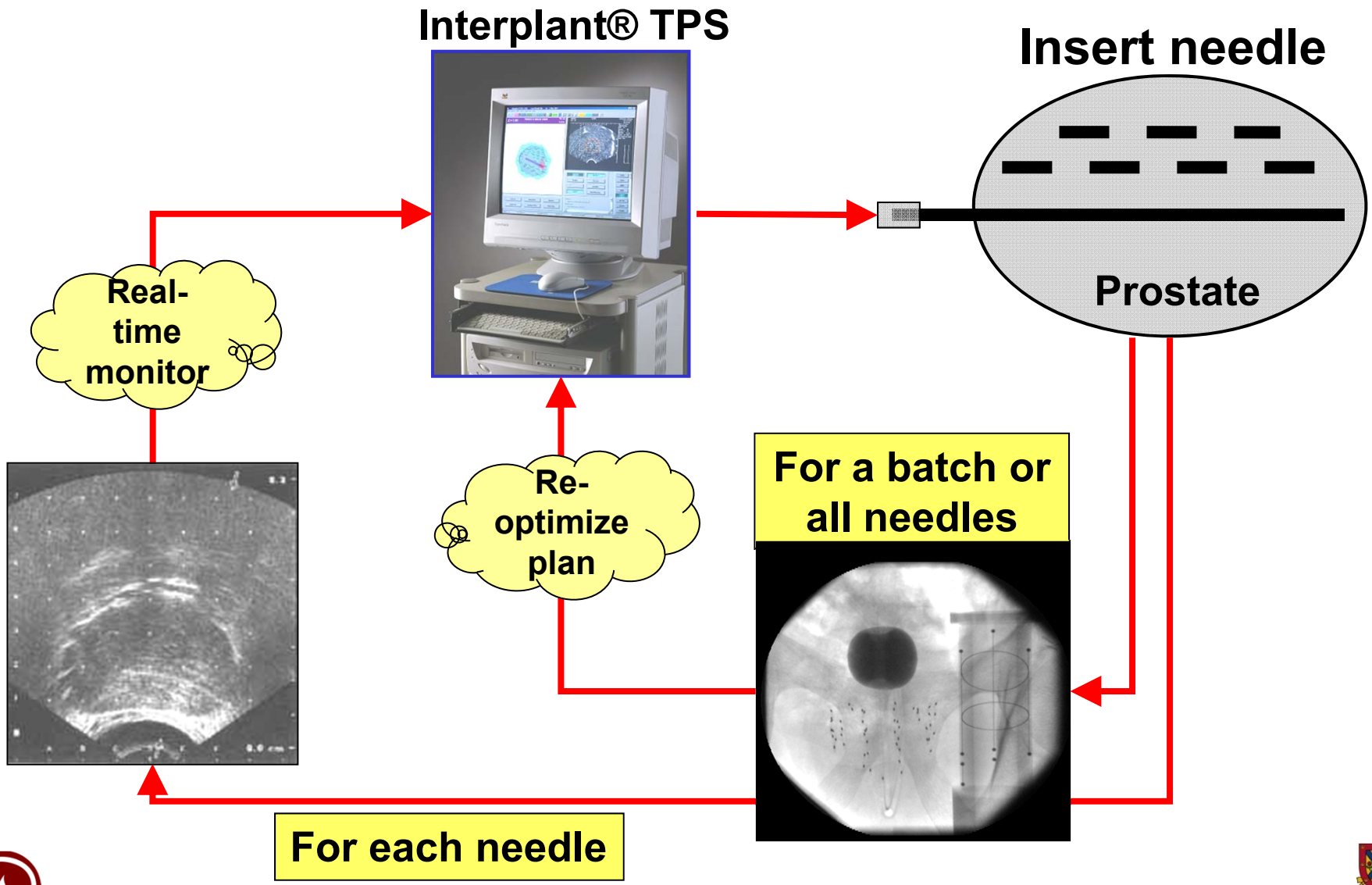
(2) Motion and Deformation Caused by Needle and Probe





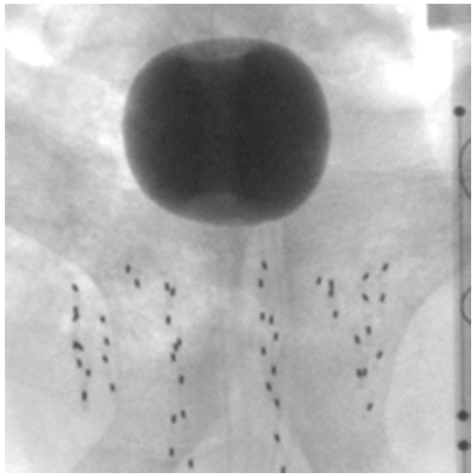
(3) Intra- and Post-Operative Edema

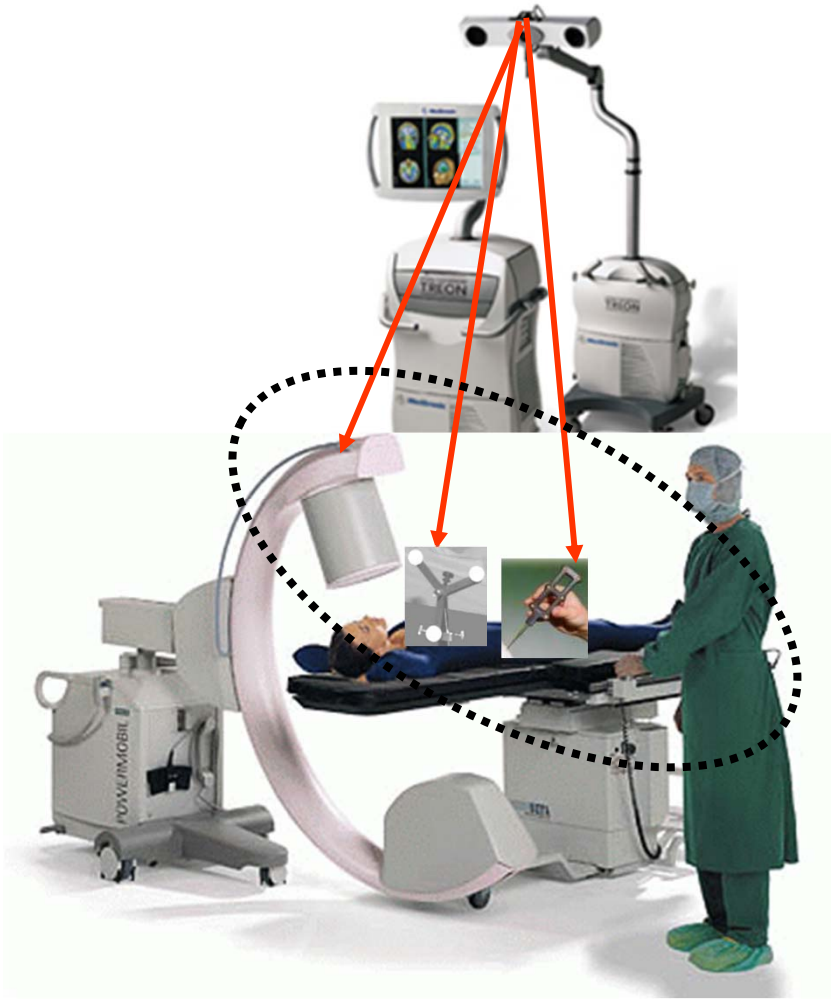
Registration of TRUS to Fluoro (RUF)



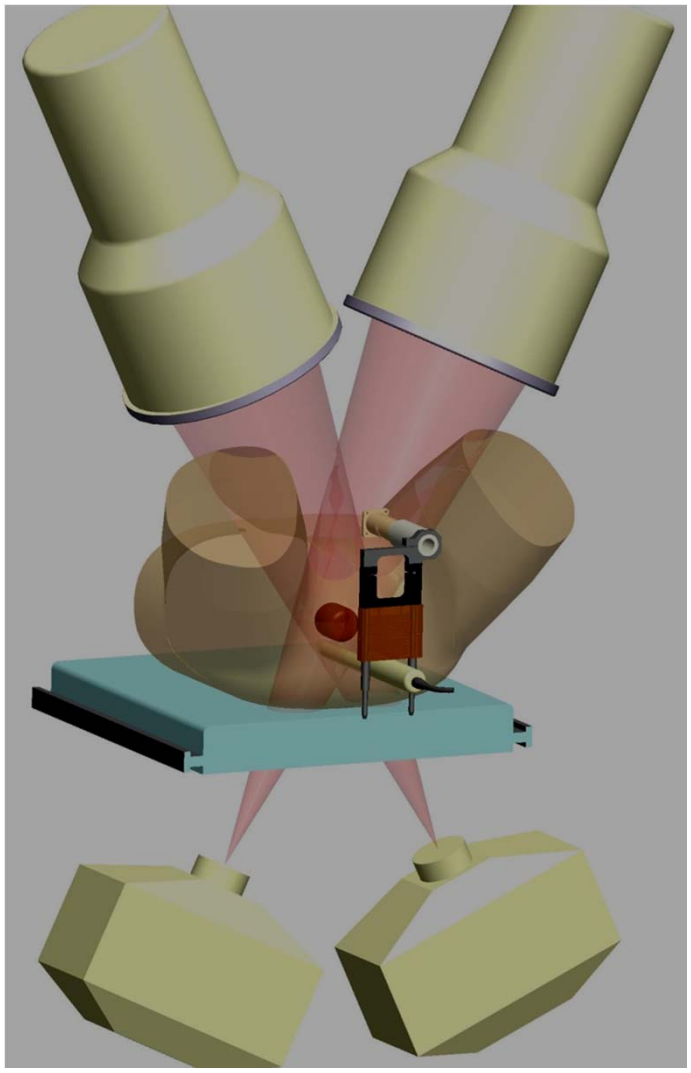
Why C-arm fluoroscopy is so difficult?

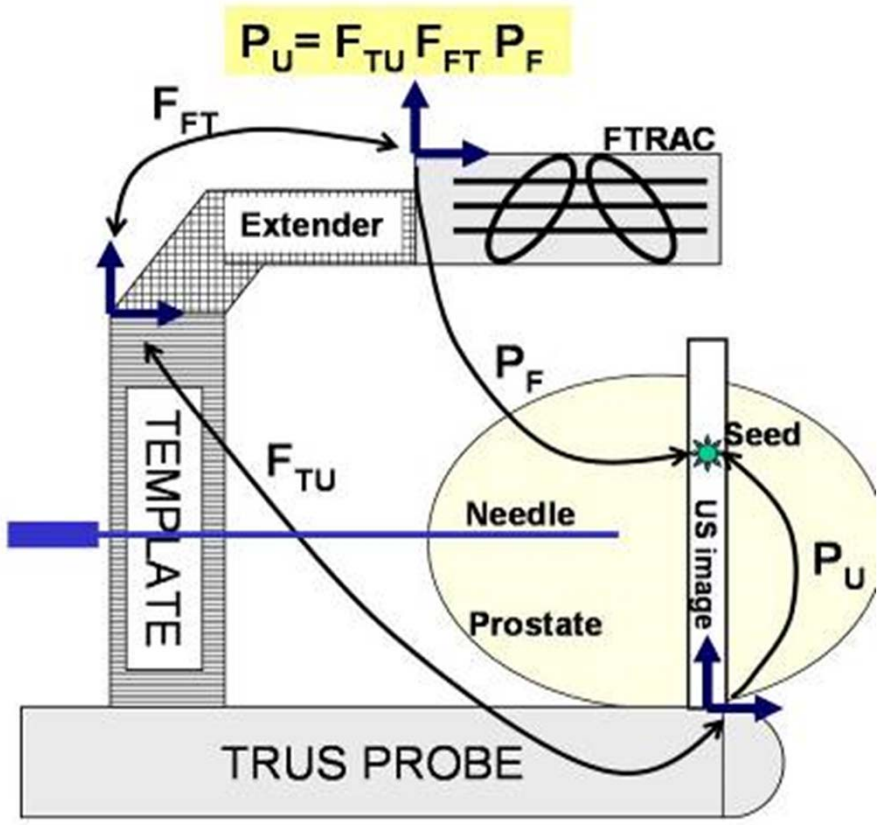
- **Must track the C-arm, tool, and patient simultaneously**
- **Requires online calibration distortion correction**
- **Seed reconstruction seems hopeless…**





RUF registration chain



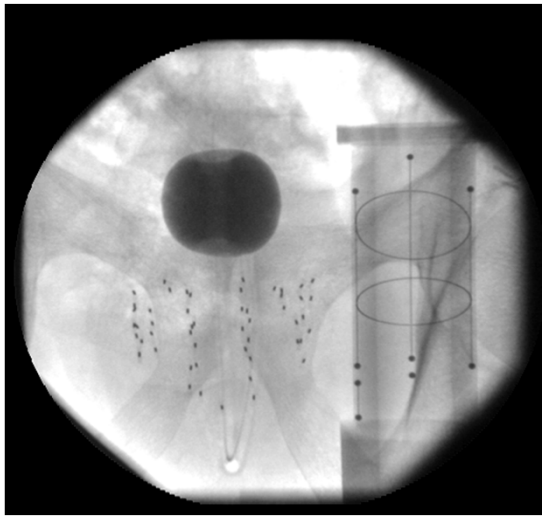


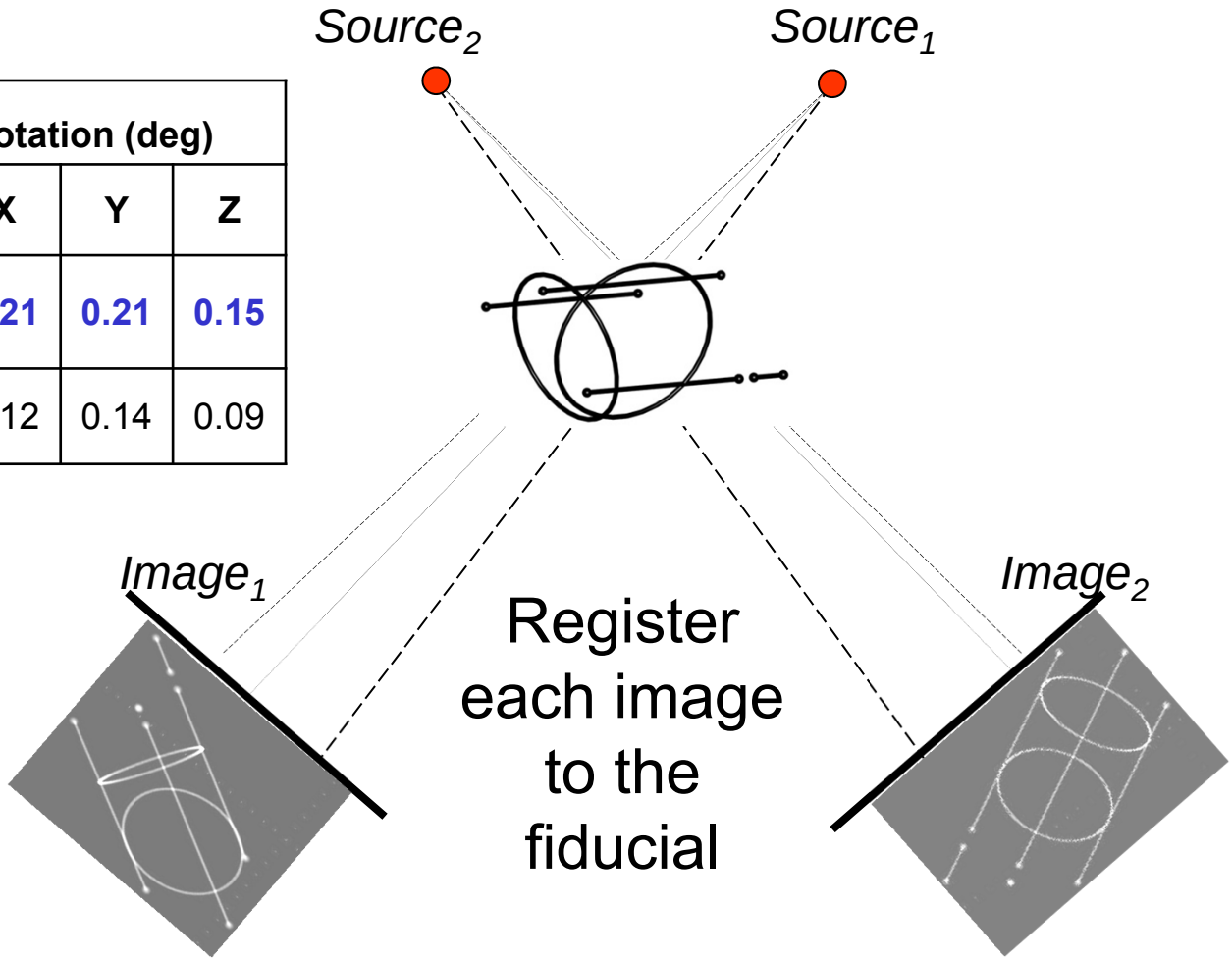
Jain *et* al, MICCAI 2007
Jain et al. AAPM, 2007

FTRAC: Fluoroscope tracking fiducial`

Calculates relative imaging poses

	Translation (mm)			Rotation (deg)		
	X	Y	Z	X	Y	Z
Mean	**0.07**	**0.04**	**0.55**	**0.21**	**0.21**	**0.15**
STD	0.05	0.03	0.32	0.12	0.14	0.09

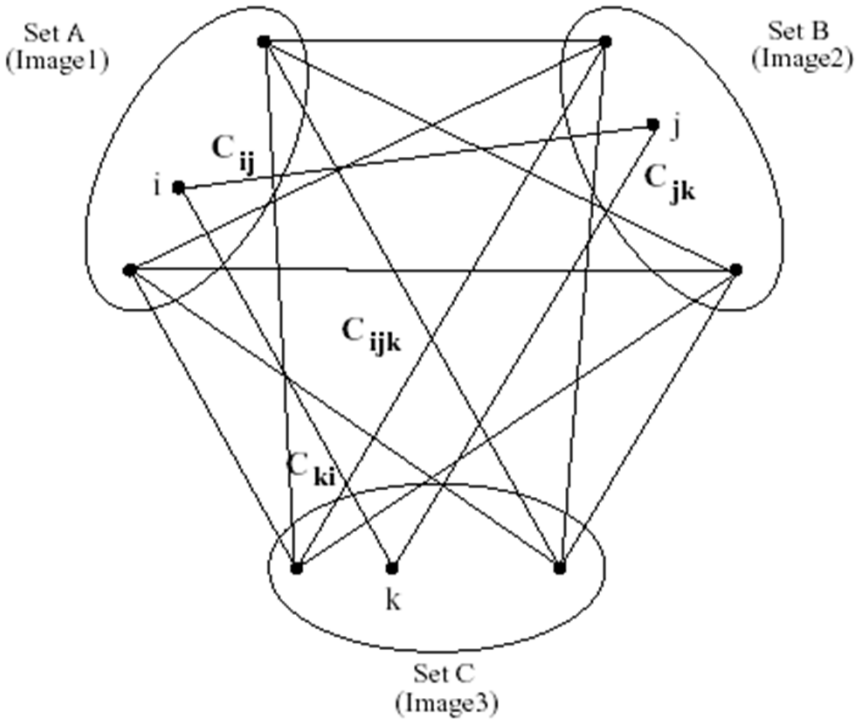




Jain *et* al, Med Phys 2005

MARSHAL: Matching and Reconstruction with the Hungarian Algorithm

- **Maps seed matching to network flow optimization**
- **Solves NP-hard seed matching in quasi polynomial time**



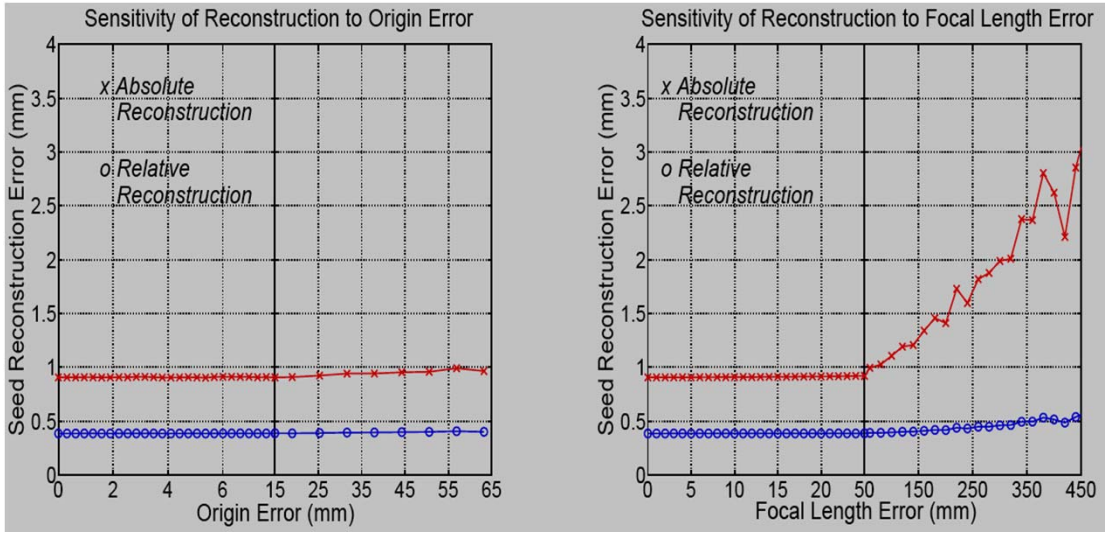
- Recovers hidden seeds
- Considers seed orientation
- Reconstructs 99.8% of all seeds from 4 images
- Reconstruction error of 0.63 mm (STD= 0.24 mm)
- Mismatched seeds have a mean error of 0.9 mm

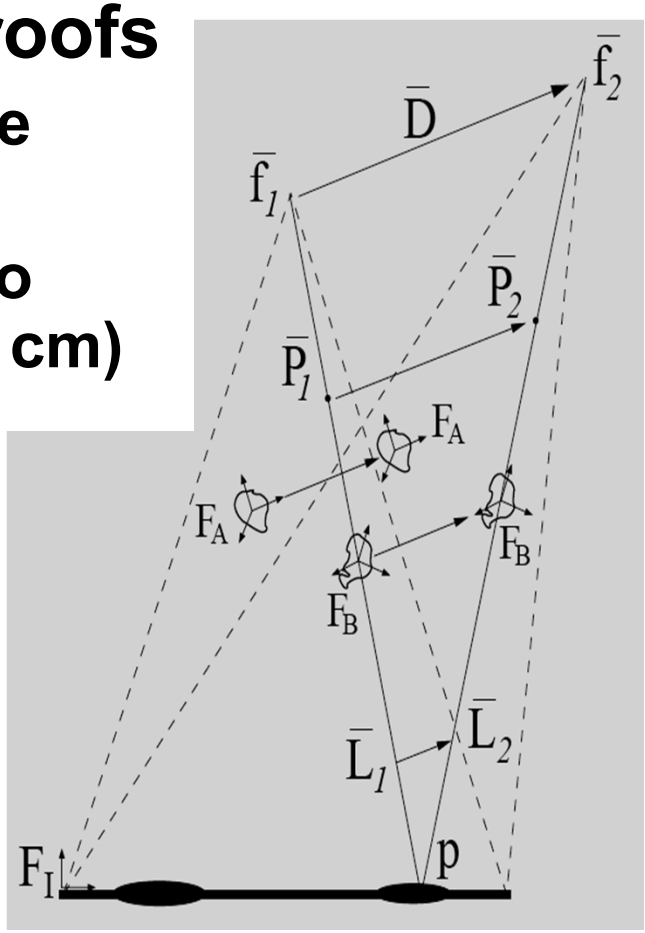
Jain *et* al, MedPhys 2005
Jain et al, MICCAI 2006
Zhou et al, SPIE 2006

We use average C-arm without on-line calibration & distortion correction

Mathematical and experimental proofs

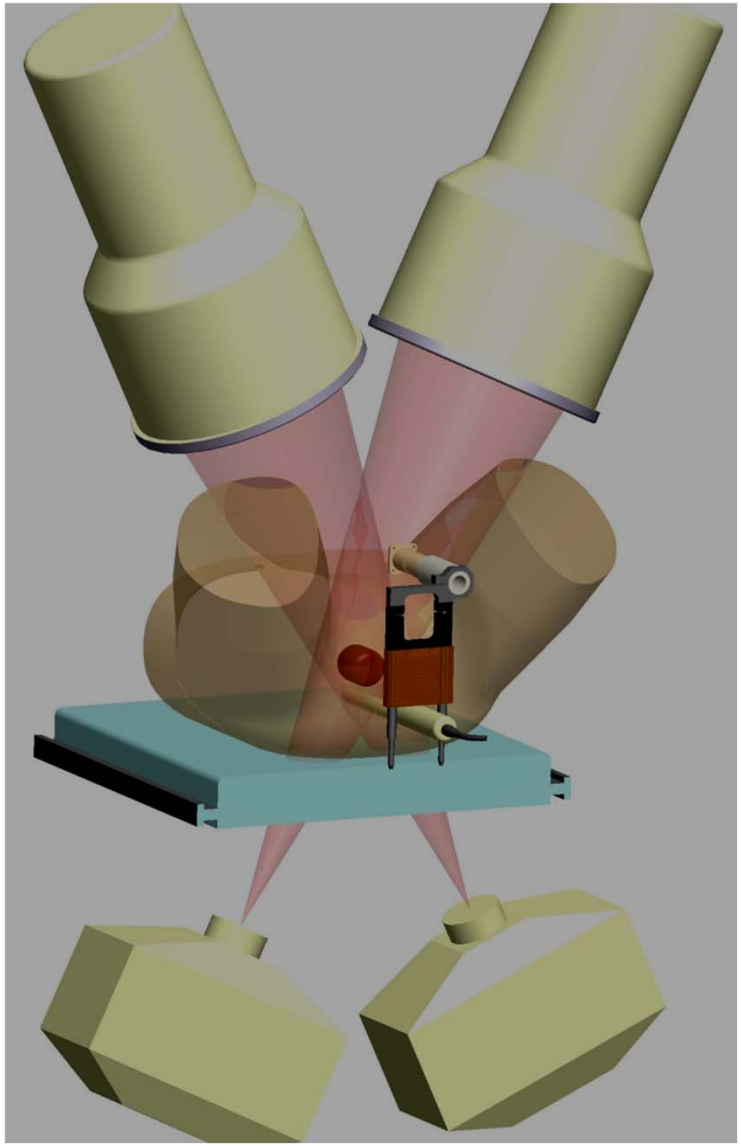
- Calibration does not affect the relative position of seeds
- FTRAC and MARSHAL are resistant to even very large calibration errors (5+ cm)

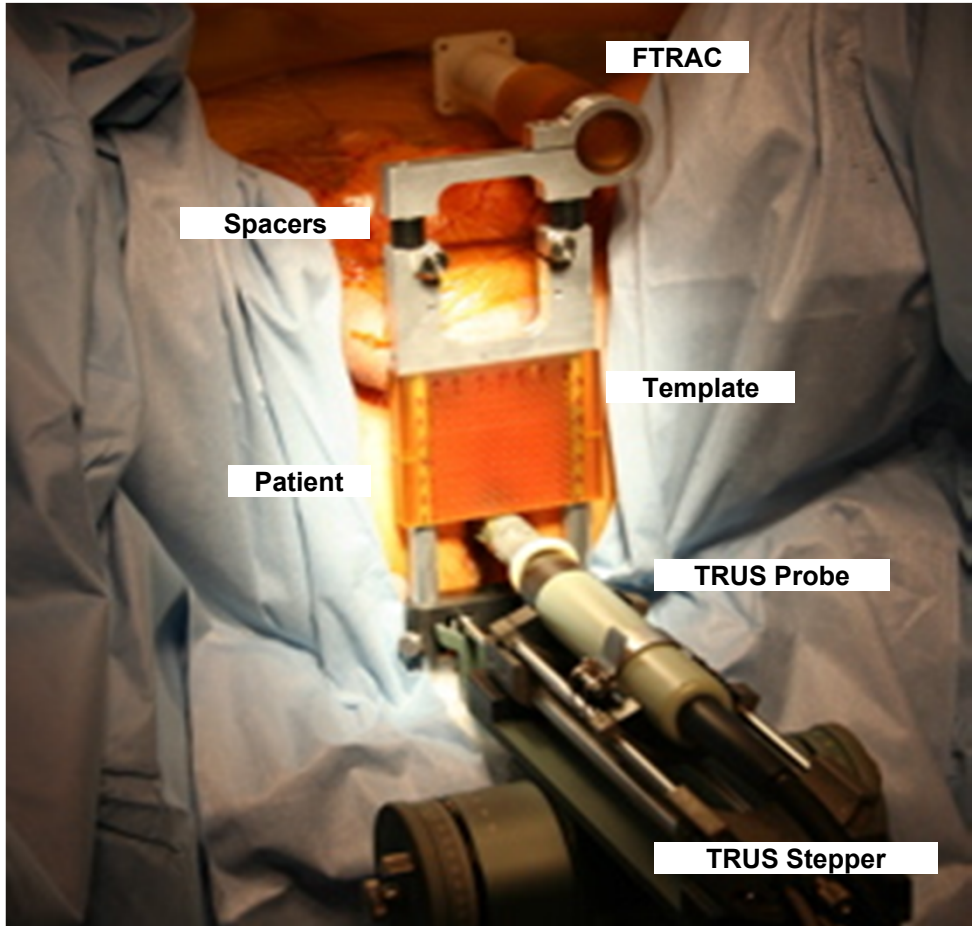




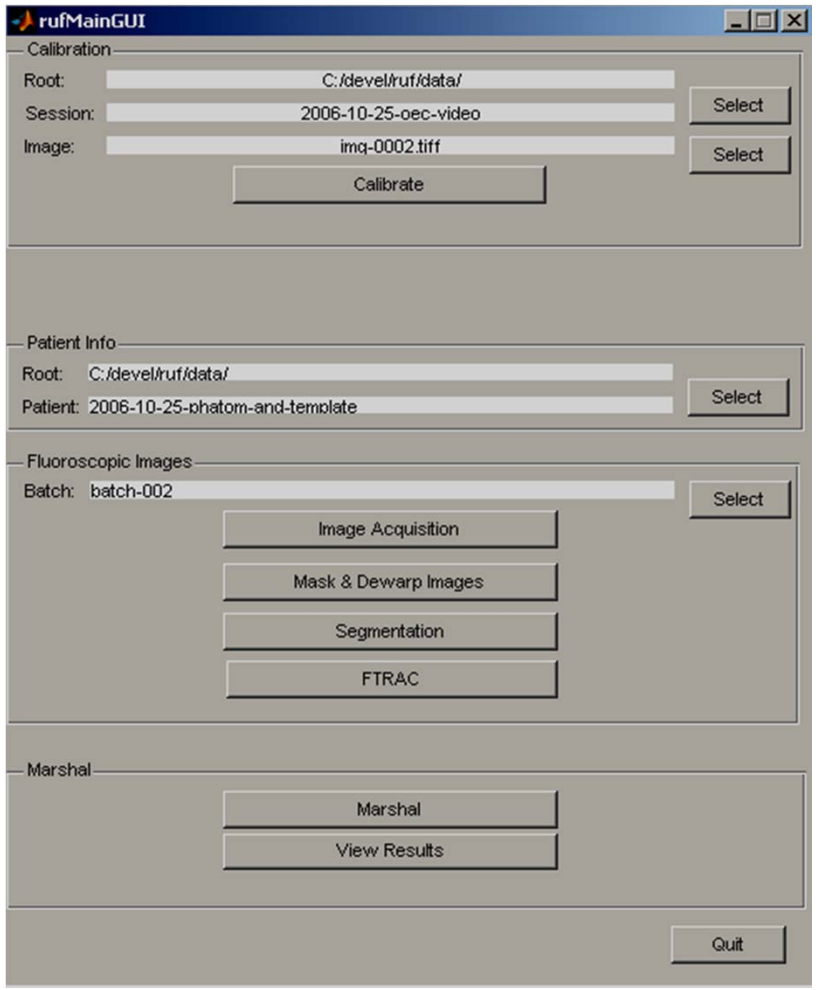
Jain *et* al, MICCAI 2005
Jain et al, Med Phys 2005
Jain et al, MICCAI 2006

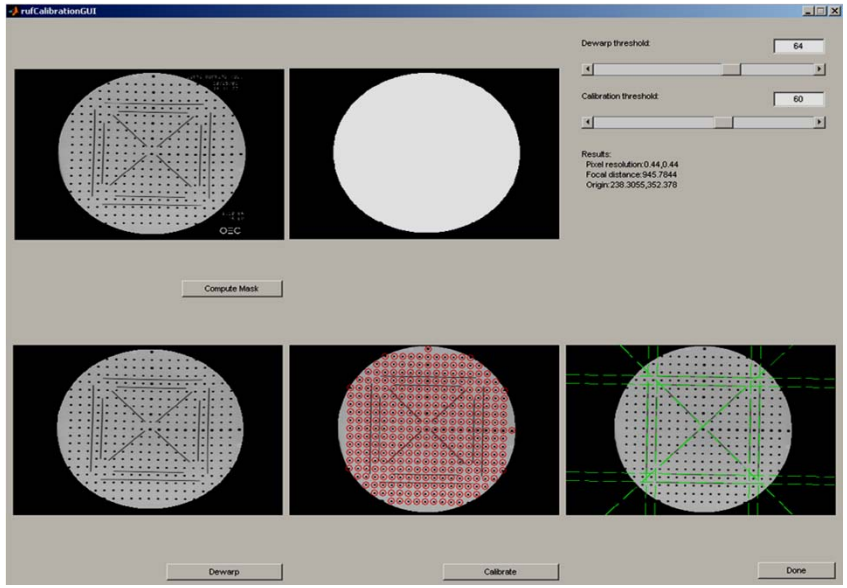
Clinical setup

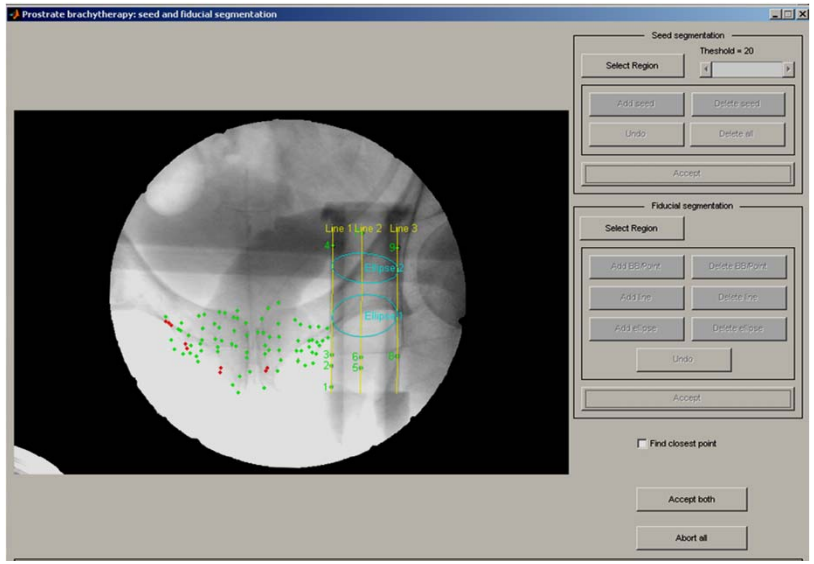




RUF software interface





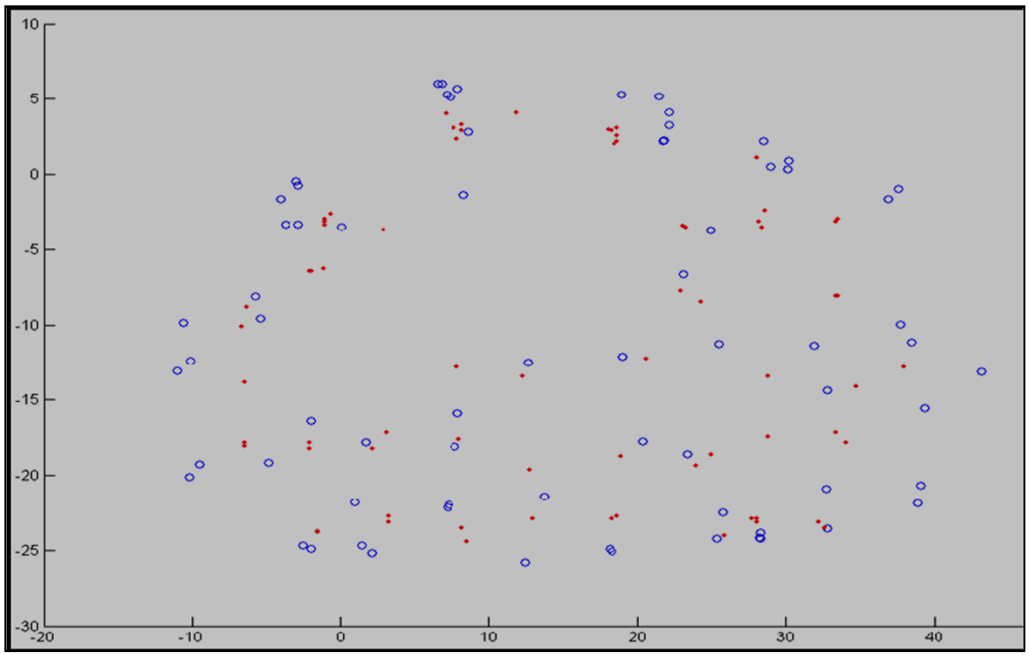


Jain *et* al, AAPM 2007
Jain et al, MICCAI 2007

Clinical trial results

Intra-operative edema quantified at 1/3, 2/3 and complete implant

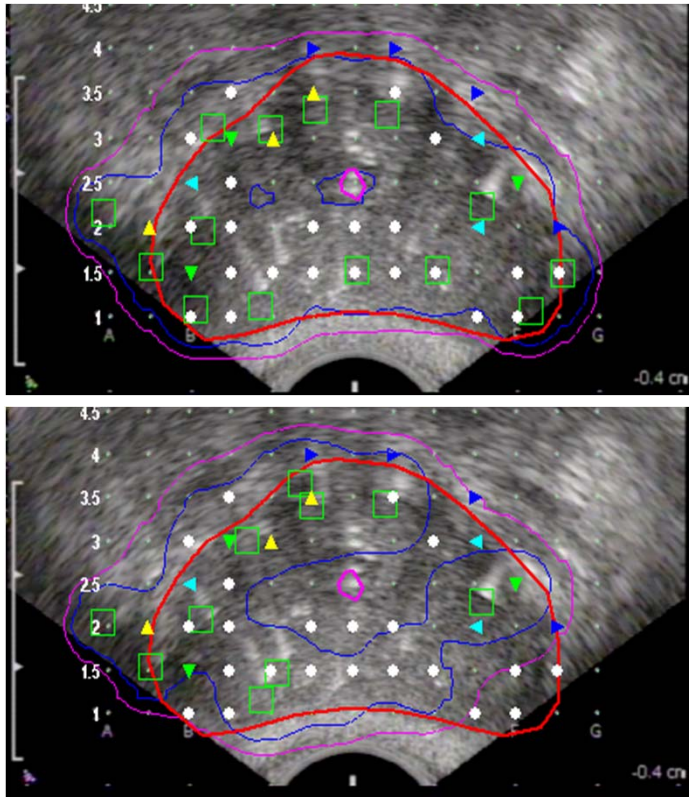
mean 4.6 mm (STD 2.4 mm, max 12.3 mm)



Planned seeds and actual seeds

Colds spots found on exit dosimetry and fixed

Average 4 extra seeds, max 9



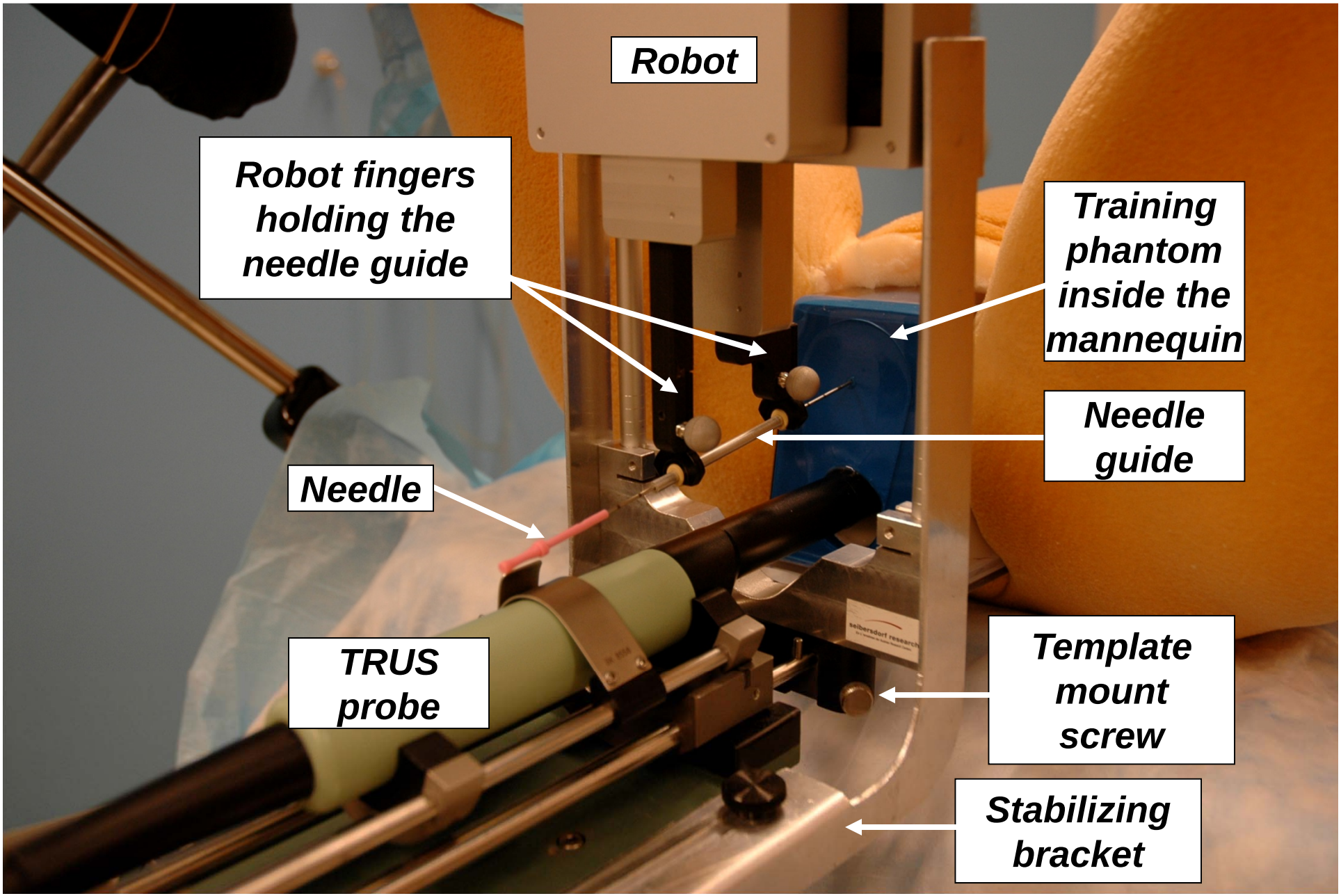
Screen captures from the Interplant® brachytherapy TPS

Jain *et* al, AAPM 2007
Jain et al, MICCAI 2007
Song et al, ASTRO 2007

Replace template w/ 4DOF robot

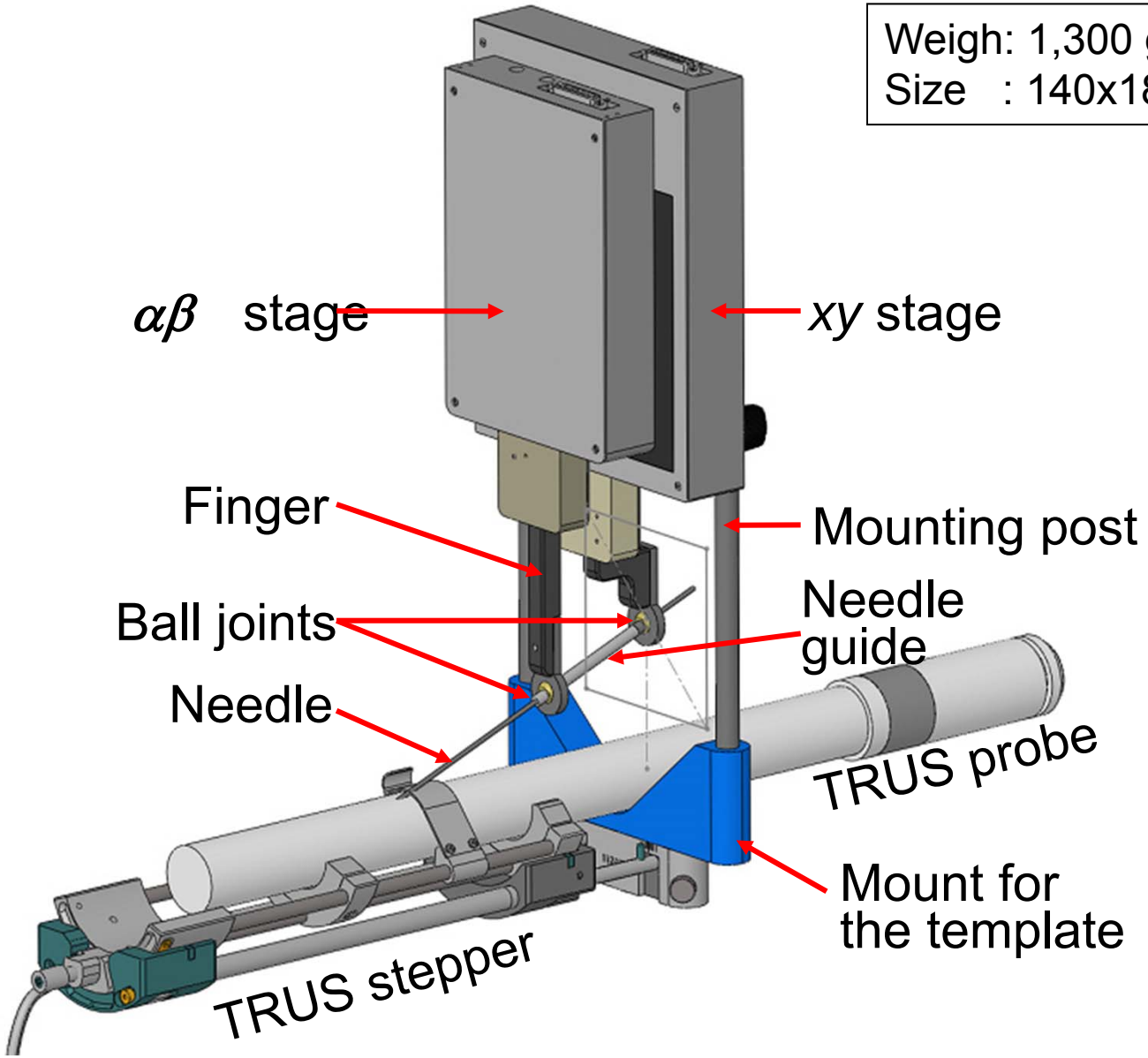
Does not alter clinical setup & workflow

Robot setup


Robot
Robot fingers holding the needle guide
Training phantom inside the mannequin
Needle guide
Needle
TRUS probe
Template mount screw
Stabilizing bracket

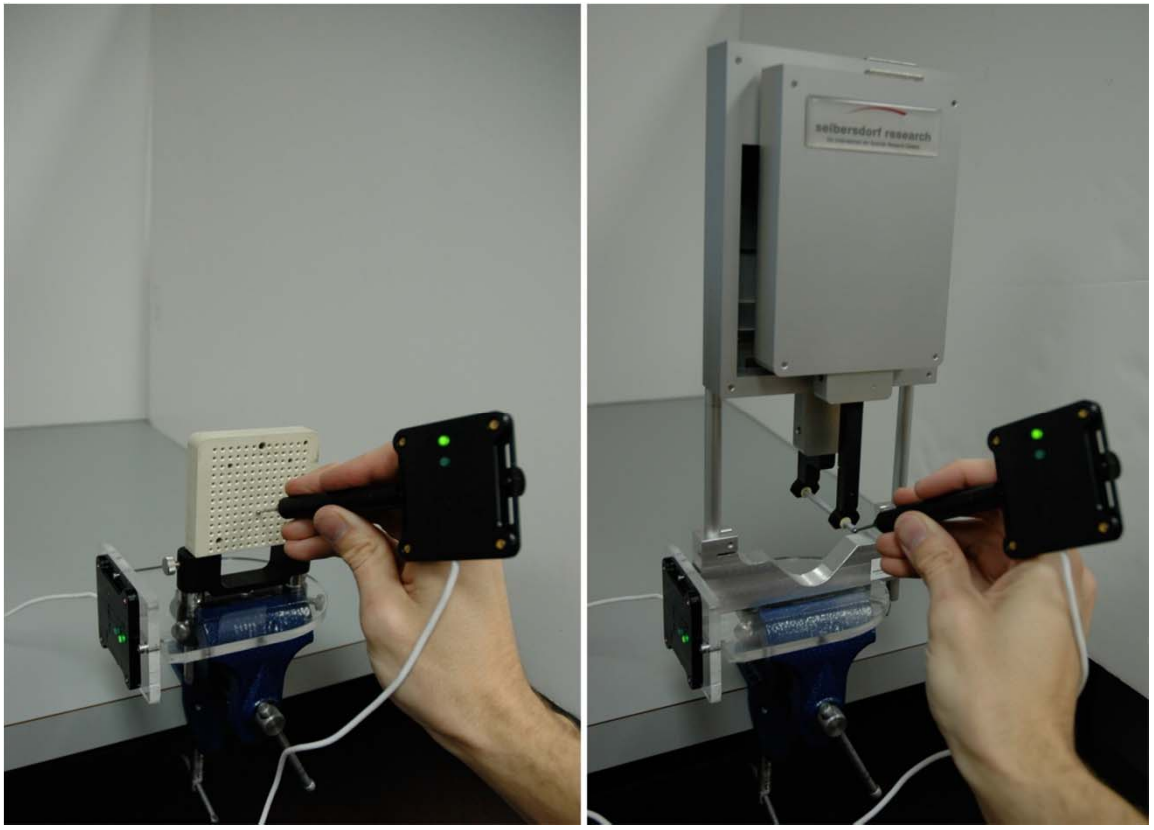
“Sandwich” robot

Weigh: 1,300 g
Size : 140x180x65 mm



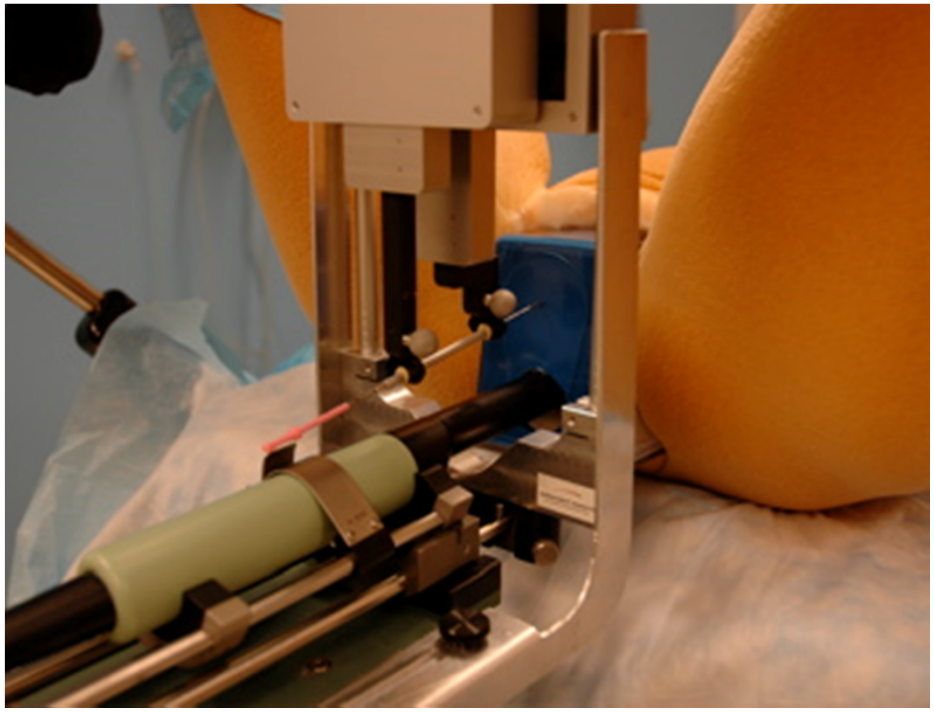
Robot & template are interchangeable

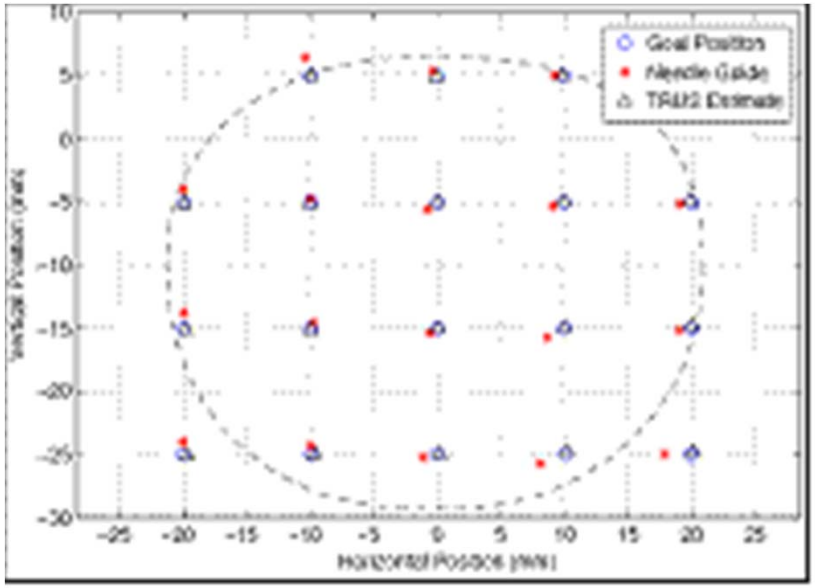
- Translation error: 0.25mm (STD=0.17mm)
- Rotation error: 0.75° (STD=0.37°)

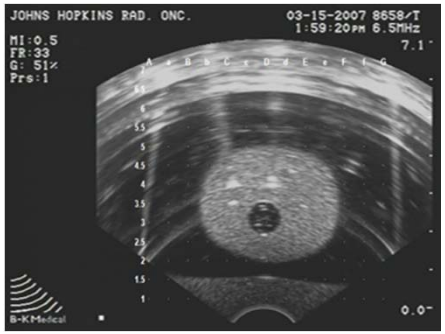


- **Can revert to template if necessary**
- **No need for pre-op calibration**

Accurate needle placement w/ TRUS



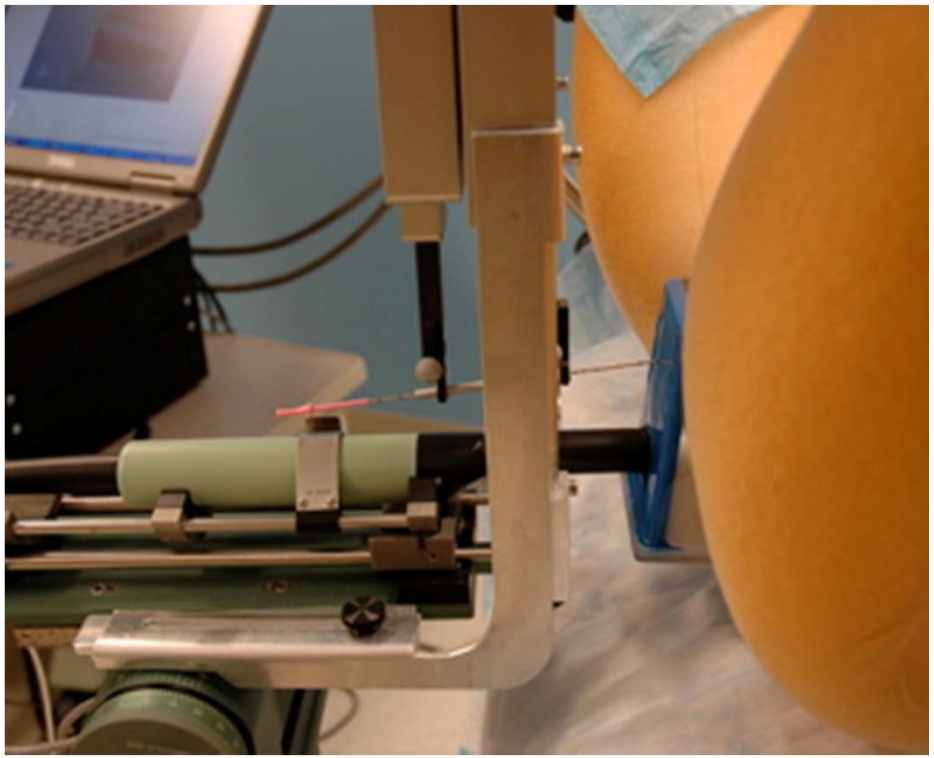




- **Avg. 1.04 mm (STD=0.50 mm)**
- **Relative to TRUS**
- **18 samples over prostate**

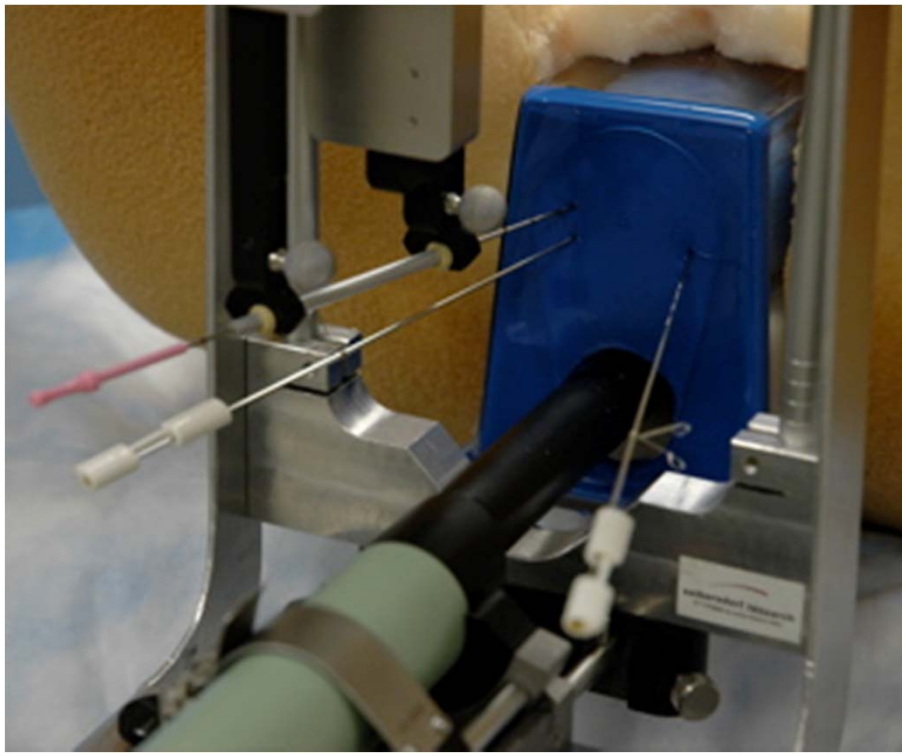
Additional benefits

Pubic arch interference reduced by slanted needles

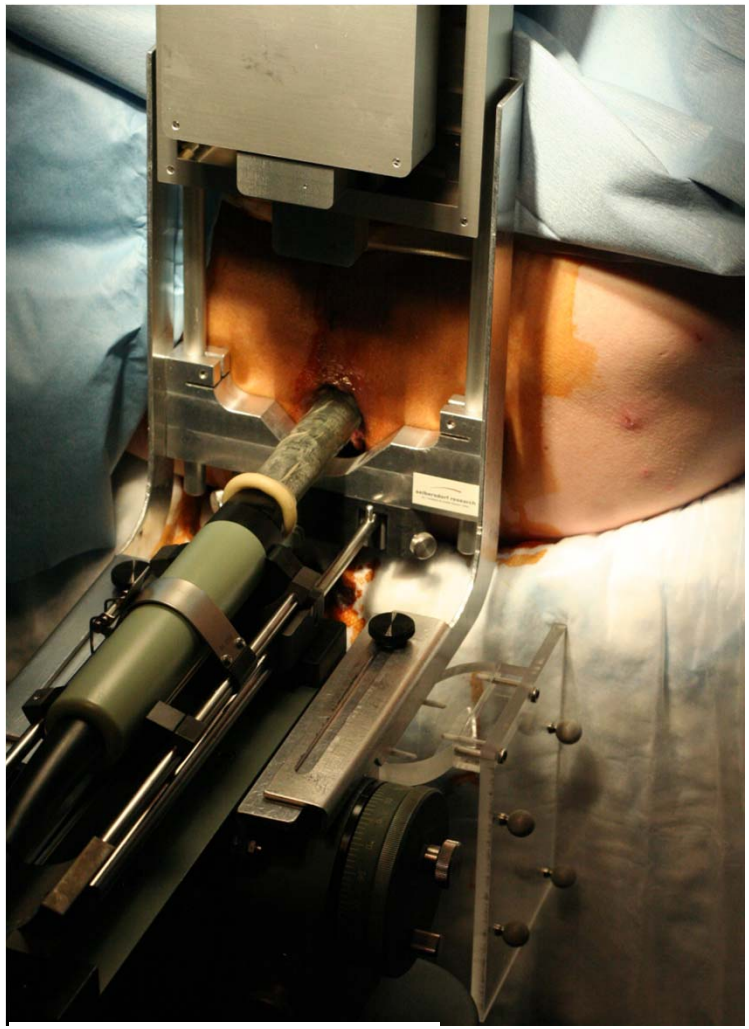


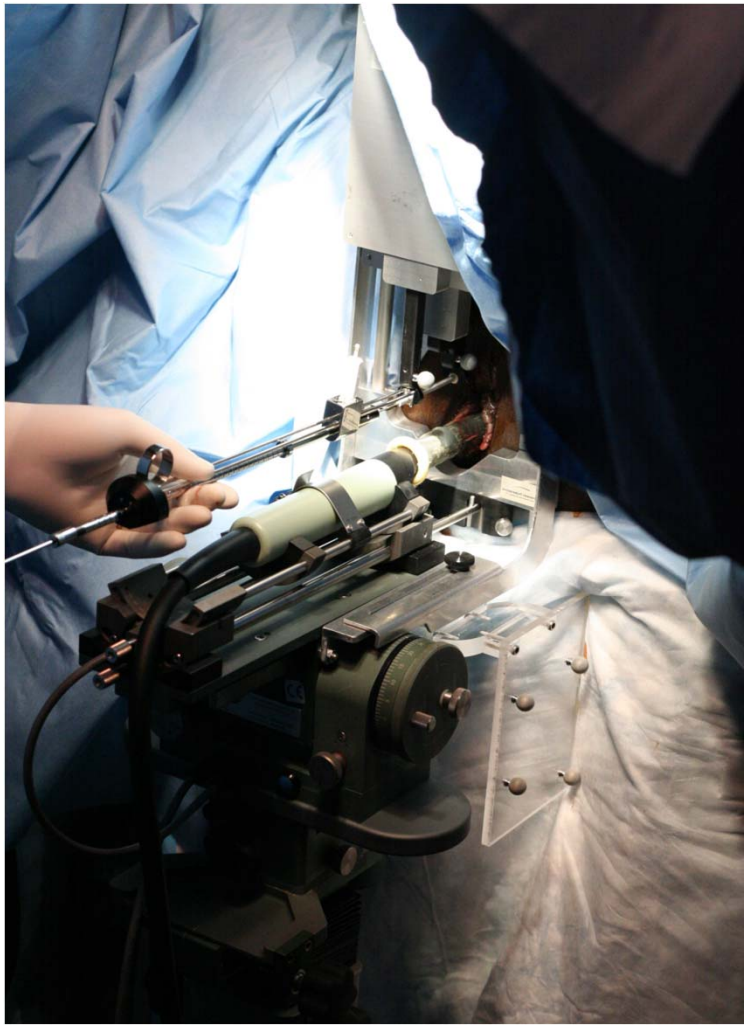
Prostates >55cc, about ⅓ of candidates

No apparent interference with stabilization needles



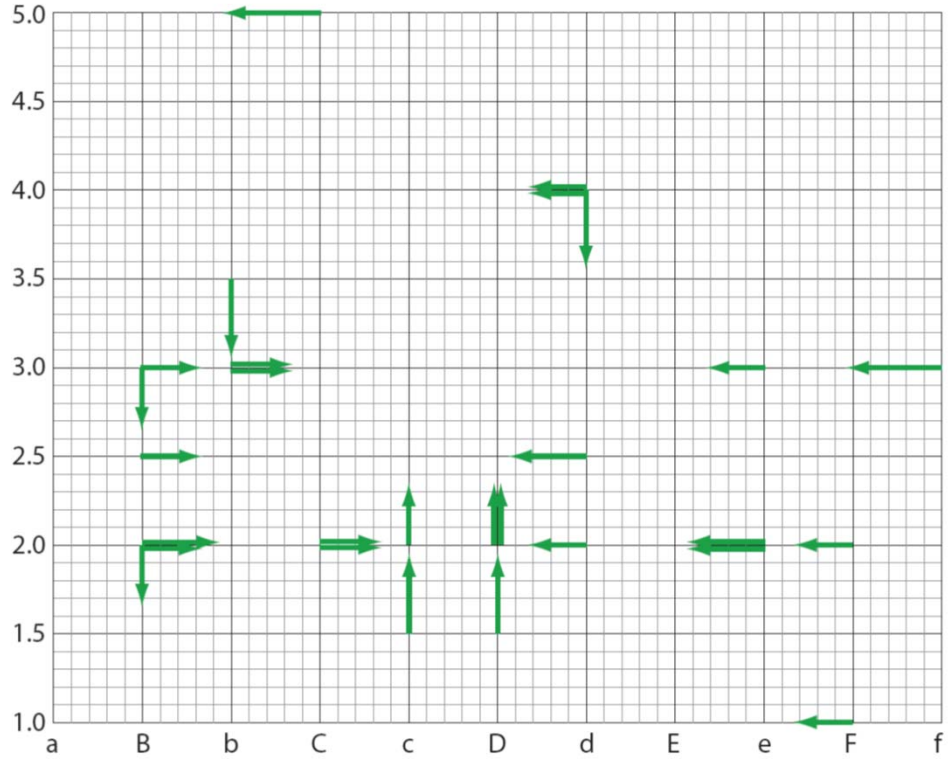
Successful clinical trial





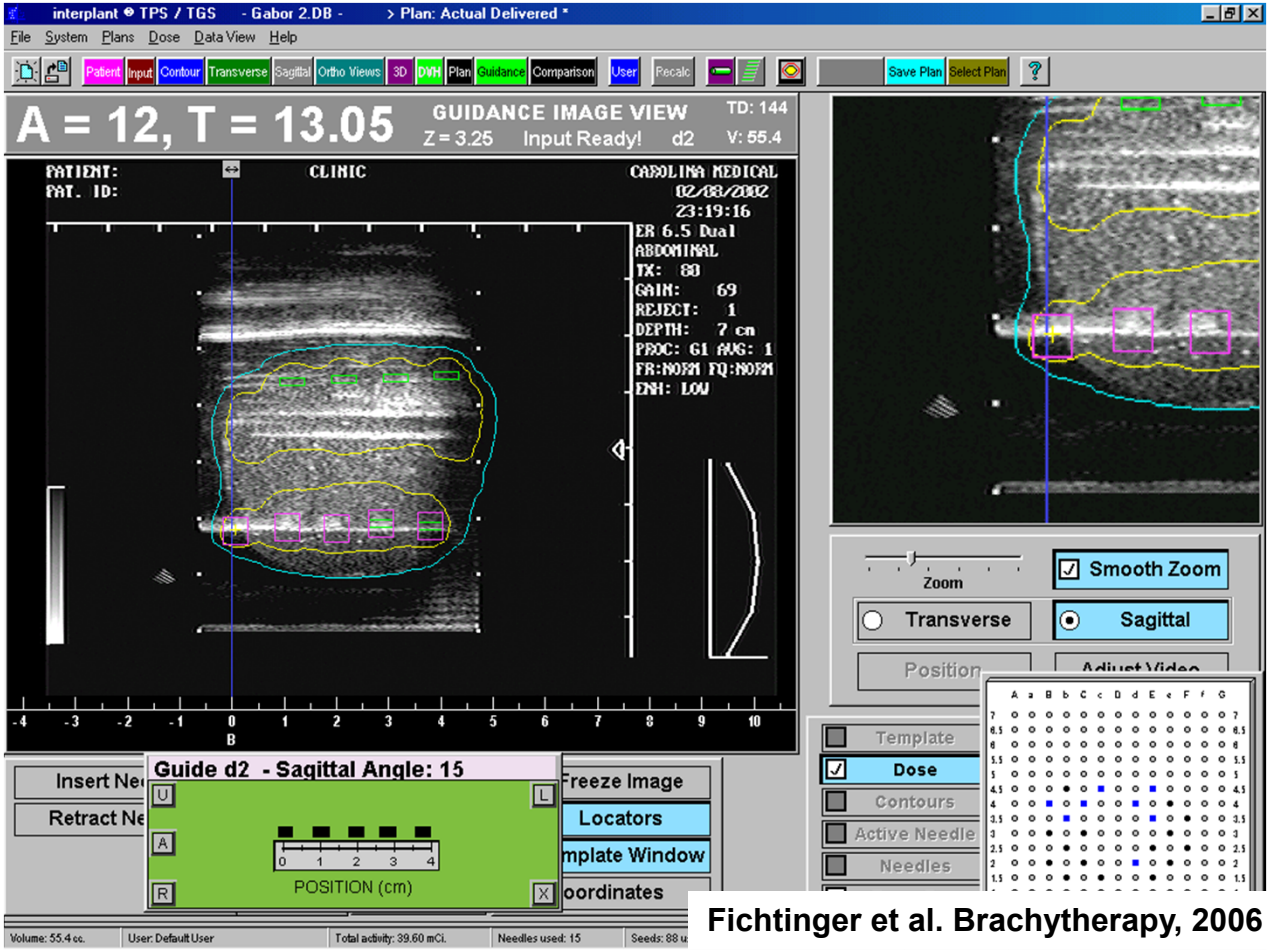
Six patients done

Needle adjustments – clinical results from five patients w/ 185 needles



Direction and magnitude of corrective adjustments (≥ 3 mm) made to the needle position for all 5 patients. Note the pattern of needles requiring correction toward the center of the prostate, consistent with a tendency for tissue deflection toward the edges of the prostate.

New paradigm: “Dynamic Dosimetry”



Fichtinger et al. Brachytherapy, 2006

Optimize dose on the fly, relative to prostate

Dynamic dosimetry is a reality (see posters W2, W35, H45)

Speed and accuracy depends on identification of seeds in ultrasound

Extra time increases the chance of edema