Surgical Simulation Research Initiatives

Roger Smith, PhD, roger.smith@flhosp.org
Sanket Chauhan, MD, sanket.chauhan@flhosp.org

Juan Cendan, MD, Asst Dean for Simulation
jcendan@mail.ucf.edu

May Liu, Product Manager for Simulation
May.Liu@intusurg.com

Approved for Public Release.

Focused Topic

Surgical Simulation Research Initiatives

Modeling and simulation is becoming an important technique for developing and testing medical equipment, training healthcare professionals, and conducting research on medical topics. This workshop will present some of the most current research efforts and product developments in **surgical** simulation.

The instructors will present work in simulators to support robotic surgery, digital tissue models, telesurgery, and a number of related technologies. The Nicholson Center for Surgical Advancement at Florida Hospital is bringing these technologies together to enable the delivery of certified education for surgeons and other healthcare professionals.

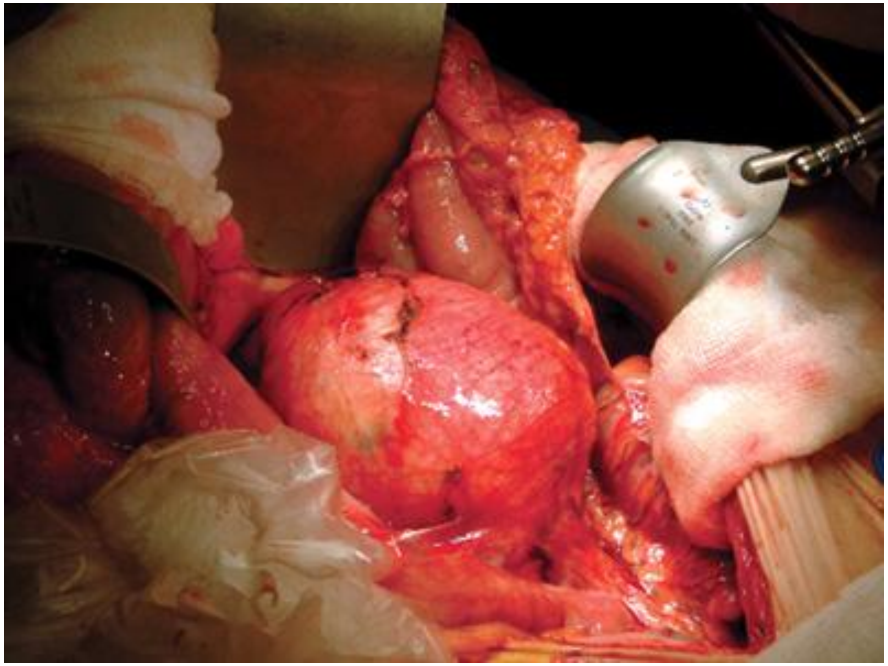
WARNING!

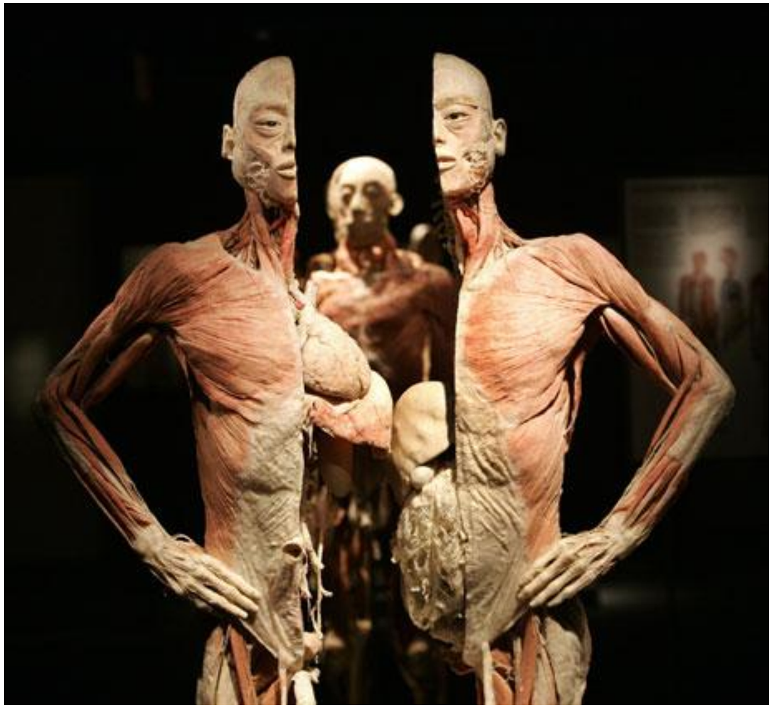
You cannot explore surgical simulation without explicit pictures, video, and models of the human body, organs, blood, and other fluids. Images of all of these are included in this workshop.

Definitions

Open Surgery

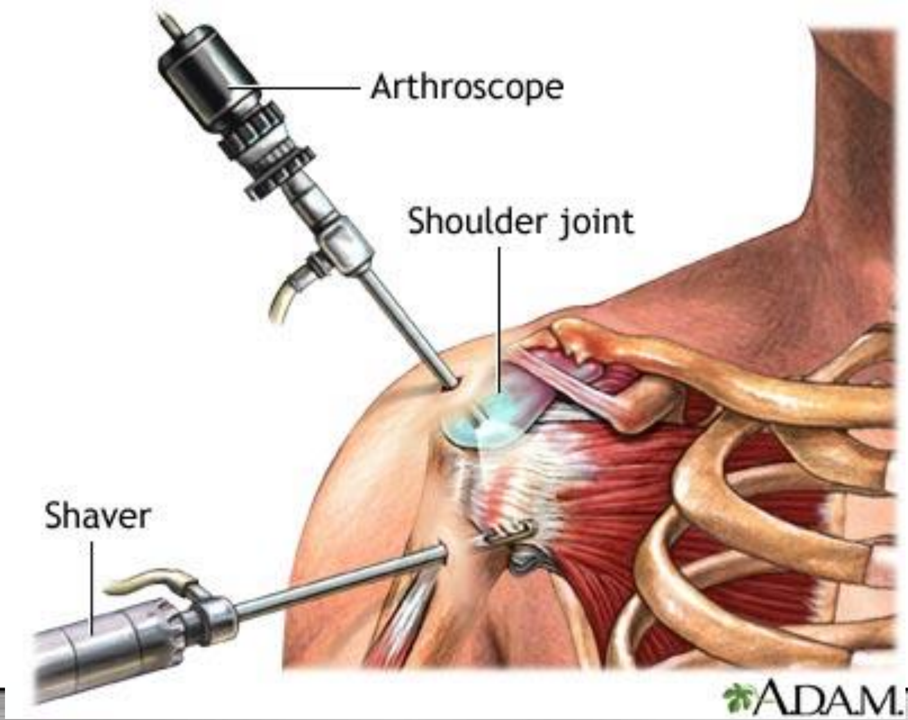
- "An *open surgery* means cutting skin and tissues so the surgeon has a direct access to the structures or organs involved. The structures and tissues involved can be seen and touched, and they are directly exposed to the air of the operating room."

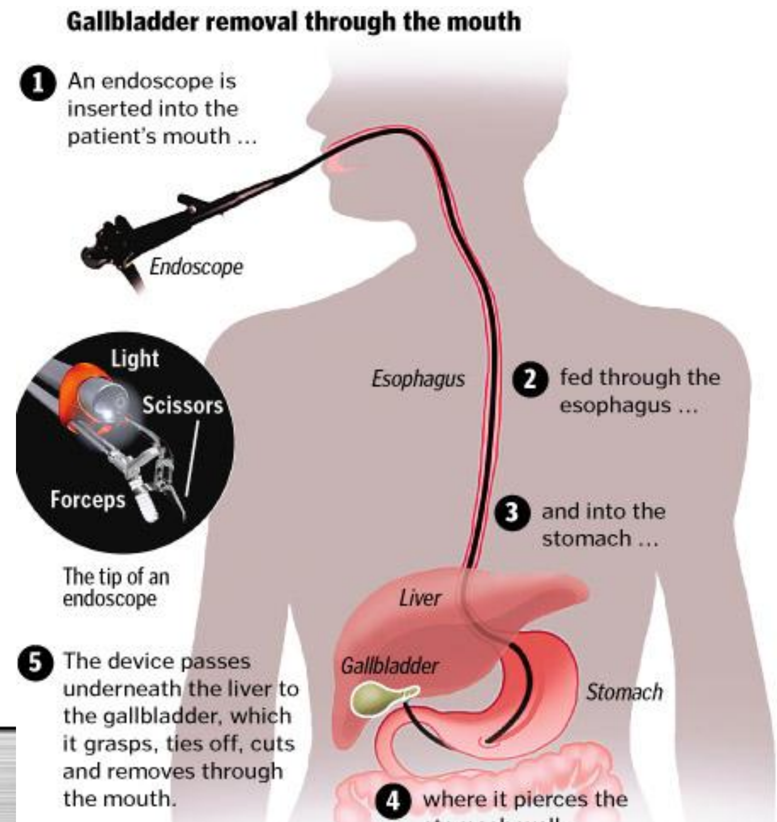




Minimally Invasive Surgery

- “A *minimally invasive procedure* is less invasive than open surgery used for the same purpose. It typically involves use of laparoscopic devices and remote-control manipulation of instruments with indirect observation of the surgical field through an endoscope or similar device, and is carried out through the skin or through a body cavity or anatomical opening. “





Laparoscopic Surgery

- “A type of minimally invasive surgery in which a small incision is made in the abdominal wall through which an instrument called a laparoscope is inserted to permit structures within the abdomen and pelvis to be seen. The abdominal cavity is distended and made visible by the instillation of absorbable gas, typically, carbon dioxide.”

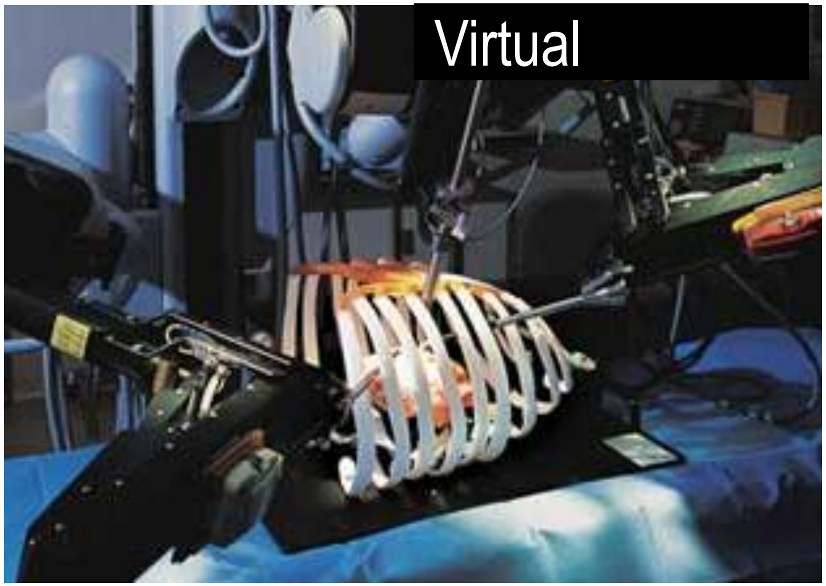
Robotic Surgery

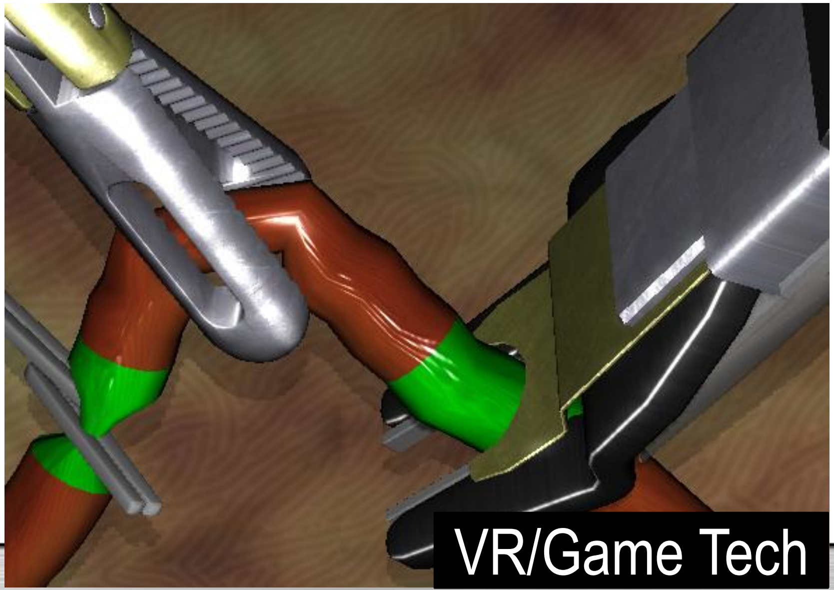
- "Robot-assisted surgery was developed to overcome limitations of minimally invasive surgery. Instead of directly moving the instruments the surgeon uses a computer console to manipulate the instruments attached to multiple robot arms. The computer translates the surgeon's movements, which are then carried out on the patient by the robot."

Unique Challenges

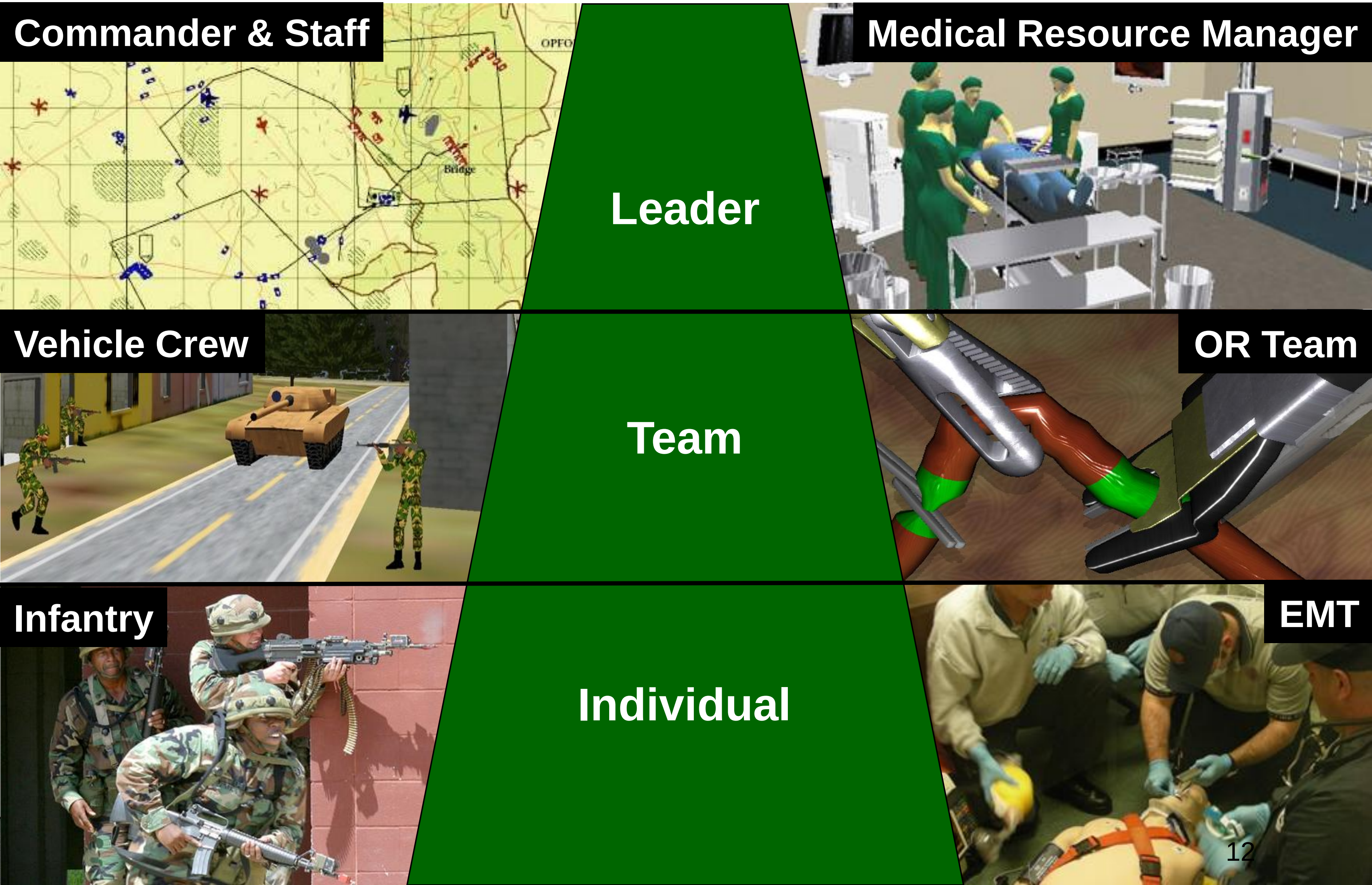
Classic Military Simulation Elements

Civilian Surgical Simulation Elements





Transferable Experience



Transferable Expertise

Similarities

Leadership:
Manage Resources, Measure Performance, Provide Feedback

Team:
Hand/Eye/Mind Coordination, Teamwork, Emotional Response, Situational Learning

Individual:
Diagnosis, Sustainment, Repair, Routing

Differences

Materials:
Hard Steel vs. Soft Tissue

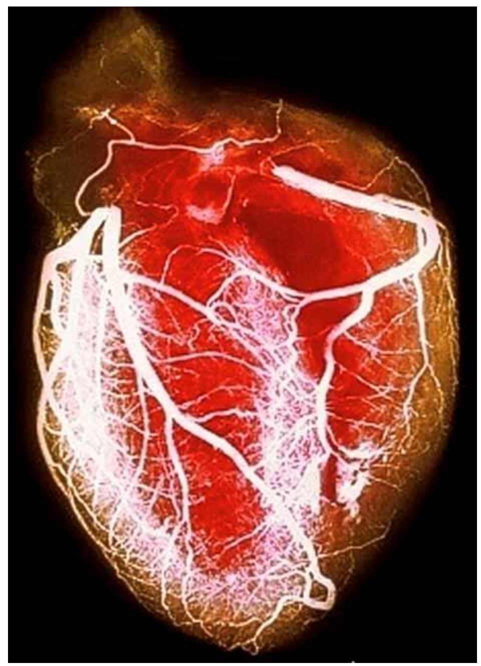
Behaviors:
Heal vs. Destroy, Tissue Response

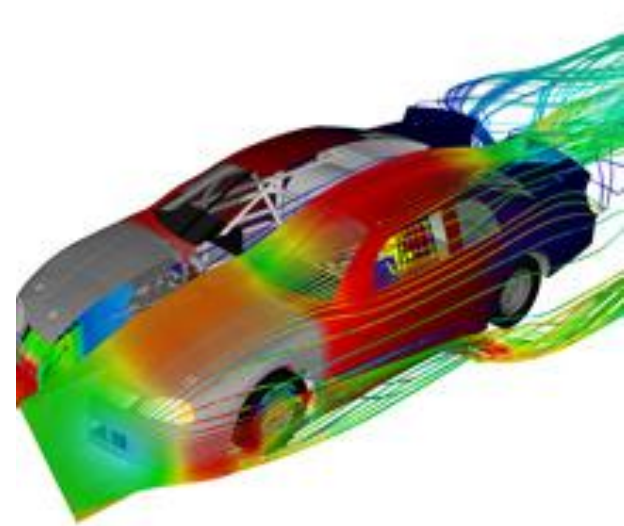
Modeling the World

Hard Objects
tanks, helos, ships

Human Body
living
tissue

Fluid Dynamics
water, air flow





Left & Right of the Blast

Dr. Joe Rosen, Dartmouth Medical School

Left of the Blast

Blast

Right of the Blast

Combat Simulations

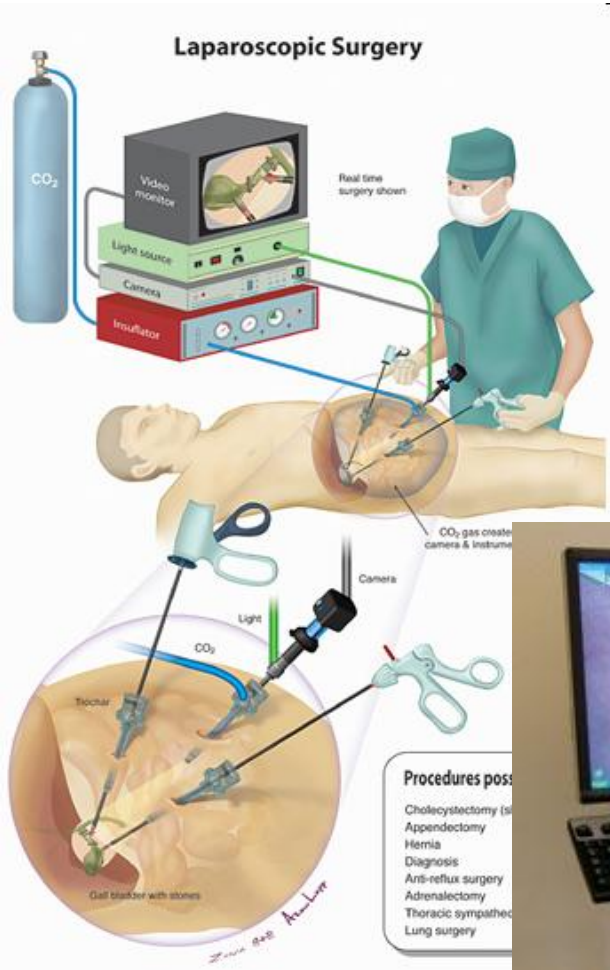
Medical Simulations

Learn to be <u>successful</u> in battle

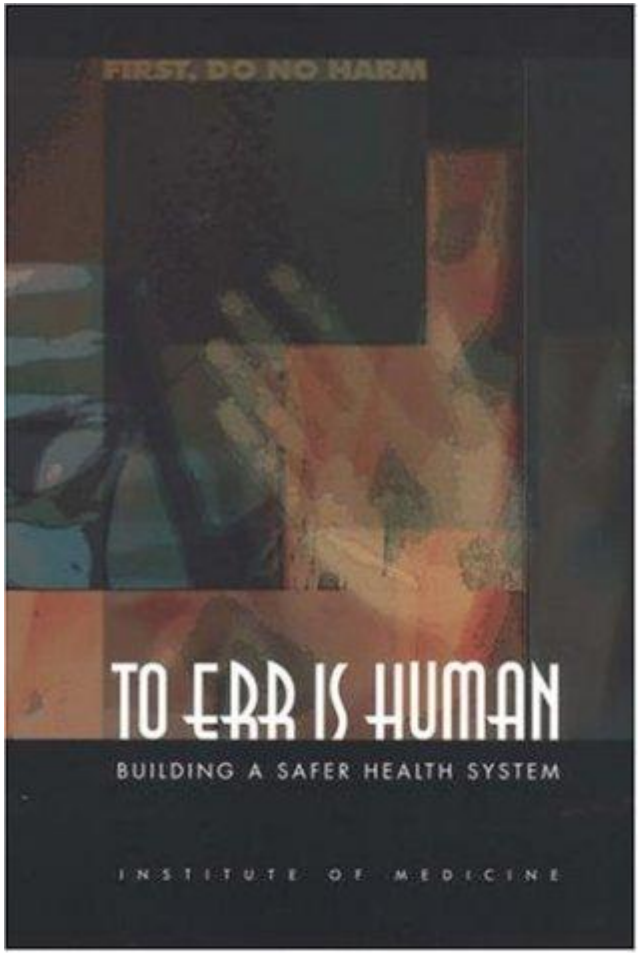
Recovering from the <u>outcome</u> of battle

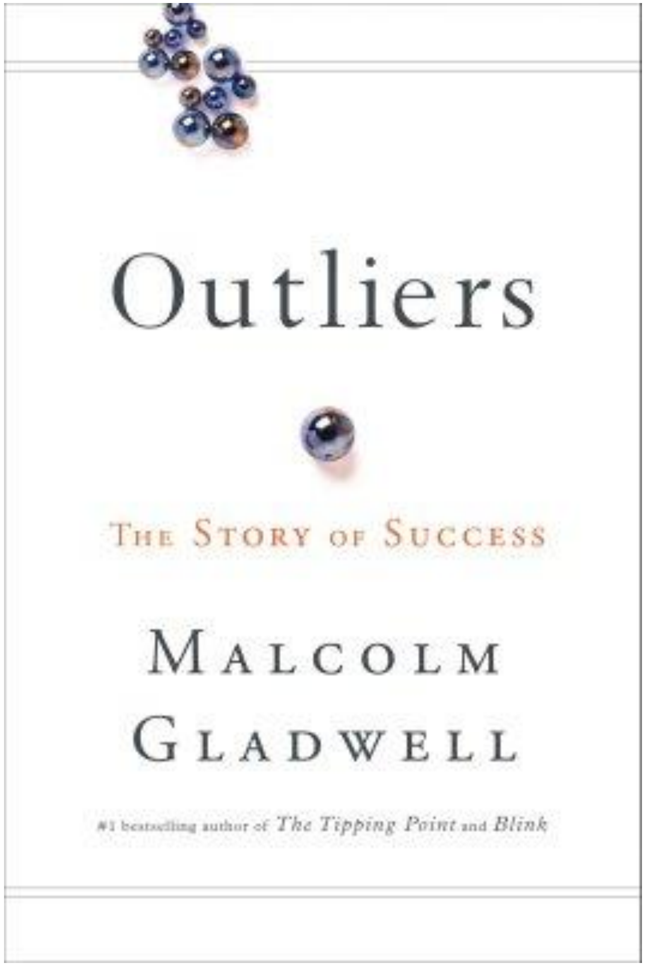
Cusp of Mortality
For a Young Soldier

The Surgical Pilot



Eliminating Errors and Creating Experts





10,000 hours to become an expert
Must it all be done on human subjects?

Training Technology Options

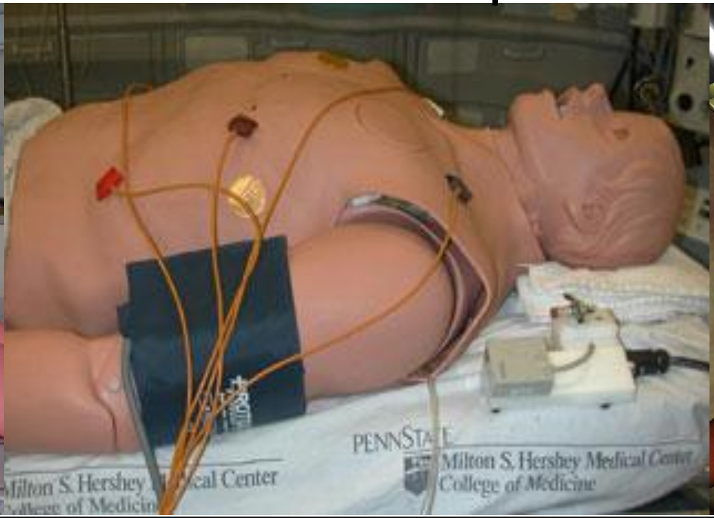
Human

Animal

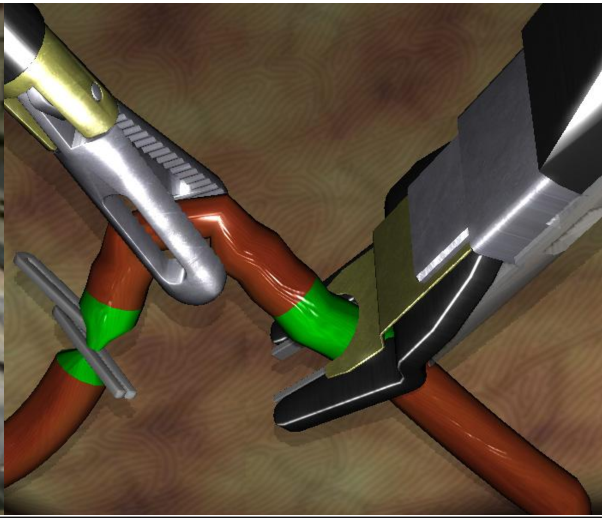
Box Trainer

Part Task

Mannequin



VR/Game Tech



Human	Animal	Box Trainer	Mannequin	Simulation	VR/Game
Learn on humans: Living patients, the newly dead, and cadavers	Learn on animals: Living and newly dead pigs, cats, and others	Learn on organs in a box: Human-shaped box contains organs, tissue, or test devices	Learn on a physical replica: A full-body device with synthetic skin, organs, and fluids	Learn on an animated machine: Includes computer, hydraulics, pneumatics, and electrical responses	Learn on computer images: Mathematical models, visual images, sounds, and some tactile feedback
<u>Advantage</u> Exact Replica, Existing OR	<u>Advantage</u> Similarities, Availability	<u>Advantage</u> Availability, Convenience, Human Shape	<u>Advantage</u> Human Shape, Logistics	<u>Advantage</u> Rich Experience, Multi-Function, Programmable	<u>Advantage</u> Rich Experience, Flexibility, Low Cost
<u>Disadvantage</u> Scarcity, Single Use, Ethical Issues	<u>Disadvantage</u> Anatomy, Single Use, Social Mores	<u>Disadvantage</u> Not Alive, Single Use, Animal Organs	<u>Disadvantage</u> Static, Lacks Realism	<u>Disadvantage</u> High Cost, Complexity	<u>Disadvantage</u> Screen-barrier, Non-tactile
<u>Examples</u> Cadavers Live Patients	<u>Examples</u> Porcine Labs	<u>Examples</u> MIC-Trainer	<u>Examples</u> CPR Annie	<u>Examples</u> Sim One HPS	<u>Examples</u> MIST-VR LapSim

Components of a Surgical Simulator (Harders, 2008)

Model Generation

Clinical Expertise

Vascular Structures

Bleeding Simulation

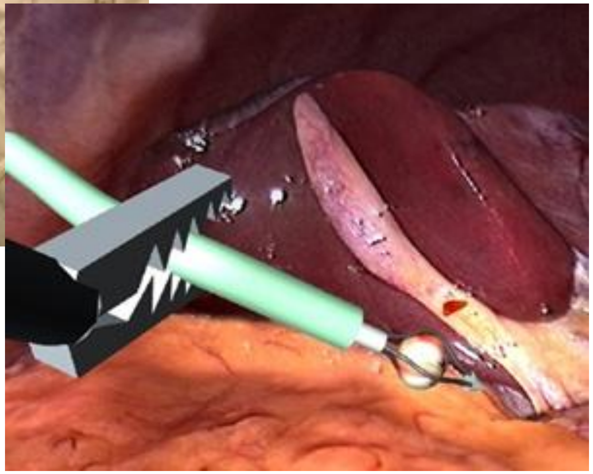
Tissue Parameters

Tissue Cutting

Organ Texturing

Tissue Deformation

Haptic Interface



Collision Detection

Immersive OR

Fluid Simulation

Motivation

Medical Education – Explosion of Information

- **Medical procedures are becoming more numerous and more complex – medical knowledge has "hypertrophied"** (Cooke, 2006)
- **Training residents to a common level of knowledge and competence is already impossible** (Satava, 2008)
- **Some procedures lend themselves well to computer-based training tools**
- **Laparoscopic surgery is especially amenable because of the intermediation of the camera, computer monitor, and long-rod effectors in surgery**

“The Perfect Storm” (Murphy, 2007)

- Risk to patient health. (McDougall, 2007)
- Cost is a barrier to training. (Bridges, 1999)
- Availability of training opportunities. (Birden, 2007; Davis, 1999)
- Access to training. (Dunkin, 2007; Spitzer, 1997)
- Limited working hours. (Satava, 2004)
- Ethics of practicing on patients. (Satava, 2004; Murphy, 2007)
- Expectations around computer technologies. (Murphy, 2007)
- Insurance coverage of educational actions. (Satava, 2004)
- Volume of unique procedures. (Reznick & MacRae, 2006)
- Complexity of modern surgery. (McDougall, 2007)
- Quality of VR technology. (Murphy, 2007)
- Professional Acceptance. (Ziv, 2003)
- Learning from Mistakes. (Ziv, 2005)
- Proficiency-based Medicine. (Murray, 2005)

Powerful Motivations

- **Motive 1: Lower Cost**
- **Motive 2: Better Access to Symptoms/Cases**
- **Motive 3: Reduced Training Time**
- **Motive 4: Reduced Errors**

Similar for Military, Industrial, and Medical Training

Motive 1: Lower Cost

- **Surgery as a teaching event takes considerably longer.**
- **Ties up resources that could generate additional revenue. (Bridges & Diamond 1999)**
  - **Accumulates to 186 hours over a 4 year residency**
  - **Estimate operating room costs at $257.40 per hour.**
- **Adds $47,970 to the cost of a medical education.**
- **Other Cost Estimates**
  - **US operating room $1,500 per hour** (Frost & Sullivan, 2004)
  - **Swedish operating room $1,000 per hour** (Hyltander, 2003)
  - **"OR costs $250 per 15 minutes" (**Satava, 2008).
- **$186,363 to $279,545 during four year residency.**

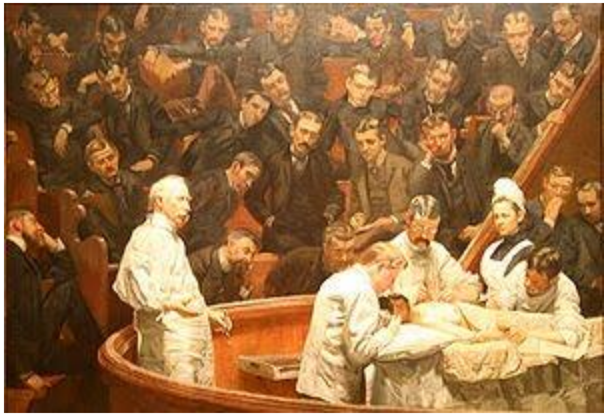
Simulator ROI

Category	Description	Fixed Cost	Recurring Over Residency (4 Years)	After Residency (5th Year)	Total over 5 Years
Investment	AccuTouch Simulator	(72,000)	(18,664)	0	(90,664)
Time Savings	Instructor time		23,040	0	23,040
	Additional Procedures		0	114,400	114,400
Reduction in Errors	Complications		0	0	0
	Cancellations		13,600	0	13,600
Faster Time to Competence	Residents generating revenue		78,000	0	78,000
Equipment Breakage	Reduction due to better training		5,428	5,428	10,856
Other Financial Benefits	Reduction in alternative training		4,400	0	4,400
	Revenue from selling time on simulator		93,000	0	93,000
	Total Cost/Benefit	**(72,000)**	**198,804**	**119,828**	**246,632**

Derived from Frost & Sullivan, 2004

Motive 2: Better Access

- "The traditional Halstedian apprenticeship model of 'see one, do one, teach one' is no longer adequate to train surgeons, since good laparoscopic skills cannot be developed by merely watching an expert. Laparoscopic proficiency is only realized after sufficient practice in the minimally invasive environment. To this end, a variety of approaches have been developed to teach laparoscopic skills outside of the operating room; these methods include practicing on animal models or artificial tissues, training boxes, and virtual reality simulators." (Pearson et al, 2002)
- In laparoscopy, "see one" does not contribute to the learning process. Learning begins with "do one" (Jordan et al, 2001; Gallagher et al, 2001b; Madan & Frantzides, 2007).



Better Access, Better Training

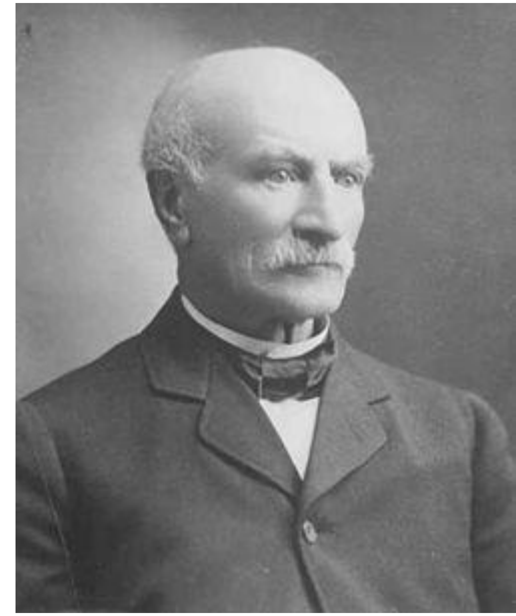
- **<u>Proficiency is reached after 10 to 30 surgeries</u>. VR systems allow these to be moved off of patients** (Grantcharov et al, 2003b and 2004; MacFadyen et al, 1998)
- **Modern methods for delivering medical care are much <u>more complicated</u>** (Cooke et al, 2006)
- **<u>Expectations of the public are higher</u> now than when the current apprenticeship model was created** (Cooke et al, 2006)
- **Resident restriction of <u>80 hours per week</u> is limiting training opportunities** (McClusky et al, 2005; Brunner et al, 2005; Eastridge et al, 2003)
- **<u>Repeated practice of procedures</u>, standardized tasks, and objective measurements are important factors in mastering laparoscopic skills and these are all <u>lacking or limited in traditional OR-based training</u>** (Grantcharov et al, 2003b and 2004)
- **Experiments allowing high school students to use MIST-VR** (Ali et al, 2002)
- **Experiments on resident performance with little sleep** (DeMaria et al, 2005)

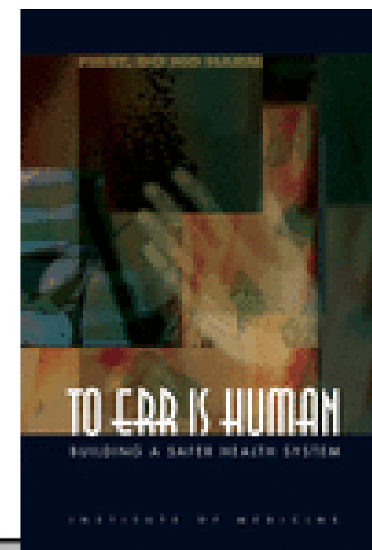
Motive 3: Reduced Time

- **Both MIST-VR and GI-Mentor differentiate experienced from inexperienced subjects based on their performance scores with the simulator** (Adamsen et al, 2005)
- **MIST-VR simulator could determine which students would never achieve proficiency in laparoscopy and should be dropped from a training program** (Gallagher et al, 2004)
- **Non-VR trained students are nine times more likely to fail to make progress in their performance than those who use VR in their training** (Seymour, 2002)
- **Students trained in VR are 29% faster at performing laparoscopic surgeries and make up to five times fewer mistakes** (Enochsson et al, 2004; and Seymour, 2002)

Motive 4: Reduced Errors

- **“There is no excuse for the surgeon to learn on the patient.”** (William J. Mayo, 1927).
- **Medical error is responsible for between 44,000 and 98,000 deaths per year** (IOM, 1999).
- **Laparoscopic surgery has an <u>error rate that is three times higher</u> than that of open surgery. Error rate has not been decreasing over an eight year period as surgeons become more experienced at the procedures** (Huang et al, 2005).
- **VR systems are one tool that can improve the performance of surgeons because they become familiar with the appearance of organs and tissue on a two dimensional computer monitor** (Huang et al, 2005).
- **In laparoscopy, observation does little to convey the skills that must be mastered. Only actual practice has been effective at this** (Jordan et al, 2001; Gallagher et al, 2001b; Madan & Frantzides, 2007).





Misleading Assumptions on Traditional Methods

- **Assumption 1: Didactic Education is Effective**
  - **Though surgeons or residents may learn new information during educational lectures, they do not incorporate it into their practice. It has no impact on their actions in delivering medicine.** (Davis et al 1995 & 1999; Weller et al 2005)
- **Assumption 2: Cost of Systems is Not an Issue**
  - **Scientific vs. Financial view of health care**
- **Assumption 3: Sufficient Access to Faculty and Patients is Possible**
  - **Availability of faculty is a major limitation in medical education** (Dunkin et al, 2007; Satava, 2008)
  - **Many studies assume adequate access a priori** (Gerson & Van Dam, 2003)
- **Assumption 4: Practicing on Live Patients is Acceptable**
  - **Medical schools, faculty, and residents are finding new restrictions on the type and amount of training that can be conducted with a live patient** (Murphy et al, 2007; Murray et al, 2005; Satava, 2004a; Ziv et al, 2005).

Historical Background

Mrs. Chase (1911)

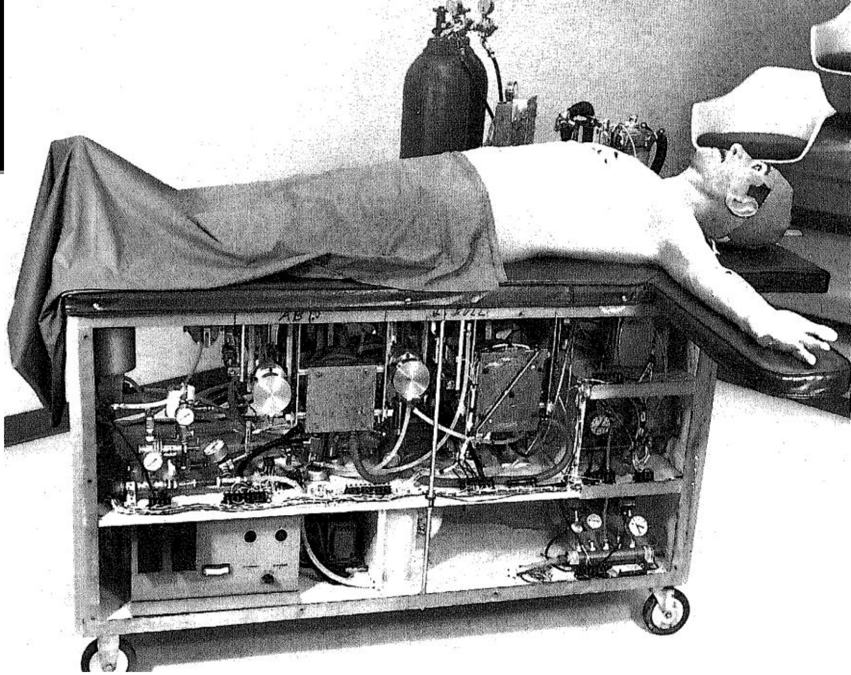
First commercial manikin-based simulator was introduced in 1911 – Mrs. Chase

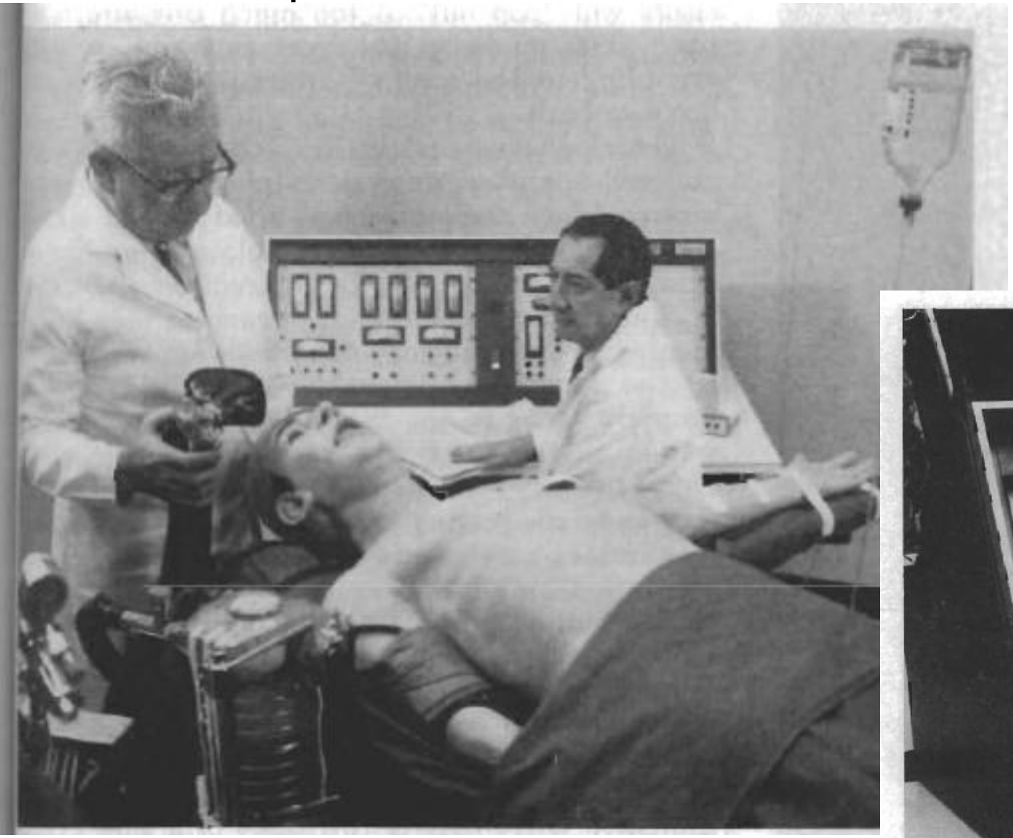
Resusci Annie (1960)

1960 – First manikin specifically built for resuscitation was introduced – Resusci Annie

Sim One (1967)

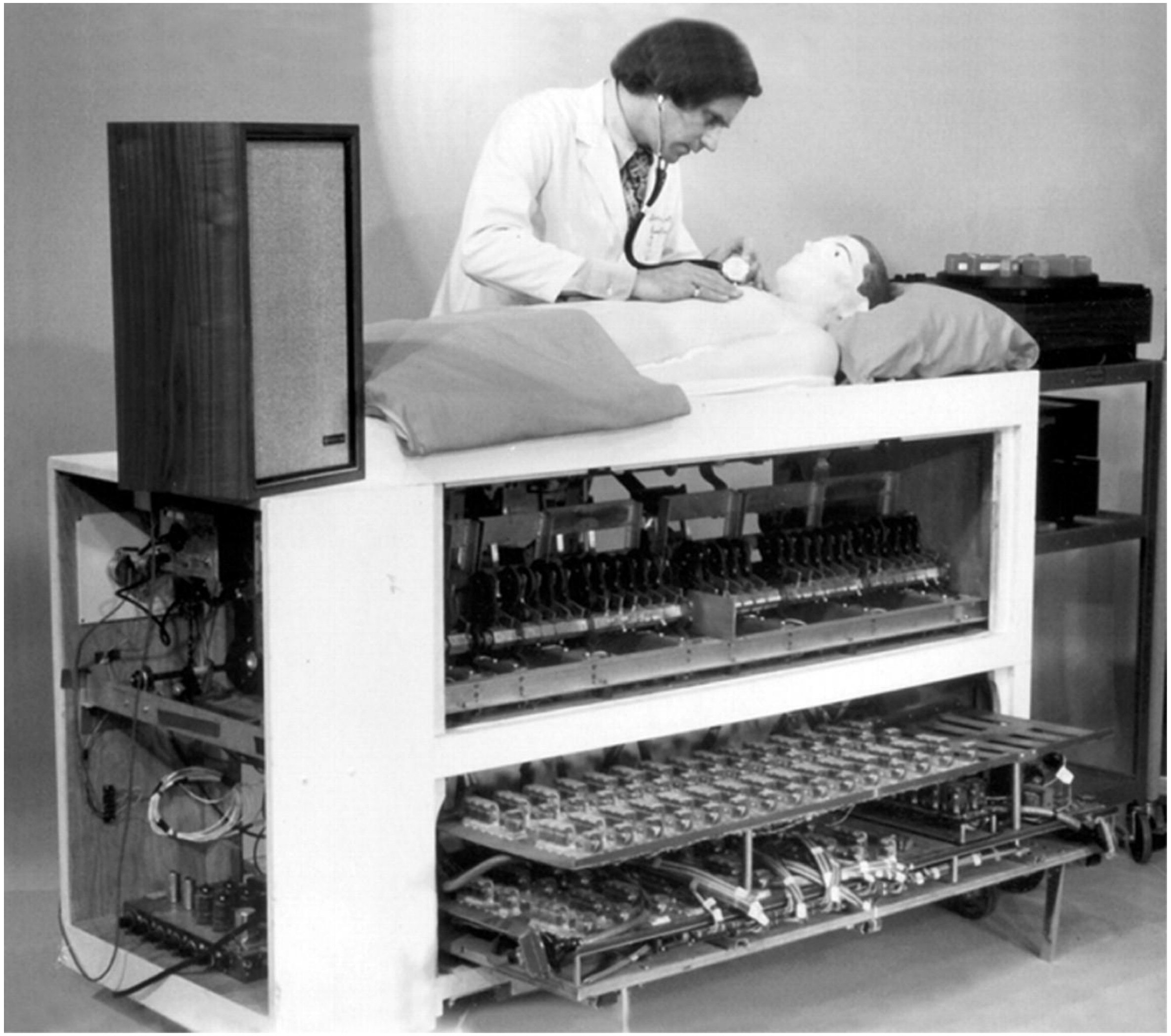
$272,000 grant from Dept of Education in 1964. Built by a AeroSpace General, USC Medical School, and LA County General Hospital.





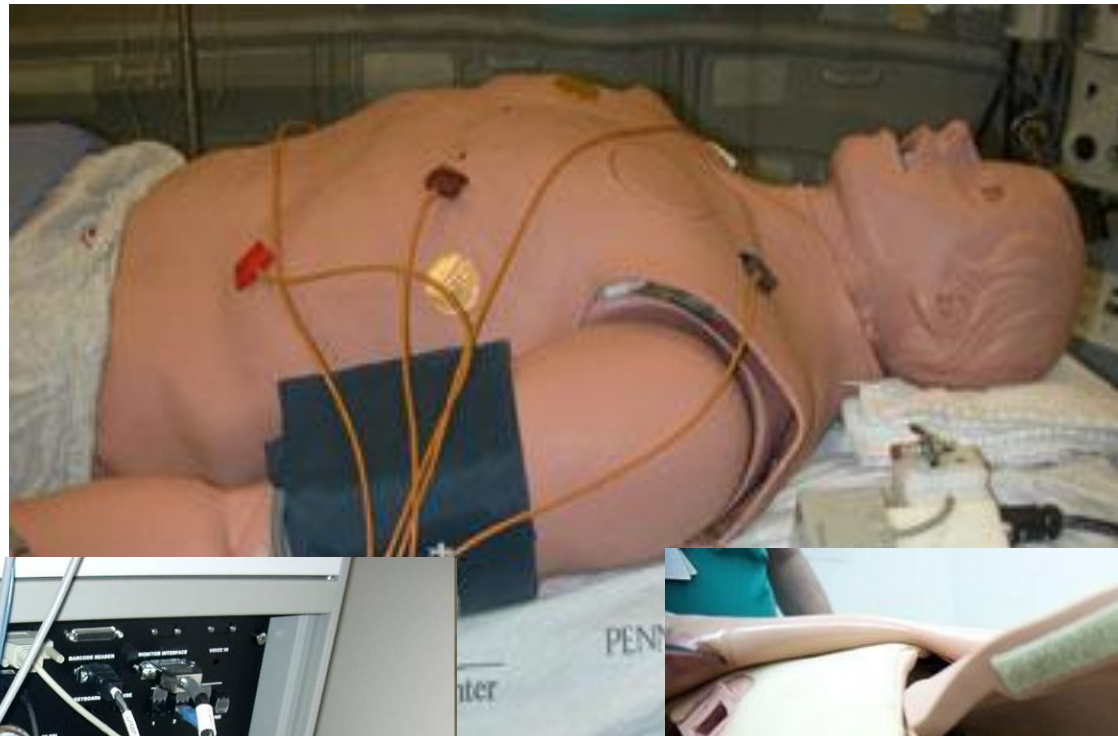
Denson JS, Abrahamson S. A computer-controlled patient simulator. *Journal of the American Medical Association* 1969; 208:504–8.

From Cooper 2008



MedSim Eagle (1986)

METI HPS (1996)



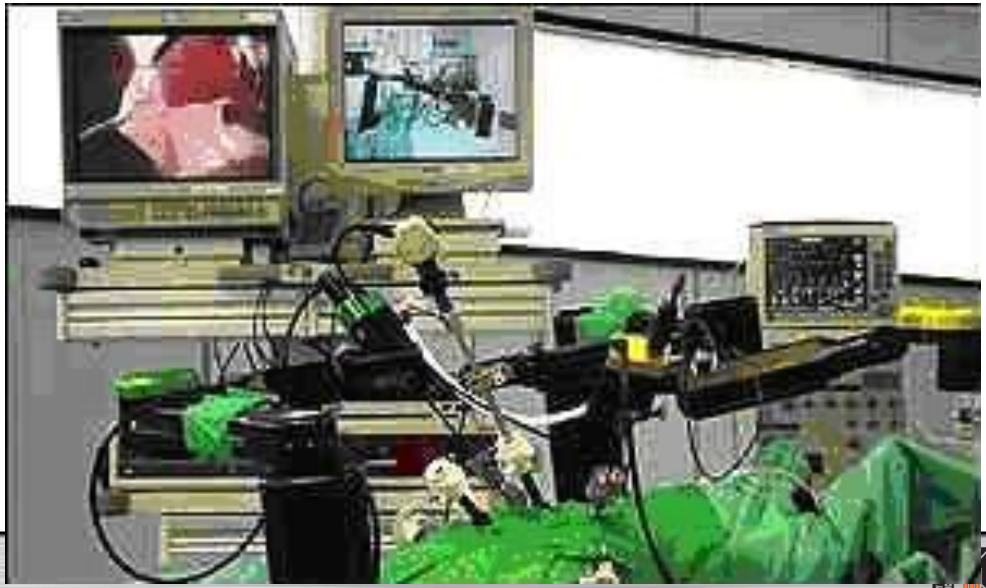
Laerdal SimMan (2000)

Break #1

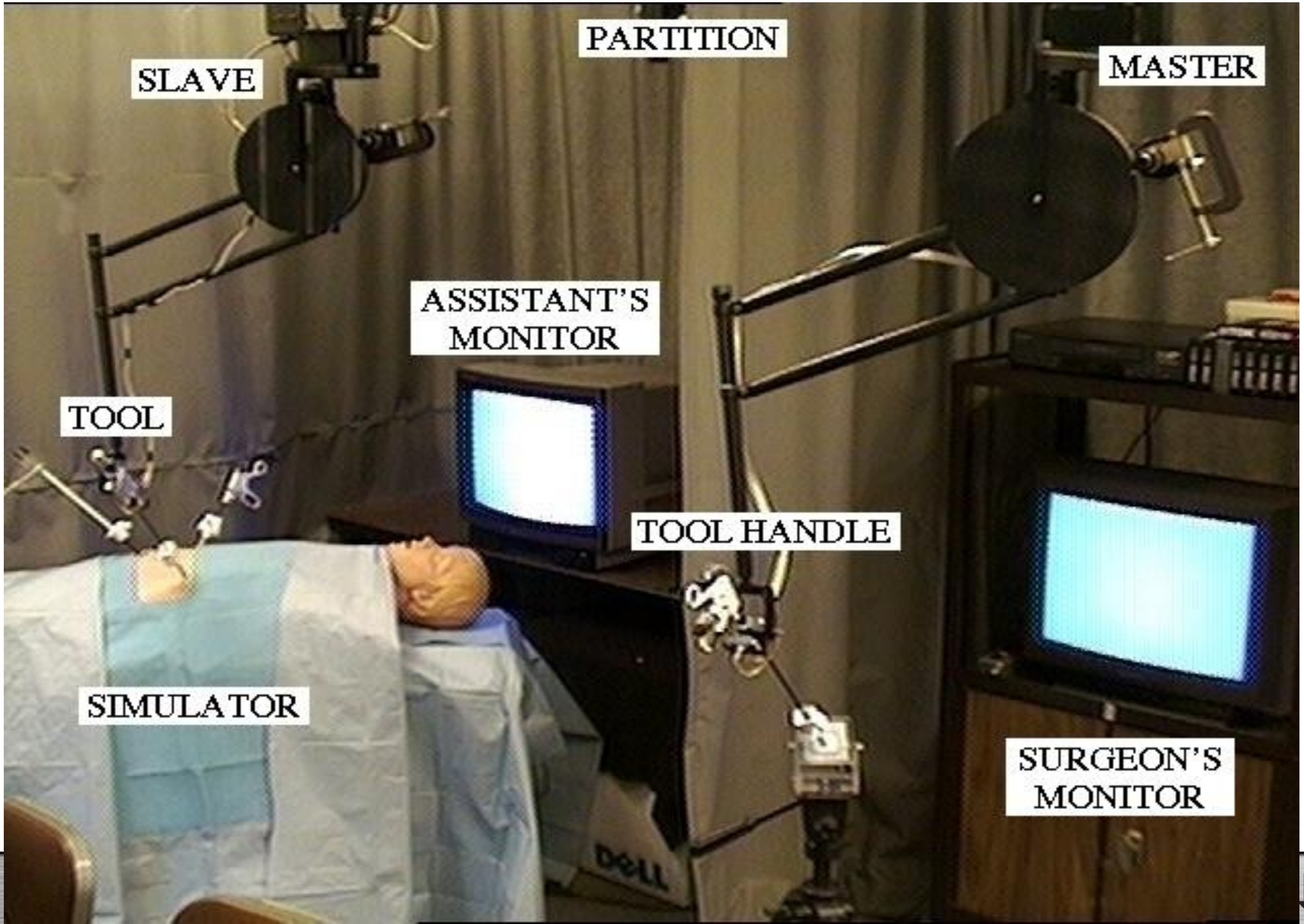
Telesurgery Connections

World's First Telesurgery

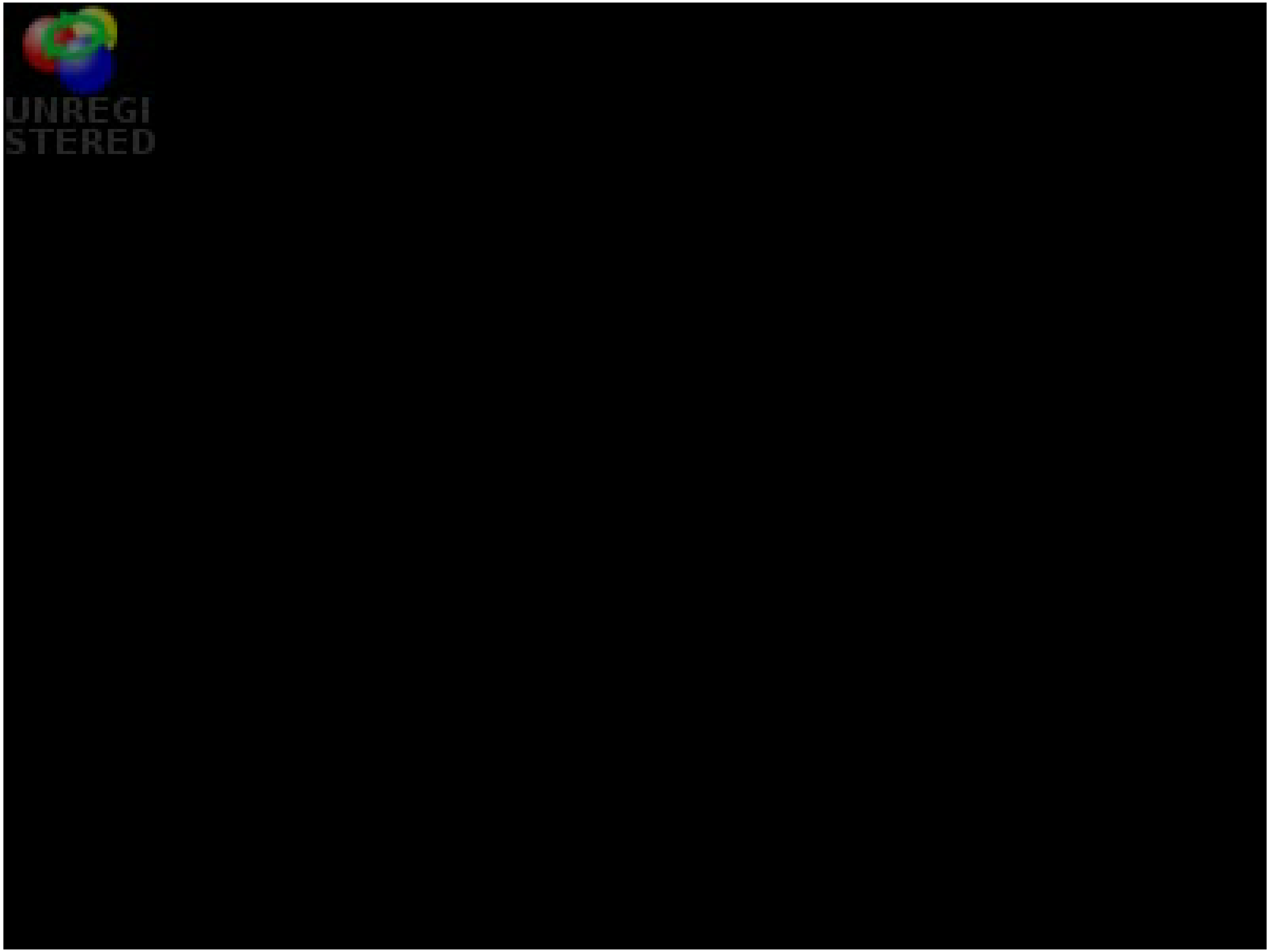
- September 2001: Tele- chole (gall bladder removal)
- Surgeon in New York, Patient in France
- Round trip distance =8,700 miles
- Round trip data time = 200 ms
- Collaborators: Prof Jacques Marescaux, New York & European Institute of Telesurgery, Strasbourg
- http://news.bbc.co.uk/2/hi/science/nature/1552211.stm



Telesurgery research at MIT

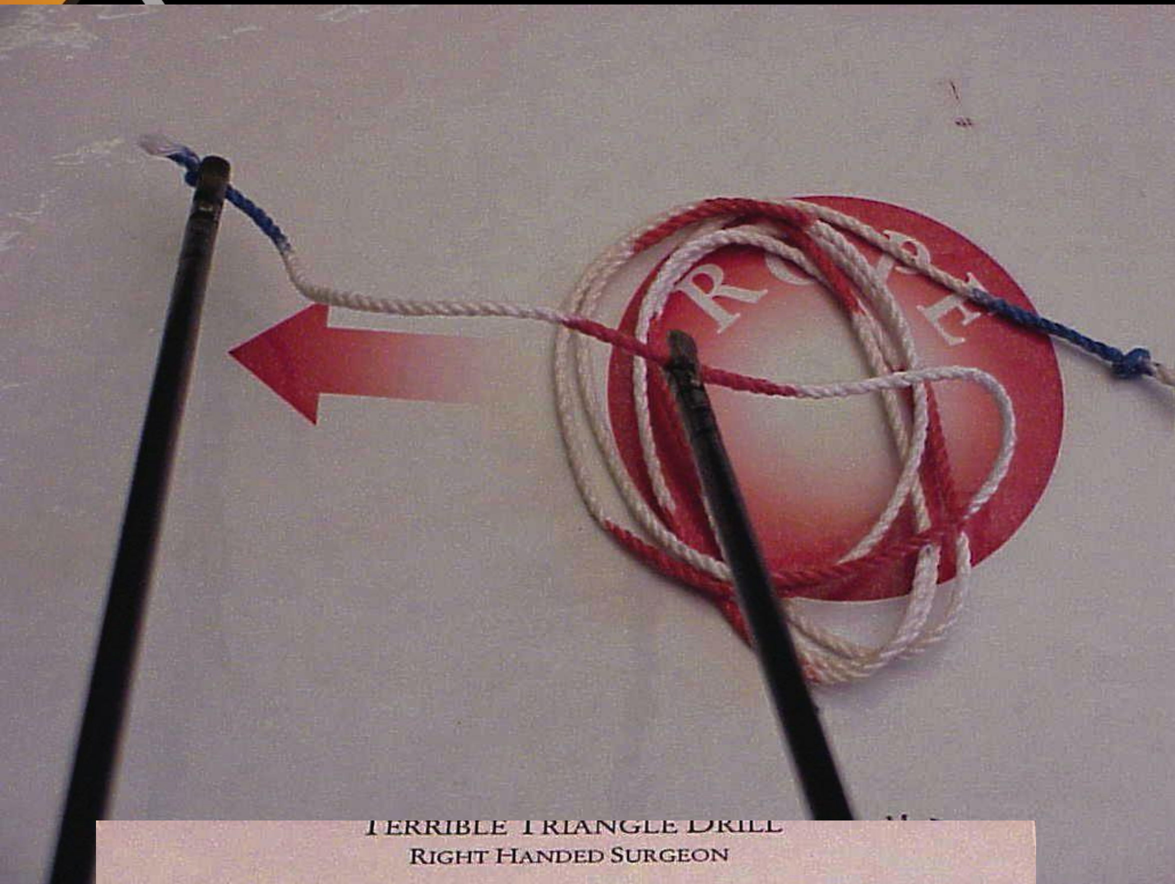


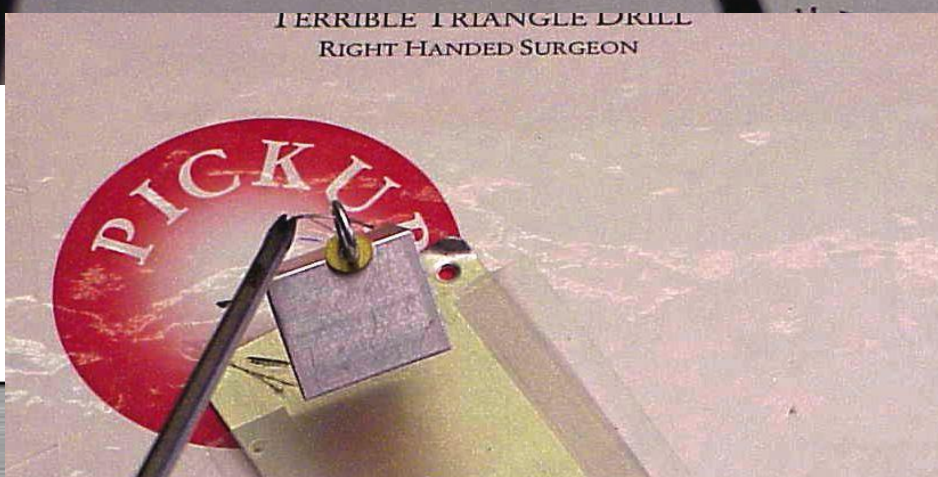
Intuitive Surgical's da Vinci Robot

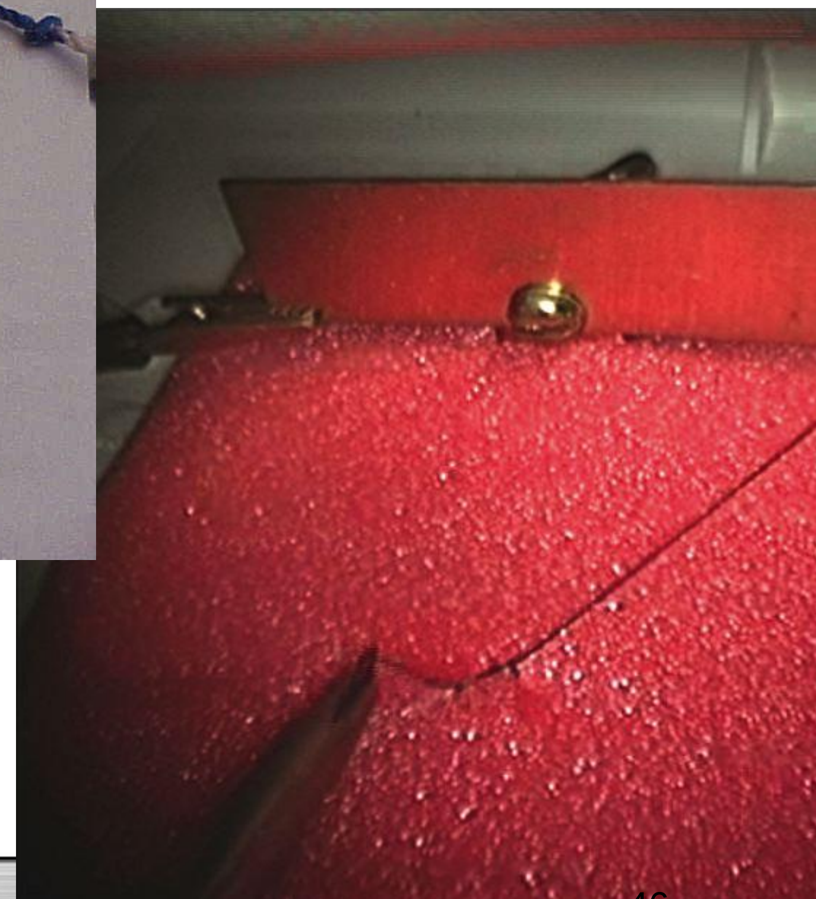


Tactile Models

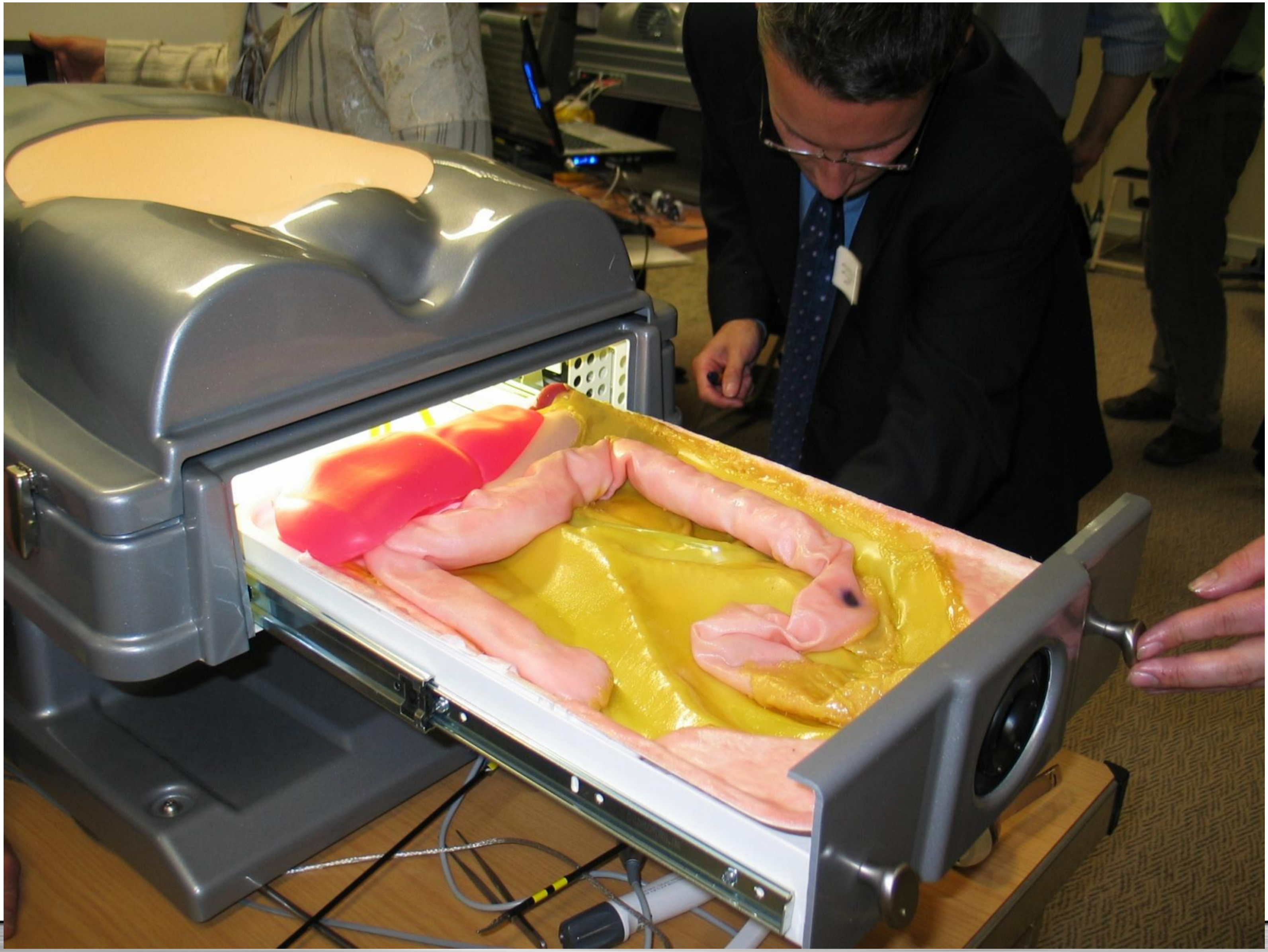
Butch Rosser's Laparoscopic Top Gun



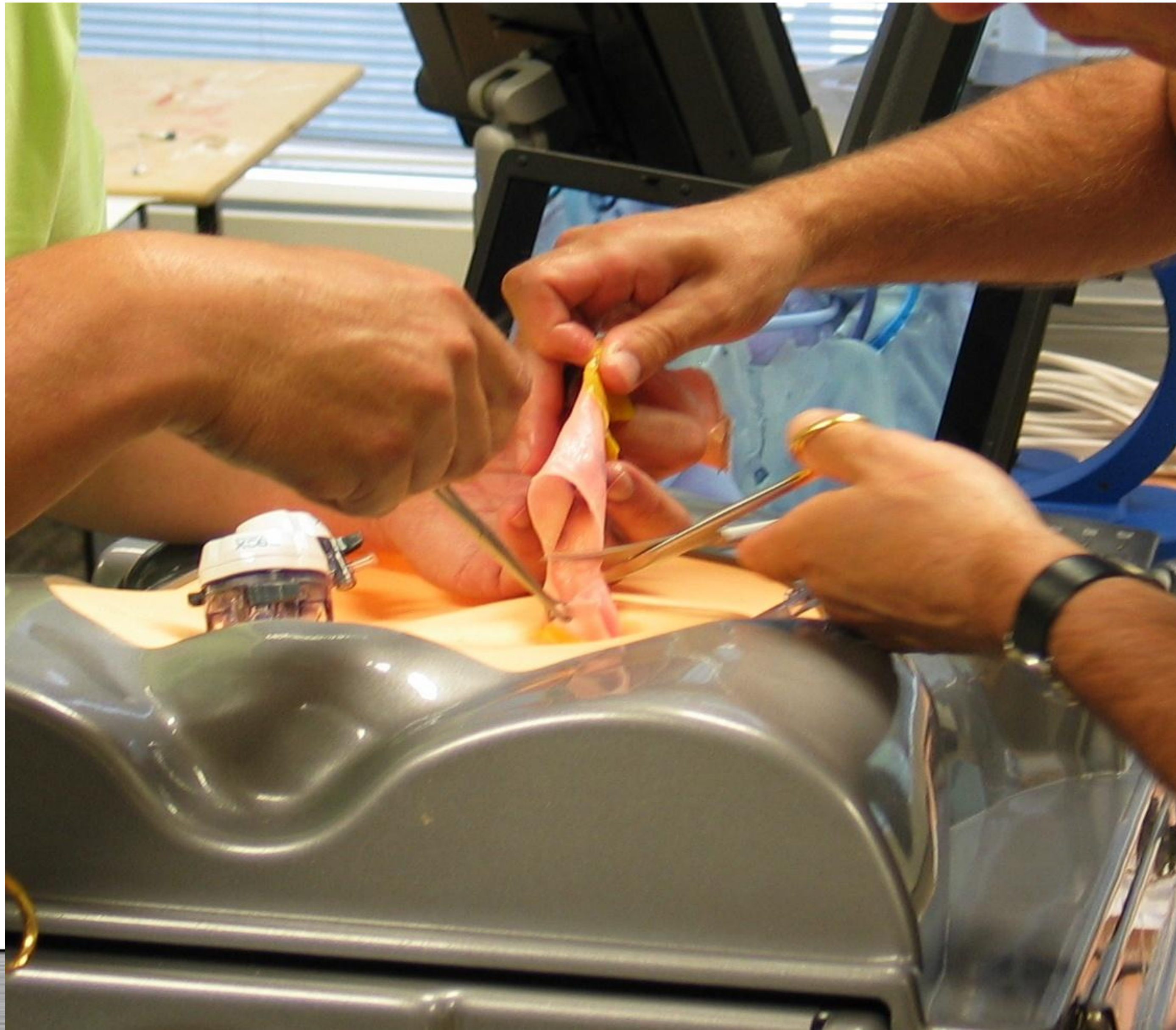




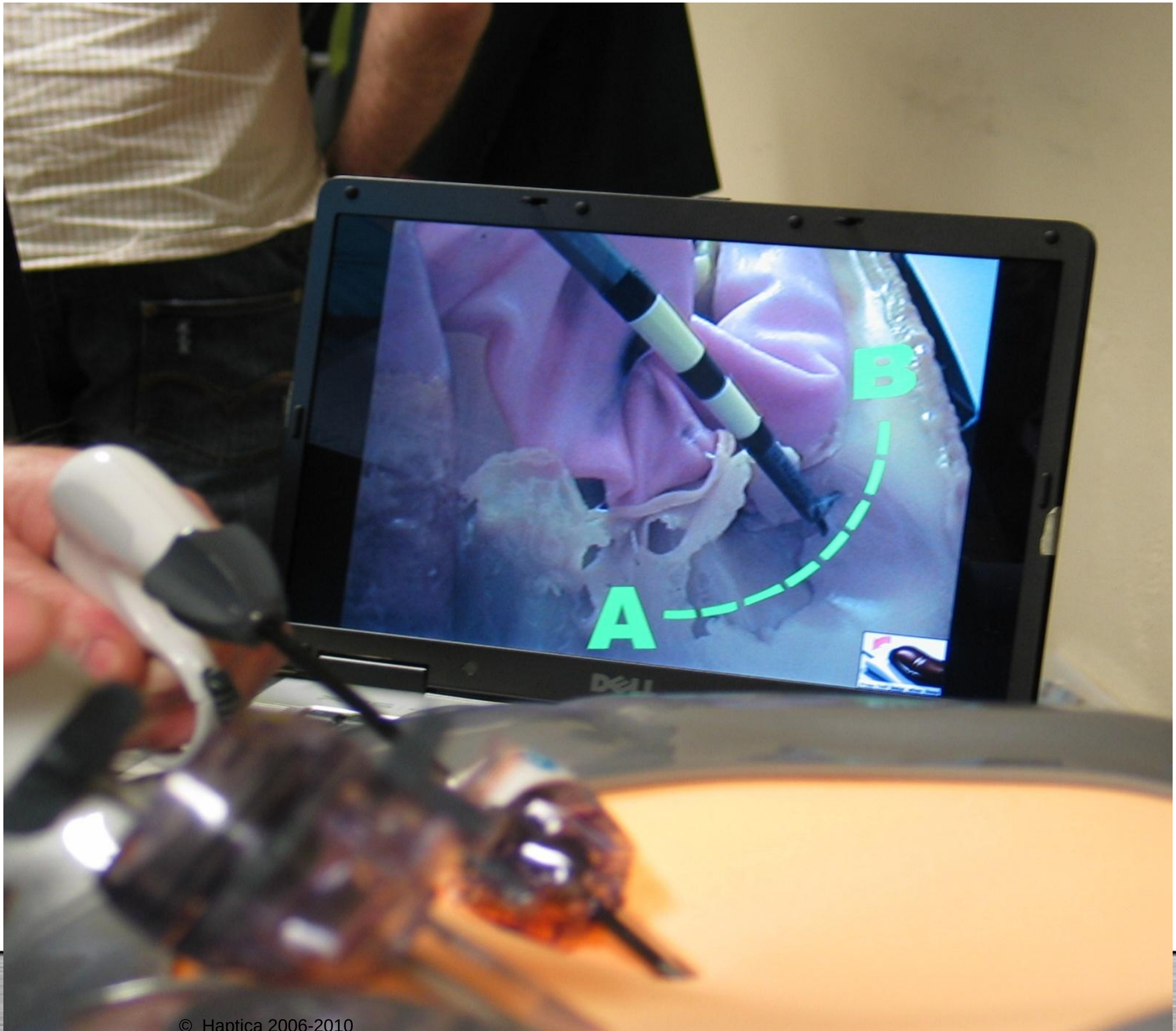
Box Trainers with artificial tissue



Simulated patient, real instruments



Computer augmented box trainer (Instruction)

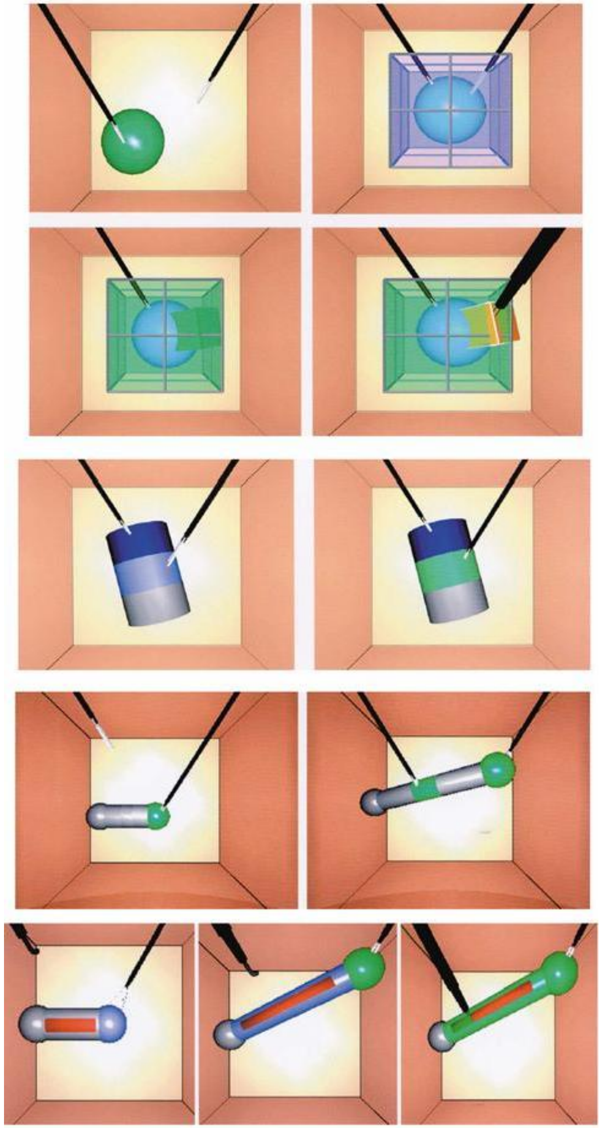


Computer augmented box trainer (Blood)

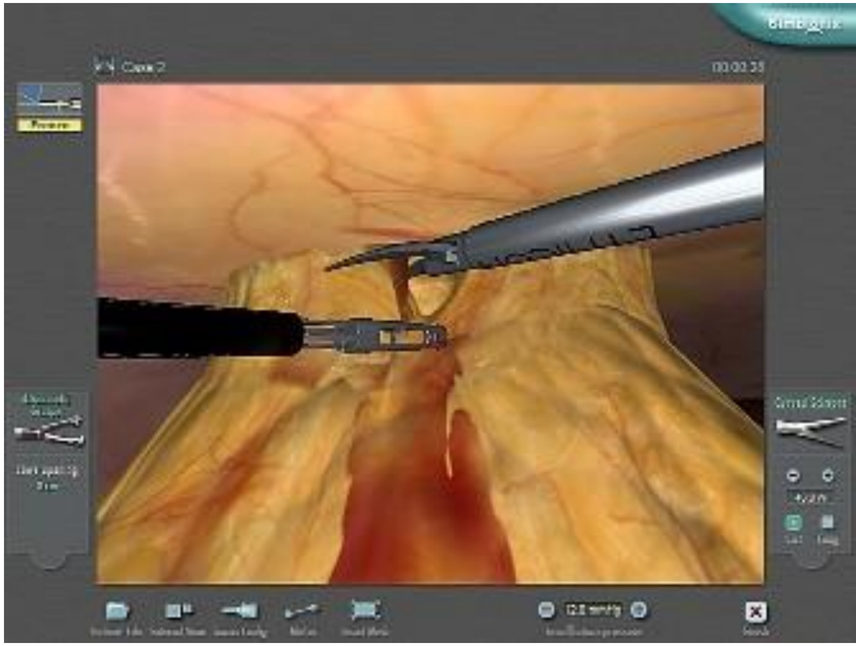
Haptic enhanced box trainer

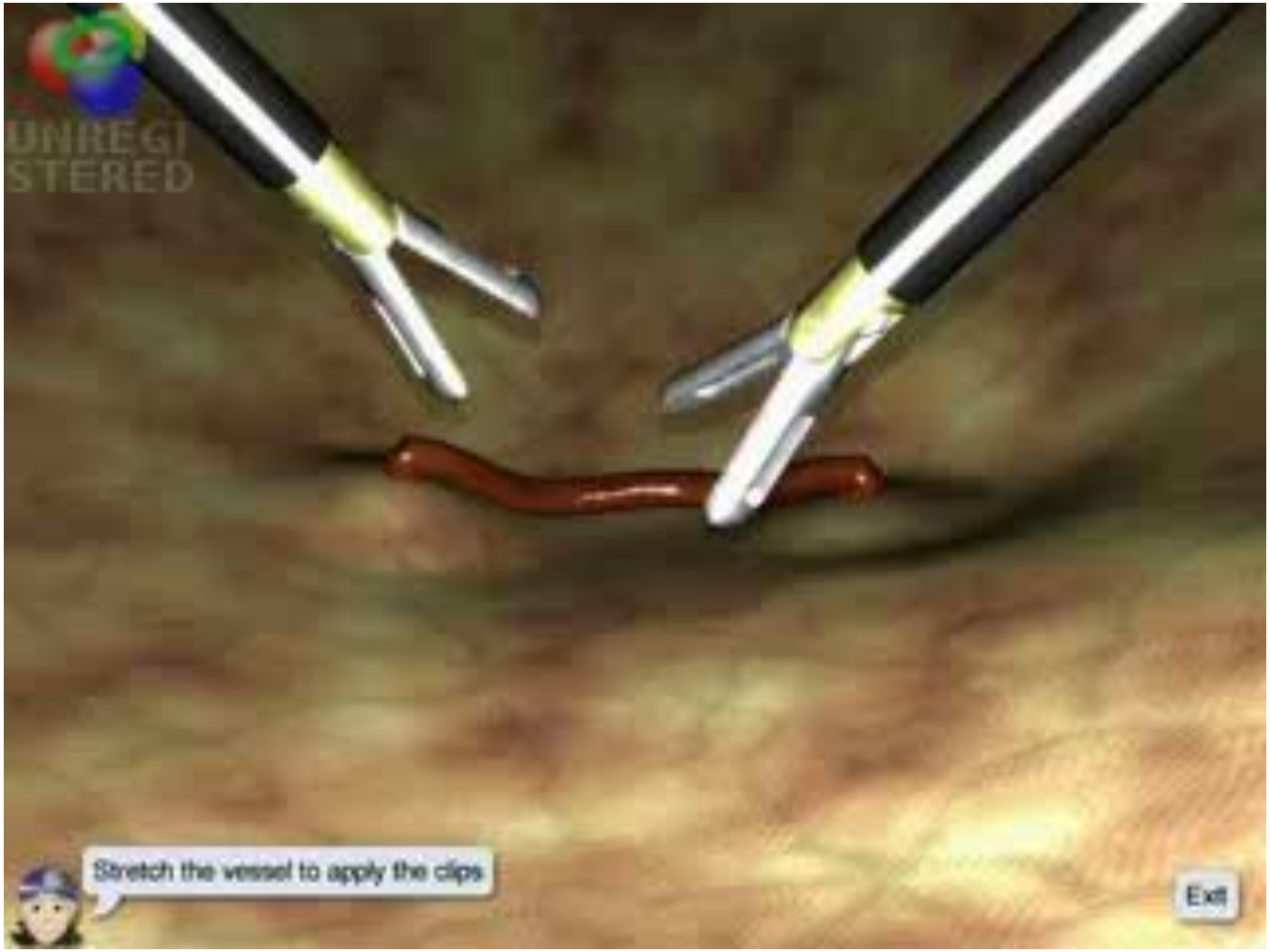
Laparoscopic Explosion

MIST-VR



Simbionix Lap Mentor

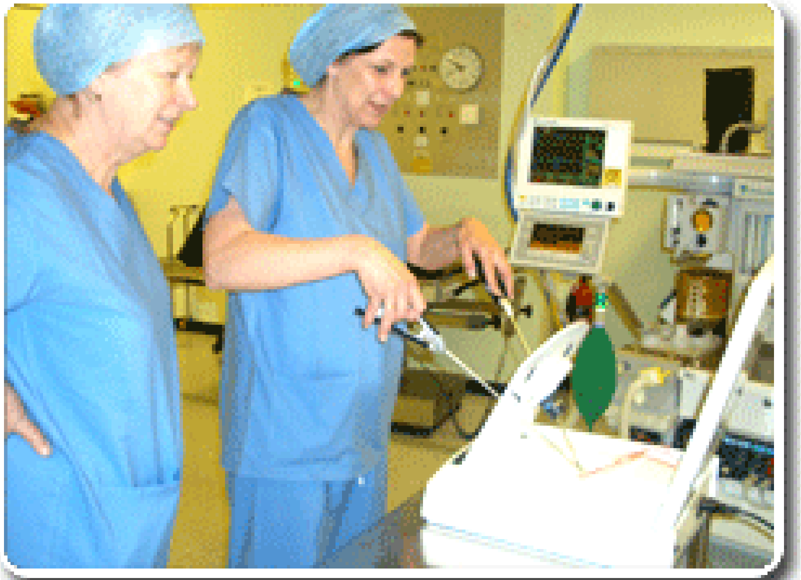



UNREGI
STERED
Stretch the vessel to apply the clips
Exit

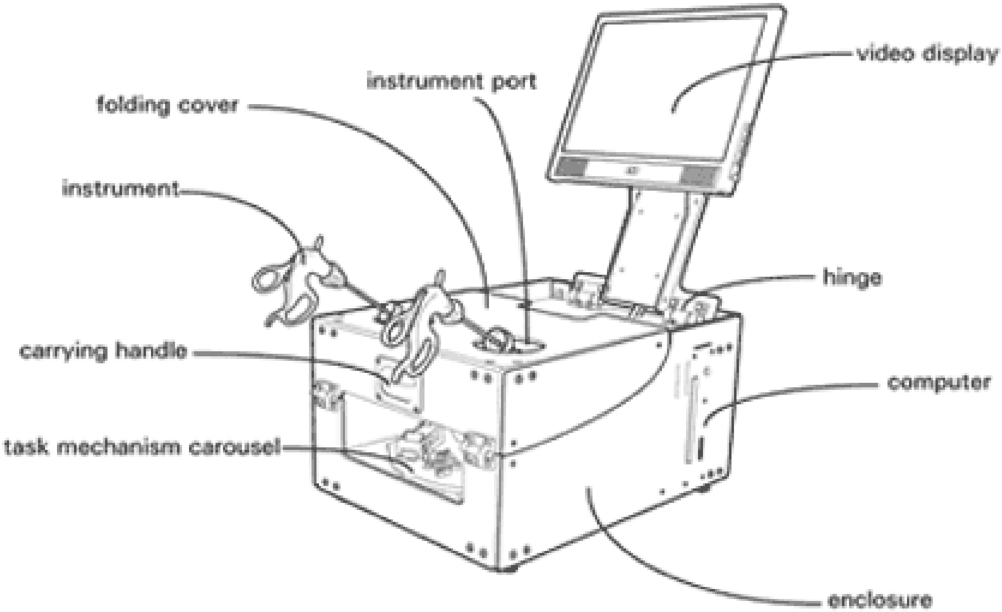
ProMIS by Haptica

Immersion Medical Lap VR

iSurgical's i-Sim



RealSim's LTS

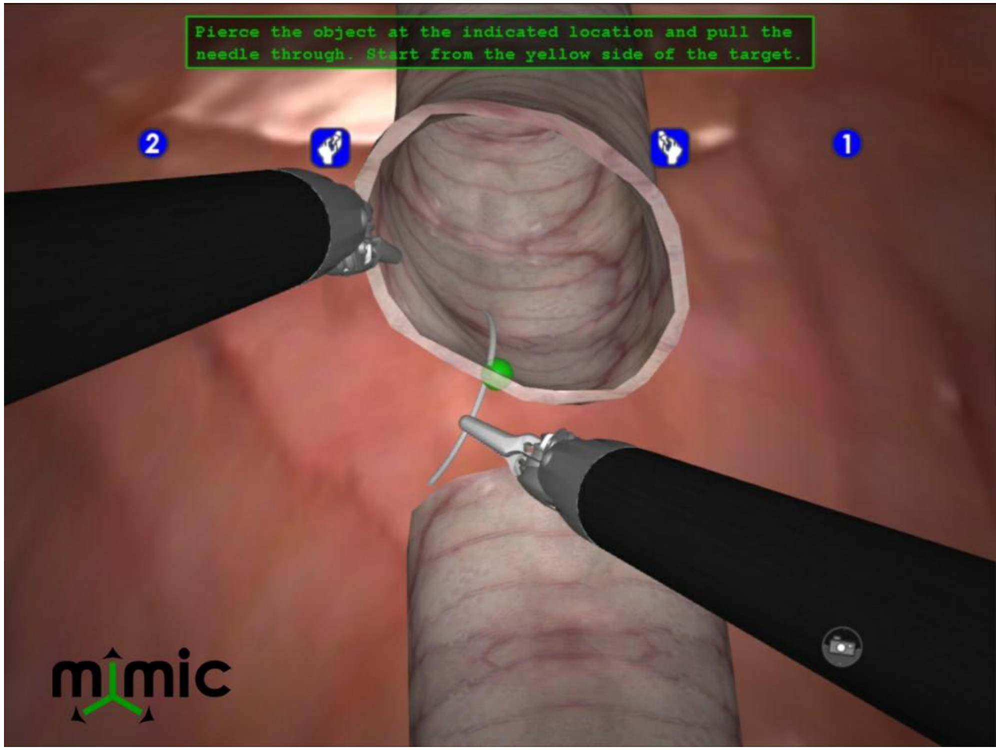


Robotic Surgical Simulator

- Stand-alone surgical simulator
- No consumables or disposables required
- Allows performance analysis and measurement
- User does not require monitoring
- New surgical procedure modules can be added
- Does not require an operating room environment and can be set up in a location most advantageous to access and training needs
- Monitor allows a user or tutor to observe the procedure
- Comprehensive curriculum to train for motor, and cognitive skills

RoSS

MIMIC dV-trainer



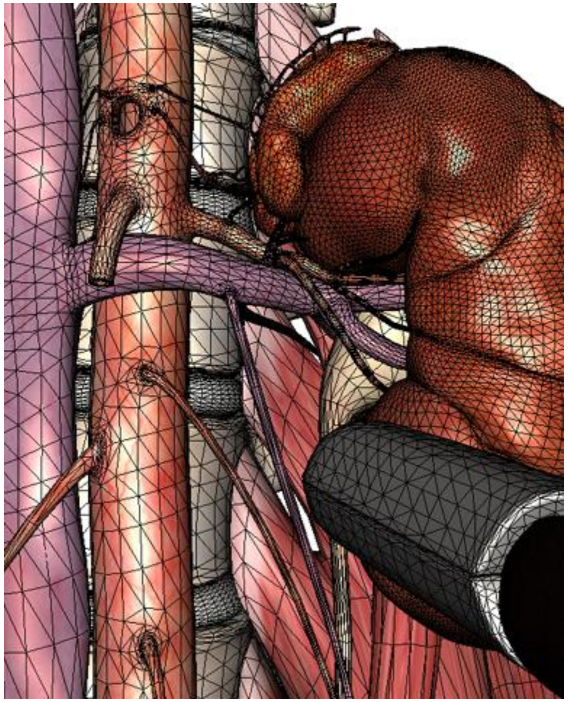
MIMIC dV Trainer

MIMIC Thread the Rings

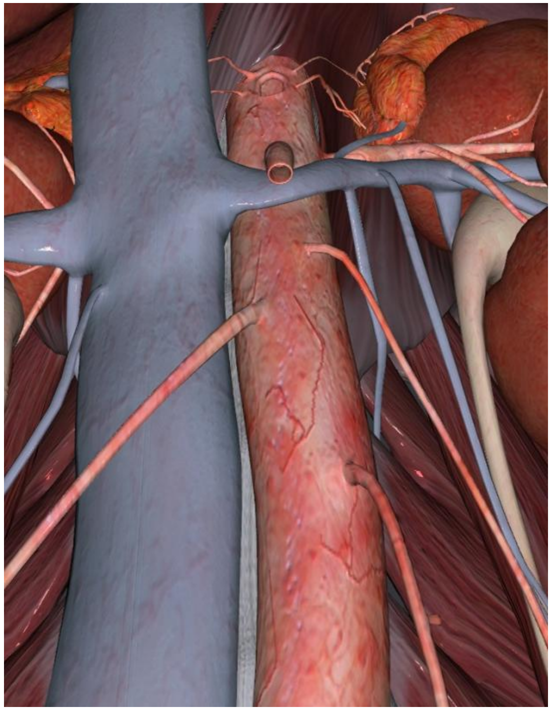
Virtual Reality

Surgical Scene Generation (Harder, 2008)

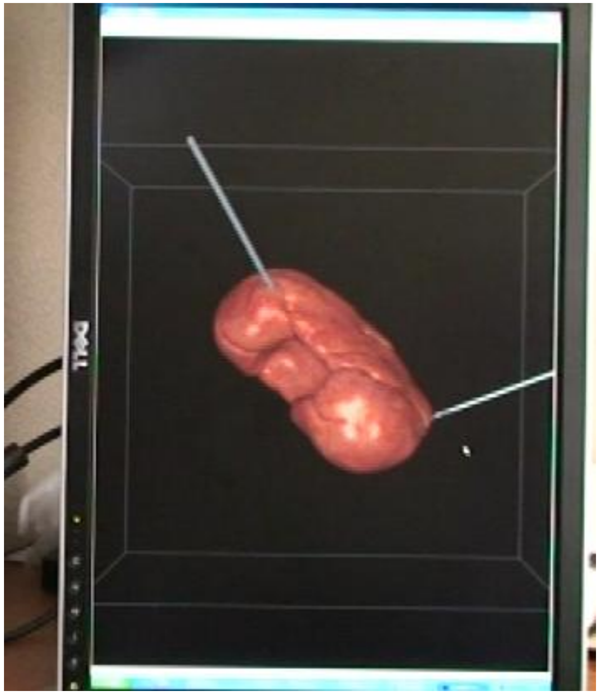
Geometry
- Complex
- Non-linear
- Non-uniform



Appearance
- Layered
- Translucent
- Dense

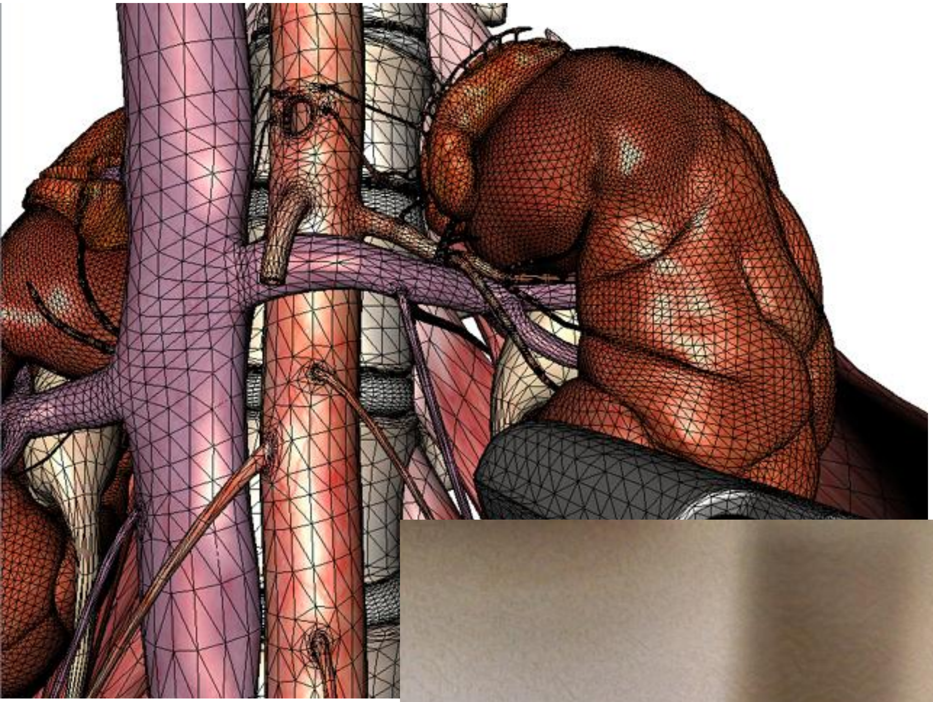


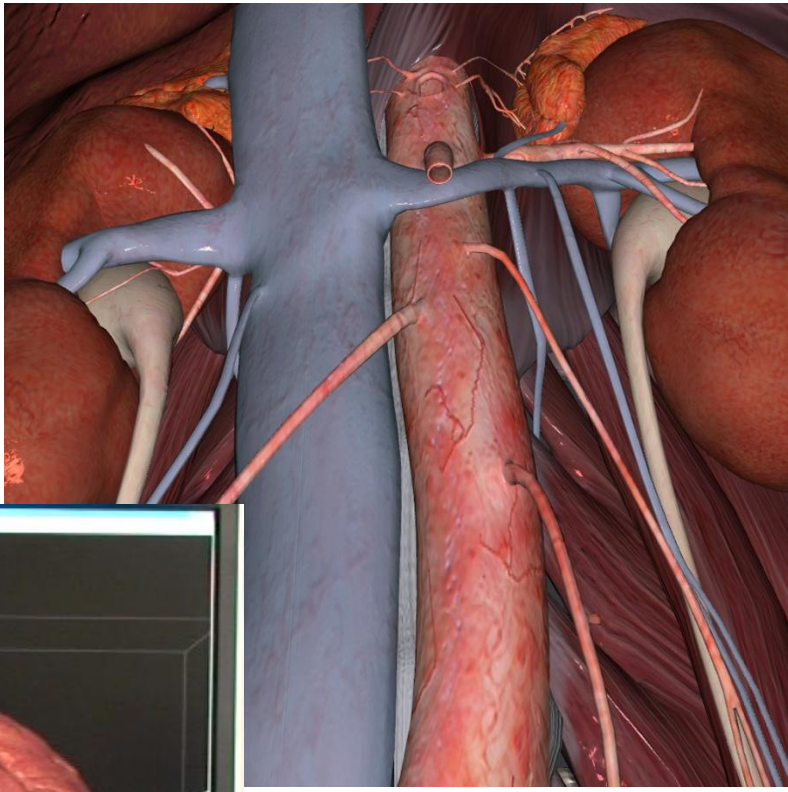
Dynamics
- Nerve movement
- Blood flow
- Elasticity

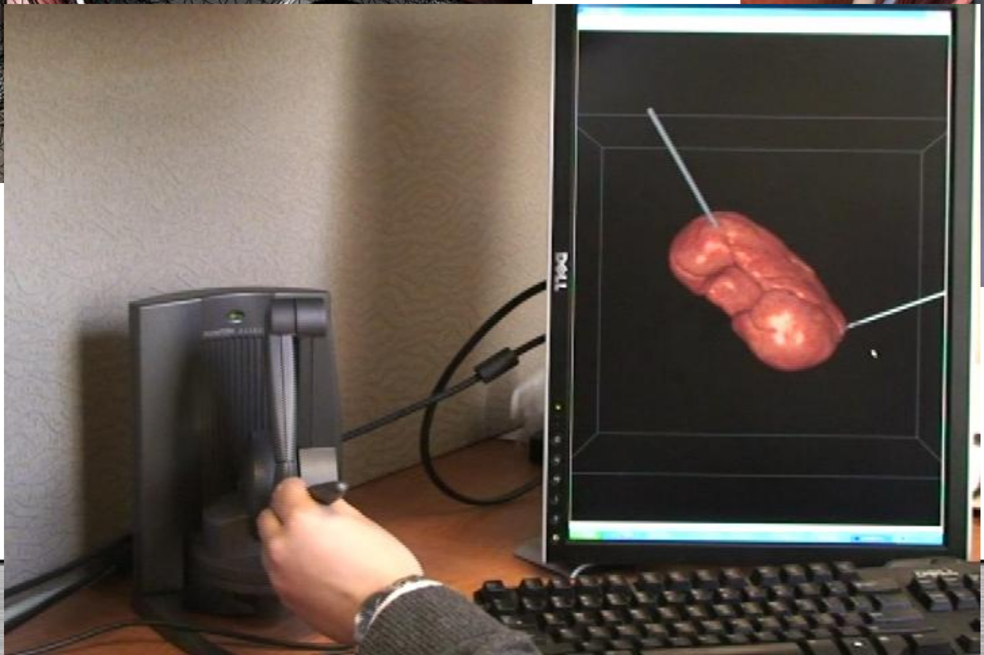


Univ Minnesota CREST

Center for Research in Education and Simulation Technologies, Rob Sweet, MD



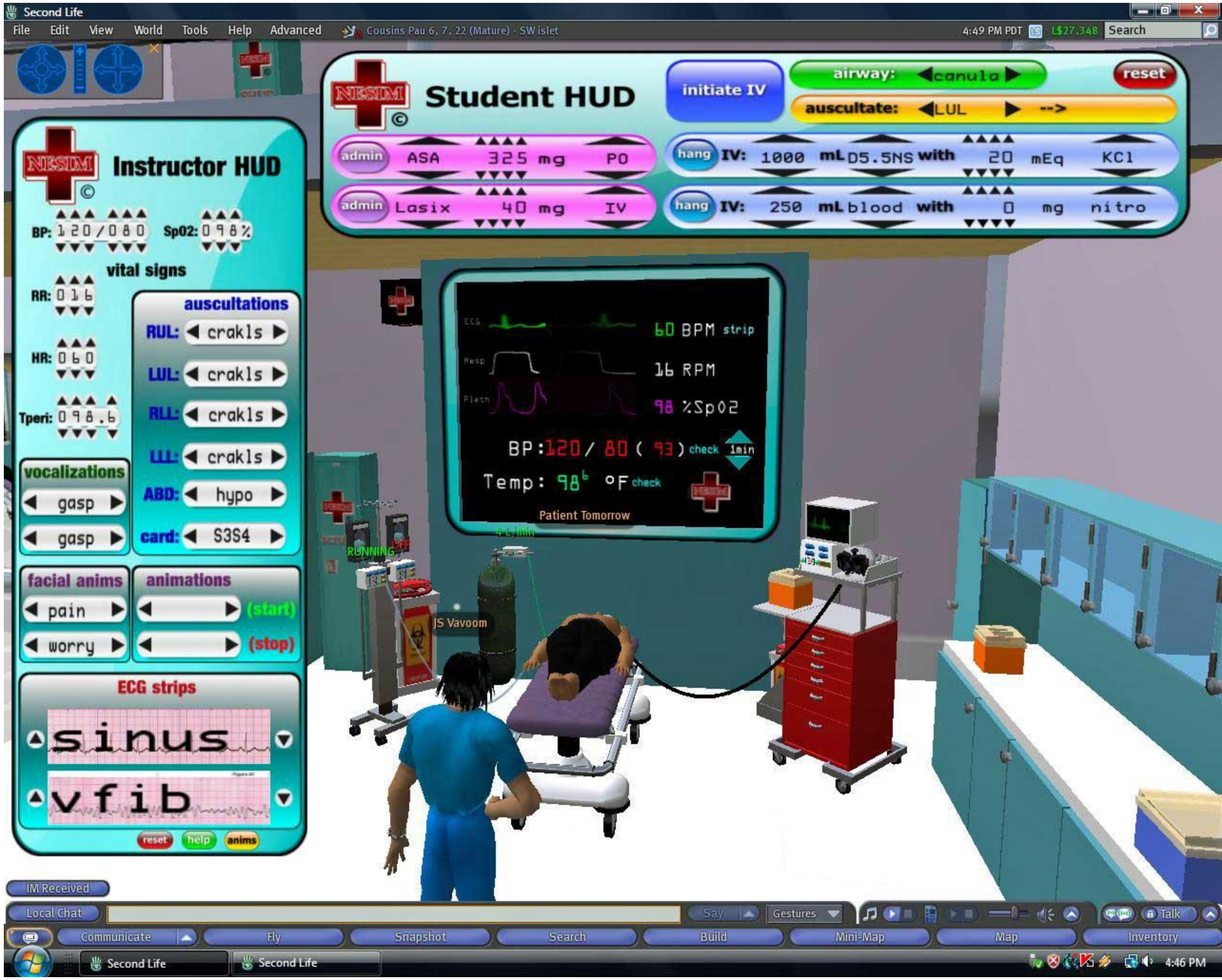




Heart Surgery: Simulation + Animation

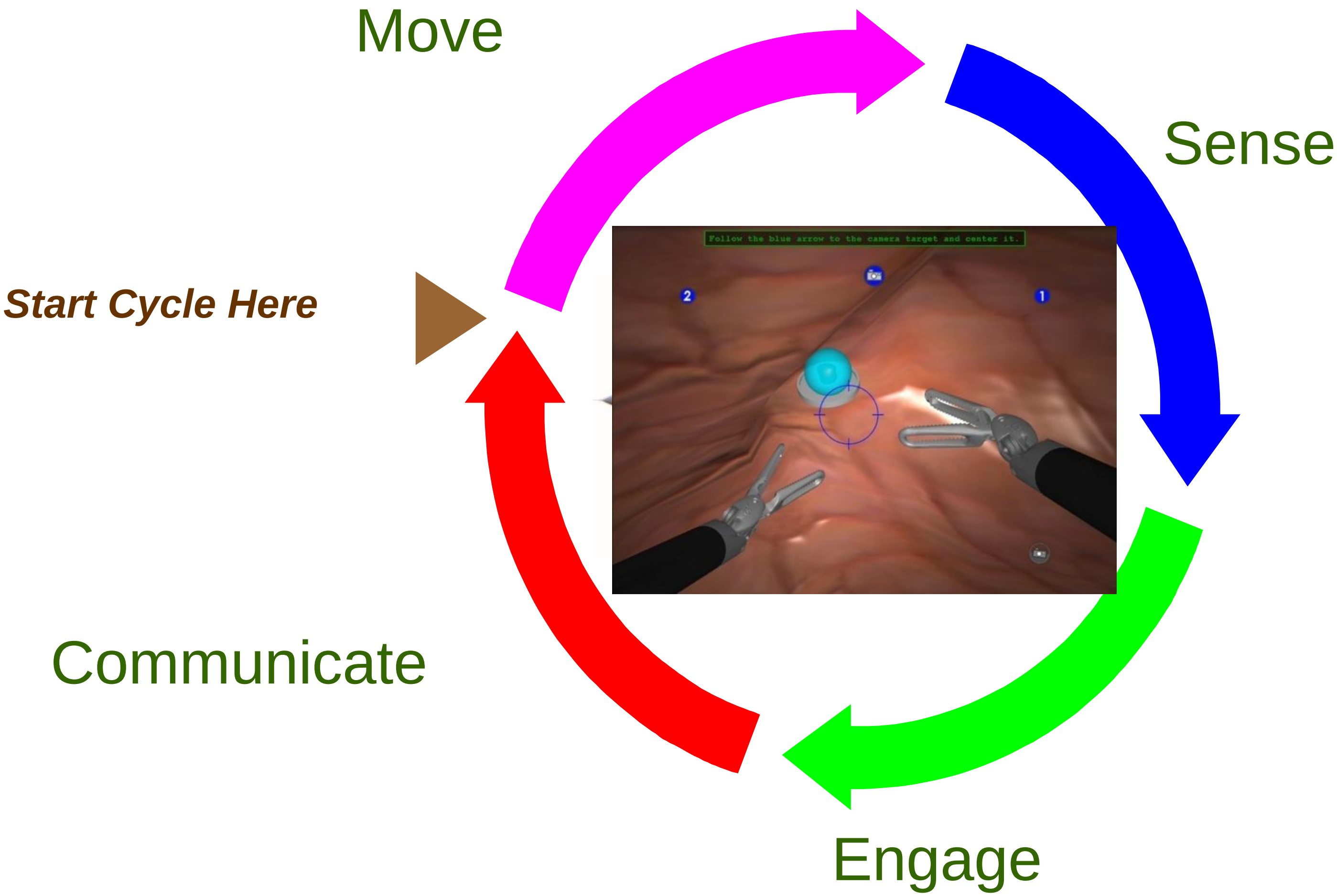
Second Life ER/ED – a leader & staff trainer

- Vesim (Nesim) emergency dept simulator area (Cousins Pau Island)
- Apply learned concepts with a patient avatar.
- Promote critical thinking and decision making.
- Encourage team collaboration.
- Real time simulations
- Practice in groups



Modeling Techniques

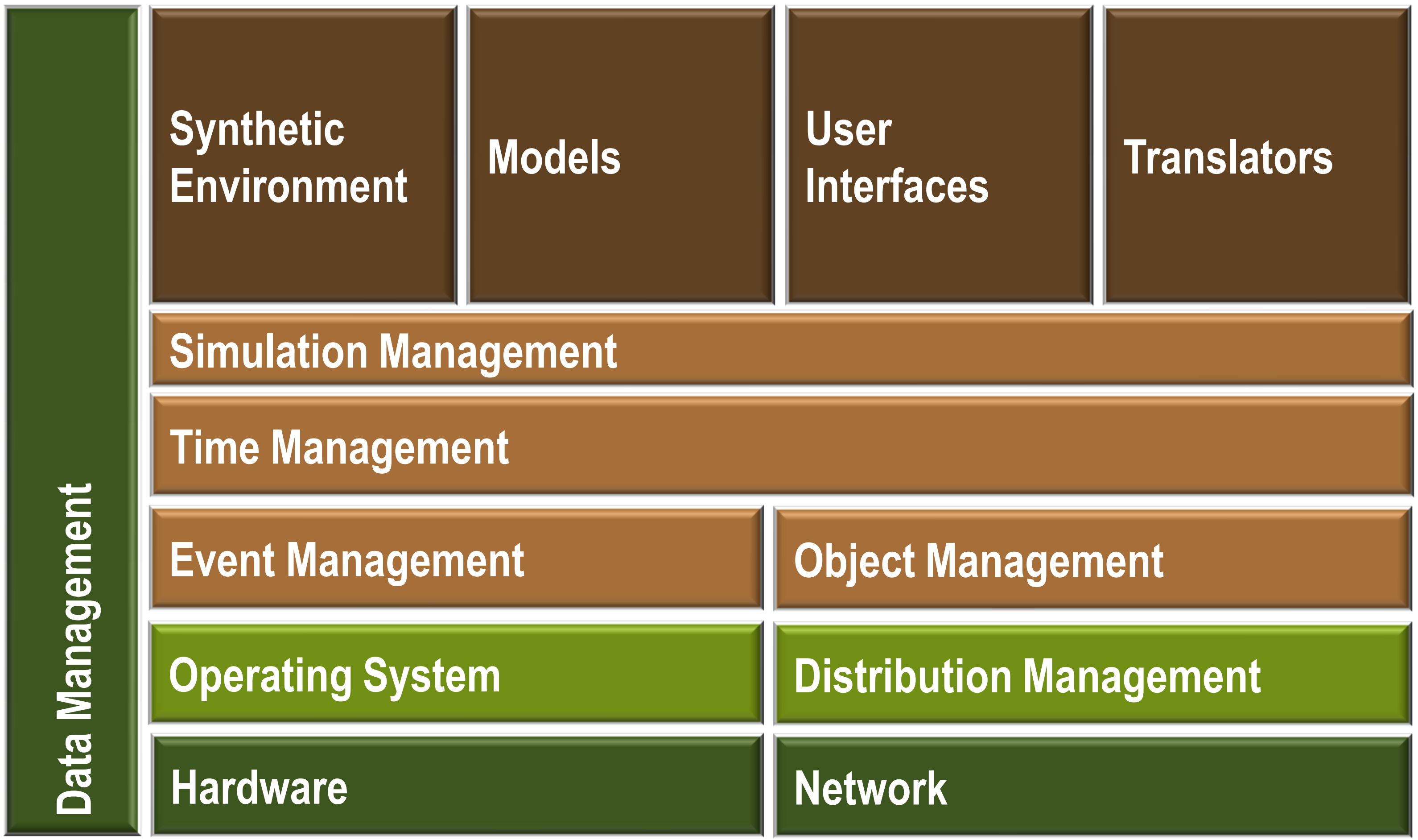
Physical Modeling Cycle



Modeling Approaches

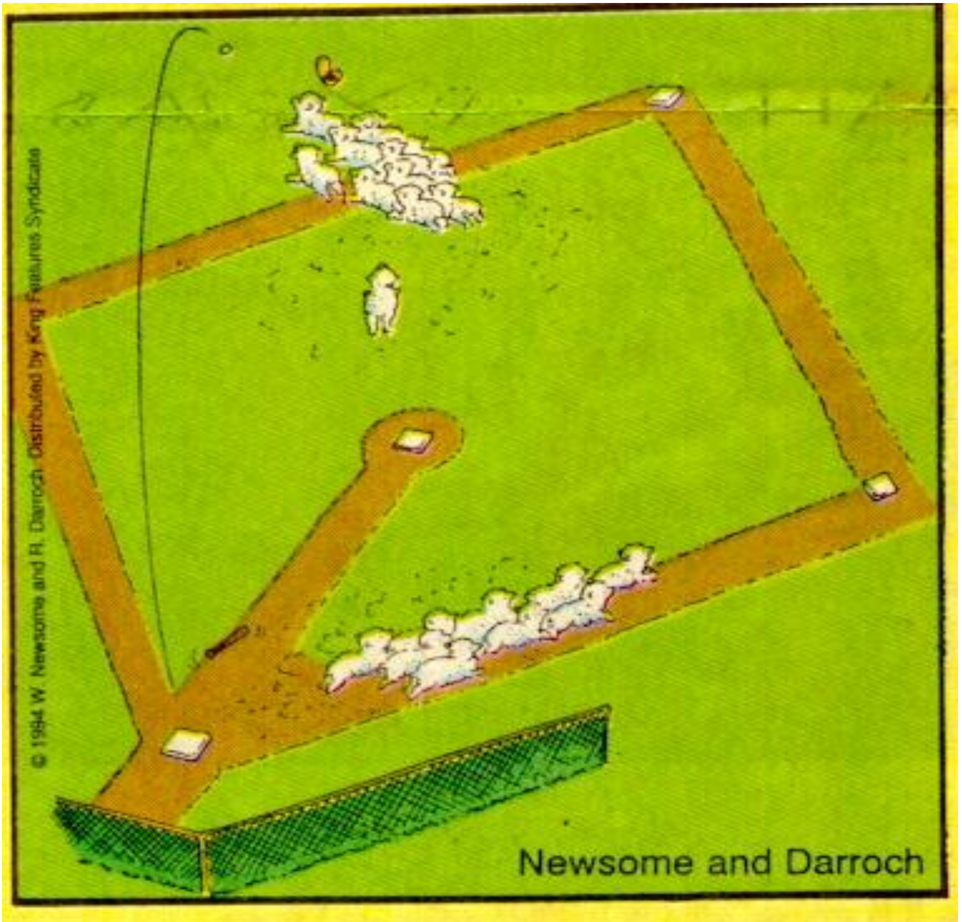
- **None – Omit Feature and Behavior from the Simulation**
- **Geometry – Size and placement of organ**
- **Stochastic – Probability of Injury, Mean Time Between Failure**
- **Logical – Tissue Properties, Flow Rates**
- **Physics – Force, Mass, Friction, Vector Tracing**
- **Artificial Intelligence – Human Decision & Perception**

Simulation Software Components



From *Military Simulation and Serious Games*, Roger Smith (a DiSTI Course)

Don’t Be a Sheep



Sheep baseball.

The world does not need more sheep building simulations.

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