Notes on Medical Robotics and Computer-Integrated Surgery,

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Medical Robotics

- Medical robots have a potential to fundamentally change surgery and interventional medicine
- exploits the complementary strengths of humans and computer-based technology.
- The robots may be thought of as information-driven surgical tools
- Enable human surgeons to treat individual patients with greater safety, improved efficacy, and reduced morbidity than would otherwise be possible.
- The consistency and information infrastructure associated with medical robotic and computer-assisted surgery systems have the potential to make *computer-integrated surgery* as important to health care as computer-integrated manufacturing is to industrial production.

Medical Robotics

- Medical robotics is ultimately an application-driven research field.
- Development of medica lrobotic systems requires significant innovation and can lead to very real, fundamental advances in technology,
- Medical robots must provide measurable and significant advantages if they are to be widely accepted and deployed.
- These advantages are often difficult to measure, can take an extended period to assess, and may be of varying importance to different groups.
- See table 63.1 in article Medical Robotics and Computer-Integrated Surgery

Medical Robotics: Advantages

- Can *significantly improve surgeons' technical capability* to perform procedures by exploiting the complementary strengths of humans and robots
- Medical robots can be constructed to be more precise and geometrically accurate than an unaided human.
- They can operate in hostile radiological environments and can provide great dexterity for minimally invasive procedures inside the patient's body.
- These capabilities can both enhance the ability of an *average* surgeon to perform procedures that only a few exceptionally gifted surgeons can perform unassisted
- Also makes it possible to perform interventions that would otherwise be completely infeasible.
- *Promote surgical safety* both by improving a surgeon's technical performance and by means of active assists such as *no-fly zones* or *virtual fixtures*
- Integration of medical robots within the information infrastructure of a larger CIS system can provide the surgeon with significantly improved monitoring and online decision supports, thus further improving safety.
- *Promote consistency* while *capturing detailed online information* for every procedure.
- Flight data recorder model where entire procedure is archived for training/learning

Table 63.1 Assessment factors for medical robots or computer-integrated surgery systems (after [63.1])

Assessment factor	Important to whom	Assessment method	Summary of key leverage
New treatment options	Clinical researchers, patients	Clinical and trials preclinical	Transcend human sensory-motor limits (e.g., in microsurgery). Enable less invasive procedures with real-time image feedback (e.g., fluoroscopic or MRI-guided liver or prostate therapy). Speed up clinical research through greater consistency and data gathering
Quality	Surgeons, patients	Clinician judgment; revision rates	Significantly improve the quality of surgical technique (e.g., in microvascular anastomosis), thus improving results and reducing the need for revision surgery
Time and cost	Surgeons, hospitals, insurers	Hours, hospital charges	Speed operating room (OR) time for some interventions. Reduce costs from healing time and revision surgery. Provide effective intervention to treat patient condition
Less invasiveness	Surgeons, patients	Qualitative judgment; recovery times	Provide crucial information and feedback needed to reduce the invasiveness of surgical procedures, thus reducing infection risk, recovery times, and costs (e.g., percutaneous spine surgery)
Safety	Surgeons, patients	Complication and revision surgery rates	Reduce surgical complications and errors, again lowering costs, improving outcomes and shortening hospital stays (e.g., robotic total hip replacement (THR), steady-hand brain surgery)
Real-time feedback	Surgeons	Qualitative assessment, quantitative comparison of plan to observation, revision surgery rates	Integrate preoperative models and intraoperative images to give surgeon timely and accurate information about the patient and intervention (e.g., fluoroscopic x-rays without surgeon exposure, percutaneous therapy in conventional MRI scanners). Assure that the planned intervention has in fact been accomplished
Accuracy or precision	Surgeons	Quantitative comparison of plan to actual	Significantly improve the accuracy of therapy dose pattern delivery and tissue manipulation tasks (e.g., solid organ therapy, microsurgery, robotic bone machining)
Enhanced documentation and follow-up	Surgeons, clinical researchers	Databases, anatomical atlases, images, and clinical observations	Exploit CIS systems' ability to log more varied and detailed information about each surgical case than is practical in conventional manual surgery. Over time, this ability, coupled with CIS systems' consistency, has the potential to significantly improve surgical practice and shorten research trials

Complementary Strengths: Surgeons/Robots

ble 63.2 Complementary strengths of human surgeons and robots (after [63.1])

	Strengths	Limitations
Iumans	Excellent judgment Excellent hand–eye coordination Excellent dexterity (at natural *human* scale) Able to integrate and act on multiple information sources Easily trained Versatile and able to improvise	Prone to fatigue and inattention Limited fine motion control due to tremor Limited manipulation ability and dexterity outside natural scale Cannot see through tissue Bulky end-effectors (hands) Limited geometric accuracy Hard to keep sterile Affected by radiation, infection
obots	Excellent geometric accuracy Untiring and stable Immune to ionizing radiation Can be designed to operate at many different scales of motion and payload Able to integrate multiple sources of numerical and sensor data	Poor judgment Hard to adapt to new situations Limited dexterity Limited hand–eye coordination Limited haptic sensing (today) Limited ability to integrate and interpret complex informat

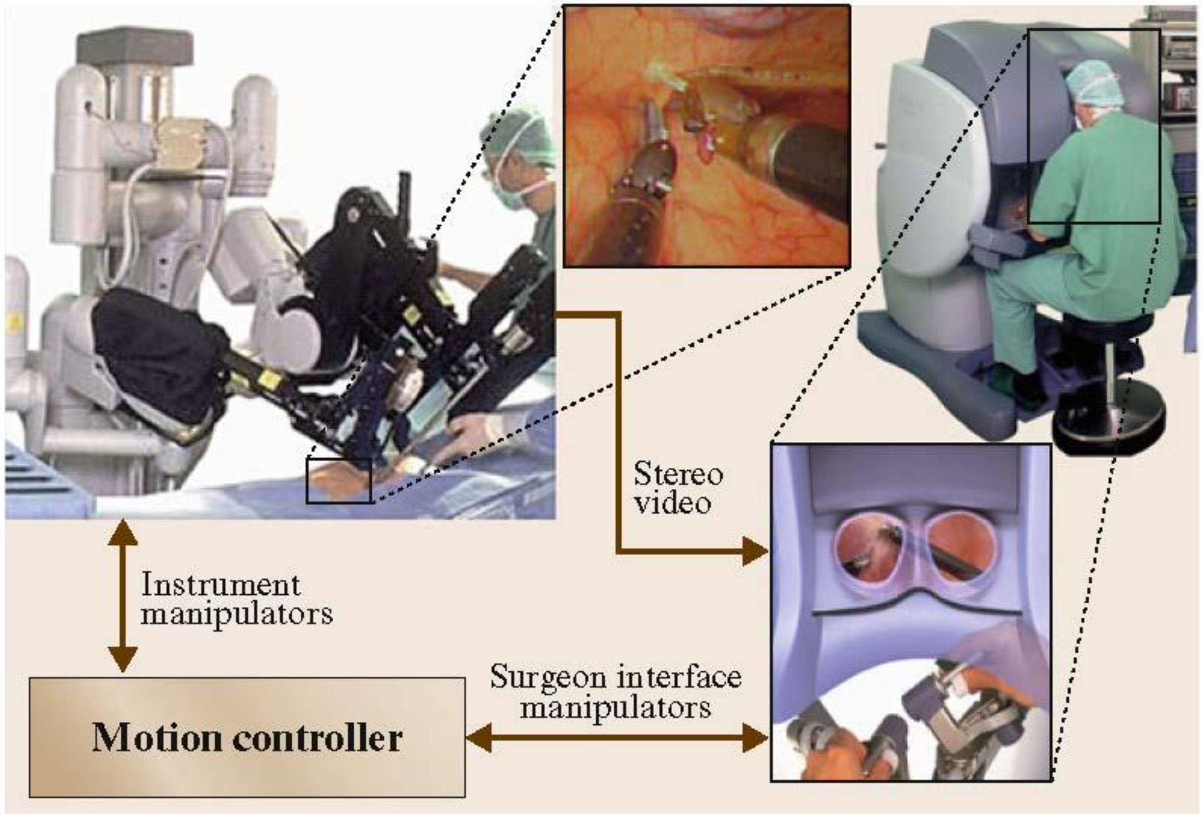
Medical Robotics

- *Surgical CAD/CAM:* process of computer-assisted planning, registration, execution, monitoring, and assessment
- Exploits the geomertic accuracy of the robot
- Computer Integration of multiple data sources: X-Ray, CT,. MRI, Ultrasound
- Goal is not to *replace the surgeon, but to improve his/her ability to treat the patient*
- Think of robot as a *surgical assistant*

Surgeon Extender Robots

- manipulate surgical instruments under the direct control of the surgeon, usually through a teleoperator interface
- Can extend human capabilities: tremor removal, superhuman precision, ability to reach remote interior areas, remote access to patient
- Example: daVinci robot, Intuitive Surgical

daVinci Surgical Robot

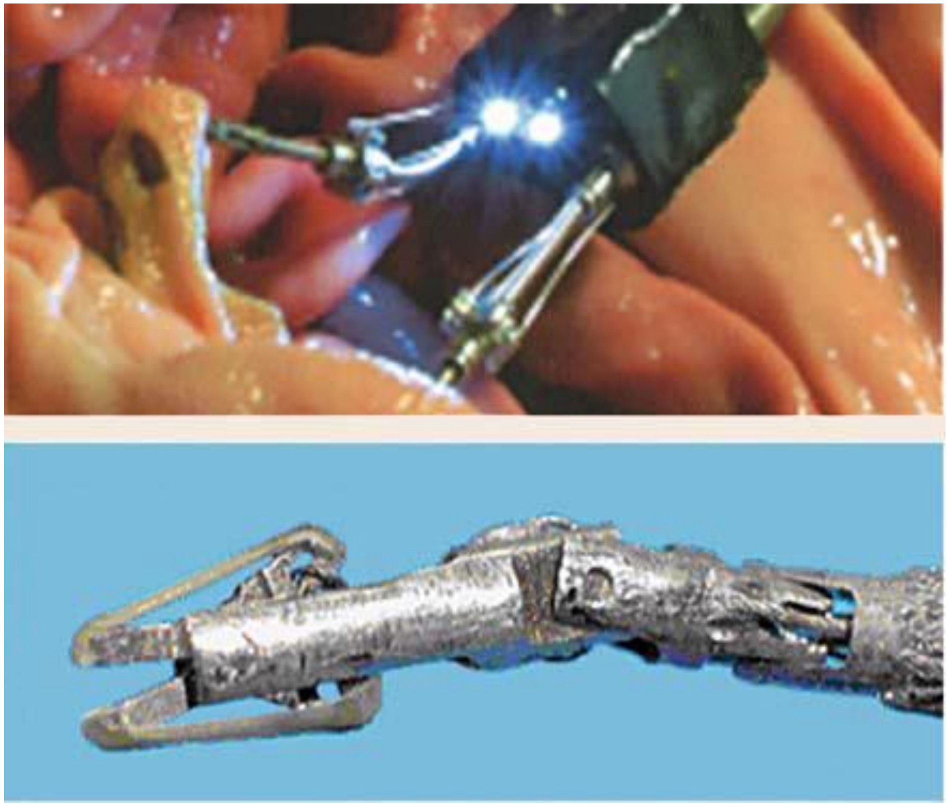


Robot arms to hold instrument
Stereo display
6 DOF tool wrist
Integrated master controller
Standard laparoscopic paradigm –replaces human arms with robot arms

Robodoc: Robotic Hip Replacement

- Register CT to patient
- Automated machining of femur to accept prosthesis
- Monitors force, position, bone movement online

Mechanical Design



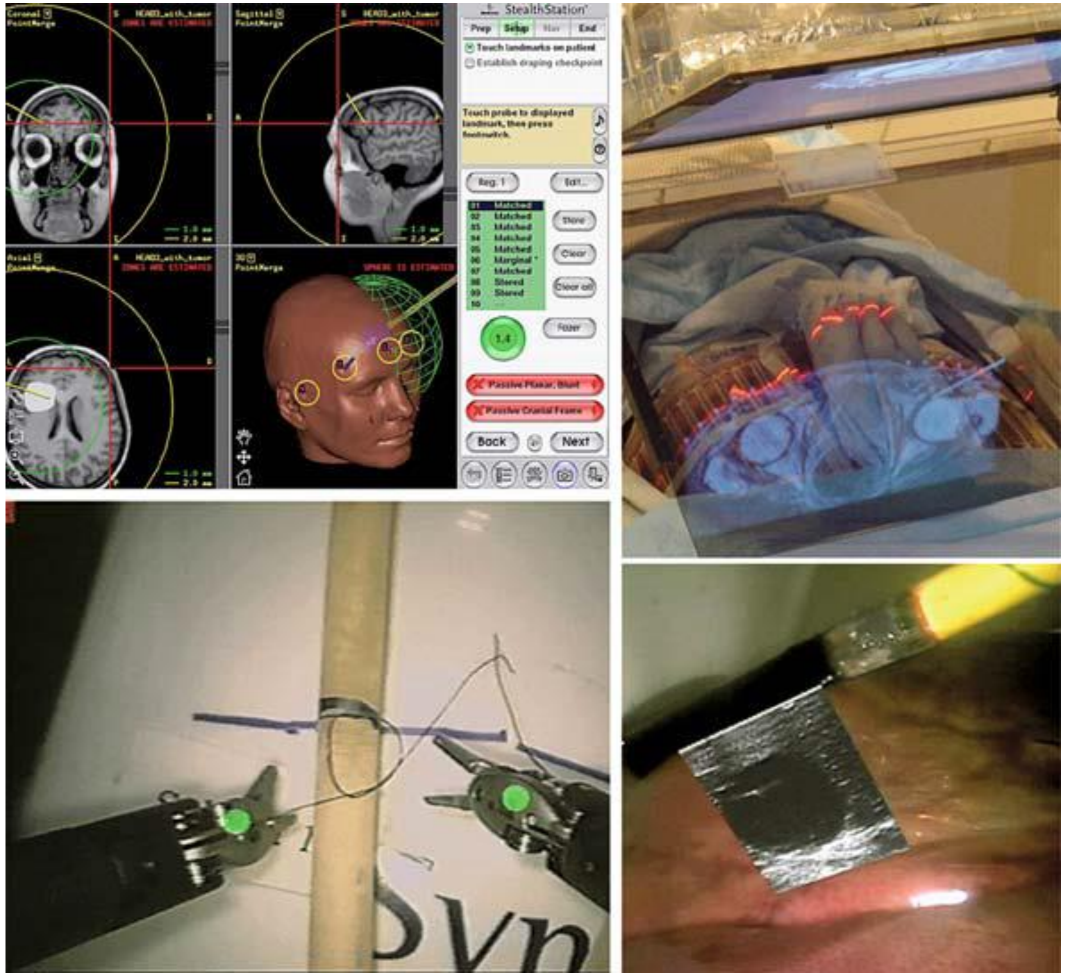
Human-Machine Cooperative Manipulation

- Patient specific data can be used during procedure
- Register pre-op patient data (CT, MRI etc) to in-vivo patient during procedure
- Use patient data constraints to improve safety and accuracy
- Important: provide required assistance without increasing burden on surgeon

Research in Imaging and Modeling of Patients

- Medical image segmentation and image fusion to construct and update patient-specific anatomic models
- Biomechanical modeling for analyzing and predicting tissue deformations and functional factors affecting surgical planning, control, and rehabilitation
- Optimization methods for treatment planning and interactive control of systems
- Methods for registering the *virtual reality* of images and computational models to the *physical reality* of an actual patient
- Methods for characterizing treatment plans and individual task steps such as suturing, needle insertion, or limb manipulation for purposes of planning, monitoring, control, and intelligent assistance
- Real-time data fusion for such purposes as updating models from intraoperative images
- Methods for human–machine communication, including real-time visualization of data models, natural language understanding, gesture recognition, etc.
- Methods for characterizing uncertainties in data, models, and systems and for using this information in developing robust planning and control methods

Information Enhancement: HRI



- (**a**) Display from a typical surgical navigation system, here the Medtronic StealthStation
- (**b**) the JHU image overlay system] uses a mirror to align the virtual image of a cross-sectional image with the corresponding physical position in the patient’s body
- (**c**) Sensory substitution display of surgical force information onto daVinci surgical robot video
- (**d**) Overlayof laparoscopic ultrasound on tot he daVinci surgical robot video monitor

Mobility Inside the Body

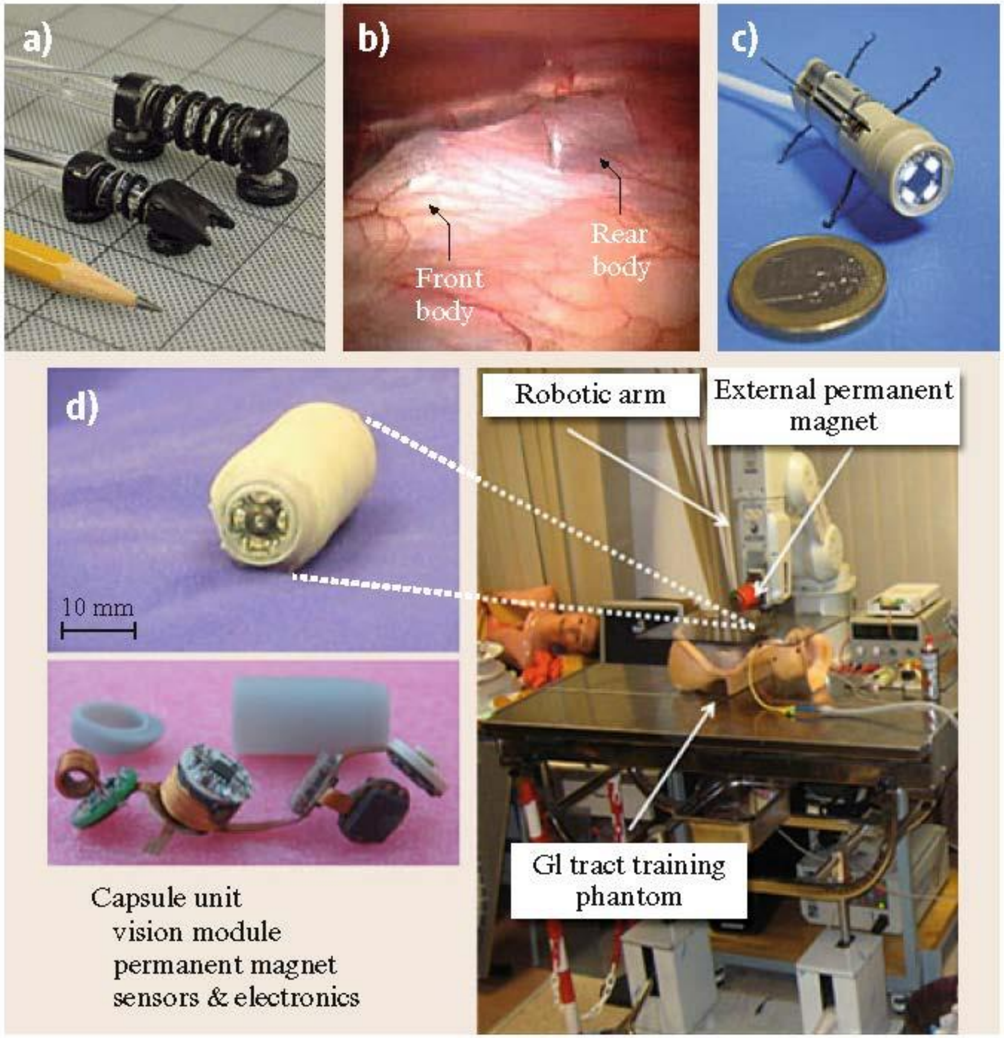


Fig.63.11a–d Mobility inside the body. **(a,b)** *HeartLander* device for crawling across the surface of the heart (after [63.31]). **(c)** Legged capsule for gastrointestinal diagnosis and therapy (after [63.28, 148]), **(d)** magnetic capsule for exploration of the GI tract, showing *left* capsule and components and *right* magnetic dragging platform based on a permanent magnet driven by a robotic manipulator (after [63.143])

Medical Robotics: Conclusions

- exploiting technology to transcend human limitations in treating patients
- improving the safety, consistency, and overall quality of interventions
- improving the efficiency and cost-effectiveness of care
- improving training through the use of simulators, quantitative data capture and skill assessment methods, and the capture and playback of clinical cases
- promoting more effective use of information at all levels, both in treating individual patients and in improving treatment processes