Lecture 1:
Design Considerations for Medical Robots

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ICRA 2016 Tutorial on Medical Robotics

lecture objectives

- Define surgery and minimally invasive surgery
- Explain the function and advantages/disadvantages of current commercial robot-assisted surgical systems
- Highlight design features of current and future generations of robotic devices

Surgery

Material courtesy Sherry Wren, MD, Stanford Medical School

What is Surgery?

- Removal, implantation, insertion, re-vascularization, re-routing, transplantation, release, inspection, fusion, arresting, stopping, bypassing of various tissues/organs in the body
- Treats wide variety of diseases and conditions
- 52 million inpatient, 20 million outpatient surgeries in US
- 235 million worldwide

Surgery Basics

- Patients present electively, urgently, and emergently in clinics, offices, and emergency rooms
- Evaluation done: histology/pathology, lab work, imaging, and other testing based on medical conditions
- Diagnosis made and discussion about role of surgery done
- Risk-benefit discussed and then consent

Surgical Approach

- There are choices:
  - open
  - endoscopic
  - endovascular
  - MIS (laparoscopic or robotic)

- Choice depends on surgeon expertise, patient wishes, and data if available

- Technology disruptions in recent history: endovascular, minimally invasive surgery

Warning!

If you are sensitive to graphic images/videos of surgical procedures, please step out for about 10 minutes.

Open Surgery

- Advantages:
  using hands, full haptic senses, excellent instruments, wide visual field, requires fewer devices, huge variety of instruments

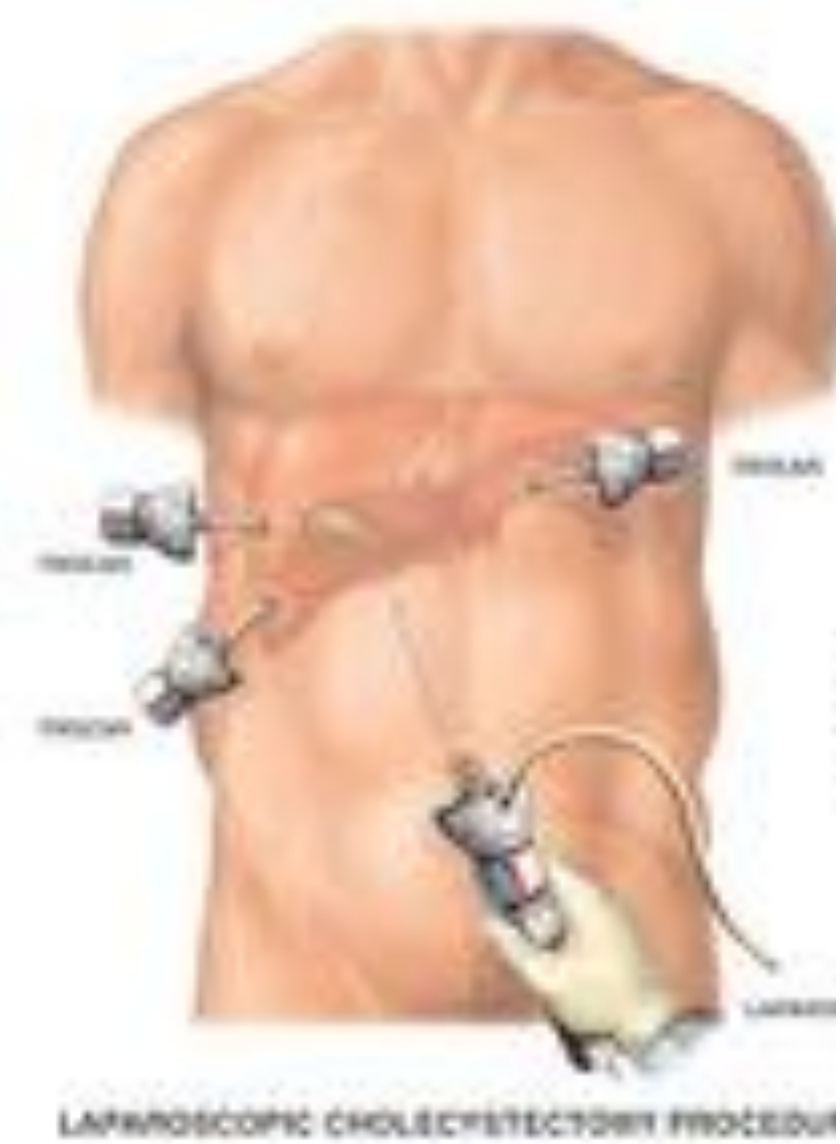
- Disadvantages:
  large incision, wound complications, long recovery, blood loss

People in the operating room

- Team sport (contact)
- Surgeon, circulating nurse, scrub nurse/tech, anesthesia, surgical assistant, anesthesia tech
- Possible people from X-ray, perfusion, brain monitoring, companies

Surgical Progress

OPEN CHOLECYSTECTOMY PROCEDURE



LAPAROSCOPIC CHOLECYSTECTOMY PROCEDU

Minimally Invasive Surgery (MIS)

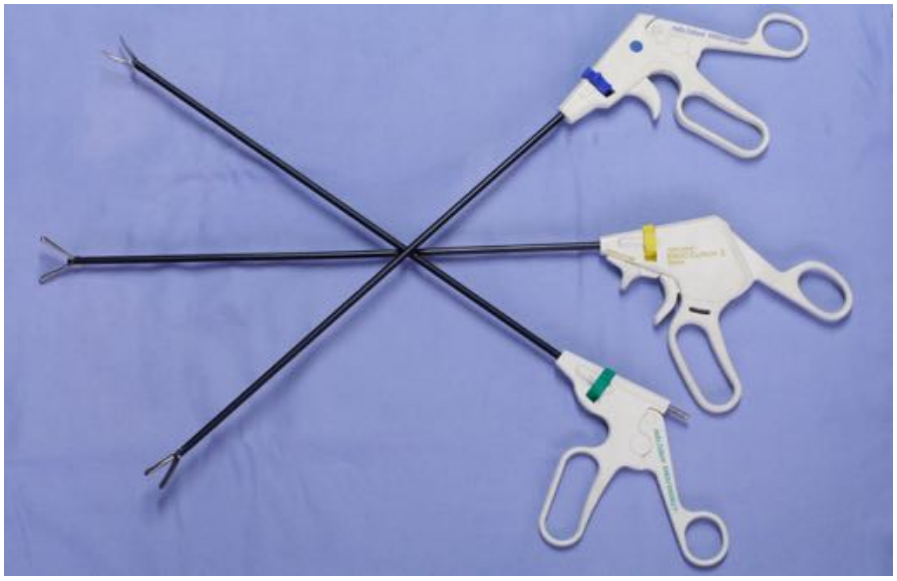
- Advantages:
  Magnified vision, smaller incisions, faster patient recovery, less blood less

- Disadvantages:
  Loss of normal haptics, instrumentation, difficulty retracting, narrow field of view, ergonomic positioning, more device reliant, limited instrument selection, worse instruments

Open

Lap

Single Port



Which approach provides better operative experience for the surgeon?

Robot-Assisted Minimally Invasive Surgery

Caveat: This is based on the da Vinci Surgical system, the most commonly used and commercially successful RMIS system to date.

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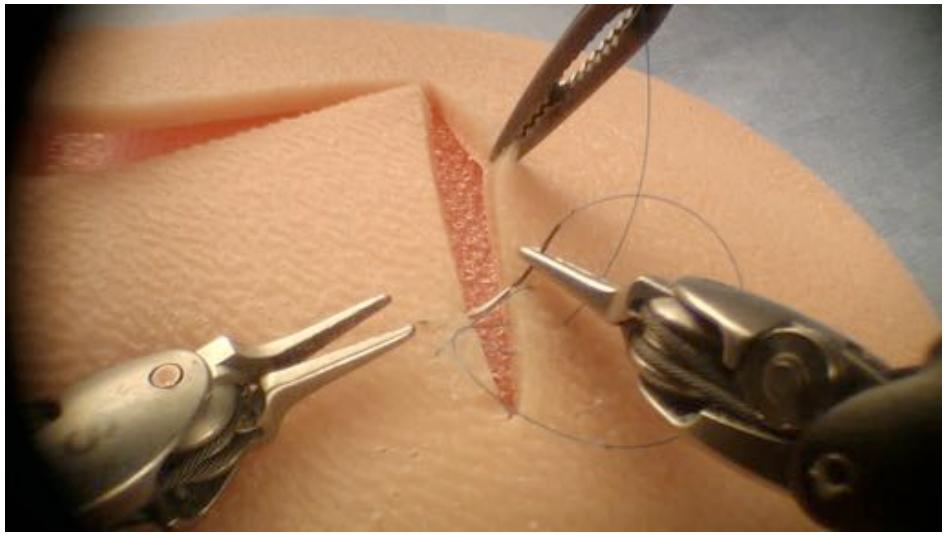
who left the room.



MIS ➔ Robotics

- MIS revolutionized surgical procedures
- Limitations of MIS
    - Loss of wrist articulation
    - Fulcrum effect on abdominal wall
    - Loss of 3-d visualization
    - Poor ergonomics
    - Only 4 degrees of freedom
    - Long instruments magnify tremor and reduce tactile sense
- Robotics developed to extend and enhance human capabilities and mitigate some downsides of lap MIS

Robotic Surgical Systems

Components:

- Console
- 3 robotic arms, 1 camera arm
- Binocular camera (3D/HD imaging)
- Visual magnification
- Hand-motion scaling removes tremor
- Surgeon controls camera plus 3 instruments
- Stable camera platform

Current Teleoperated Robotic Surgical Systems for MIS

- Wristed instruments
- 7 degrees of freedom
- No fighting abdominal wall torque
- Superior 3D visualization with magnification - controlled by surgeon
- Superior ergonomics
- No counter-intuitive movements

Advantages

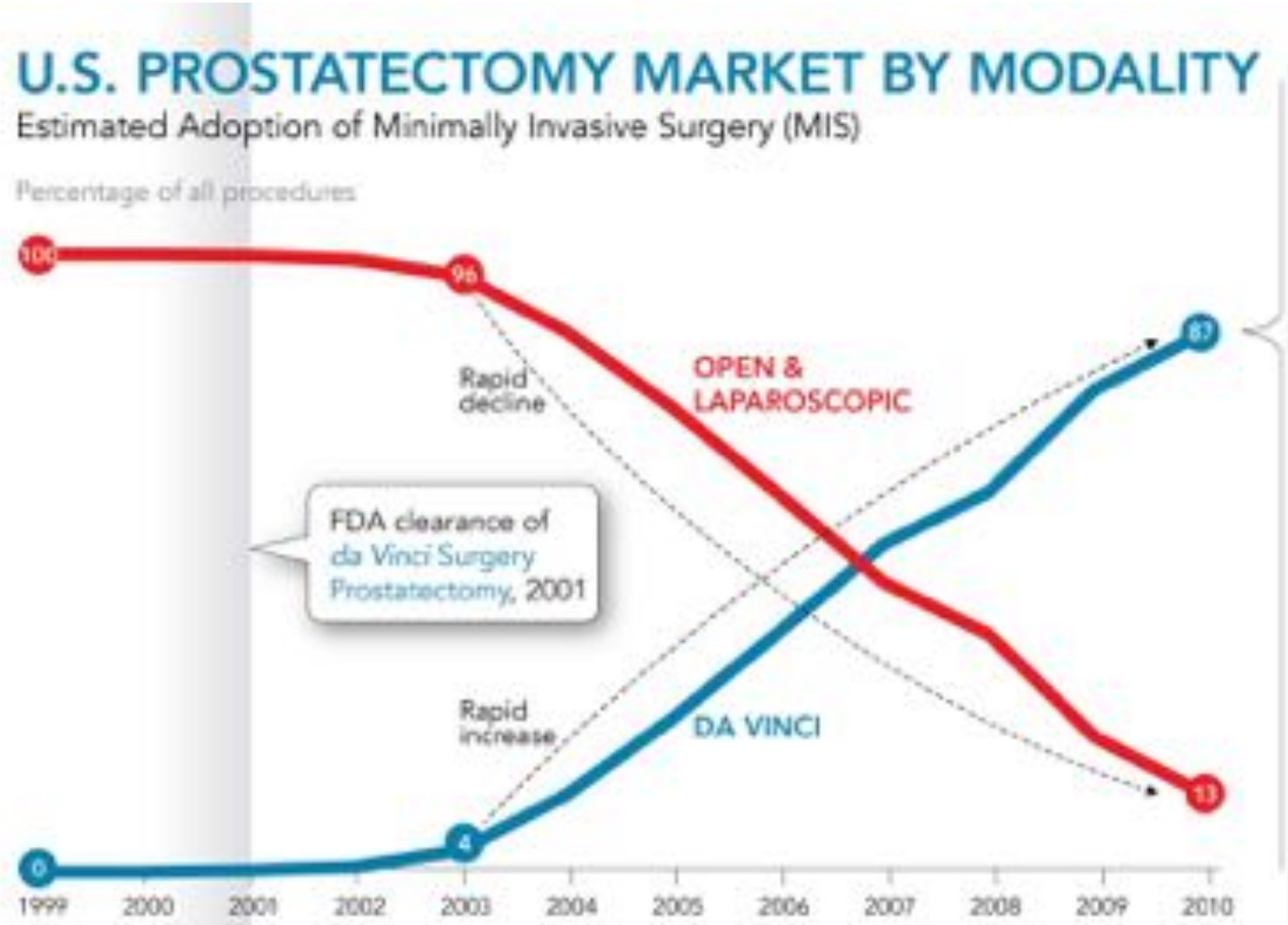
- Entry technology for difficult to perform operations
- Great for "small dark hole" operations
- Downgrades need for experienced assistant
- Surgeon's comfort
- Patient preference

Disadvantages

- Increased cost (instruments, machine, time)
- If surgeon is already skilled in lap procedure, no real advantage
- Room staff and setup is specialized
- Loss of haptics

Robotic Prostatectomy

- First common robotic operation
    - 2003 - first done
    - 2005 - <20% of all prostatectomies
    - 2008 - 75% of all prostatectomies
    - 2010 - 85% of all prostatectomies
- Allowed surgeons to do MIS approach that did not want to/ could not do it laparoscopically
- Patient driven market forces, perception it was better
- Converts open operation to MIS approach



- Lap <4% at its peak
- Robot displaced open surgery

1. Prostatectomy prevalence data: Nationwide Inpatient Sample (NIS), Healthcare Cost and Utilization Project (HCUP), Agency for Healthcare Research and Quality.
2. MIP percentage prior to introduction of robotic prostatectomy: Premiere Prospective Database 2004-2010 as cited by Davis et. Al. BJUI 2013 (accepted for publication) 3. da Vinci® Prostatectomy data: ISI Internal Estimates

VALUE OF INNOVATION *Health Affairs*, 34, no.2 (2015):220-228

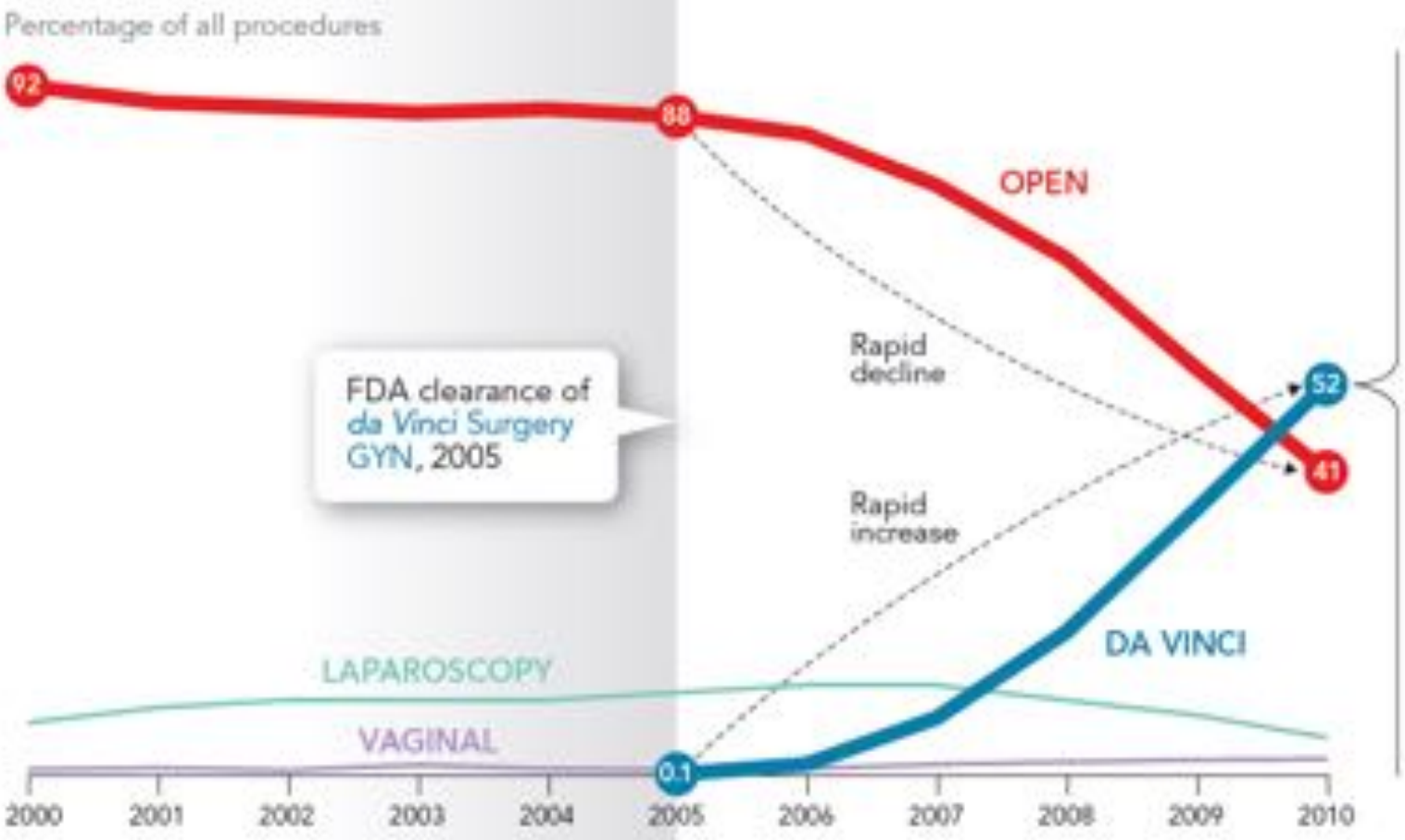
By Amitabh Chandra, Julia Thornton Snider, Yanyu Wu, Anupam Jena, and Dana P. Goldman

Robot-Assisted Surgery For Kidney Cancer Increased Access To A Procedure That Can Reduce Mortality And Renal Failure

- Robotic surgery benefits outweighed health care and surgical costs 5:1
- Cost/benefit must be measured long term
- In robotics, costs are large up front, but value accrues long-term

U.S. MALIGNANT HYSTERECTOMY MARKET BY MODALITY

Estimated Adoption of Minimally Invasive Surgery (MIS)



- Lap <15% at its peak
- Robot displaced open surgery

1. Inpatient data: Nationwide Inpatient Sample (NIS), Healthcare Cost and Utilization Project (HCUP), Agency for Healthcare Research and Quality. 2. Outpatient data: Solucient® Database - Truven Health Analytics (Formerly Thomson-Reuters) 3. da Vinci data: ISI Internal Estimates

1st 10 Robotic Cases (Curet, Arch Surg 2005)

	Laparoscopic	Robotic	p
Age (yrs)	45.5 (33-53)	38.5 (34-52)	0.91
BMI (kg/m2)	43.0 (36.2-52.8)	45.6 (36.5-59)	0.88
# Co-morbidities	2 (0-3)	1 (0-1)	0.31
OR time (min)	208 (135-315)	169 (119-294)	0.03
# Comp (major)	2	2	1
# Comp (minor)	3	2	1
Extended LOS	3 days	2 days	1
Min/BMI	5	3.8	0.04

New Fellow Trial
(SOARD 2005)

	Laparoscopic	Robotic
# patients	25 (22 F)	25 (23F)
BMI (kg/m2)	43.4 (37-55)	45.5 (35-62)
OR time (min)	149.4 (120-205)	130.8* (90-200)
Min/BMI	3.47	2.94*
LOS (days)	2.72	2.72
# Complications	1	1

*p<0.05

Robotic LAR/APR

- Growing application
- Excellent vision and retraction for pelvis (3rd arm)
- OR approaches
  - Hybrid (laparoscopic and robot)
  - Total Robotic
- Why? Lower conversion rates, new studies lower complication rates

Multivariate Regression Key Outcomes in Robotic colorectal surgery

Table 5 Adjusted mean difference for hospital charge and length of stay and adjusted odds ratios for the remaining endpoints (95 % CI)

	Adjusted mean difference/odds ratio	*p* Value
Rectal procedures		
Length of hospital stay, days	−0.28 (−0.89, 0.34)	0.76
Total charge, SUS	12,964.90 (6,534.79, 19,395.01)	<0.001
Morbidity	0.86 (0.66, 1.12)	0.75
Conversion rate	0.10 (0.06, 0.16)	<0.001
Anastomotic complications	0.87 (0.56, 1.37)	0.56
Ileus	0.97 (0.70, 1.35)	0.84
Postoperative bleeding	1.68 (0.83, 3.43)	0.15

* The conventional laparoscopy group was used as a reference

90% reduction in conversions to open

Halabi, W J Surg 2013

Robotics as an enabling technology: Advanced Imaging

- daVinci Firefly system uses a fluorophores called indocyanine green (ICG): nontoxic H_2O-soluble fluorescent dye in use >40 years for liver function test and angiography

- After IV, dose can be used for near infrared (NIR) angiography of blood vessels, identification of the extrahepatic bile ducts, and primary cancers and metastases.

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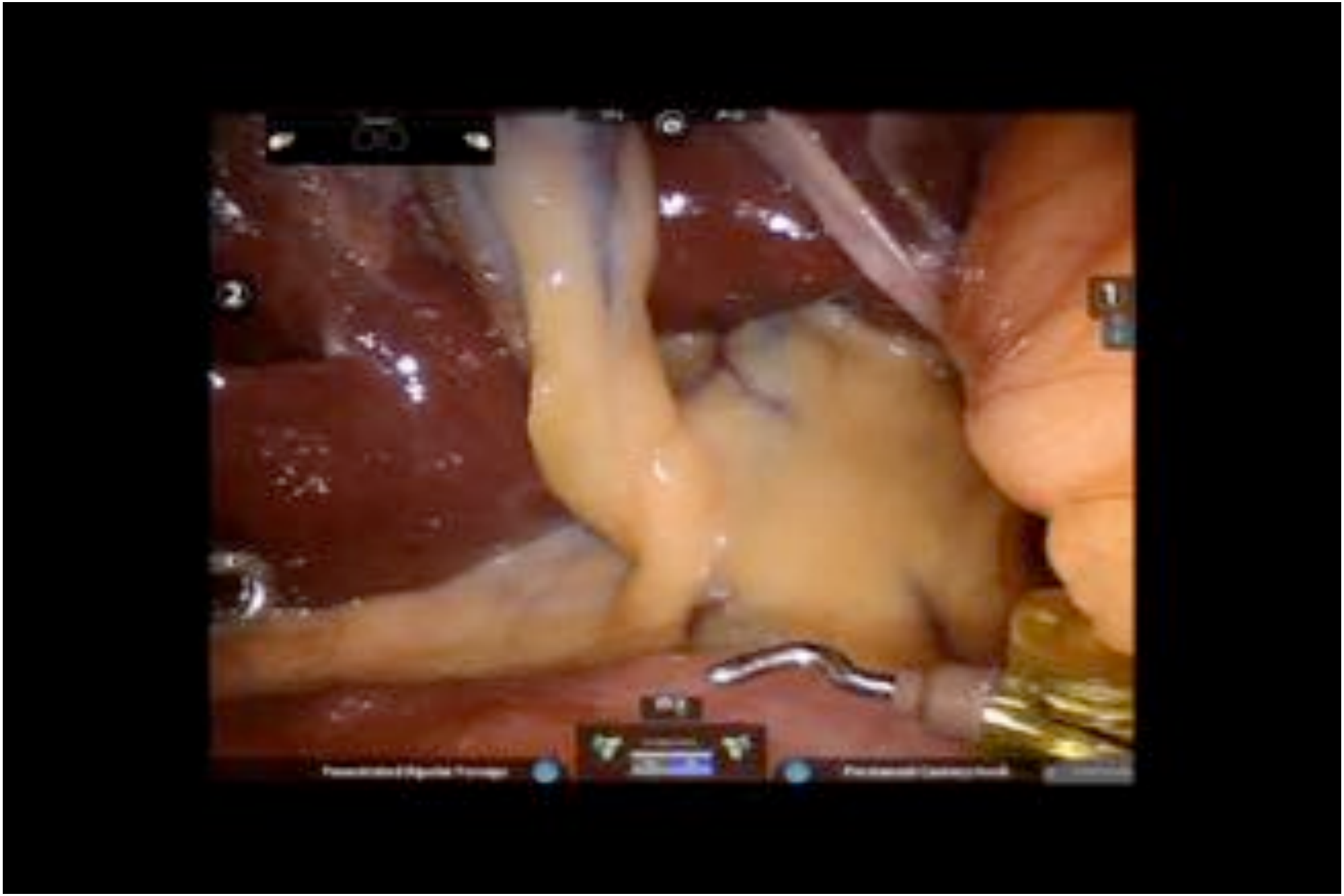
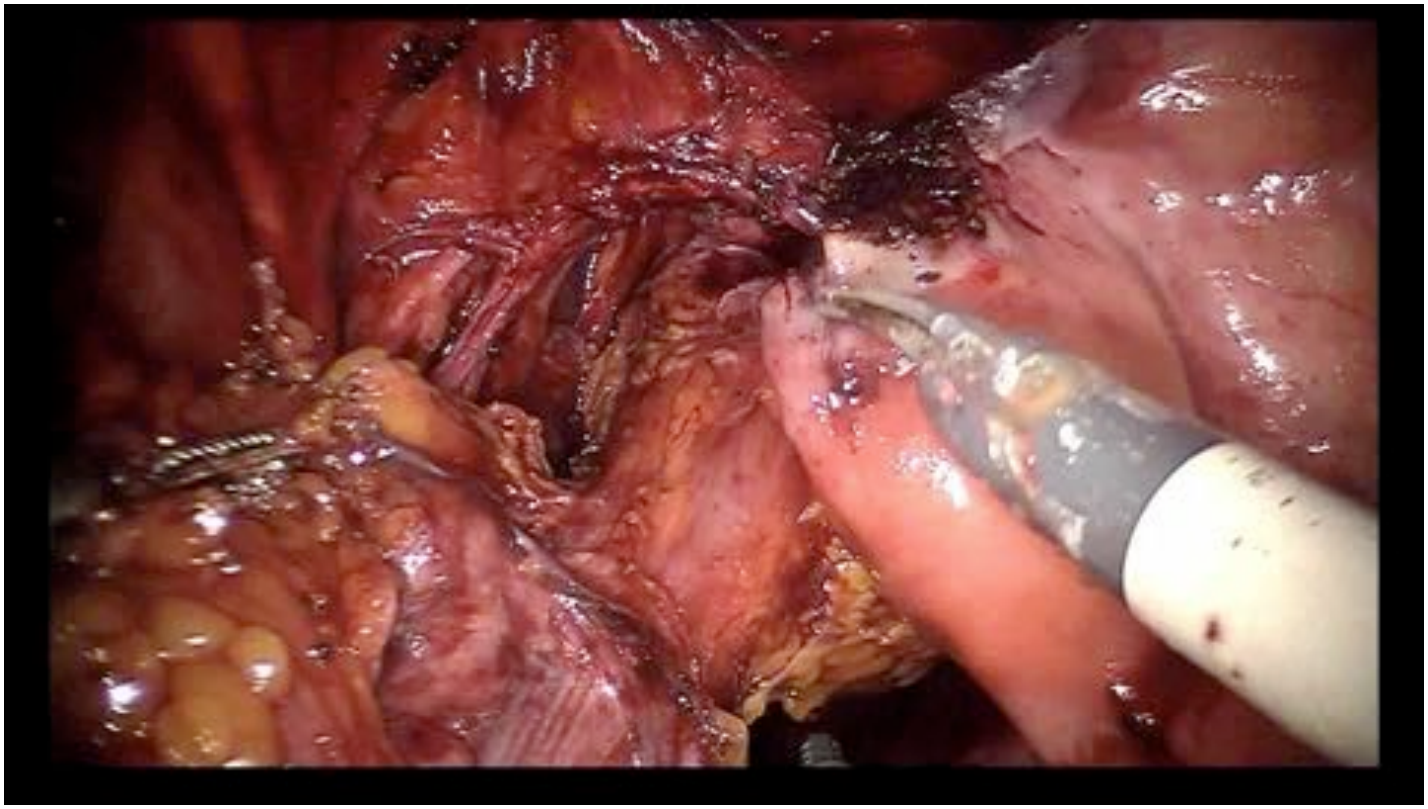
ICG and Flourocholangigraphy



Low Anterior Resection Surgery (LAR) with Firefly



- A common treatment for rectal cancer when the cancer is located well above the anus.
- During **LAR**, the entire rectal cancer, adjacent normal rectal tissue and surrounding lymph nodes are removed through an incision made in the lower abdomen.

Future Imaging Agents

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Where are we going?

Progress of Commercial Systems

- Haptics/ Tactile
- Robotic arm flexibility
- Integrated platforms
- New procedures

Hansen
Think Surgical
Medrobotics
Vytronus
Auris
Verb
… many more

TransEnterix

Titan Medical SPORT

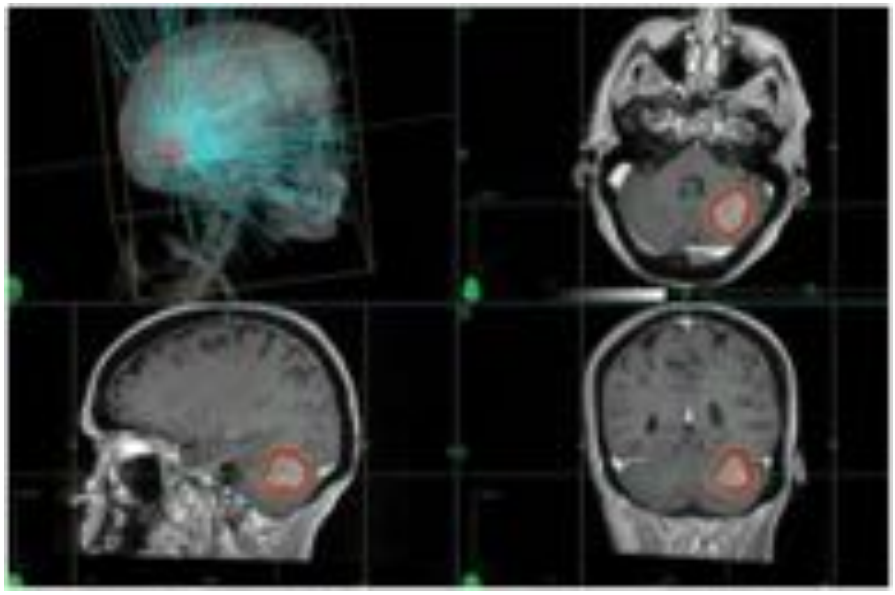
MAKO Surgical

A.R.A.K.N.E.S.
Array of Robots Augmenting the KINematics of Endoluminal Surgery

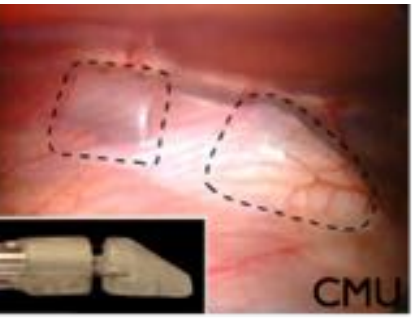
Single Incision Access

not yet FDA cleared for surgical application (?)

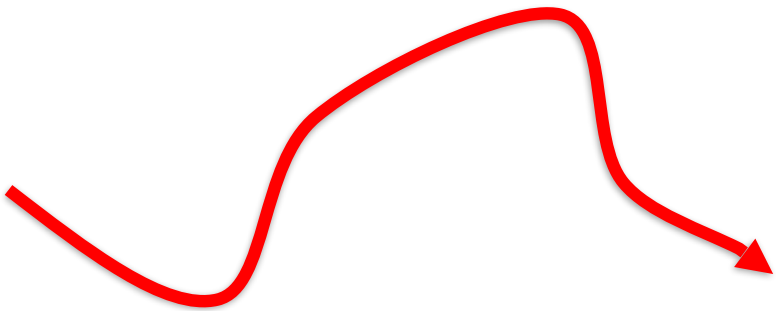
“Surgery” without cutting: Cyberknife

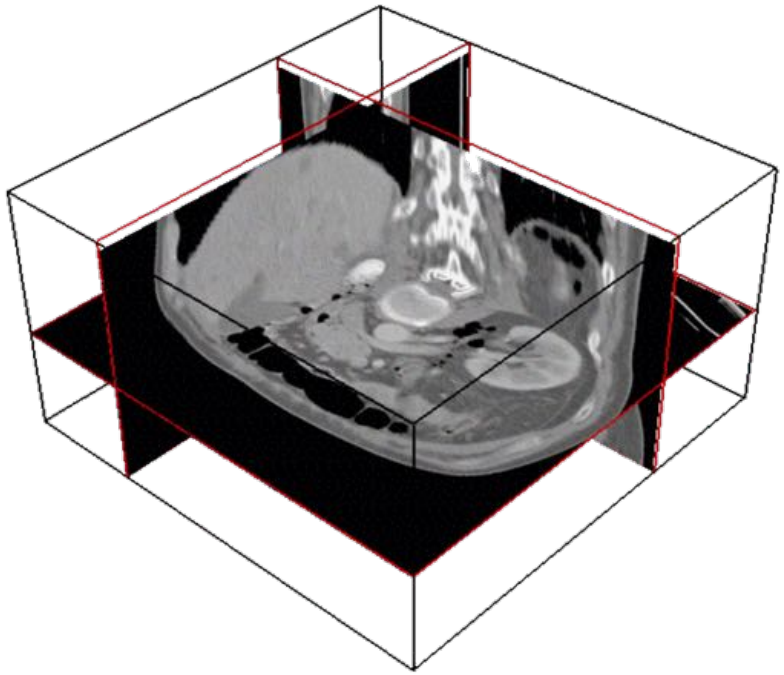


Emerging from the Lab

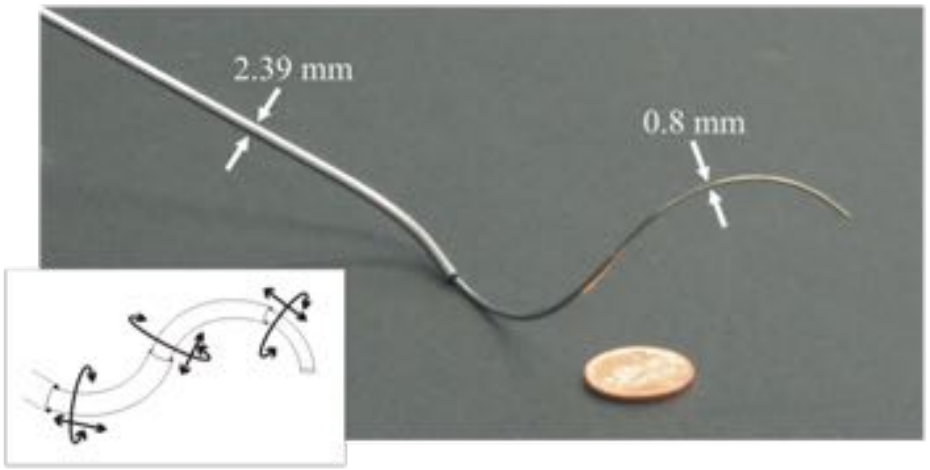


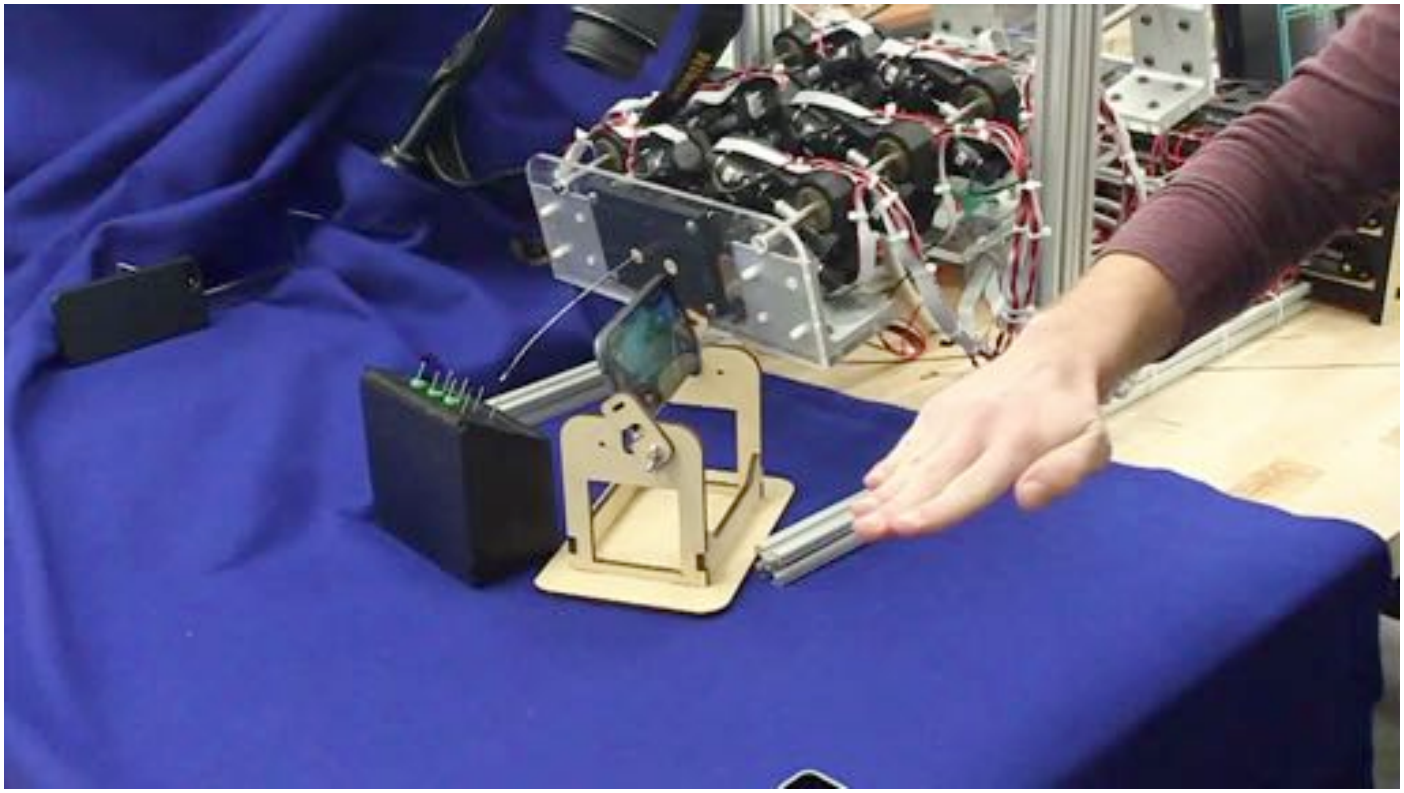
Access + Information





Active Cannulas





Video courtesy
Robert Webster III
(Vanderbilt University)

Conclusions

- Robotic surgery is another tool to help advance MIS surgery
- Helpful for non-expert laparoscopic surgeons to use MIS techniques
- May allow conversion of open operation to MIS approach
- Cost a major limitation but... New systems soon to be commercially available
- Integrated imaging and new imaging agents are an important part of advancement