

Robot-assisted Prostate Cancer Interventions

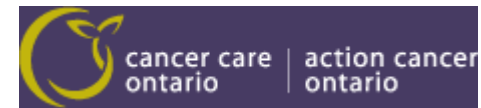
Gabor Fichtinger, Ph.D.

**Professor and Cancer Care Ontario Research Chair
Queen's University, Canada**

<http://perk.cs.queensu.ca>

Acknowledgements

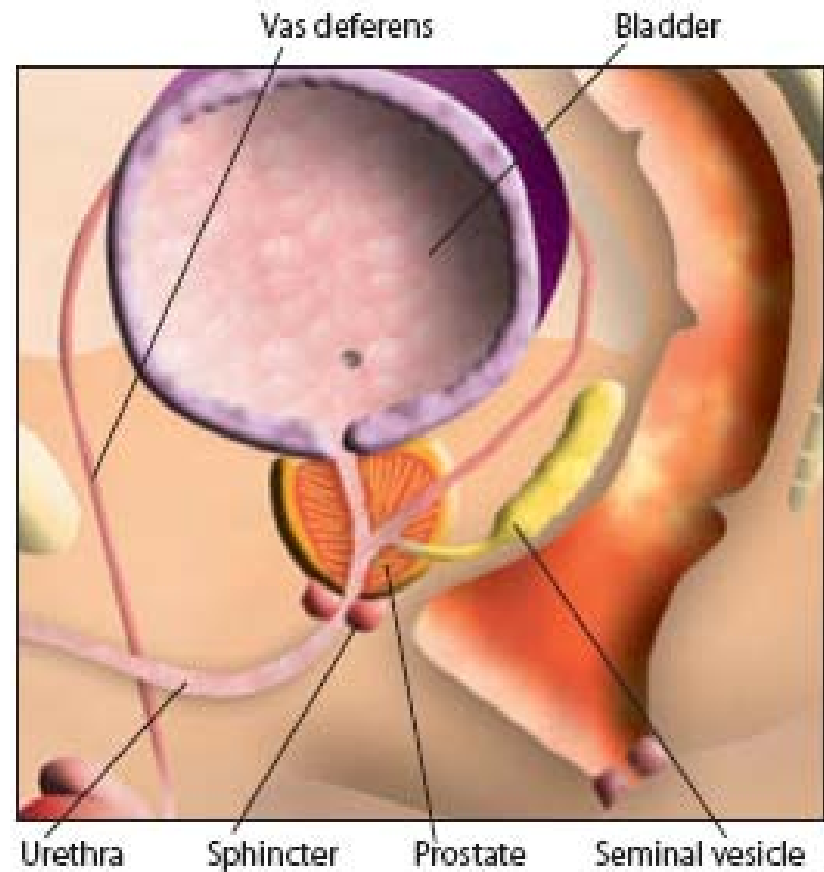
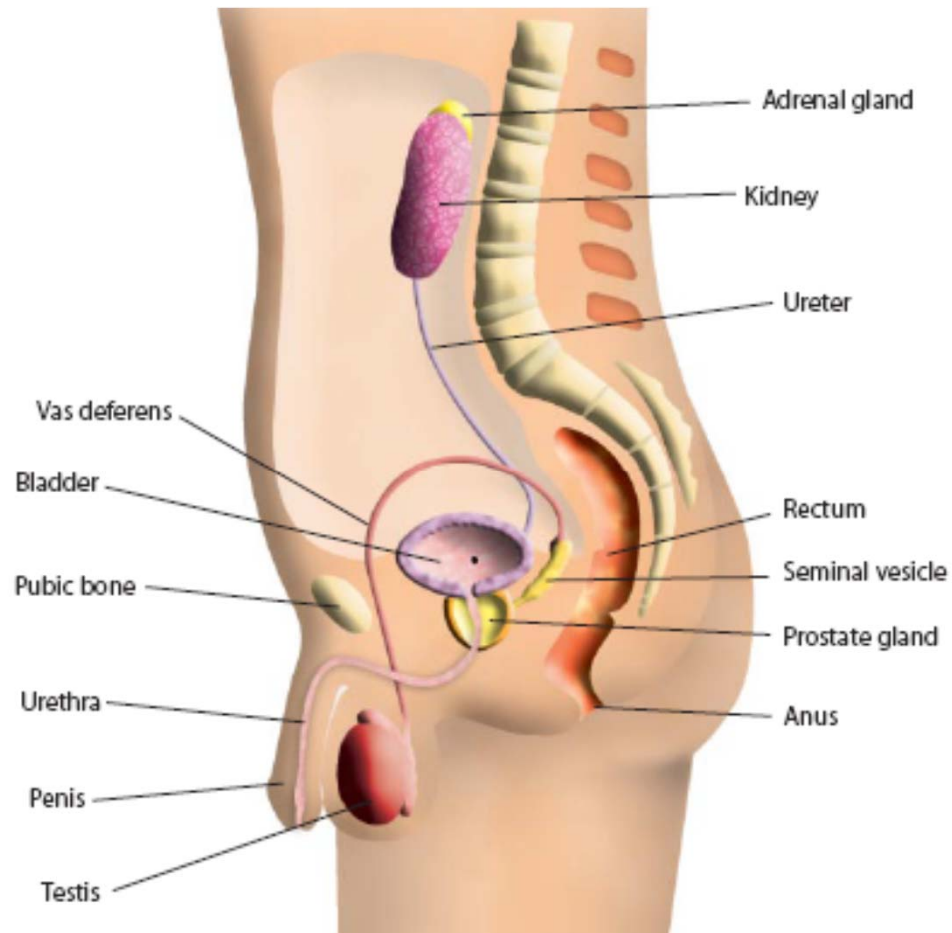
*Axel Krieger, Robert Susil, Siddharth Vikal, Csaba Csoma, Iulian Iordachita, Louis Whitcomb, Peter Guion, Cynthia Menard, Jonathan Coleman, Andras Lasso, Junichi Tokuda, Noby Hata, Helen Xu, Hadi Tadayyon, Yi Gao, Allan Tannenbaum
Clif Burdette, Danny Son, Peter Kazanzides, Jonathnan Fiene, Christopher Kennedy, Gernot Kronreif...*



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Prostate and what it does



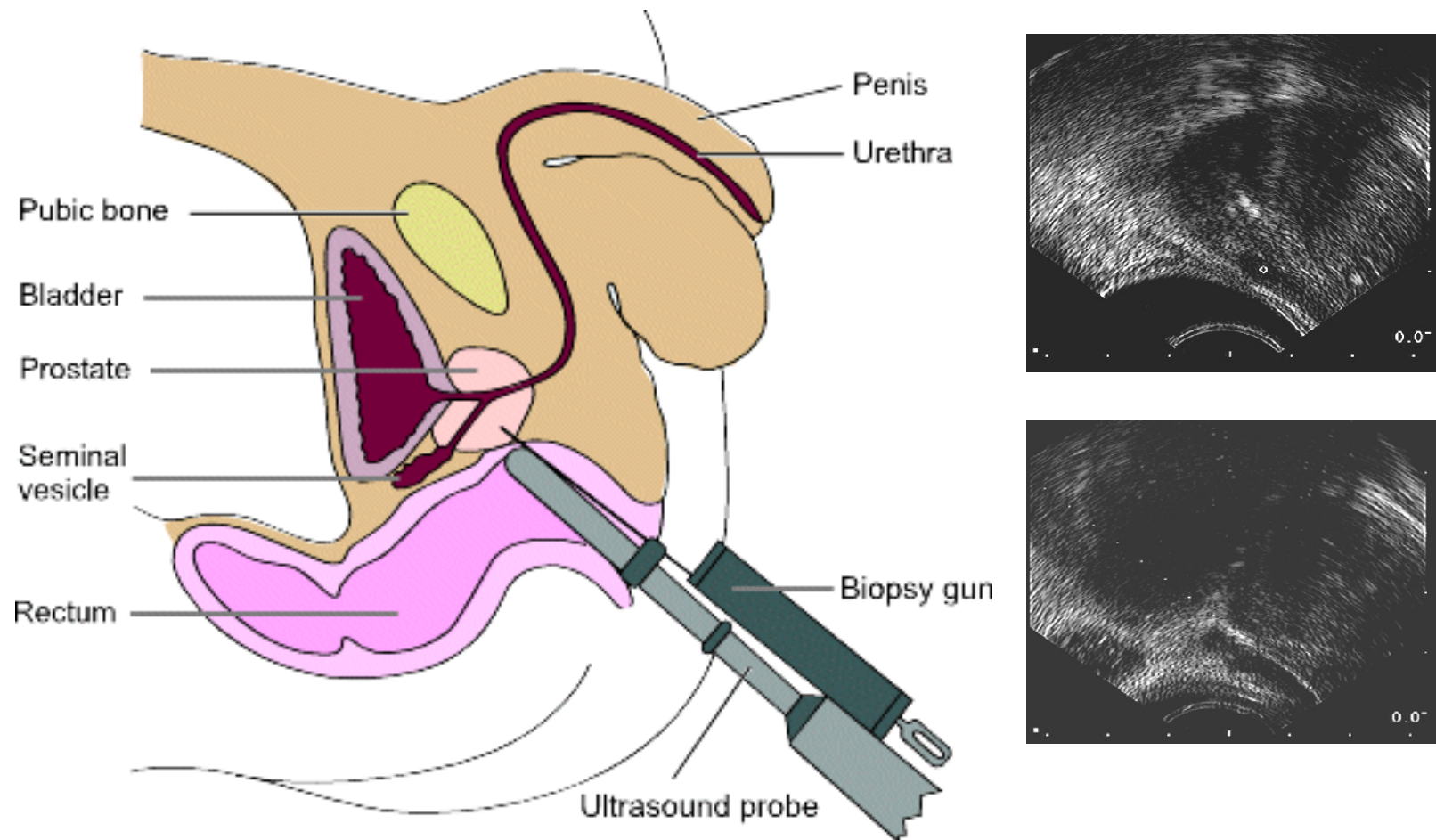
Prostate cancer stats¹

- Over 1M biopsies
- 240,000 new prostate cancer cases
- Likely double by 2025
 - **Great many negative biopsies...**
- 30,000 deaths
- >90% long term DFS w/ early stage disease
 - **Local control is quite effective**
 - **Quality of life matters the most**

¹ *Jemal et al. Cancer statistics, CA Cancer J. Clin. (2010)*



Standard of care: TRUS biopsy

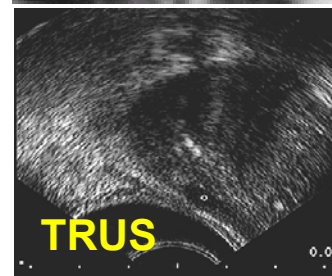
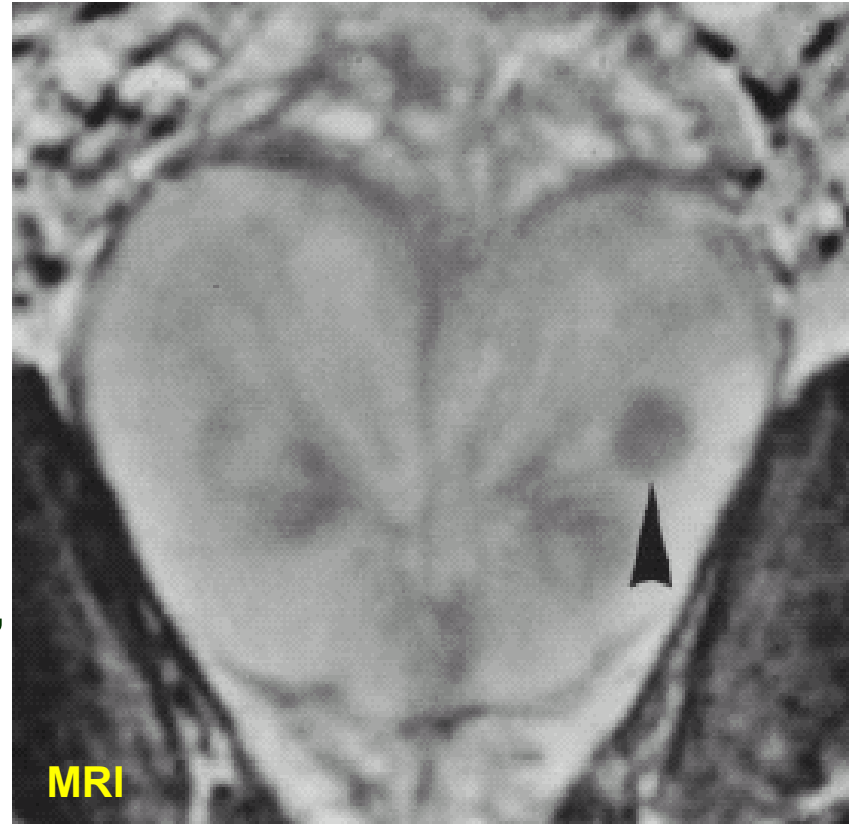


Cancers as large as a sugar cube may be missed...



Why MRI?

- No ionizing radiation
- High soft-tissue contrast
- High resolution imaging
- True 3D volumetric imaging
- Multi-parametric imaging
 - T1/T2 weighting, Functional, Diffusion, Flow, Temperature, Oxygenation, ...
- Can provide “real-time” imaging capabilities



Extreme environment



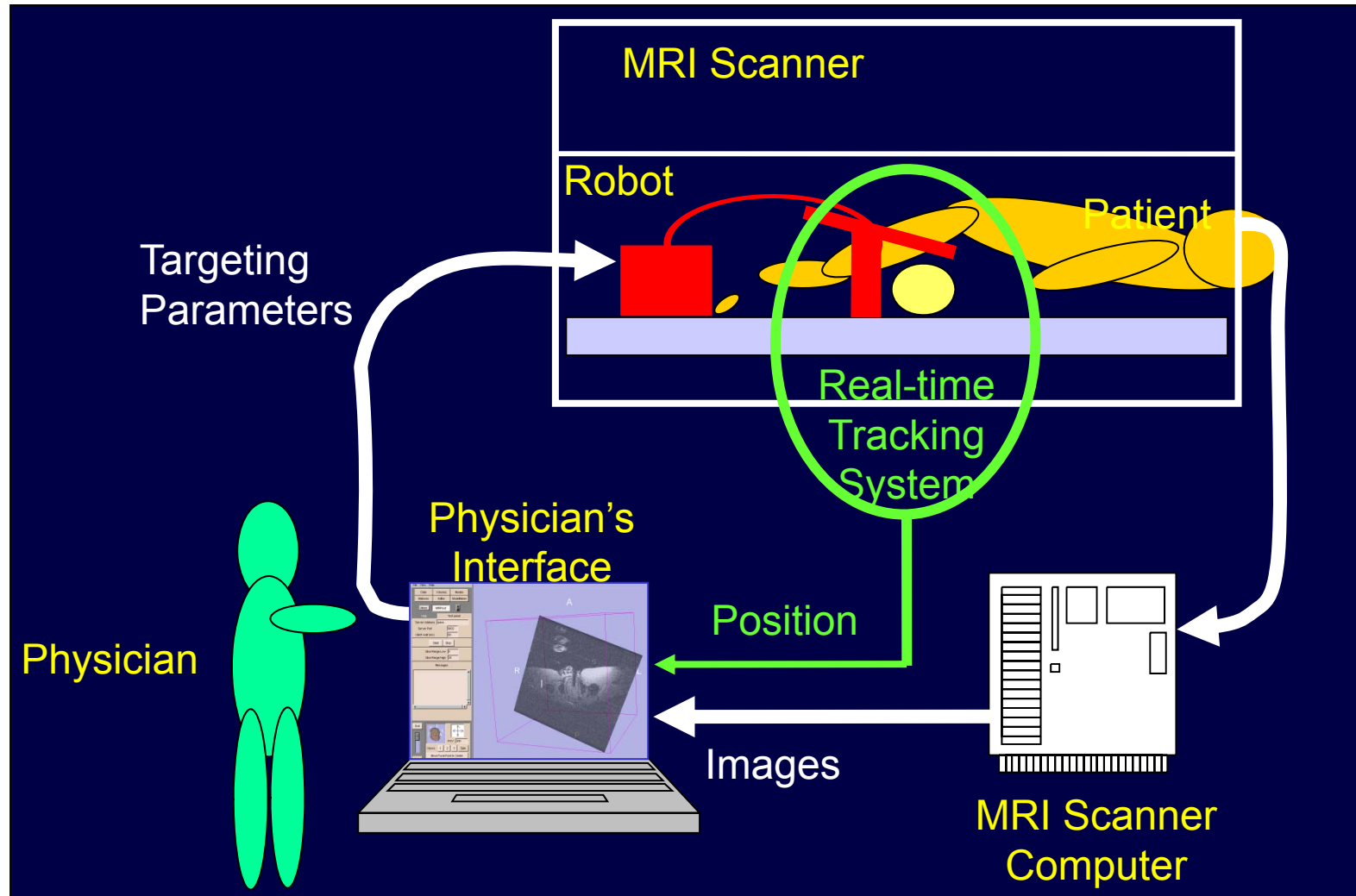
PLAY MOVIE



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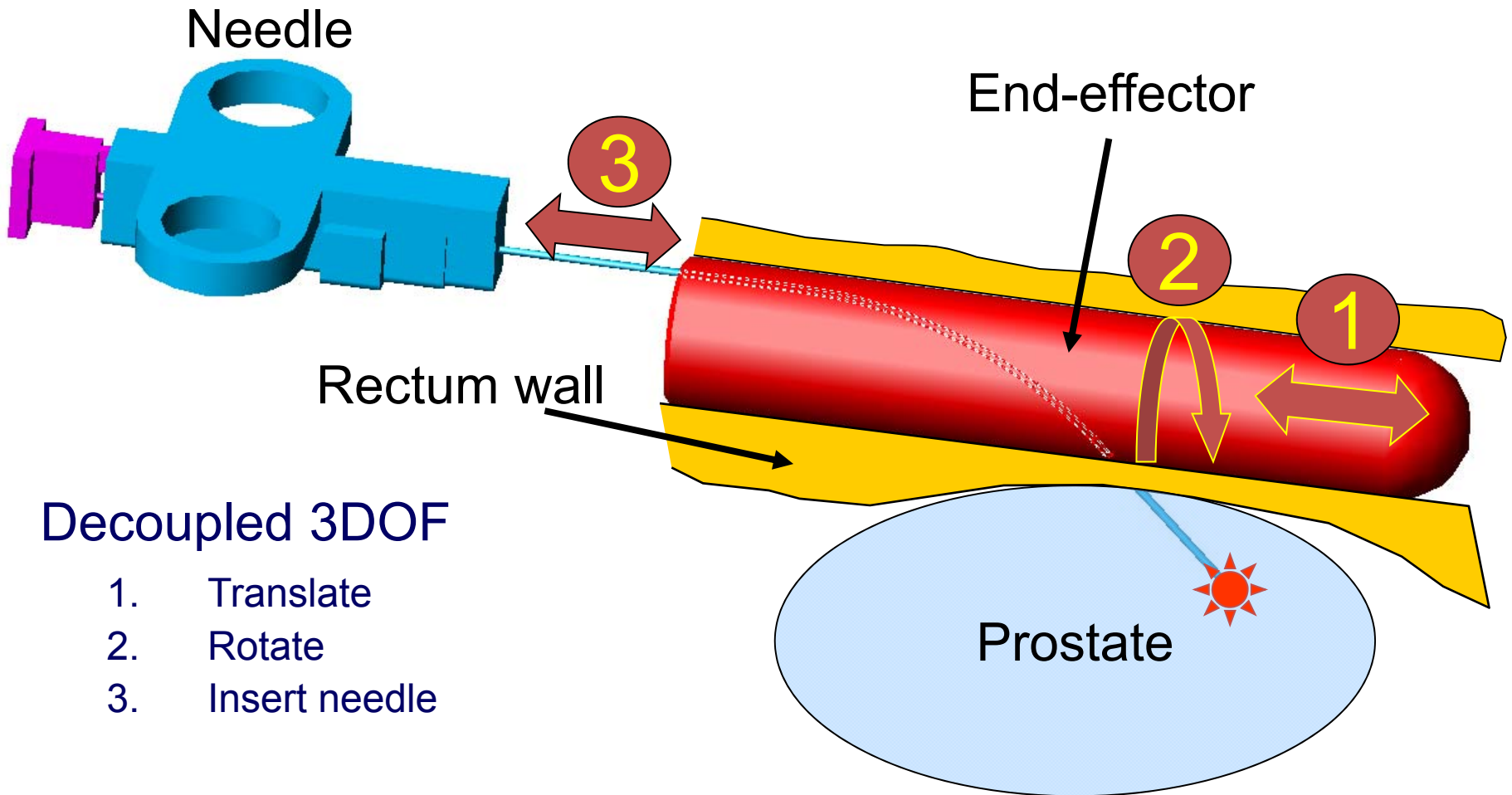
“Point & Click” concept



Fichtinger *et al.* MICCAI, 2002



Kinematic design



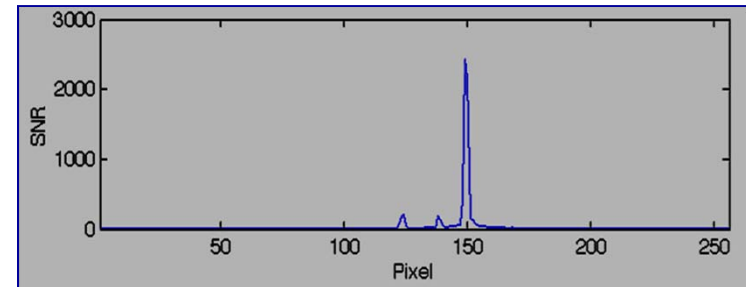
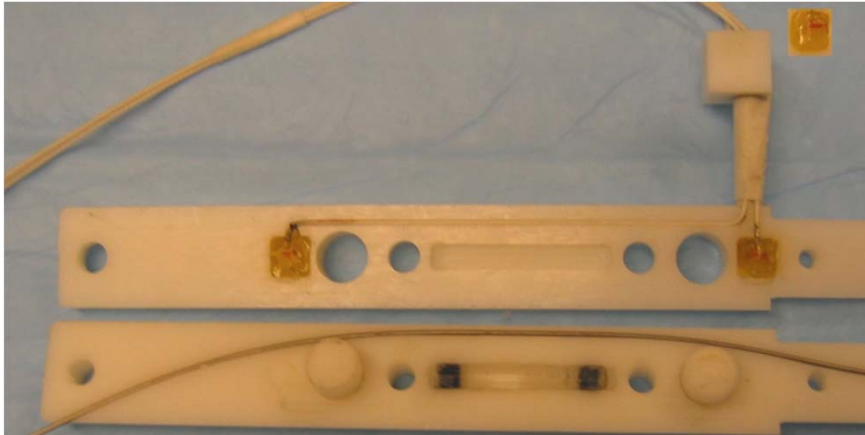
Fichtinger *et al.* MICCAI, 2002



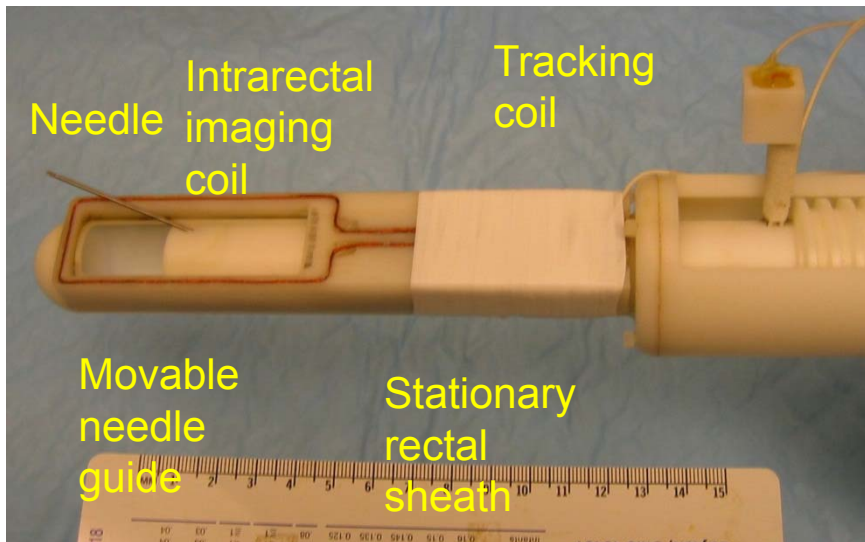
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Active MRI tracking



Signal projection for one tracking coil

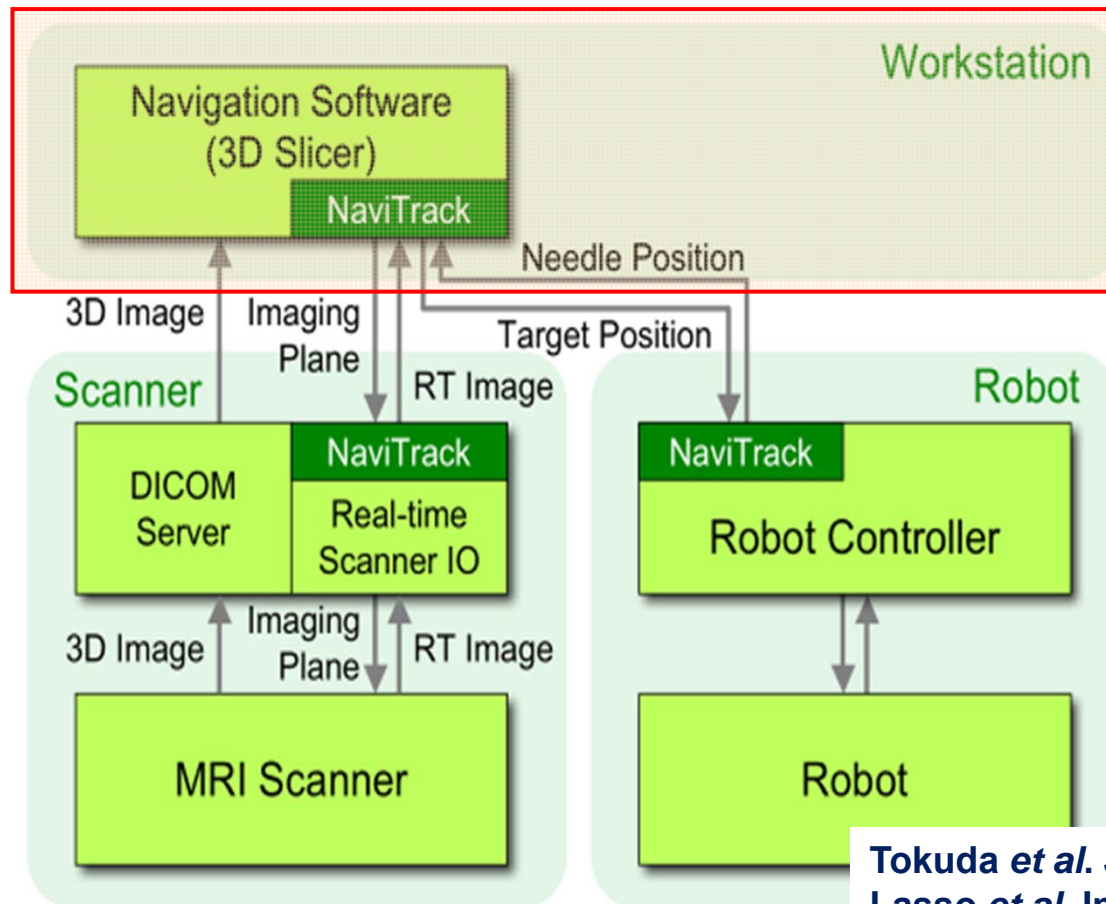


Krieger et al. IEEE TMBE, 2005



Open Source & Open Architecture

- Rapid prototyping of new apps
- Predictable performance
- Faster regulatory approval
- Sharing among institutions



Patient imaging



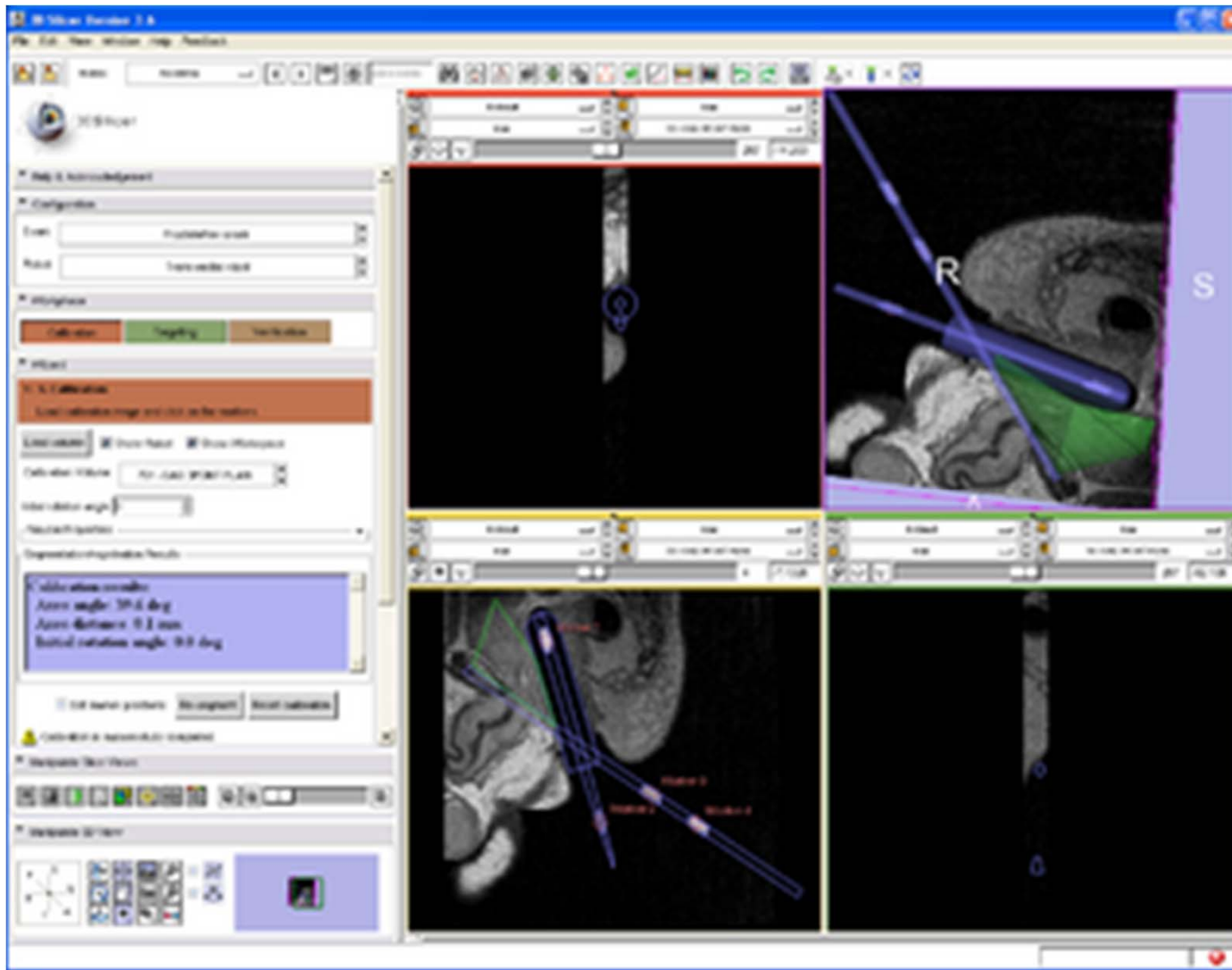
Susil et al. J. Urol, 2006



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Calibration



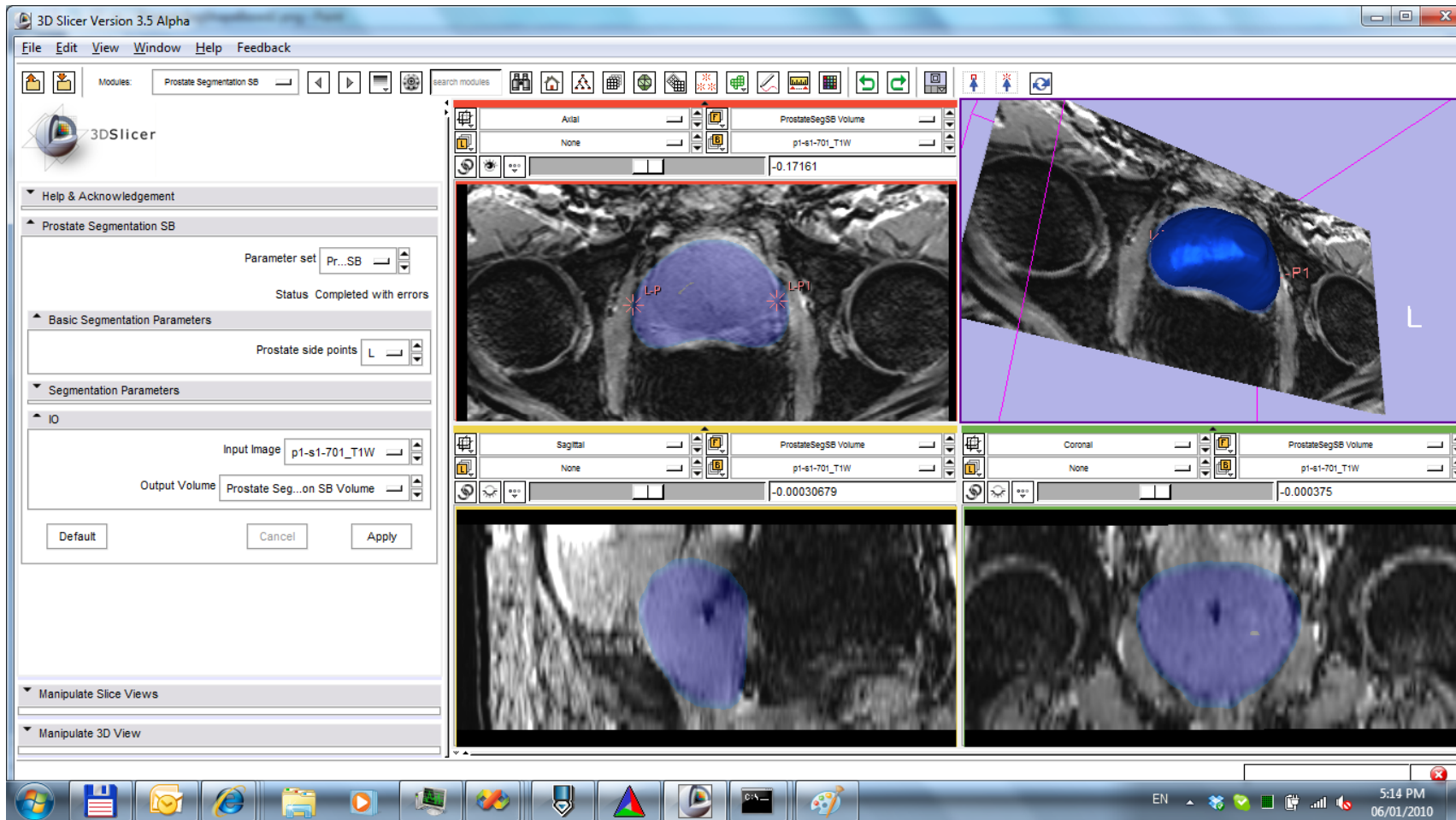
Lasso et al. NAMIC, 2010



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Modeling



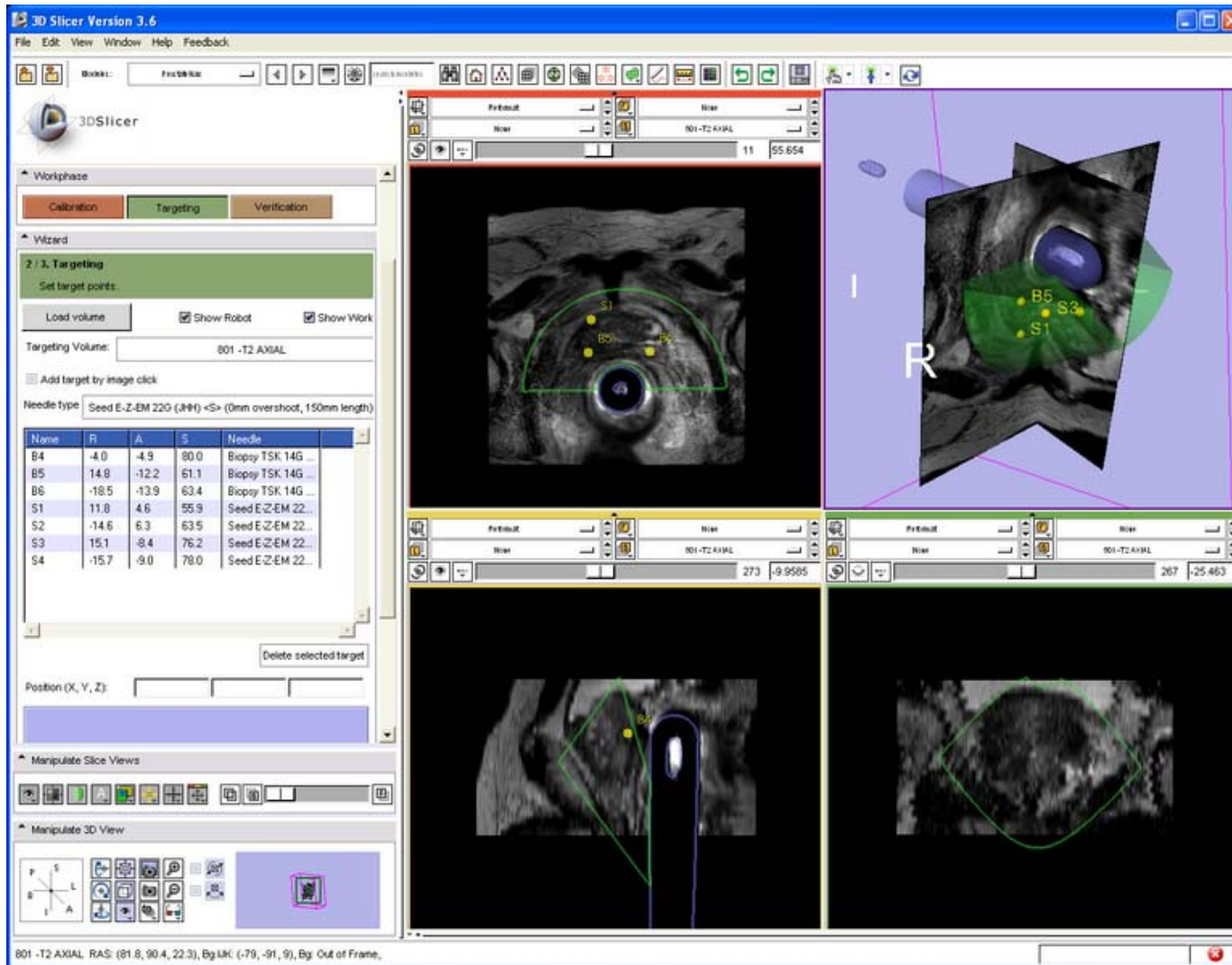
Gao *et al.* IEEE TMI 2010



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Target planning



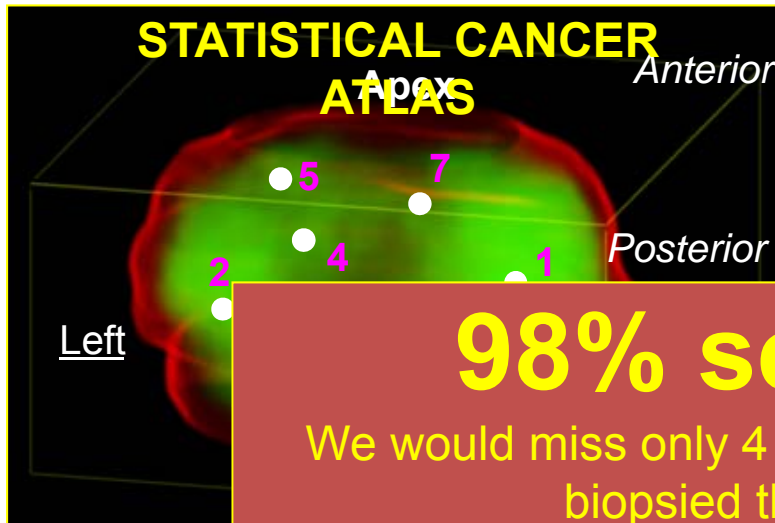
Lasso et al. NAMIC, 2010



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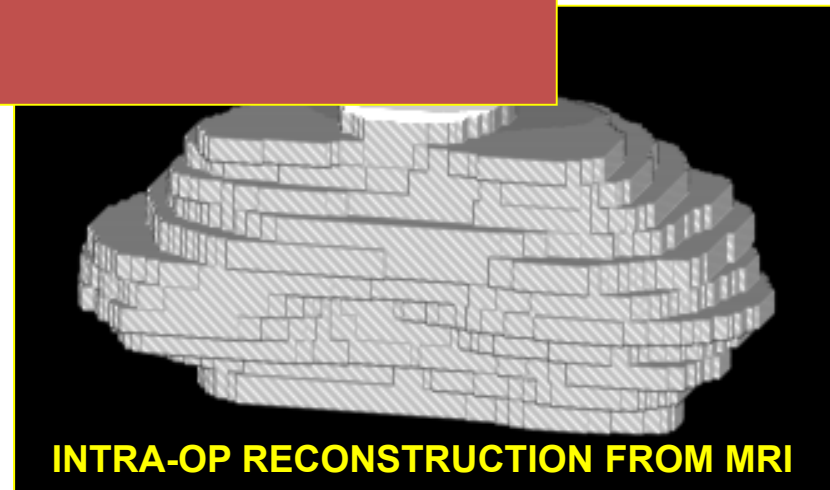
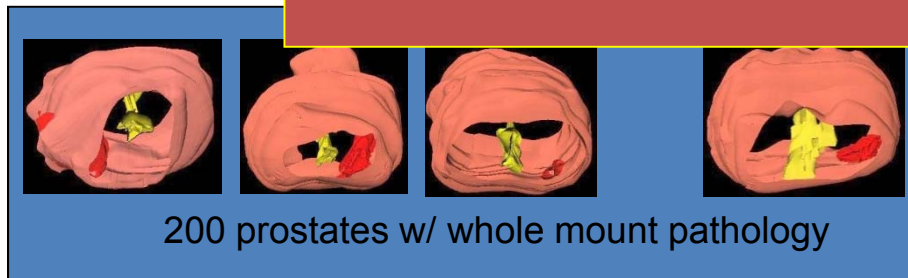


Population based planning



98% sensitivity

We would miss only 4 cancers out of the 200 if we biopsied those men today



Shen *et al.* *MedIA*, 2004
Zhan *et al.* *IEEE TMI*, 2007
Zou *et al.* *MedIA*, 2009



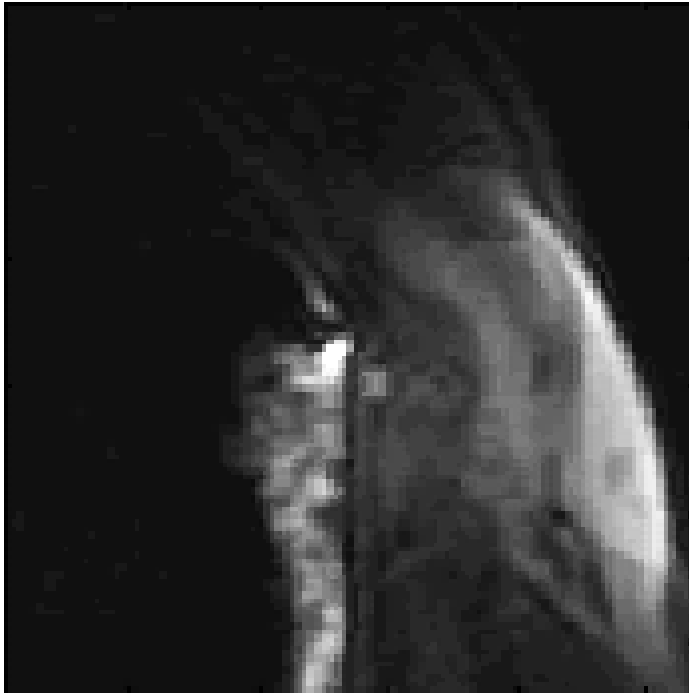
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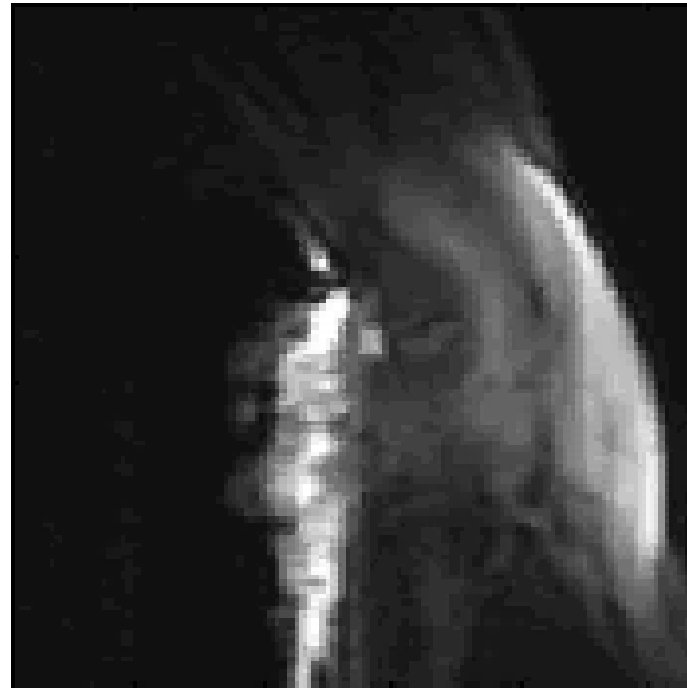
Execution



Real-time monitoring



GOOD DEPOSITION



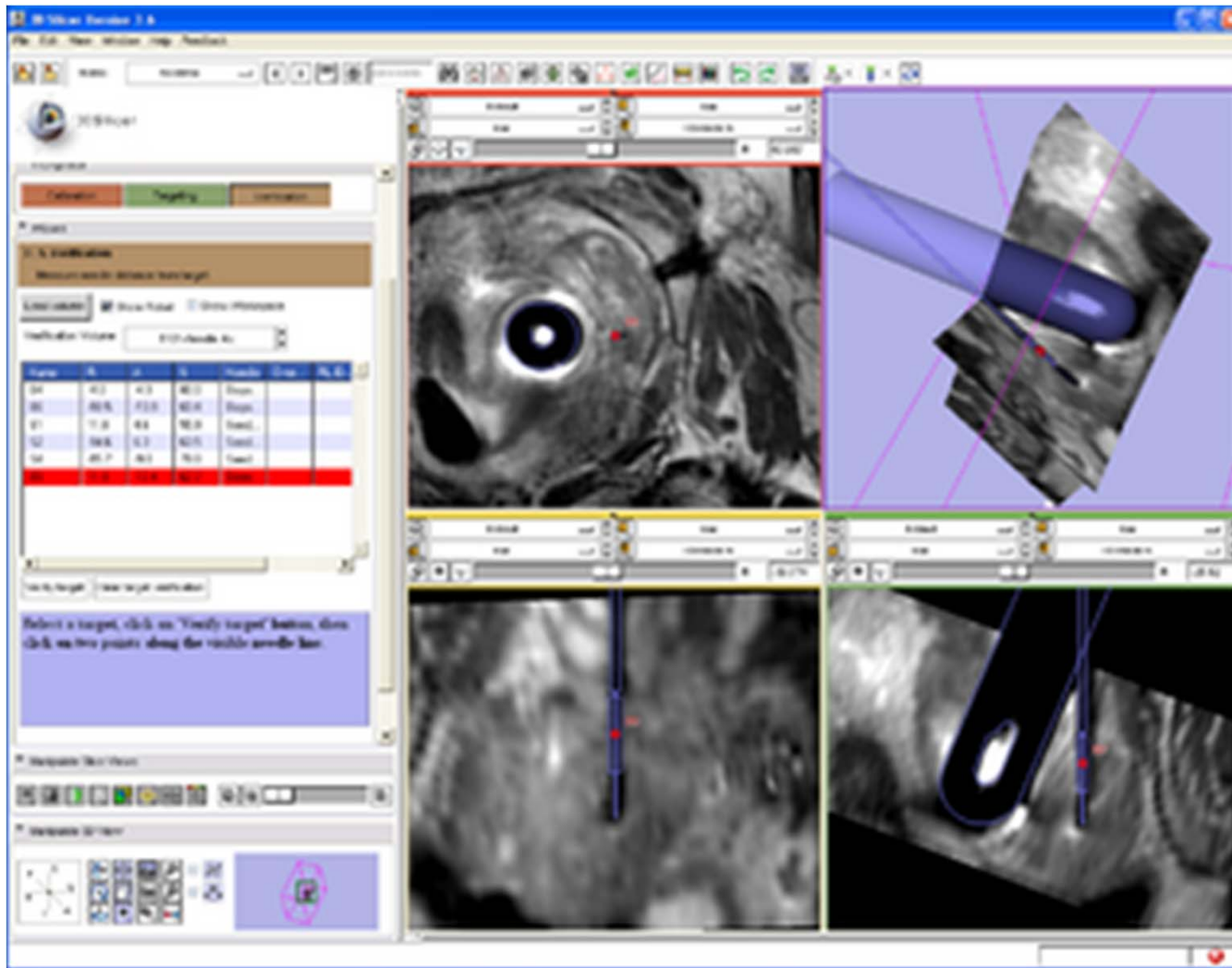
REFLUXED INJECTION

- Transrectal robotic needle placement
 - Monitoring at 10fps

Chowing *et al.* Prostate, 2006



Verification



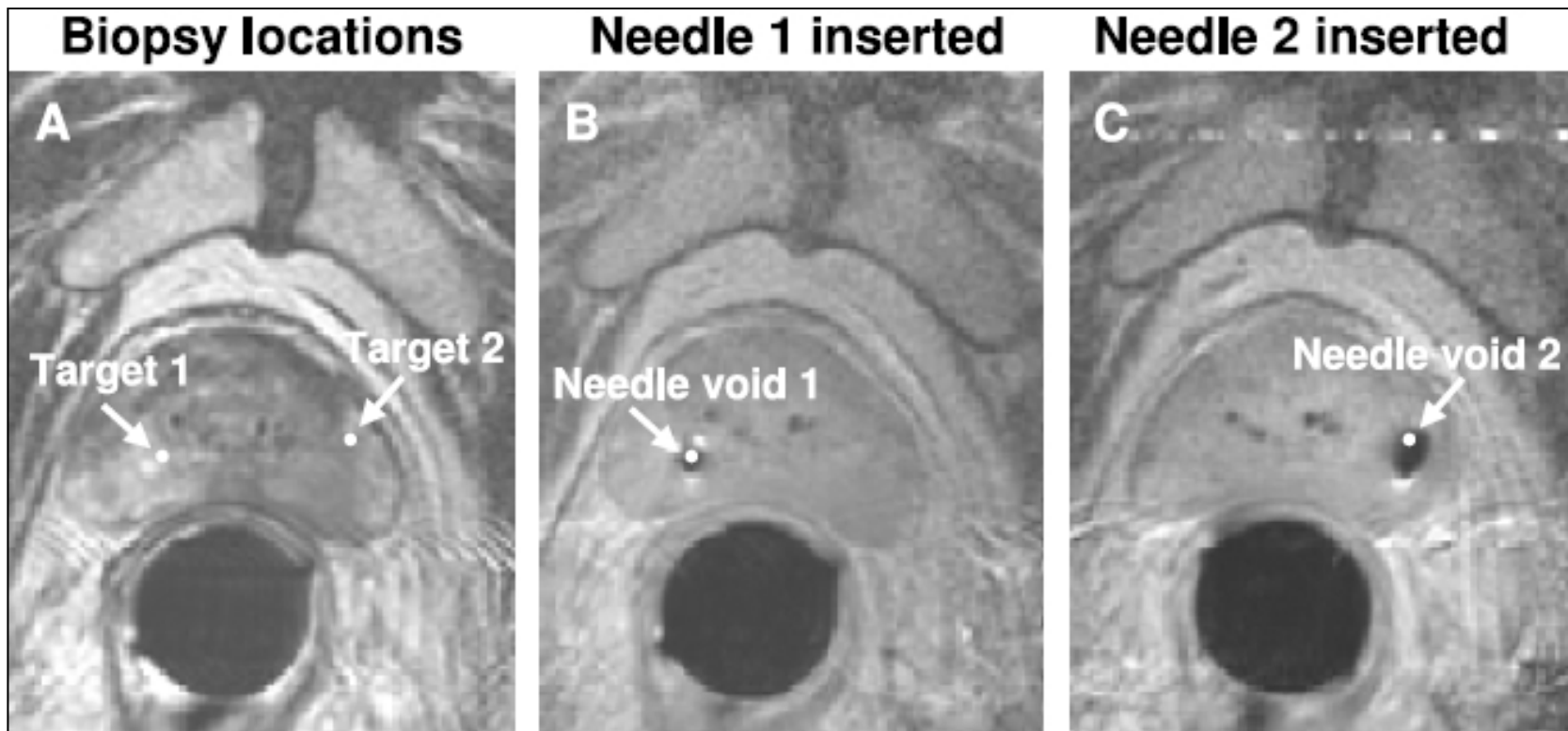
Lasso *et al.* NAMIC, 2010



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Verification (close-up)



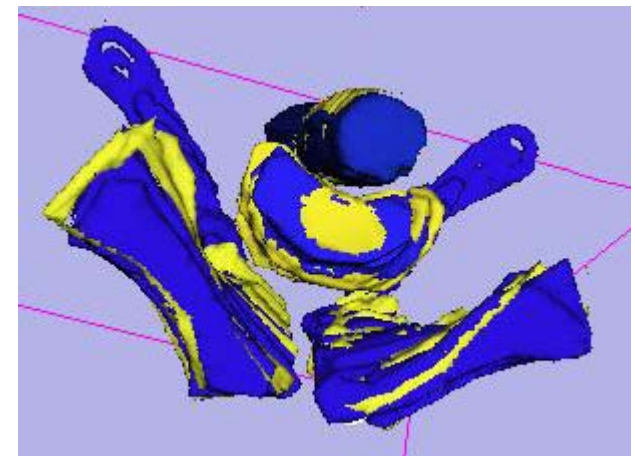
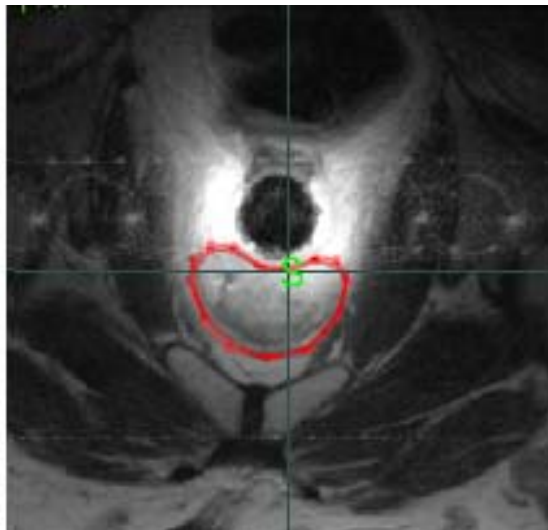
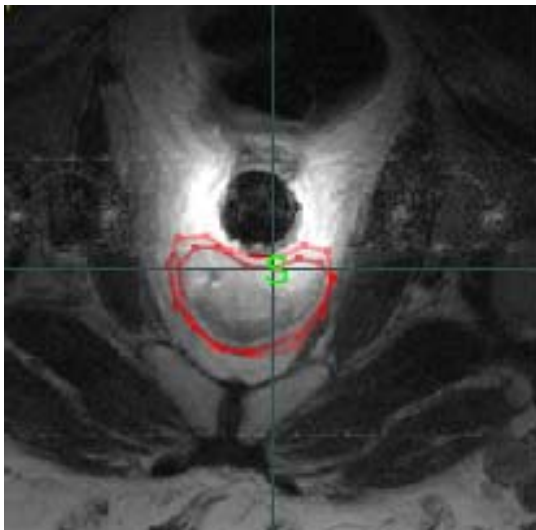
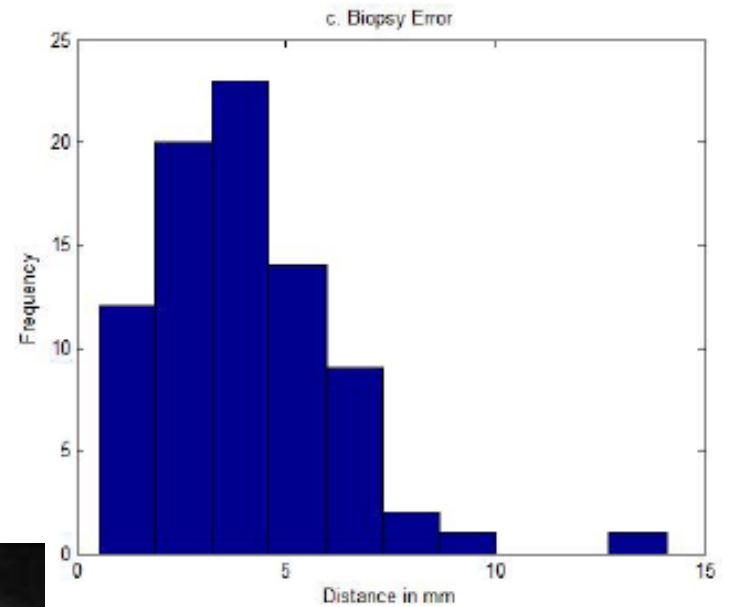
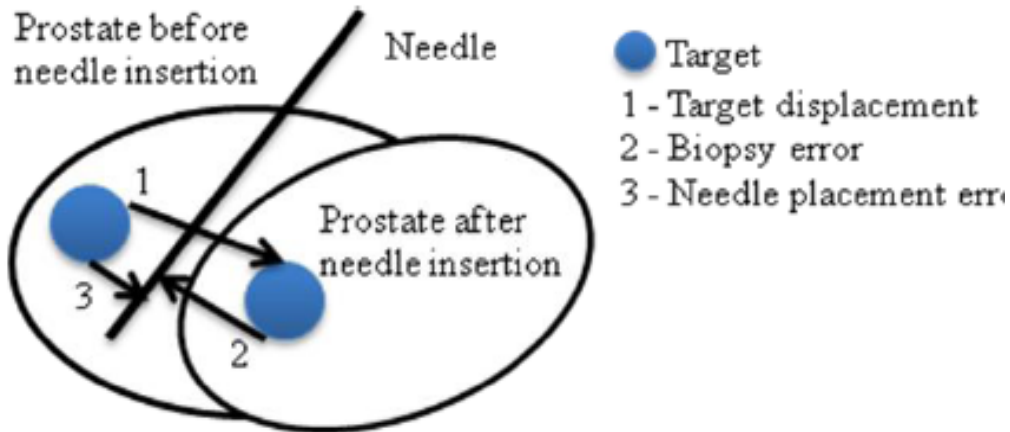
Susil *et al.* J. Urol, 2006



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Five-year retrospective

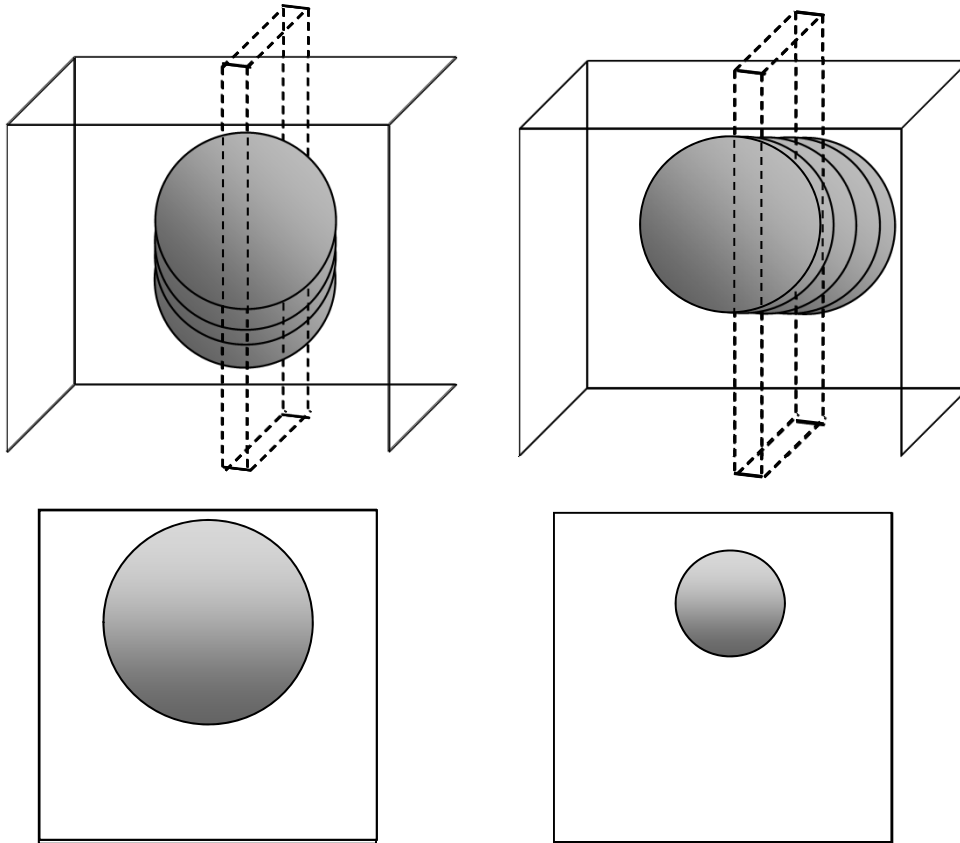


Xu *et al.* MICCAI 2010

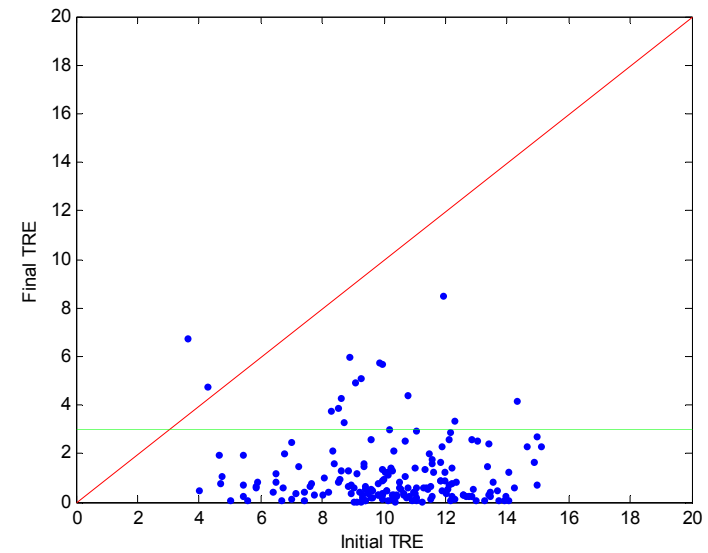


Target motion tracking

Moving prostate volume & fixed MRI slices



Simulation results



Mean TRE: 0.83mm

STD=0.54mm

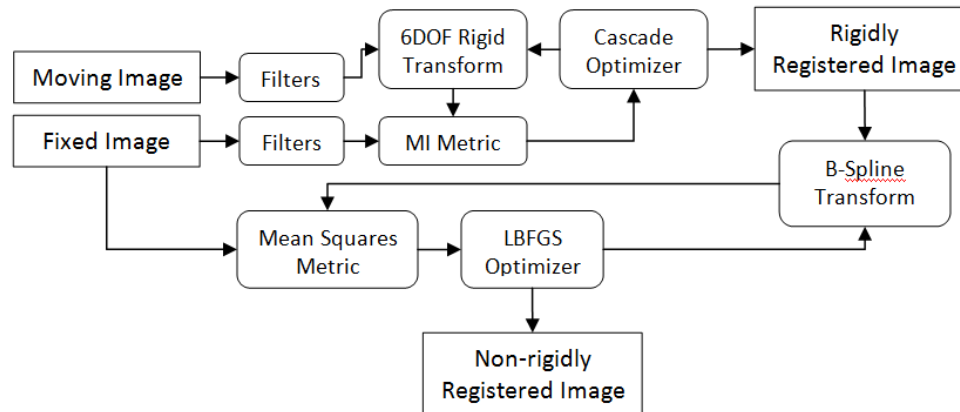
Failure rate on first run: 9%

Final failure rate: 0%

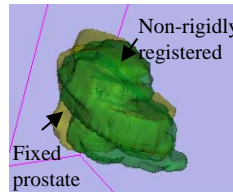
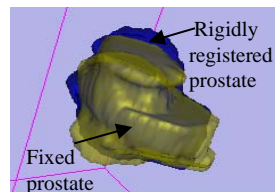
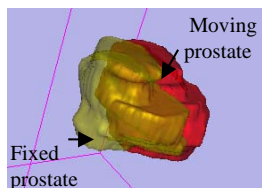
Gill et al. SMIT 2008



Target motion tracking



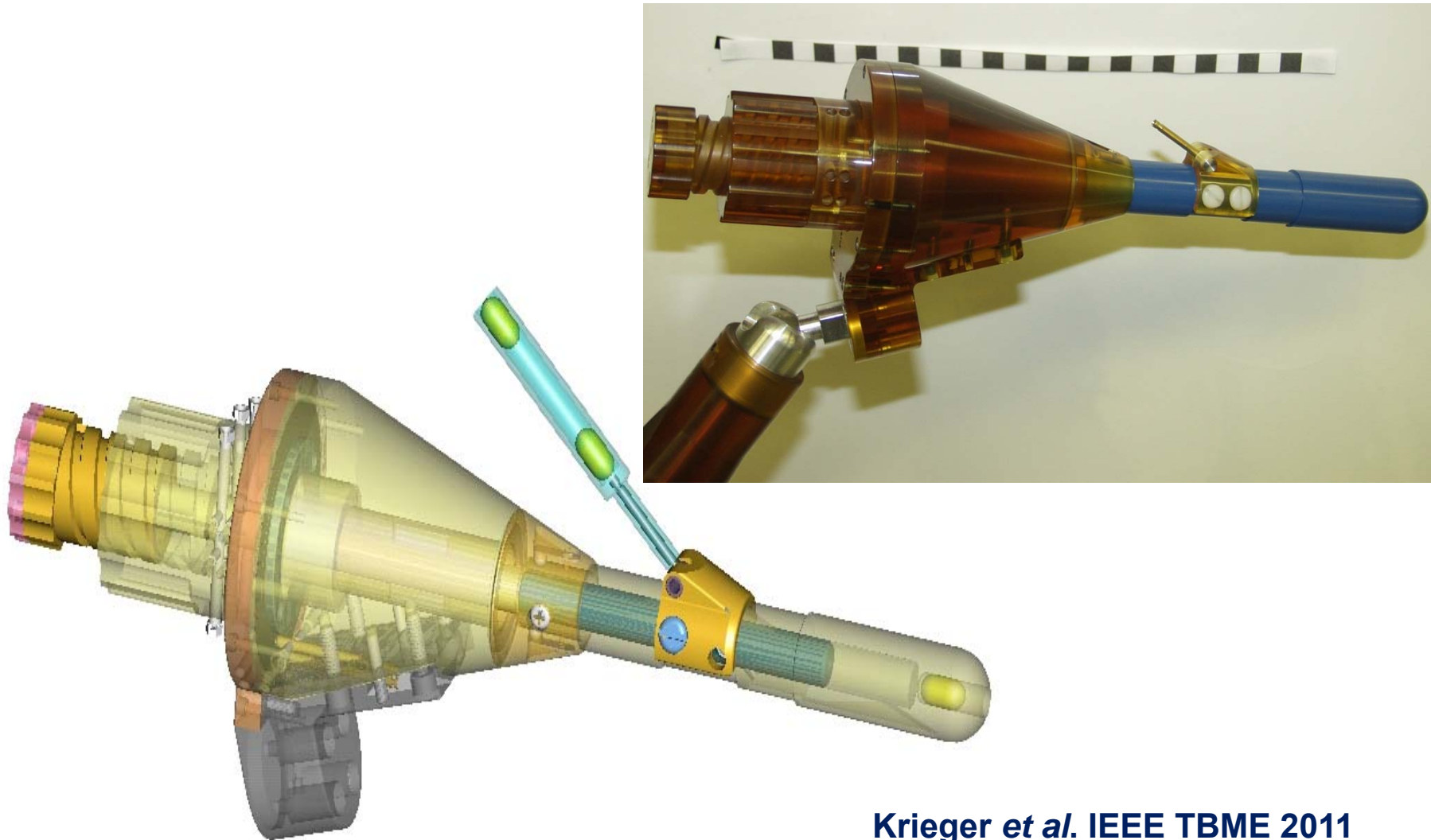
		Patient 1	Patient 2	Patient 3	Overall
	Initial target Displacement	9.85	4.33	17.33	10.50
Rigid	Tracking Error	2.26	2.22	3.65	2.71
	Registration Time	39	60	37	45
Deformable	Tracking Error	2.17	2.24	3.66	2.69
	Registration Time	58	308	147	142



Tadayyon *et al.* SPIE Med Imaging 2010
 Tadayyon *et al.* IEEE EMBS 2010
 Tadayyon *et al.* IEEE TBME 2011



Hybrid tracking



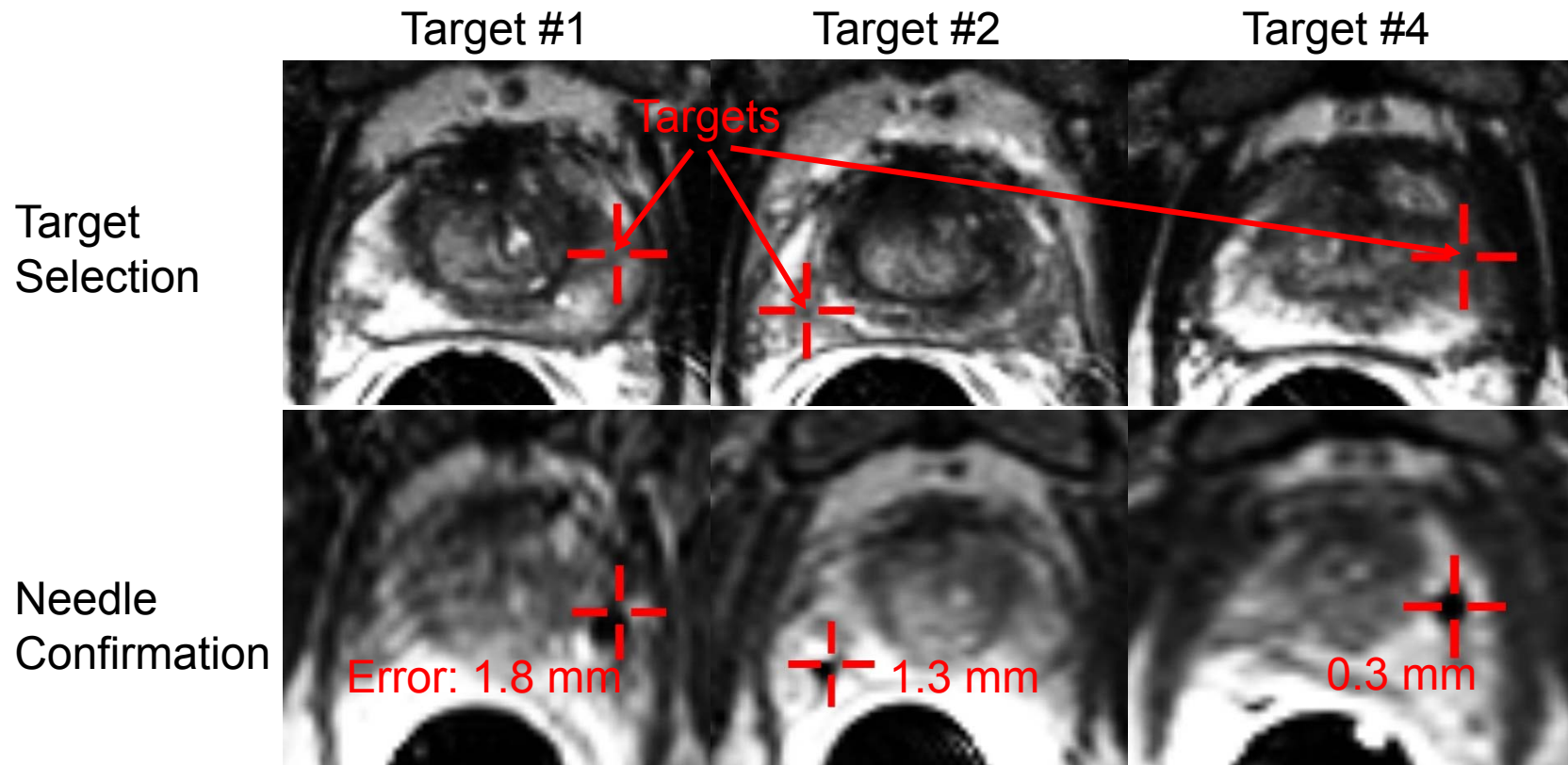
Krieger *et al.* IEEE TBME 2011



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Hybrid tracking – clinical result



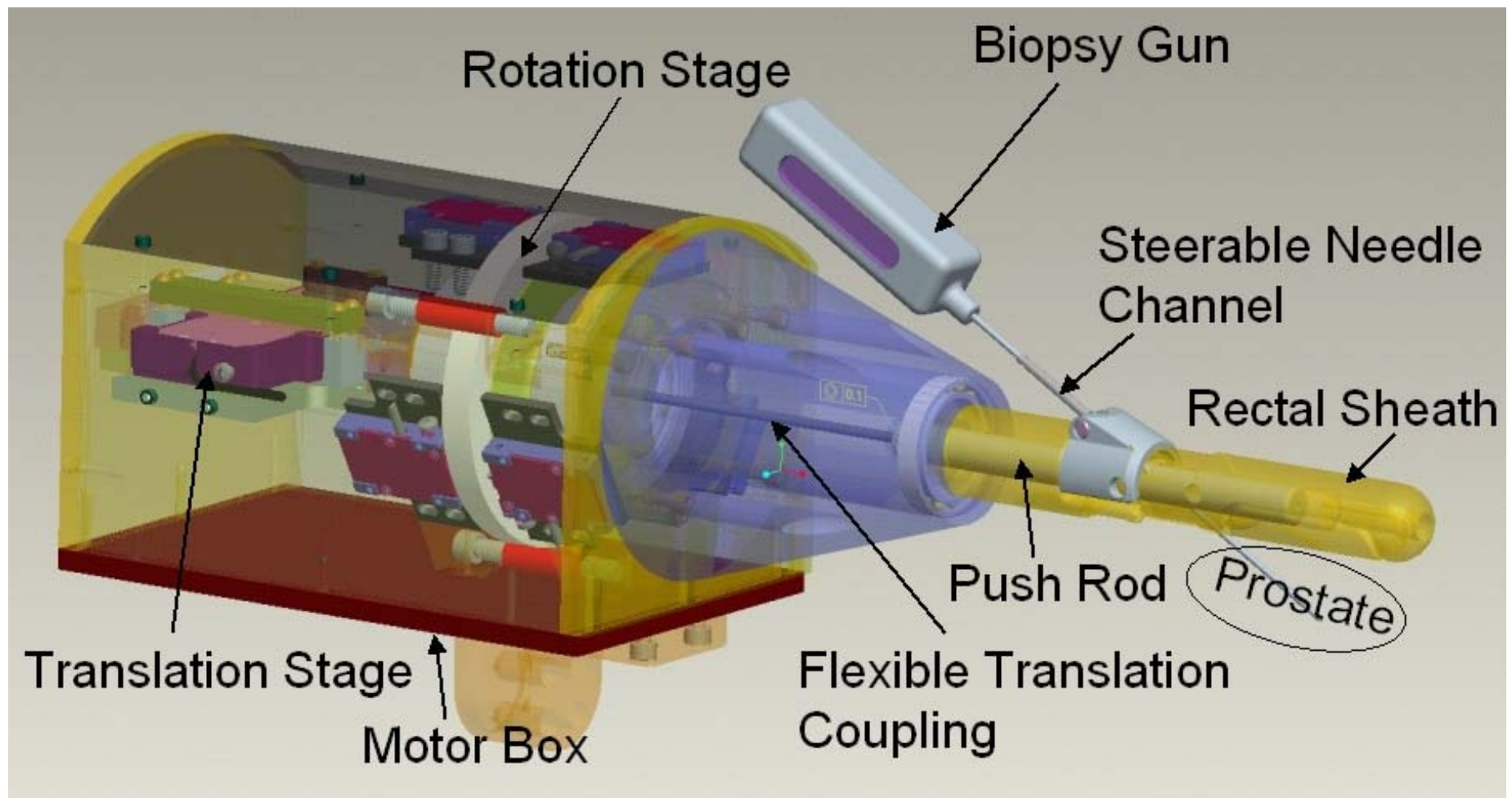
Singh *et al.* Radiation Oncology, 2007



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Actuated prostate robot design



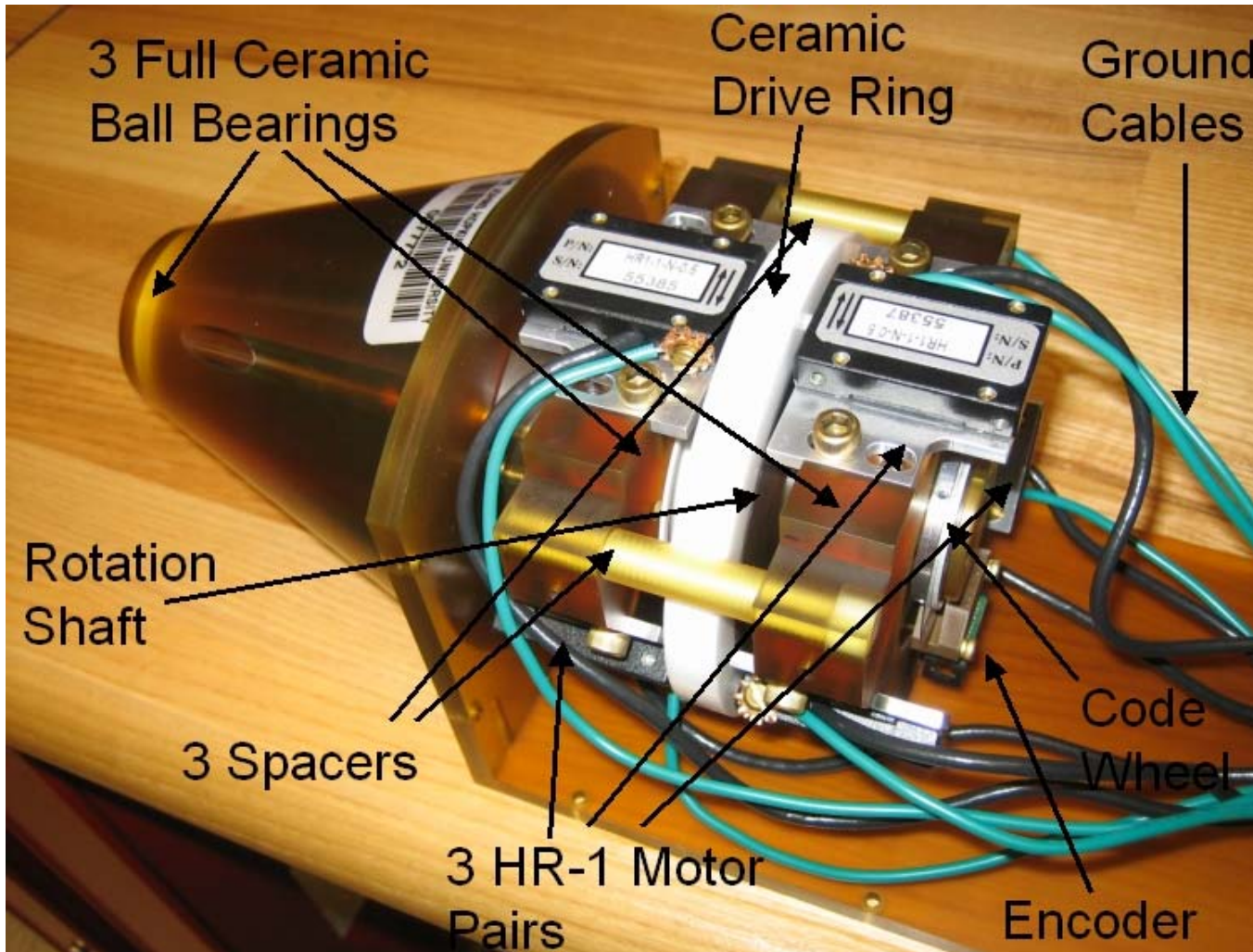
Krieger *et al.* IEEE ASME (in press)



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Actuated rotation stage



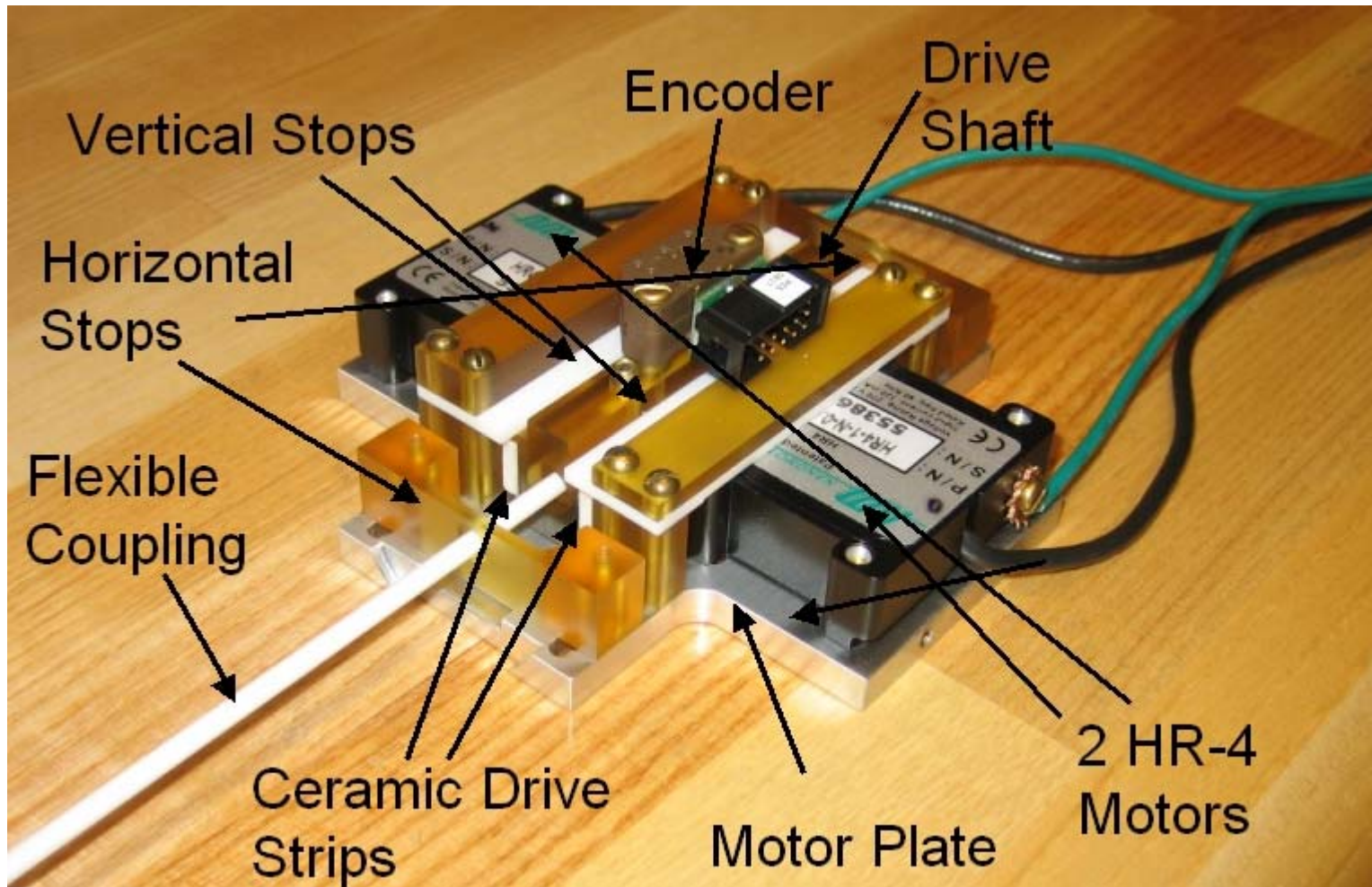
Krieger *et al.* IEEE TBME (in press)



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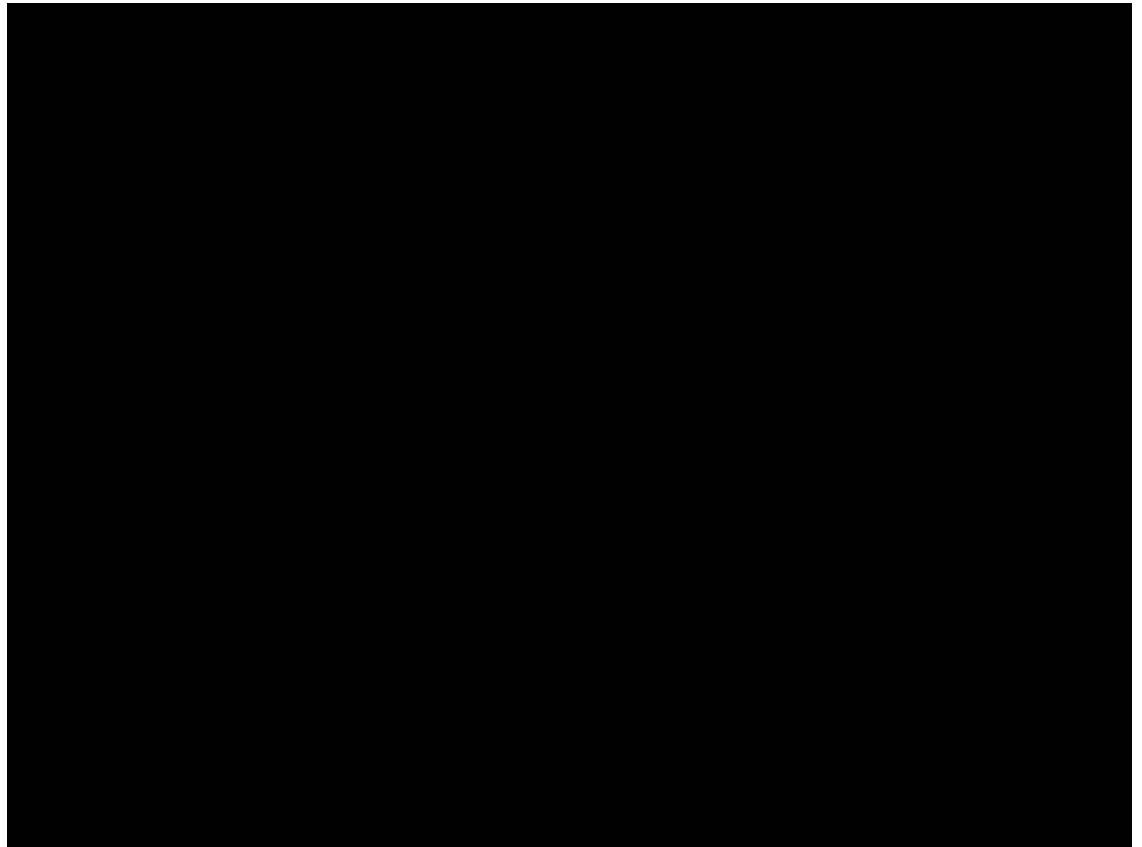
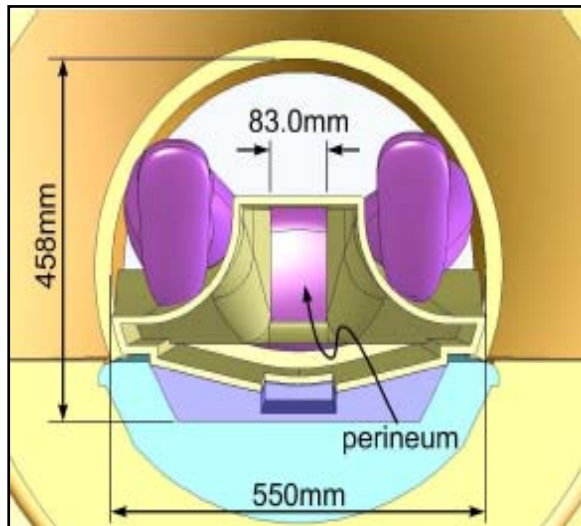
Actuated translation stage



Krieger *et al.* IEEE TBME (in press)



Transperineal in-MR intervention



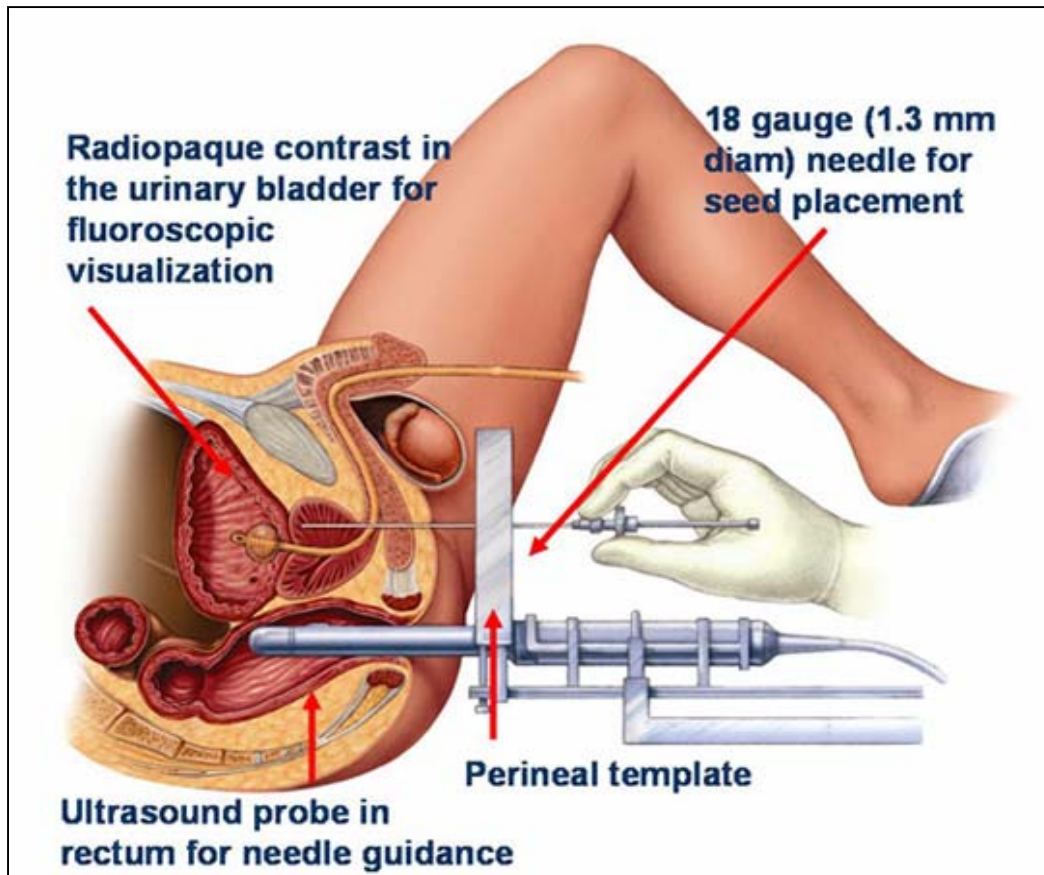
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Fischer *et al.* IEEE Trans Robotics, 2008



TRUS-guided brachytherapy

>50 000 operations each year in North America



Iodine-125 ($T_2=60$ days) or
Palladium-103 ($T_2=17$ days)

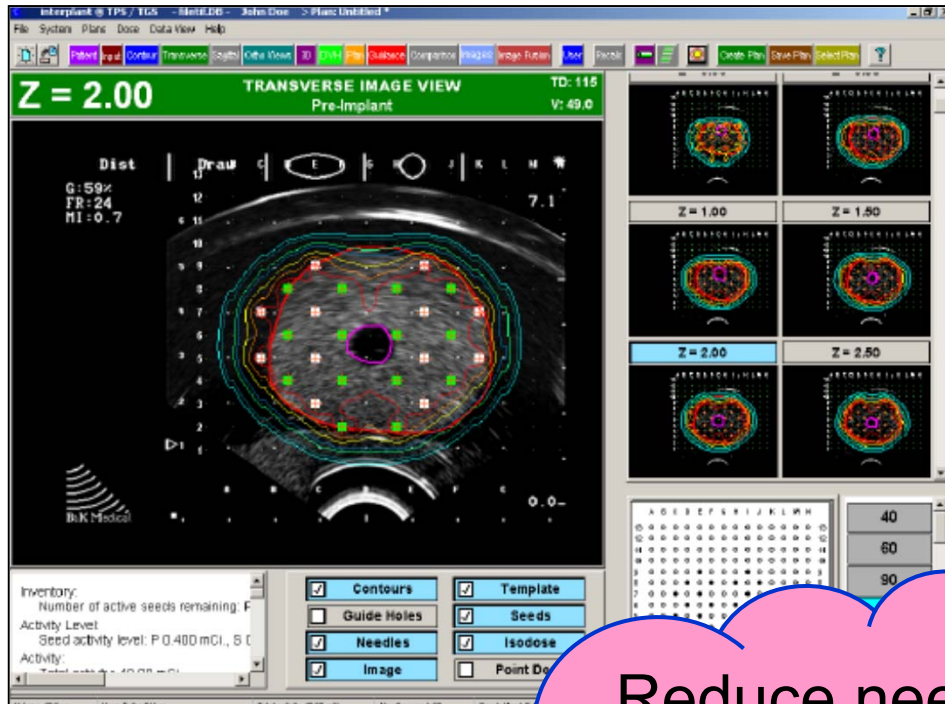
<http://delmarvacancerdoctors.com/>



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Plan v.s. actual implant



Reduce needle adjustments & needle time in prostate

Implants *NEVER*

- System mis
- Organ mot
- Needle be
- Edema

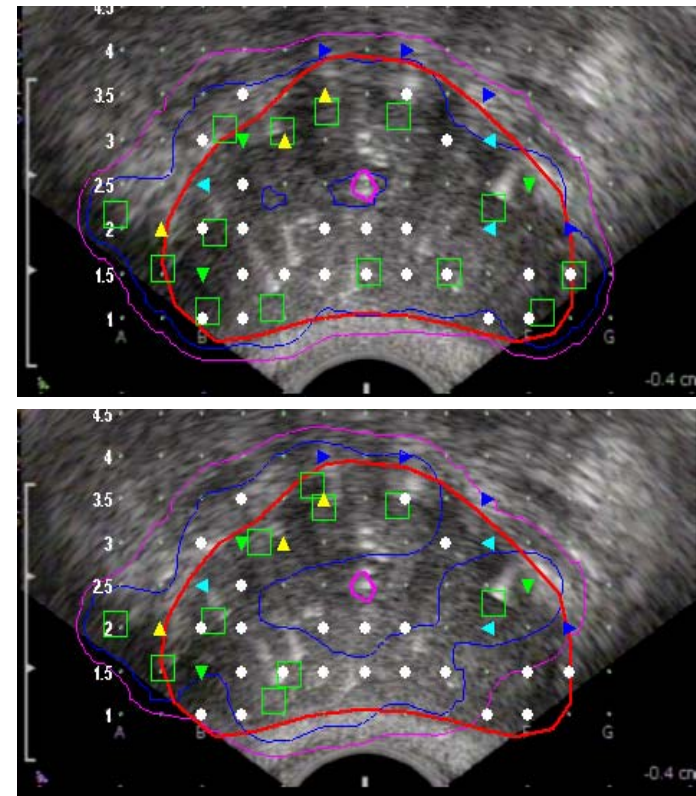
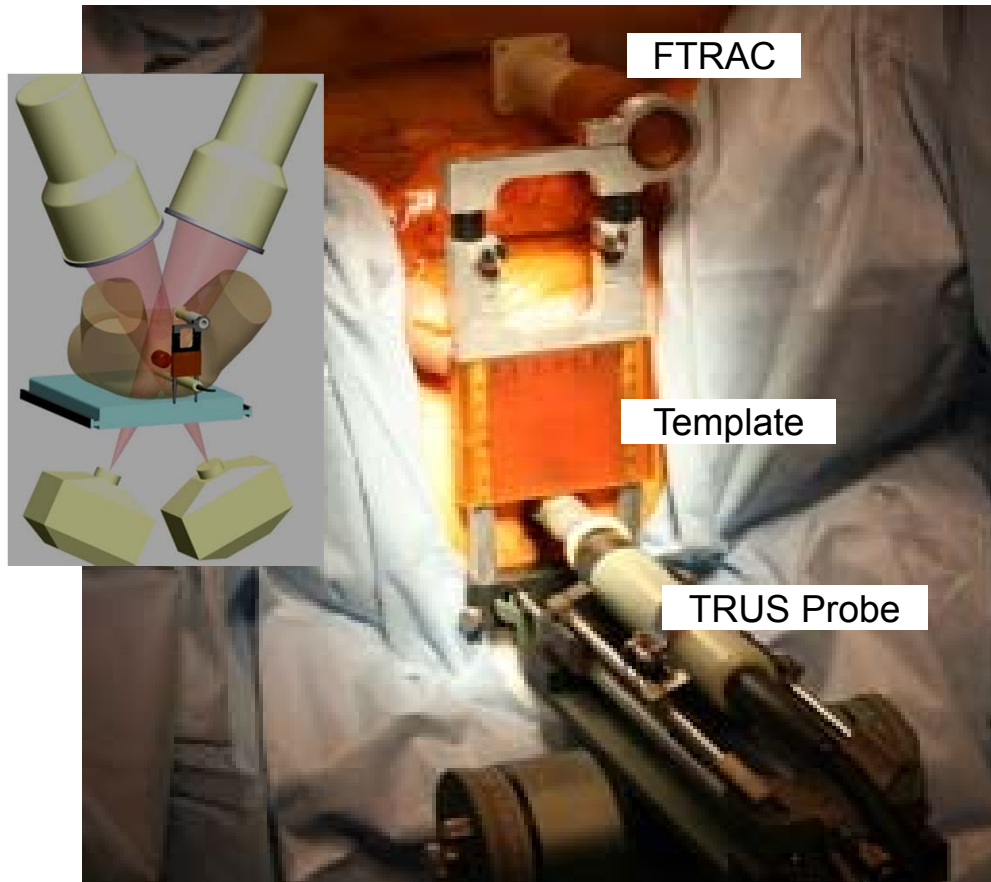
planned



Intra-operative seed migration

Intensity-based Registration of TRUS & fluoroscopy (iRUF)

- Colds spots on exit dosimetry
- Average 4 extra seeds (max 9)
- Edema: ~5.0mm (12mm max)



Fallavollita *et al.* Med Phys 2010
Dehghan *et al.* MICCAI 2011

Jain *et al.* MedIA 2011
Song *et al.* Brachytherapy 2011



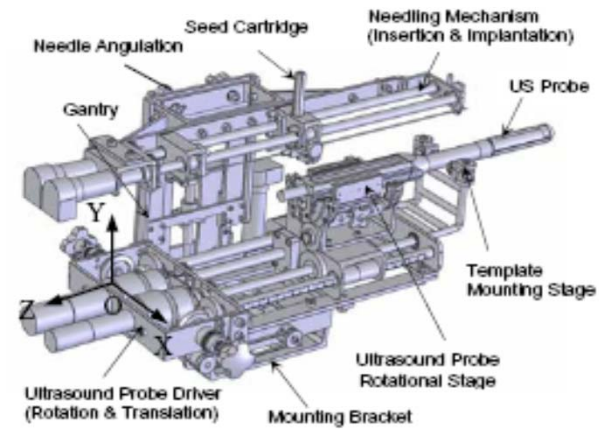
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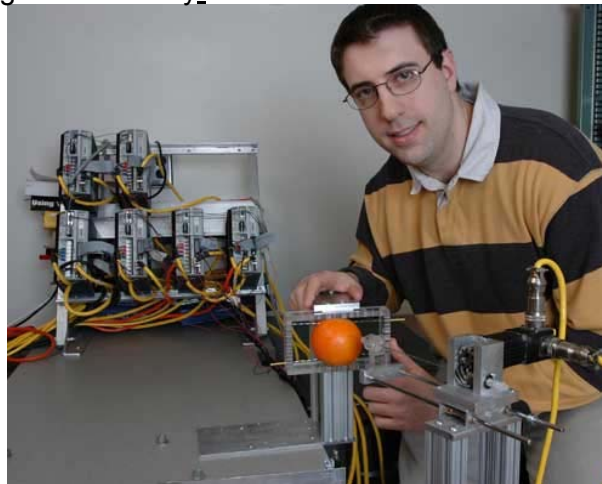
It's a lot of DOF



Sin *et al.* Nanyang Technological University



Yu & Podder *et al.* MICCAI 2006

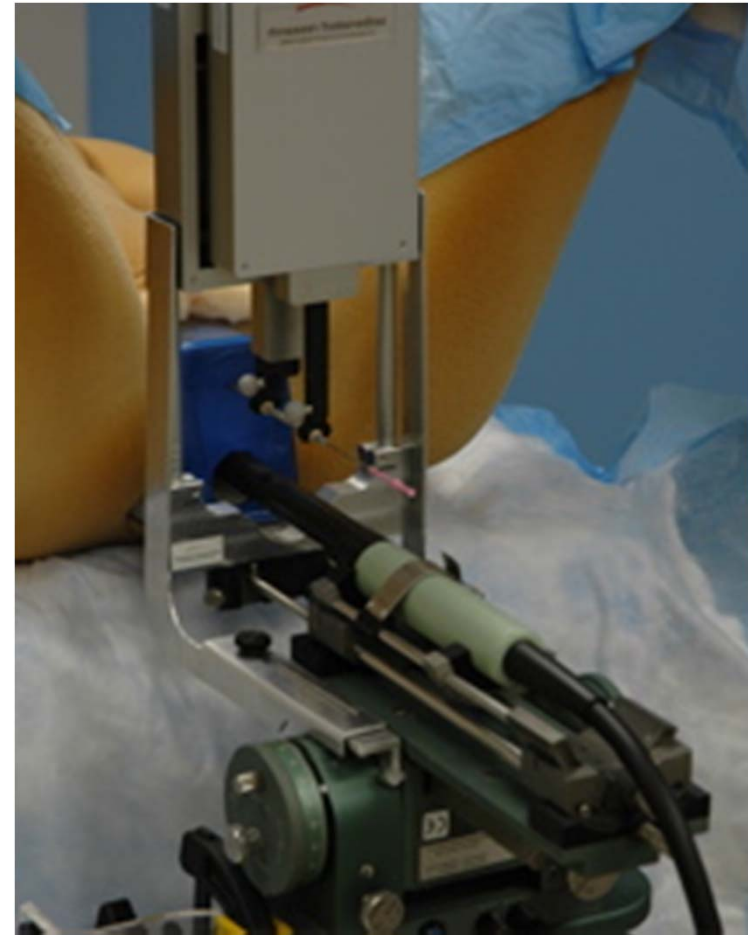
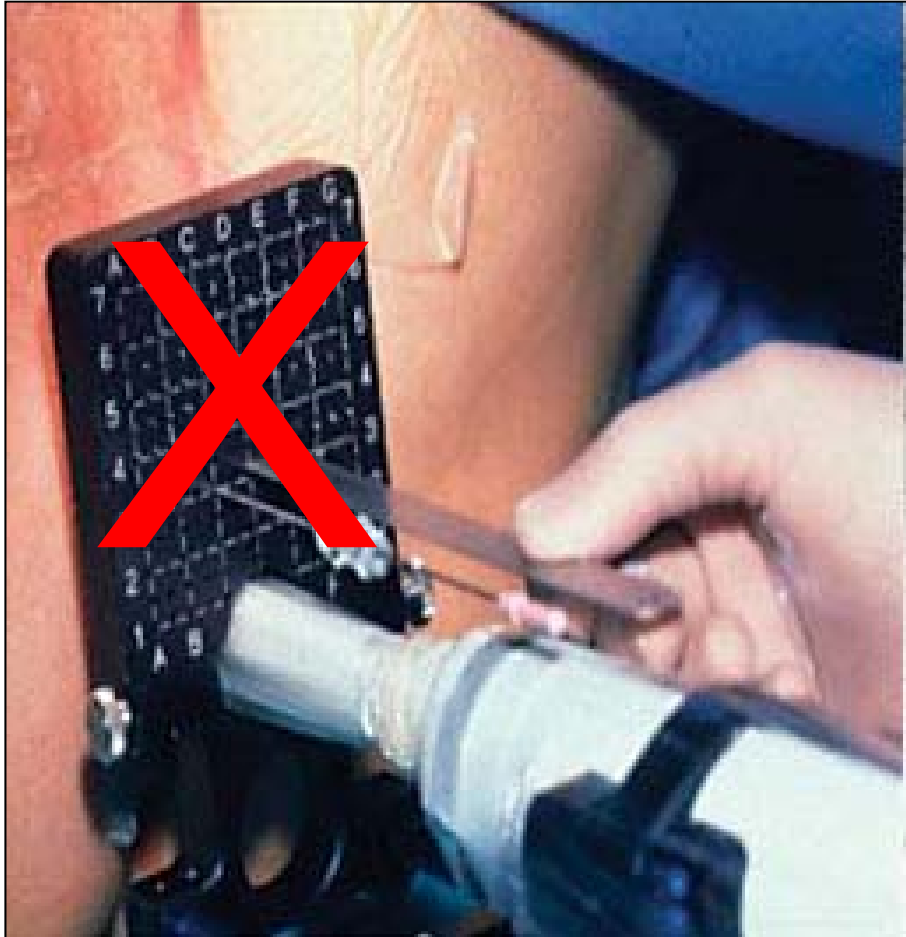


Meltsner *et al* Phys. Med. Biol. 52 6027-6037, 2007



Replace template w/ robot

Must not alter clinical setup & workflow



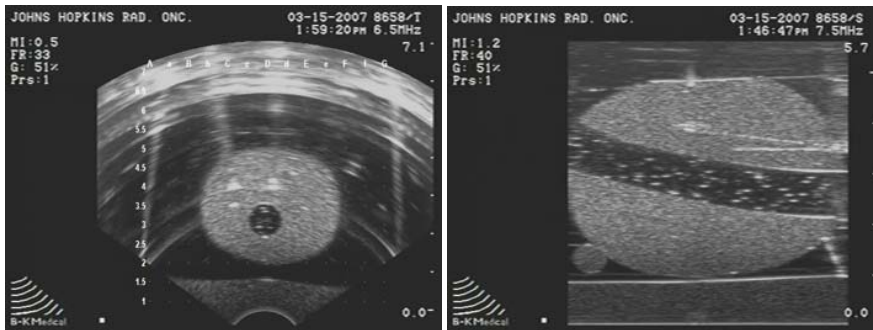
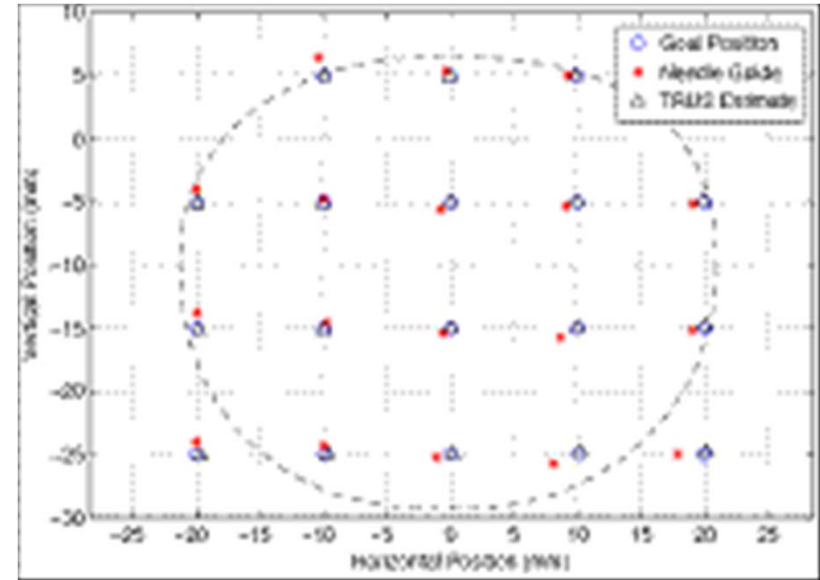
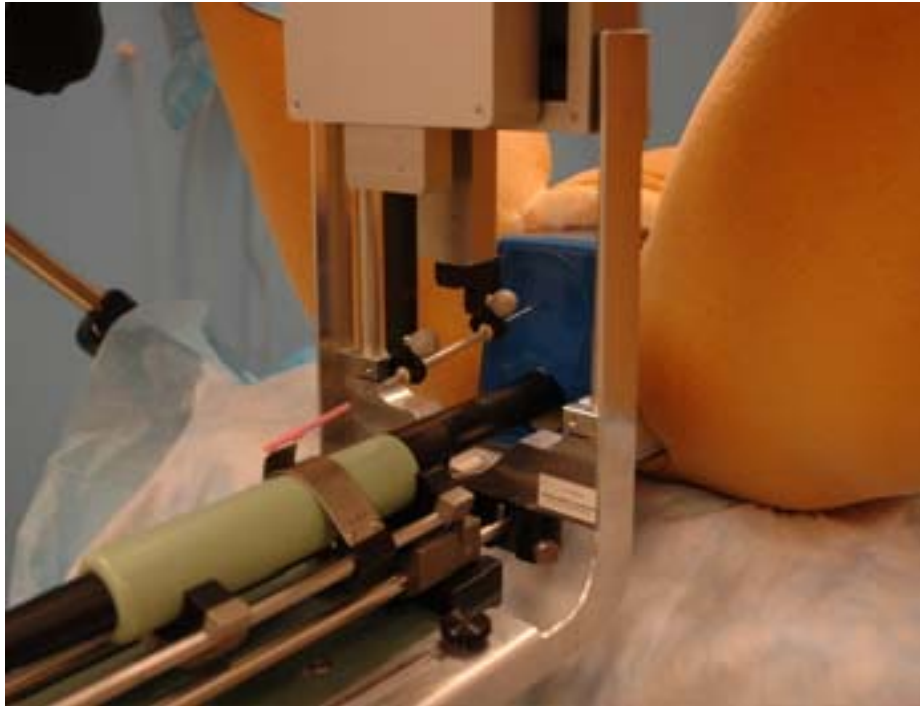
Fichtinger *et al.* *Media*, 2008



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Accurate needle placement w/ TRUS



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

Fichtinger *et al.* *MedIA*, 2008

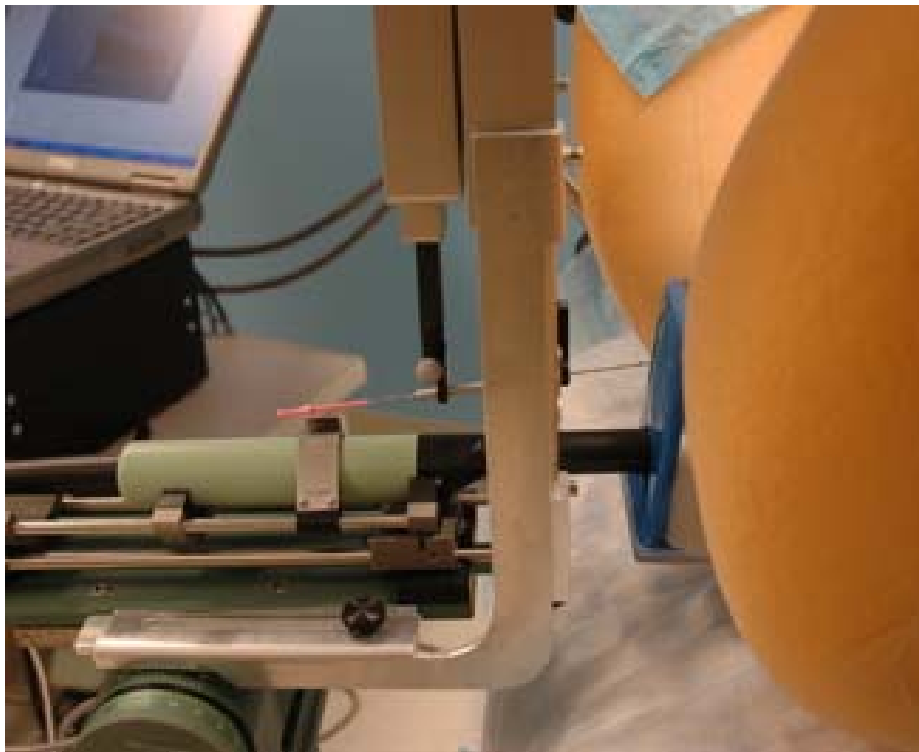


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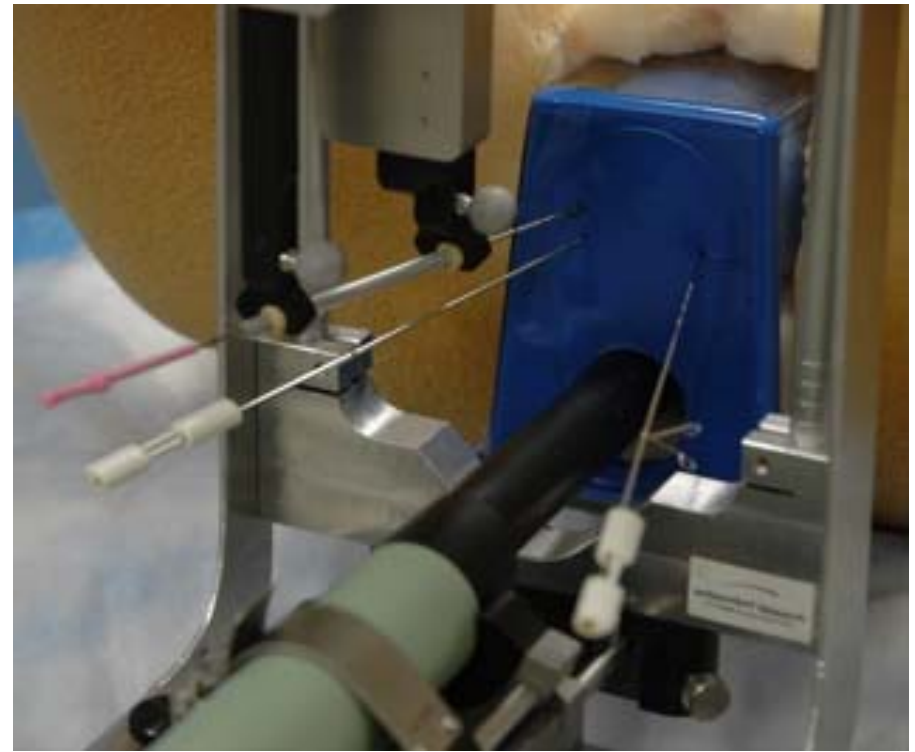
Additional benefits of robot

**Pubic arch interference reduced
by slanted needles**



Prostates >55cc, about $\frac{1}{3}$ of candidates

**No apparent interference with
stabilization needles**



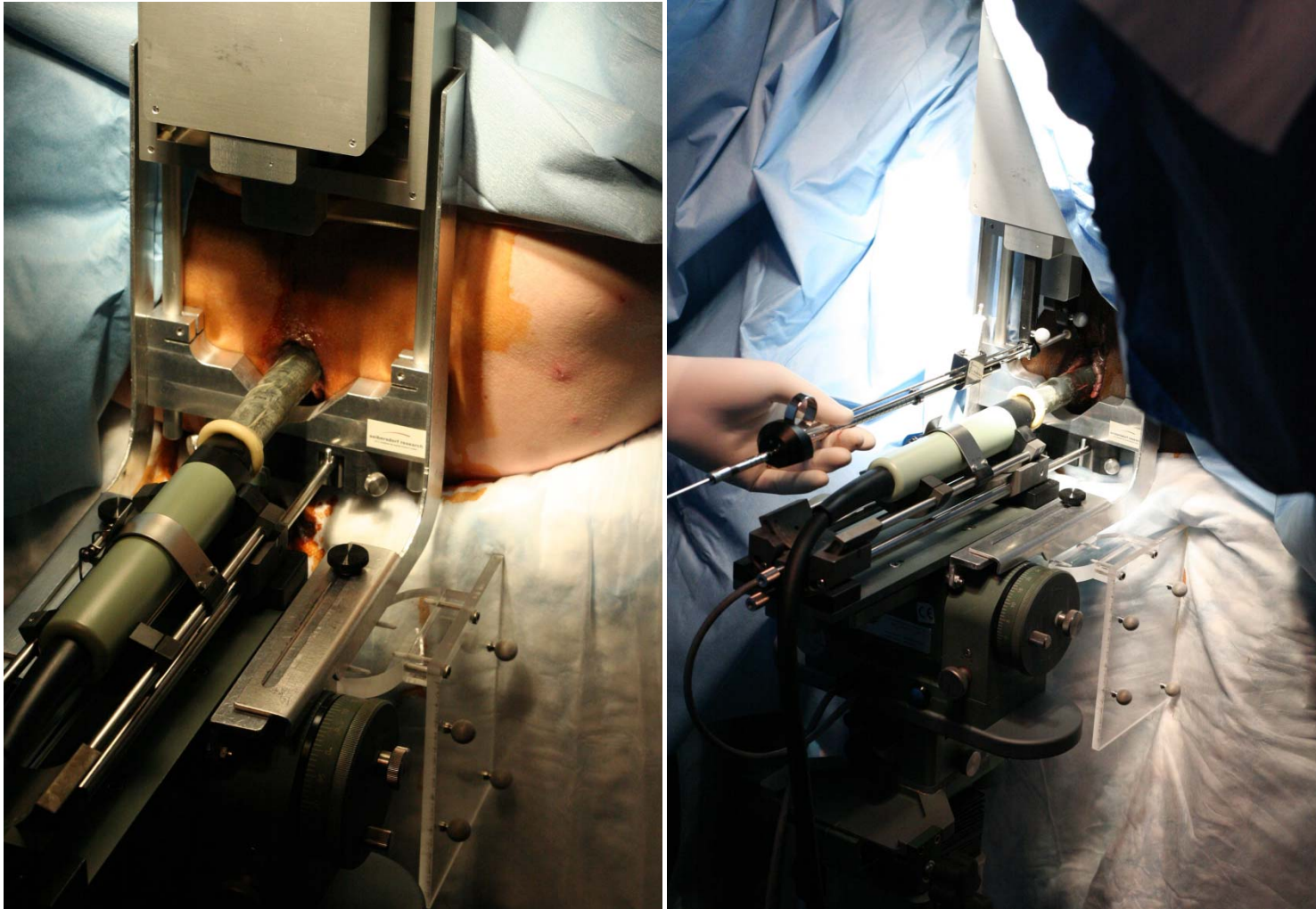
Fichtinger *et al.* MedIA, 2008



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Phase-I clinical trial



Song et al. Brachytherapy 2011



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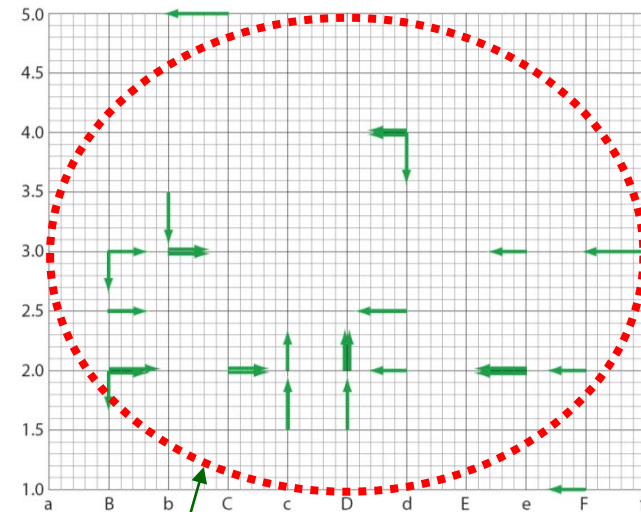


Surprising results

Summary table

	#1	#2	#3	#4	#5	Total
Prostate volume (cc)	31.1	19.2	28.4	48.2	42.9	
Total needles inserted	35	33	44	31	41	184
Total planned needles	35	31	41	30	38	175
Inserted with robot	30	33	44	31	41	179
Inserted manually	5	0	0	0	0	5
Adjustments to calibration (home)	1	3	2	1	1	8
Adjustments to correct needle pos.	4	12	12	12	14	54
> 2 mm in X	0	5	2	7	6	20
> 2 mm in Y	3	2	3	2	1	11
> 4 mm in X	0	0	0	1	0	1
> 4 mm in Y	1	0	0	0	0	1
Adjustments to modify plan	0	0	9	6	8	23
> 2 mm in X	0	0	5	3	5	13
> 2 mm in Y	0	0	4	1	2	7
> 4 mm in X	0	0	3	0	2	5
> 4 mm in Y	0	0	1	0	2	3
Implant time	1:21	0:53	1:04	0:51	1:05	

XY adjustments ≥ 3 mm



Prostate

Song et al. Brachytherapy 2011



How can we get here?

- Committed teams
- Focus on systems
- Address needs
- Be reductionist
- Rapid iteration
- Measurable goals
- Have fun!

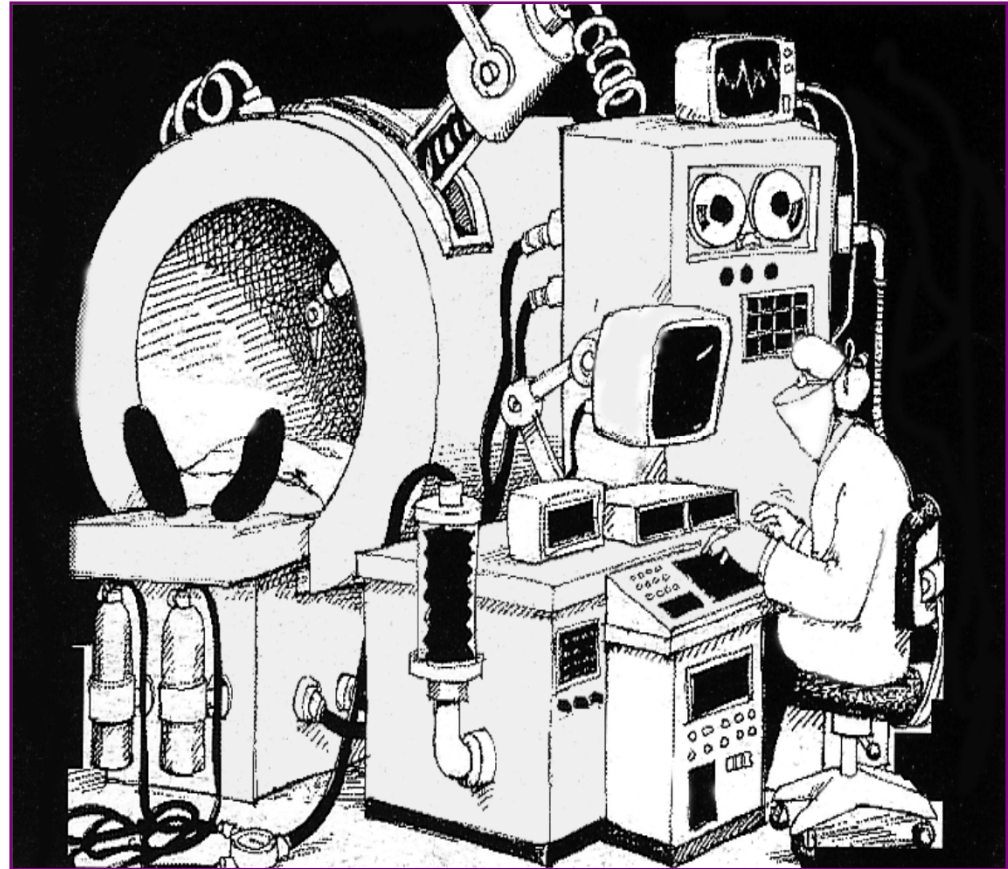


Image borrowed from Russ Taylor



Thank You!



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