Urology applications

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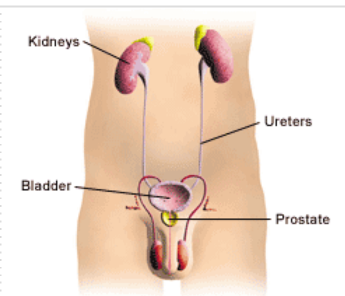
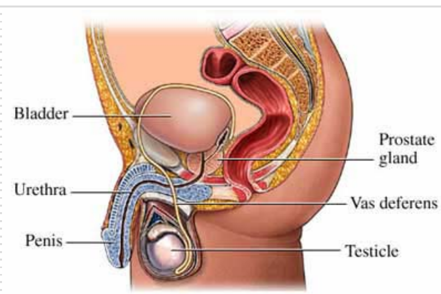
What is urology?

- Uro-genital apparatus of men
- Urinary apparatus of women
- Main organs: kidney, bladder, prostate





Clinical context

- Multi-modal imaging
- Mini-invasive procedures (coellioscopic surgery, brachytherapy, HIFU, etc.)
- Potential benefit from computer-assistance for
  - Diagnosis and planning
  - Therapy
  - Training

Summer School on Surgical Robotics Montpellier, Sept. 09

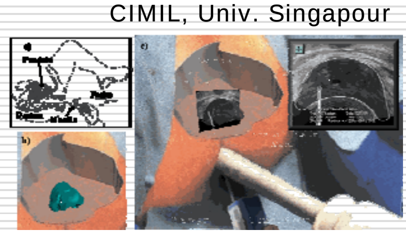
Tools proposed to the urologist

- Modeling and simulation
- Image processing
- Image fusion
- Navigation
- Augmented reality
- Robotics

TIMC, France

La Pitié Hospital, F

CIMIL, Univ. Singapour



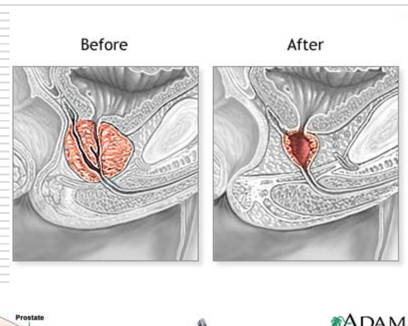
Urology applications – J. Troccaz

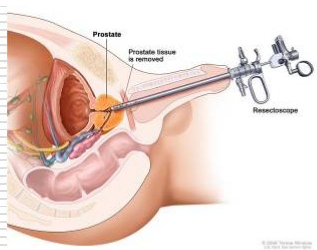
Robots in urology

- Prostate
  - Trans-Urethral Resection of the Prostate
  - Cancer
    - Radical prostatectomy
    - Biopsy
    - Brachytherapy
- Kidney
  - Percutaneous access
    - Destruction of stones
    - Biopsy
    - Destruction of tumours (Hyperthermia, RF)
  - MIS: adrenalectomy, pyeloplasty, nephrectomy, etc.
- + endoscope holders

A pioneering application: TURP

- Trans-Urethral Resection of the prostate (hyperplasia)
- Image-guided (endoscope)

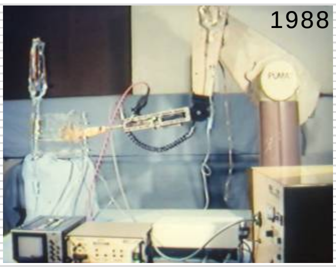


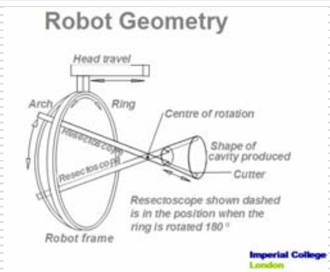


A pioneering work [Davies et al.]

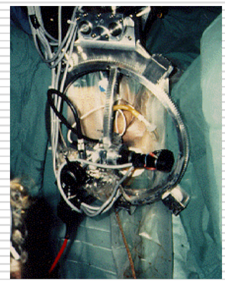
- First version: PUMA560
- Main idea: to constrain the tool to conical motions only (for safety)
- Second version: motorized frame

1988





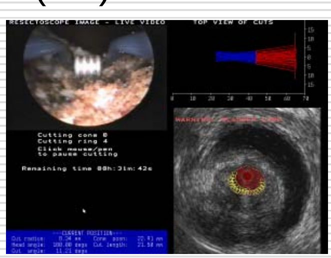
1989



Courtesy: B.L.Davies

PRrobot (Davies et al. – Imperial College of London)

- First patient operated in 1991
- Small series (40 patients)
- Not easy to automatically couple the robot control to the imaging data (US)



Courtesy: B.L.Davies

Prostate cancer

- Most frequent cancer of men in the western developed countries
- In 2005 in France: 62245 new cases (1st), 9202 deaths (4th, 2nd in men)
- Estimates in 2008 in US: 186320 new cases (1st), 28660 deaths (4th, 2nd in men)
- Diagnosis: rectal palpation, PSA, biopsies
- Treatments: none (careful watching), surgery (open, MIS), chemotherapy, radiotherapy, brachytherapy, HiFU, cryoablation, etc.

Robots in prostate cancer applications

- DaVinci's leader application (radical prostatectomy)
- Image-guided (US/MRI) prostate biopsy
- Image-guided (US/MRI) prostate brachytherapy

The DaVinci system

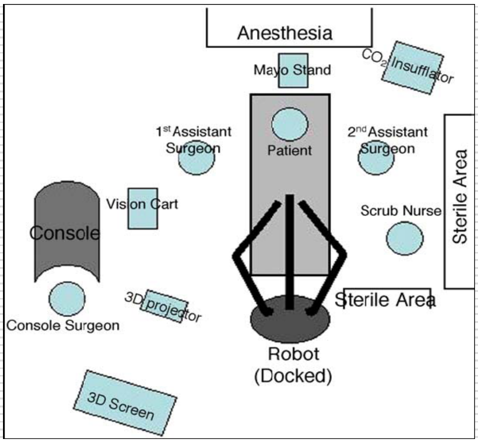
- Master-slave robot
- Stereo-endoscopy (HD)
- Endowrist

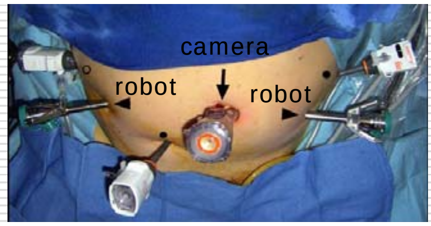
Intuitive Surgical Inc.

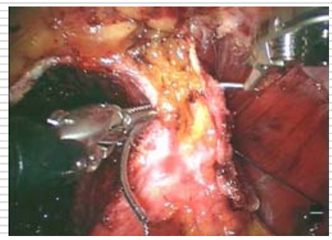
DaVinci for radical prostatectomy

- Cancer to be totally removed
- Critical structures to be spared: neurovascular bundles, urethra
- Potential morbidity: impotency, incontinence
- An alternative to open surgery: laparoscopic surgery
- Benefit as compared to open or laparoscopic procedures (Vattikuti series: 1100 cases [Menon04])

From [Menon et al. 2004]







 Urol Clin N Am 31(2004) 701-717

From [Menon et al. 2004]

Table 3
Odds ratio for important outcomes for laparoscopic, robotic, and radical retropubic prostatectomy performed at the Vattikuti Urology Institute

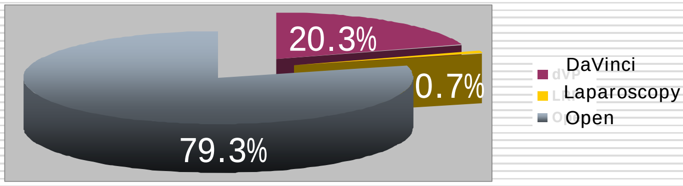
Variables	Open radical prostatectomy (reference values)	Laparoscopic radical prostatectomy (odds ratio)	Robotic prostatectomy (odds ratio)
Operating room time	163 min	1.51[a]	0.91[b]
Estimated blood loss	910 mL	0.42[a]	0.10[a]
Positive margins	23%	1	1
Complications	15%	0.67[a]	0.33[a,b]
Catheterization time	15.8 d	0.50[a]	0.44[a]
Hospital stay > 24 hr	100%	0.35[a]	0.07[a,b]
Postoperative pain score (0–10)	7	0.45[a]	0.45[a]
Median time to continence	160 d	1	0.28[a,b]
Median time to erection	440 d	NA[c]	0.4[a]
Median time to intercourse	>700 d	NA[c]	0.5[a]
Detectable prostate specific antigen	15%	1	0.5

[a] $P < .05$ compared with radical retropubic prostatectomy.
[b] $P < .05$ compared with laparoscopic radical prostatectomy.
[c] Most patients undergoing laparoscopic radical prostatectomy were not sexually active at baseline.
Abbreviation: NA, not available.
The reference values were those from conventional radical prostatectomy; odds ratio was the ratio of the observed to the reference value.
Data from Refs. [24,27].

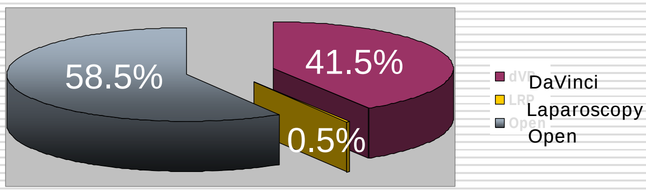
Urol Clin N Am 31(2004) 701-717

United States: about 120000 radical prostatectomies per year

2005 U.S. Radical Prostatectomy Market



2006 U.S. Radical Prostatectomy Market (Projected)



 Courtesy: Intuitive Surgical Inc.

Prostate biopsy

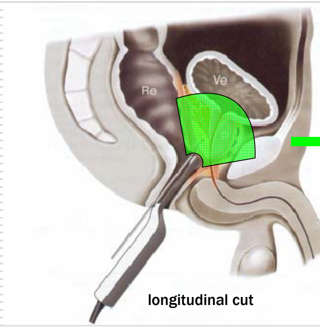
- Reference examination for cancer diagnosis
- Histopathological analysis of samples

- Sensitivity 60 to 80% - specificity 95%
- False negative leads to repeated biopsies
- Most often: transrectal, US guided
- In France (resp. USA) 10^5 (resp. 10^6) biopsy series per year

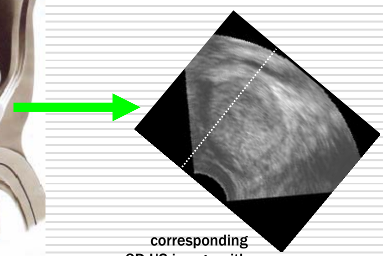
Transrectal biopsies

- 2D transrectal ultrasound (TRUS) control
- Needle guide on the probe

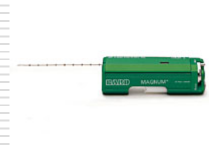
TRUS probe with needle guide

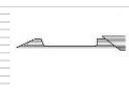


longitudinal cut



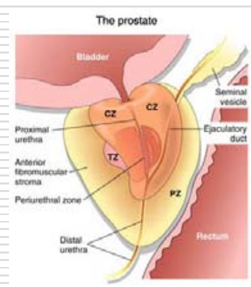
corresponding 2D US image with needle trajectory

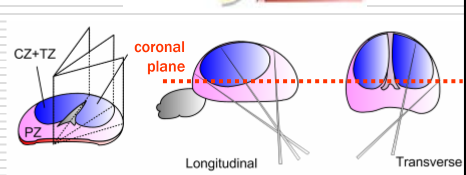


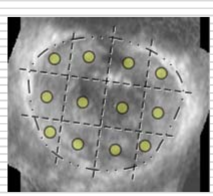


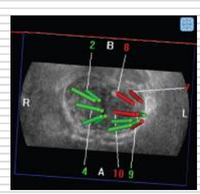
Biopsy targets

- McNeal's 3-zone model: central zone (CZ), transition zone (TZ), peripheral zone (PZ)
- 68% of cancer can be found in peripheral zone
- Prostate cancer is generally not visible
  - ➢ systematic targets (12-core protocol)







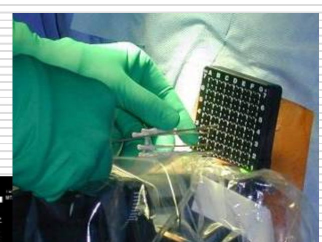


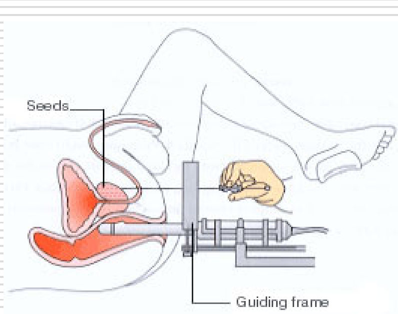
A robot what for?

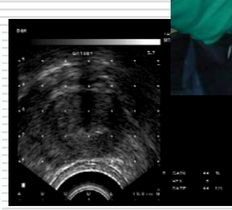
- Increased accuracy in needle and/or ultrasound probe positioning
- Possible physical disconnection of needle and probe
- Aim: improved localization of the sample in the prostate for a better localization of the cancer

US-guided prostate brachytherapy

- Insert radioactive seeds into the prostate through the perineum







US guidance

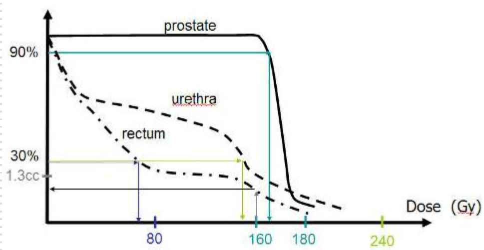
Dose planning

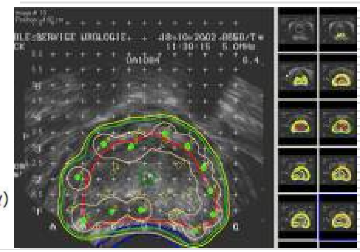
- Planned dose: for instance 160Gy
- Dose constraints:

  Prostate: 160Gy<D90<180Gy and V100>85%

  Urethra: D30<240Gy

  Rectum: less than 1.3cc>160 Gy and D90<80Gy

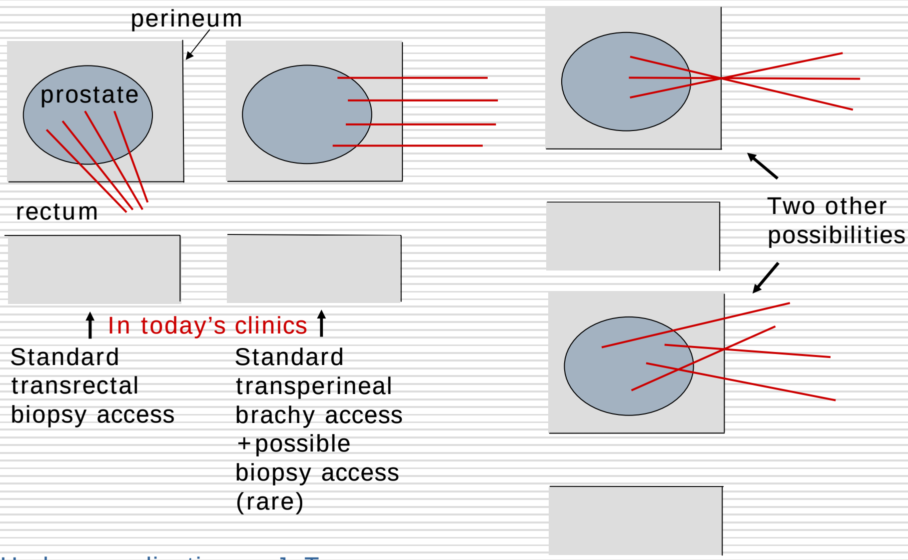




A robot what for?

- Increased accuracy in needle positioning
  - Replaces the template
  - Potentially enables doing more complex trajectories
- Possible automated seed injection
- Faster procedure
- Aim: improved dose delivery for a better control of cancer

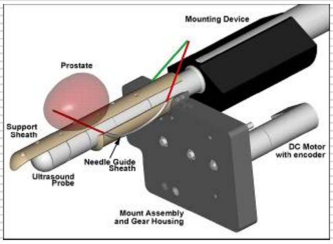
Trajectory comparison

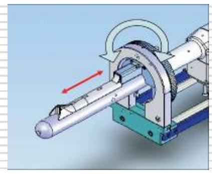


Proposed systems

- US or MRI guided (one CT-guided)
  - Most often: US guided
  - MRI requires very specific design (very limited space, MR-compatibility) and has more limited availability
- Most often: transperineal access
- Still few systems clinical trials
- Some very active groups
  - Fitchinger et al. (JHU CISST ERC, Queens Univ.)
  - Stoianovici et al. (JHU, URObotics)

Transrectal access – US-guided

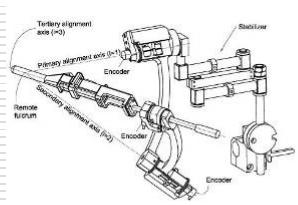


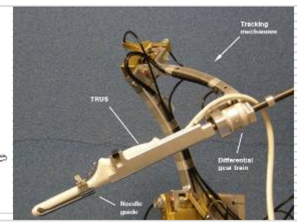


Targetscan [Andriole07]

2dofs (probe) + 2dofs (sheath) + 2 manual dofs (needle) [Fichtinger – ICRA04]

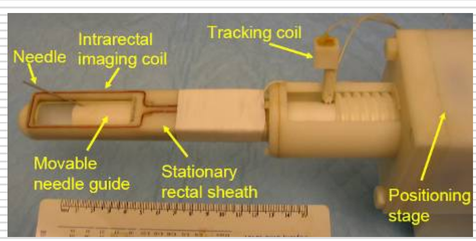
>> Mainly probe positioners



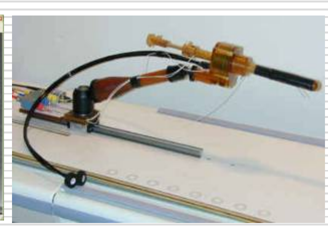


3dofs RCM passive mech. (probe holder) + 1dof (trans.) [Fenster – SPIE08]

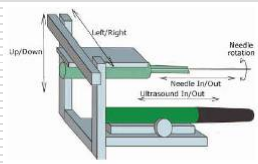
Transrectal access – MRI-guided [JHU – Fichtinger et al.]

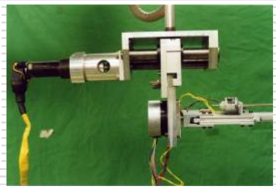


3dofs (sheath rot.+trans. plus needle trans.)

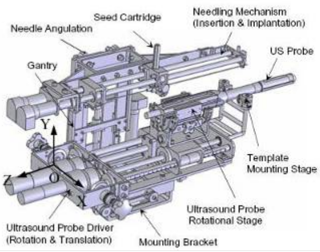


Transperineal access – US-guided





4dofs (needle) + 1dof (probe) [Davies07]



9dofs (gross pos.)+9dofs (needle)+seed injector
[Yu - MICCAI06]

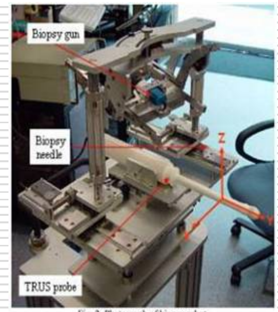


Fig. 2 Photograph of biopsy robot.

3dofs (probe) + 6dofs
(needle pos. plus insert.)
[Phee – ICRA05]

Transperineal access – US-guided (2)

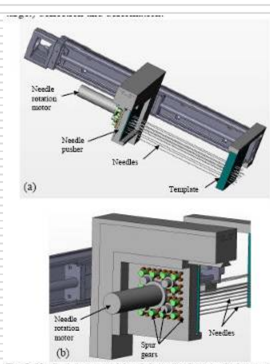
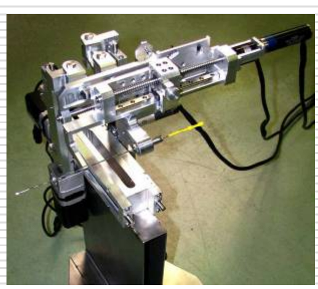
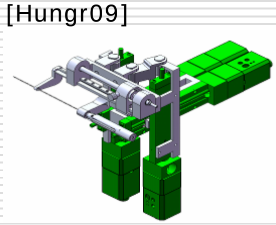


Fig. 7. Needle insertion module of the multi-channel robotic system – simultaneous rotation and insertion of multiple needles; (a) front-end & side view, (b) back-end & side view.

Multi-needle (trans.+rot.)
[Podder07]



5dofs (needle prepos.)
+ 2dofs (needle insert.)
[Hungr09]



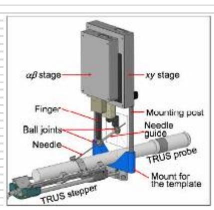
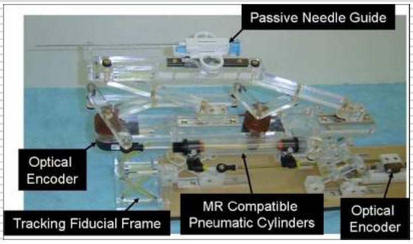
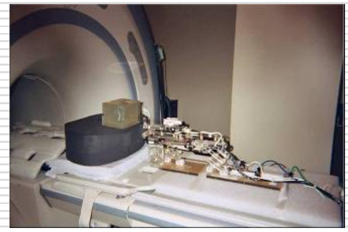


Fig. 1. CAD model of the parallel robot mounted over the TRUS probe on the mounting posts of the template

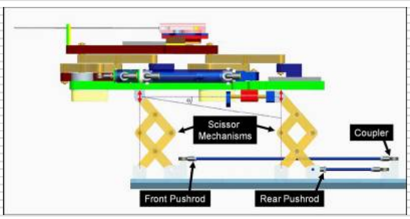
4dofs [Fichtinger – MedIA08]

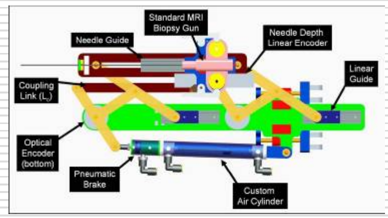
Transperineal access – MRI-guided





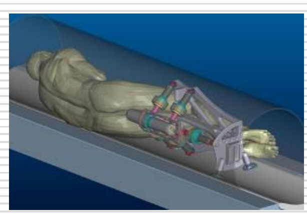
4dofs – PEEK, glass, graphite – pneumatic actuation



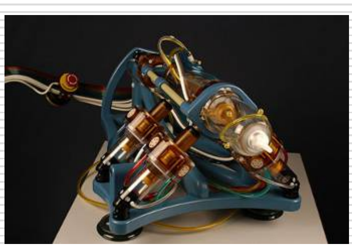


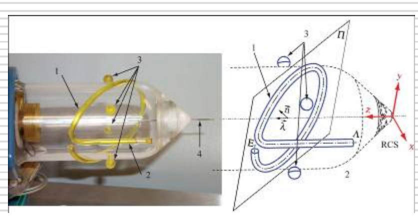
[Fischer, Fichtinger et al. – IEEE-ASME Trans.Mecha08]

Transperineal access – MRI-guided (2)



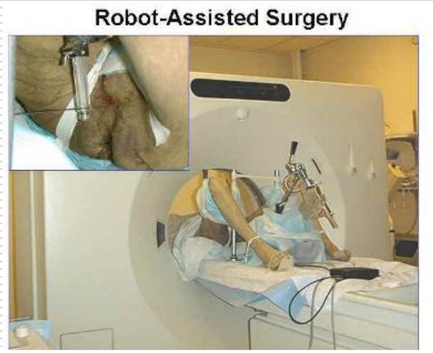
5dofs + needle insert. + seed delivery
Pneumatic actuation
[Stoianovici – IEEE-TBME07]

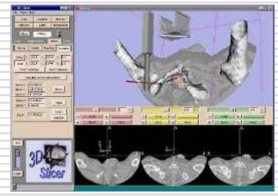


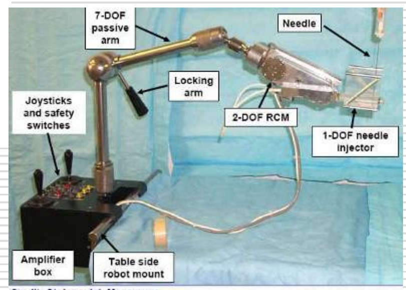


Robot registration

Transperineal access – CT-guided [Stoianovici et al.]





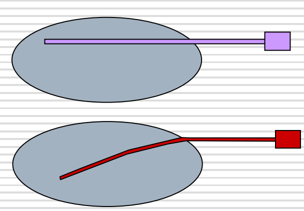


Credit: Stoianovici, Masamune

Summer School on Surgical Robotics Montpellier, Sept. 09

A major issue: accuracy

- The prostate moves and gets deformed due to:
  - Bladder or rectal filling
  - Patient leg position
  - Patient breathing
  - Ultrasound probe constraint
  - Needle penetration*
  - Bleeding
- The needles may deflect

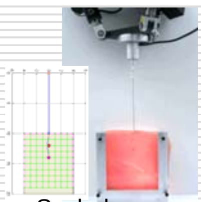


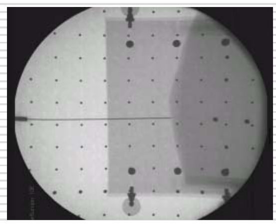
*in blue: especially for brachytherapy

Urology applications – J. Troccaz

Possible approaches

- Improved planning
  - Biomechanical modelling and simulation (tissues, needles, interactions)
- Improved control
  - Real-time image control
  - Active needle steering

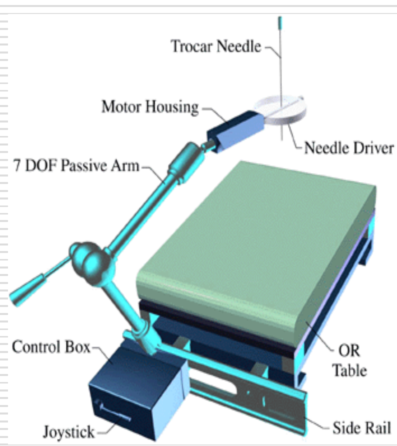




Shoham et al.
Technion, Israel

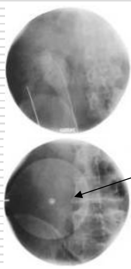
Robot for renal puncture

- Objective:
  - to make the access to the kidney under fluoroscopic control easier
  - To increase accuracy, safety and to decrease duration
- Robot PAKY (Percutaneous Access to the KidneY) [Stoianovici et al.] (URObotics, JHU)
- Similar to the manual protocol



PAKY (cont'ed)

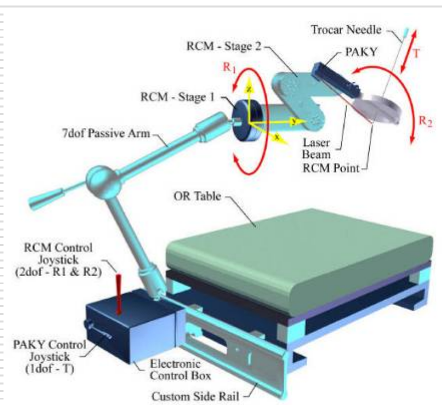
- Tests on 23 patients published [Su, Kavoussi et al.]
- Similar performances with/without the robot

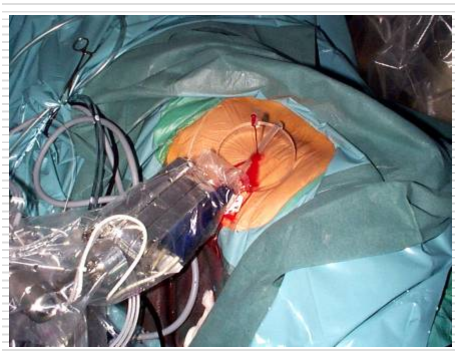


- Towards automation ?

PAKY+RCM [Stoianovici et al.]

- Extra-dofs





CT-based renal puncture [Stoianovici et al.]

Robot registration
[Taylor et al.]

Endoscope holders

- AESOP (JPL-Nasa + Computer Motion Inc.)
  - 4 active +2 passive DOFs
  - Voice control
  - More than 800 systems installed
- LER-Viky (TIMC + Endocontrol Medical)
  - 3 DOFs, <1kg, autoclavable
  - Several HCI (mini-joystick, voice control, tool tracking)
  - Validation: urologic and digestive surgery
  - EC marked in 2007, FDA approved in 2008

Conclusion

- A real clinical interest and a large potential impact
- Many systems studied and developed
- But still quite few of them clinically used
- Most attention given to the robot mechanical/kinematic design
- Still a lot to do regarding real-time image control