ME 328: Medical Robotics
Winter 2019

Lecture 10:
Port placement in robot-assisted minimally invasive surgery

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Updates

Assignment 4

Due this Wednesday (2/13, all on Canvas)

Assignment 5

Will be distributed on Wednesday (due 2/22)

Project

Project pre-proposal due this Friday (2/15)

Optional Tours

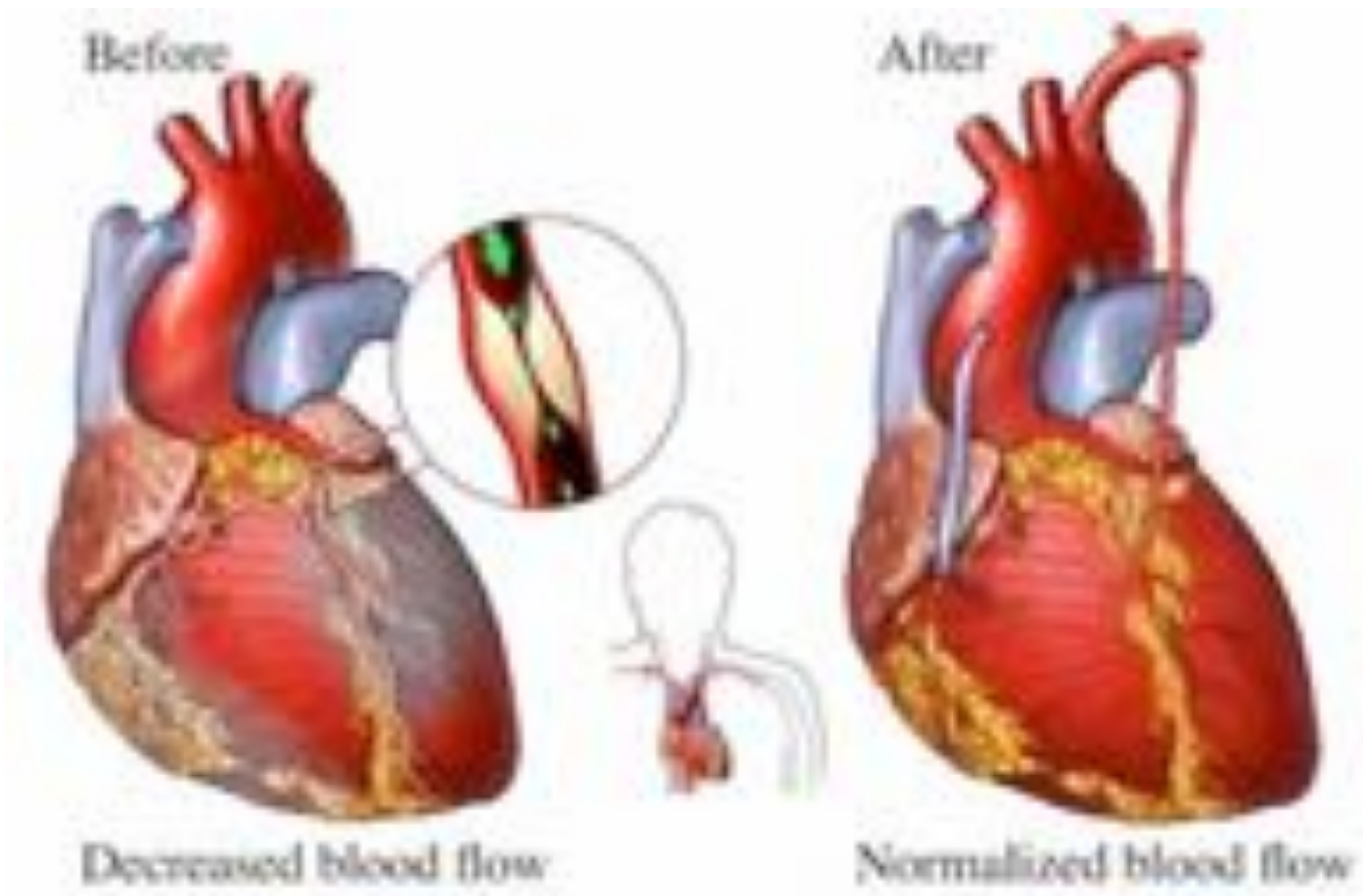
Auris on 2/22, Intuitive Surgical on 3/1 most slides courtesy of Pierre Dupont and Mahdi Tavakoli

case study/research results from:

J. W. Cannon, J. A. Stoll, S. D. Selha, P. E. Dupont, R. D. Howe, and D. F. Torchiana. Port Placement Planning in Robot-Assisted Coronary Artery Bypass. IEEE Transactions on Robotics and Automation 19(5): 912-17, 2003.

coronary artery bypass graft (CABG)

CABG is a surgery to restore blood flow to the heart muscle. This is done by using blood vessels from other parts of the body to make a new route for blood to flow around blocked coronary (heart) arteries.



CABG steps

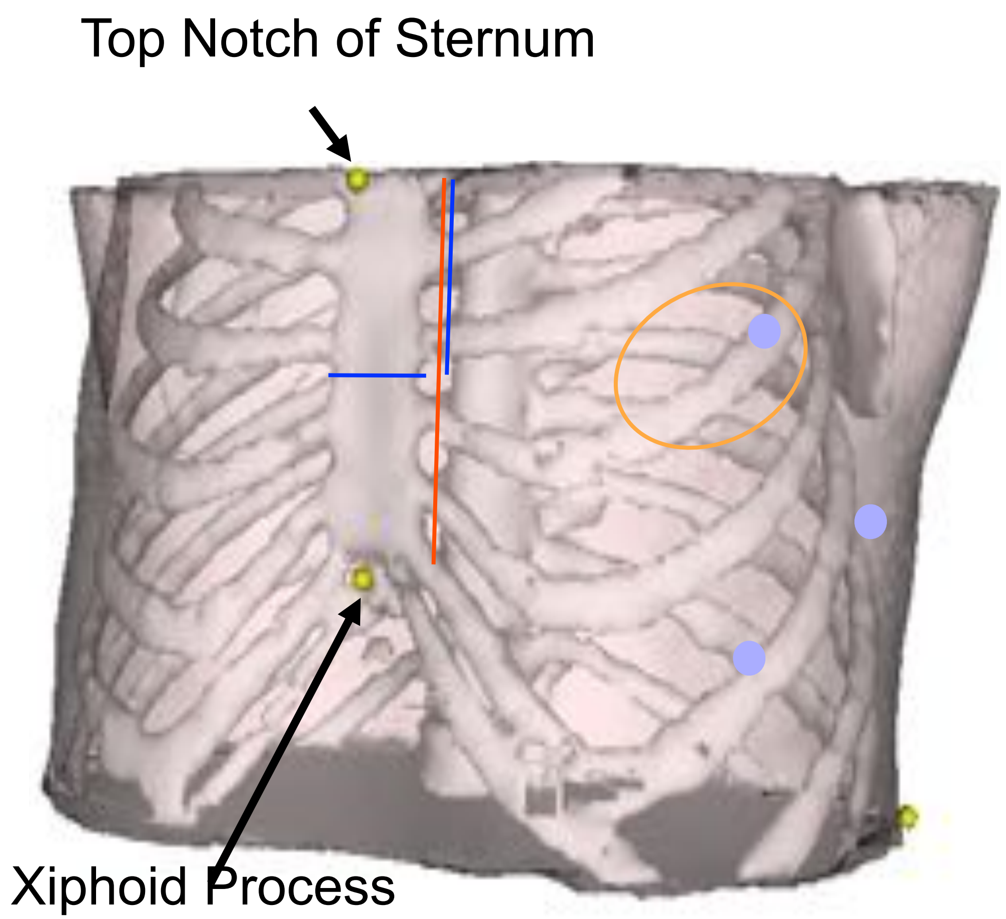
1. The heart is stopped and a heart-lung machine is connected to the patient.

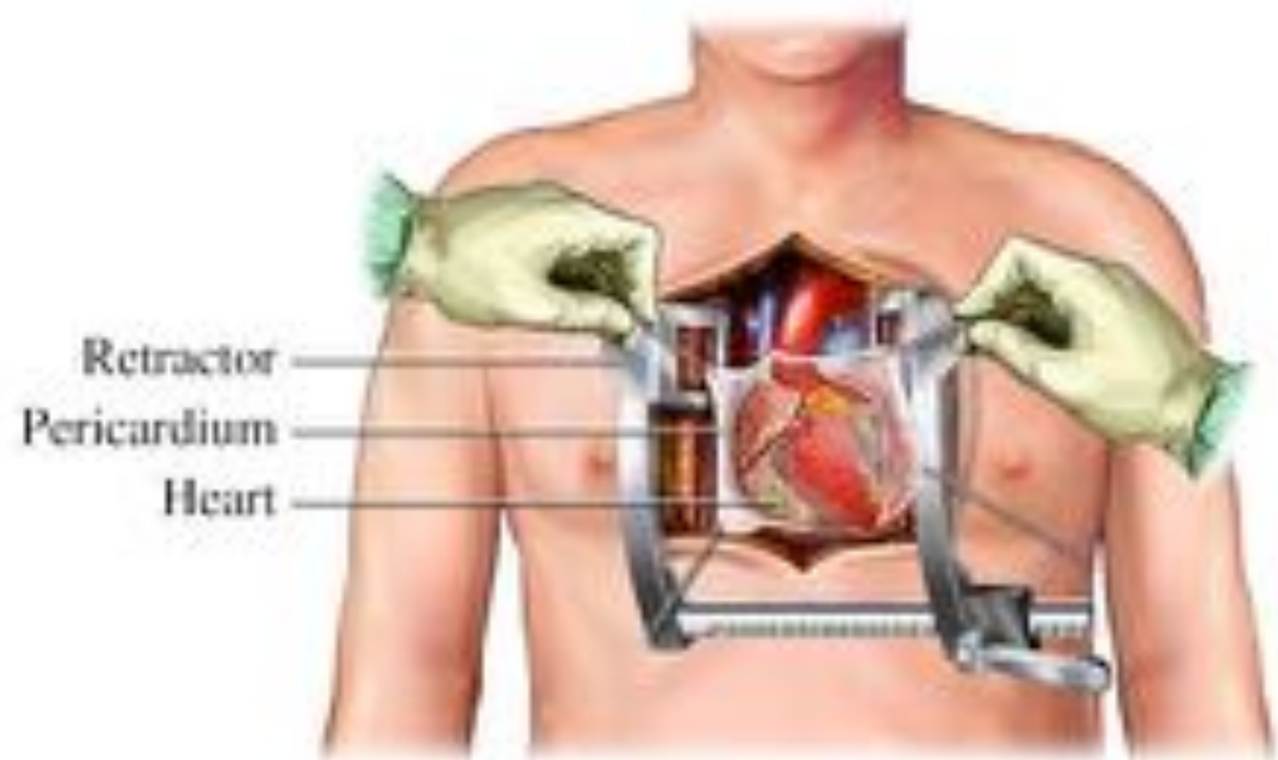
2. An artery is taken from the chest wall, or a section of vein is removed from the leg. This “donated” section of vessel will be used as the bypass.

3. The new vessel is connected (grafted) to the blocked arteries. One end will be attached just above the blockage. The other end will be attached just below the blockage.

4. Electric shocks are used to start the heart beating again and the heart-lung machine is disconnected.

non-robotic approach





http://www.heart-valve-surgery.com

requires access via: Median Sternotomy, Mini Sternotomy, or Anterior Thoracotomy

case study: algorithmic port placement for robot-assisted CABG

two procedures need to be done robotically:

1. harvest the left internal mammary (or thoracic) artery (LIMA)

2. anastomosis of LIMA and coronary artery

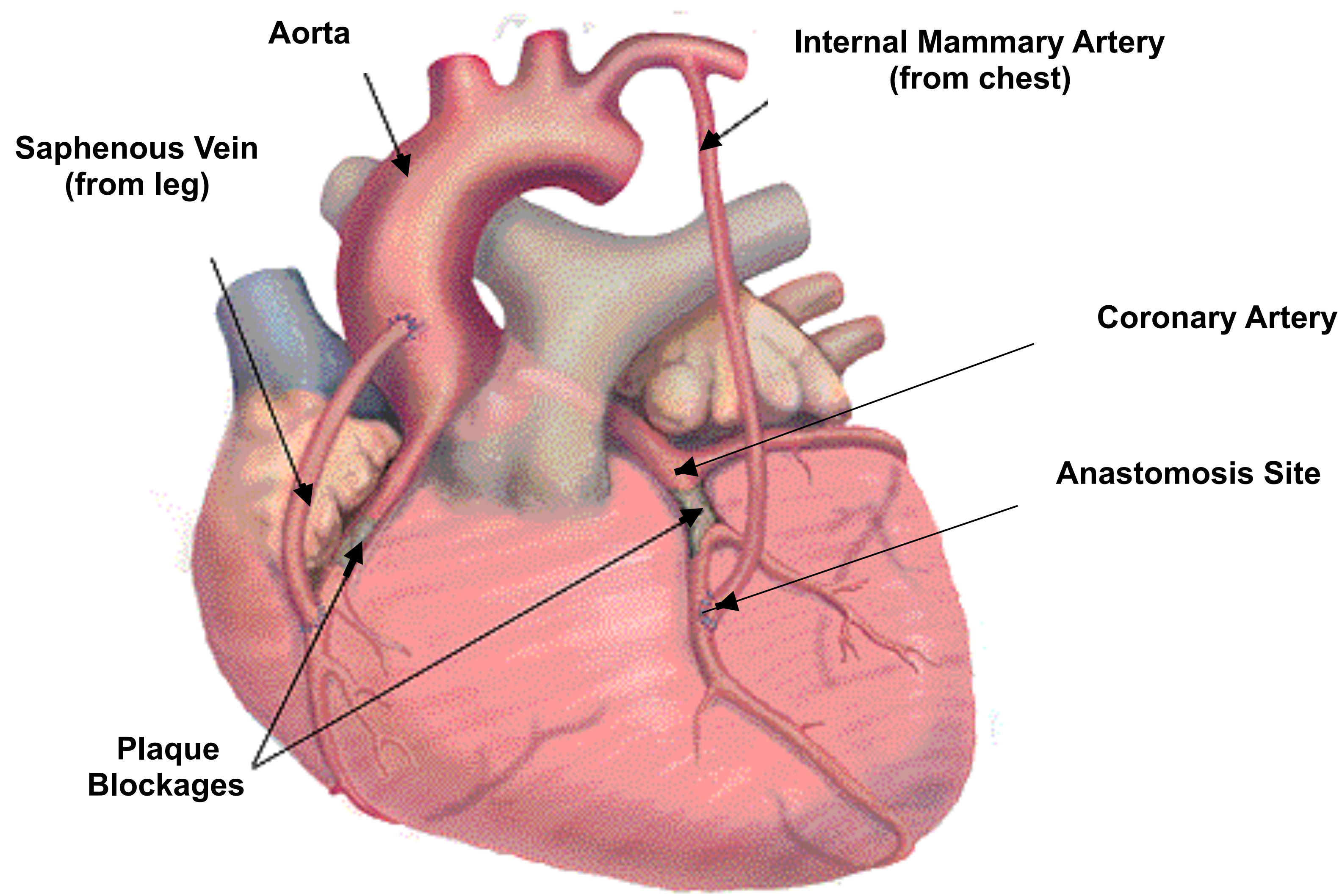


Illustration by Mitchell Christensen copyright ViaHealth 1999

study authors: Pierre Dupont (BU, now Harvard Children's), Jeremy Cannon (CHC), Shaun Selha (BU), Jeff Stoll (BU), Robert Howe (Harvard), David Torchiana (MGH)

the required workspace for the surgical instrument is a challenge

the tool workspace must include
- The underside of the chest wall for takedown of the LIMA
- The surface of the heart in the middle of the chest, where the LIMA is sutured to a blocked heart vessel

Challenge: How to reach this relatively large workspace through a single triad of intercostal ports (one endoscope + two instruments)

Port location directly influences access to the surgical sites, dexterity of the surgical instruments, and instrument collisions

how are the port locations selected?

in the literature:
templates

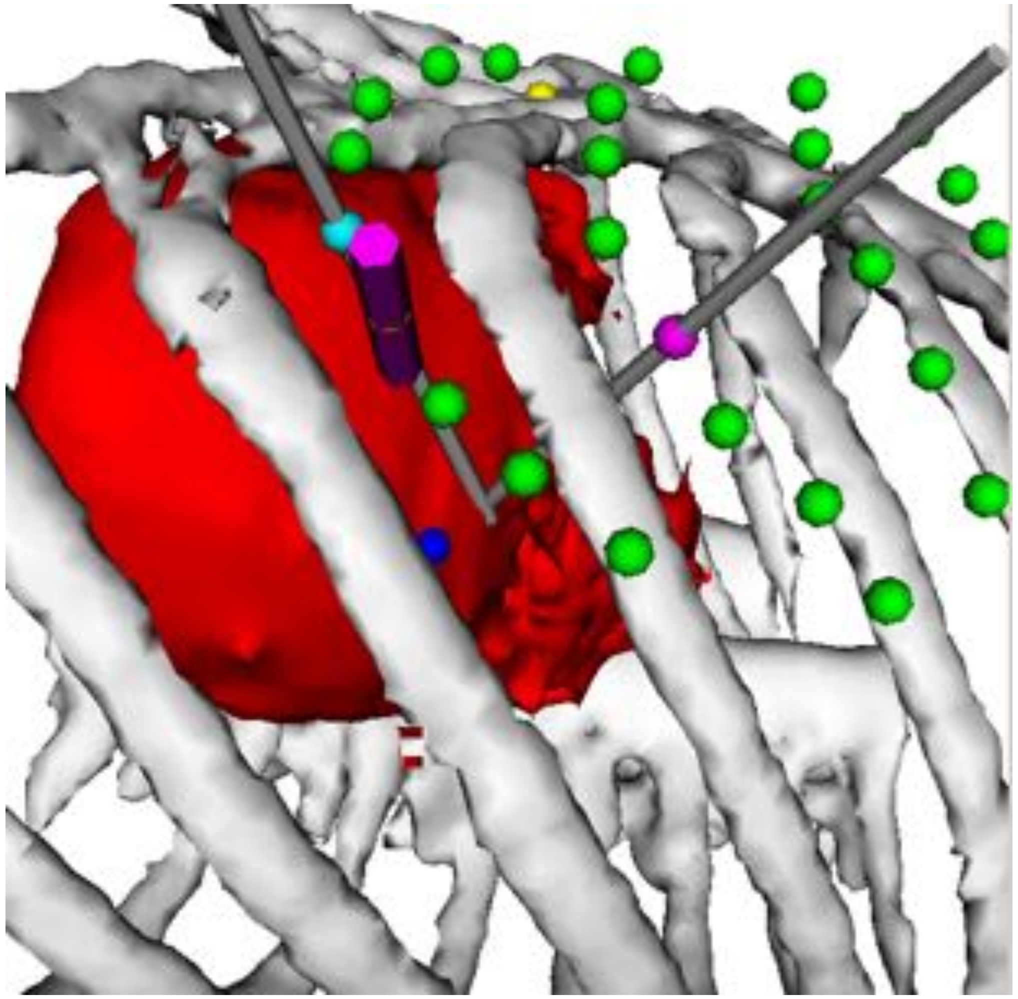
in practice:
surgeons use external landmarks and size of patient's torso to make their best guess

proposed:
given a set of internal surgical sites and knowledge of the optimal relative instrument and endoscope angles, determine where each port should be positioned in the chest wall

summary of challenges

port location problems

1. Inability to reach the surgical site
2. Inability to perform the surgical procedure due to the orientations of the tools with respect to each other and the surgical site
3. Internal instrument / endoscope collisions



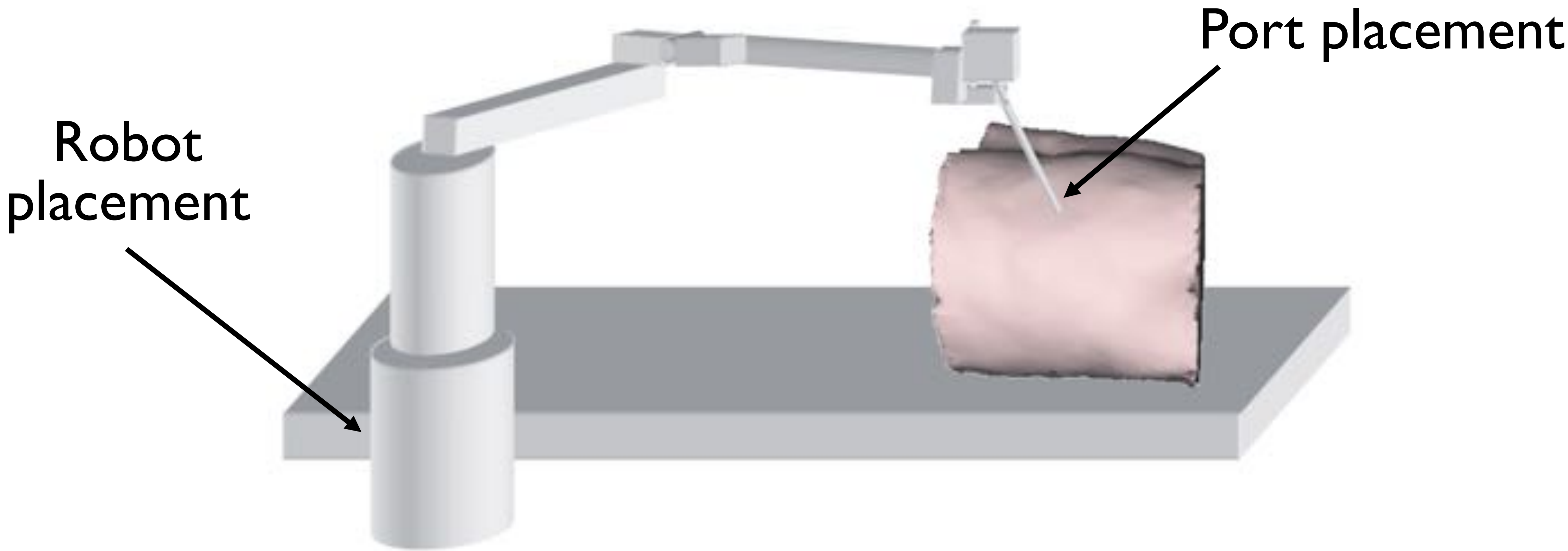
robot location problems

4. Robot singularities and joint limits
5. Robot collisions

not addressed in this case study

proposed approach

solve port placement and
robot placement problems independently

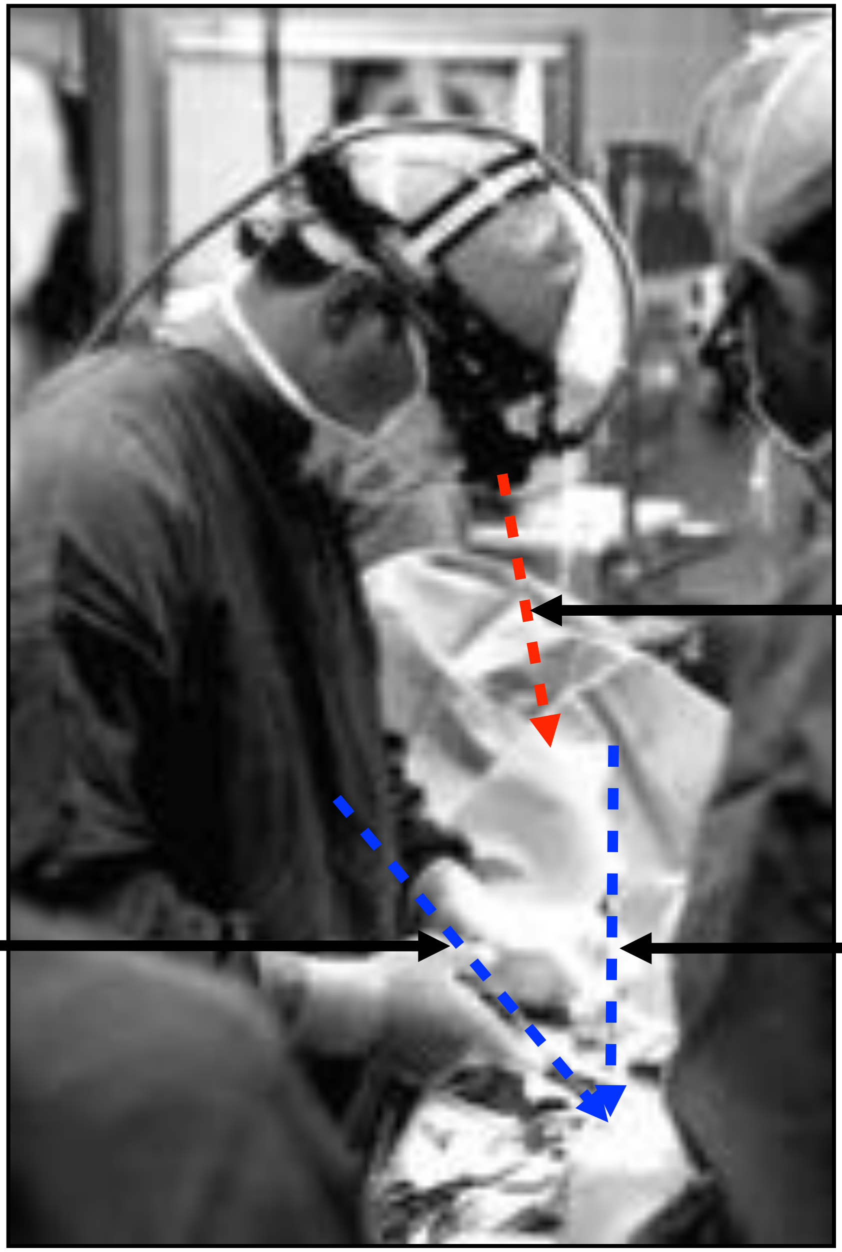


Zeus surgical robot (no longer commercially available)

quality of a given port location

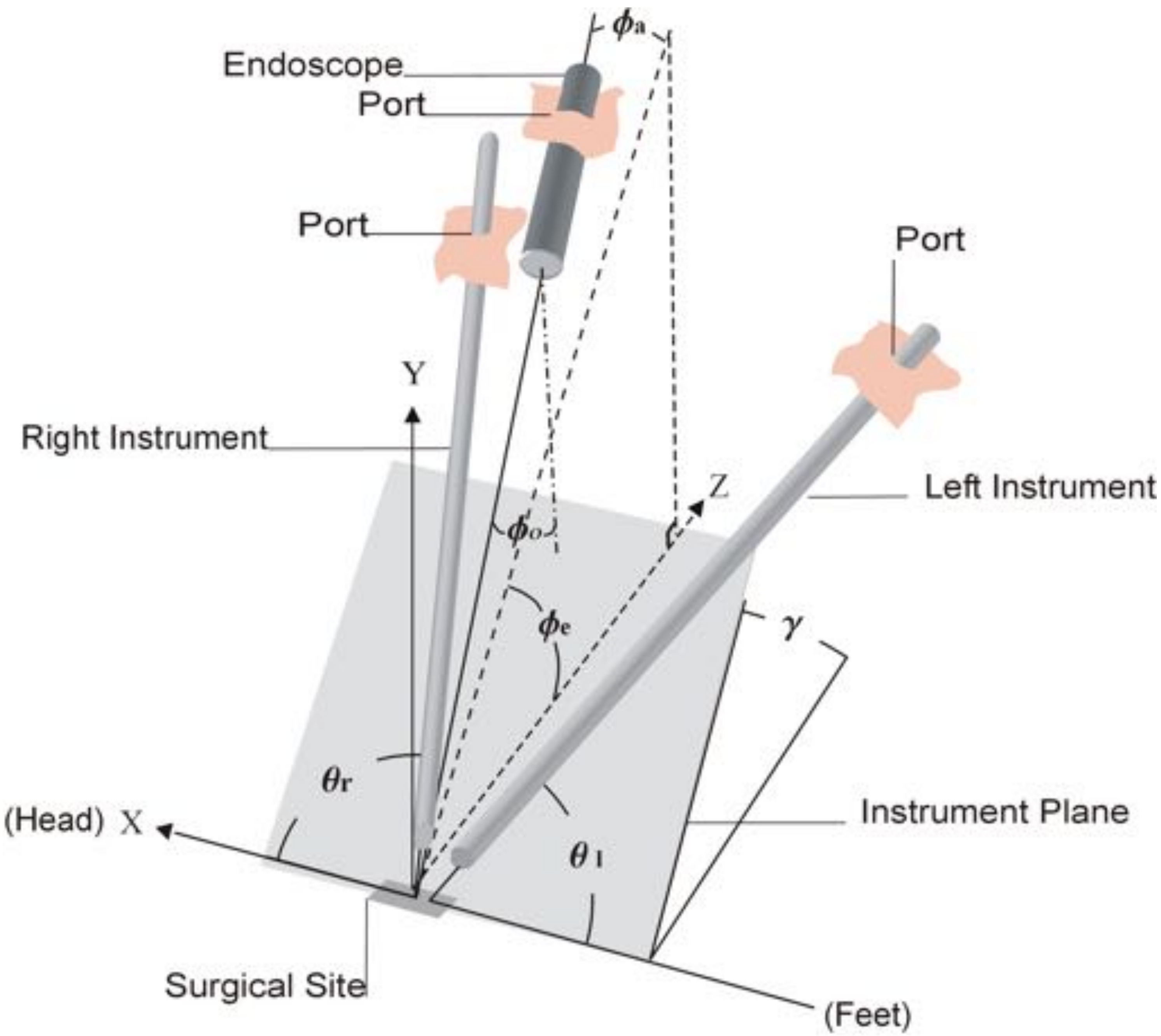
- preserve surgeon's intuition by maintaining hand-eye coordination
- orient instruments by task and with respect to the surgical site (i.e. employ relative angles that facilitate suturing, dissection, etc.)
- avoid internal collisions between the instruments and the endoscope
- permit flushing of endoscope lens
- minimize the amount of the endoscope inserted into the chest cavity

Invasive (open-chest) CABG



surgical site coordinate frame

the optimal orientations of the instruments and endoscope can be defined with respect to a coordinate frame whose origin is placed at each internal surgical site



<u>Instrument Angles</u>

θ = Yaw angle in instrument plane

γ = Elevation angle of instrument plane

<u>Endoscope Angles</u>

ϕ_a = Azimuthal angle

ϕ_e = Elevation angle

ϕ_o = Constant offset angle

how are optimal angles found?

optimal angles are based on a surgeon's experience in performing CABG

- Instrument angles are task based
- Endoscope angles are viewpoint based

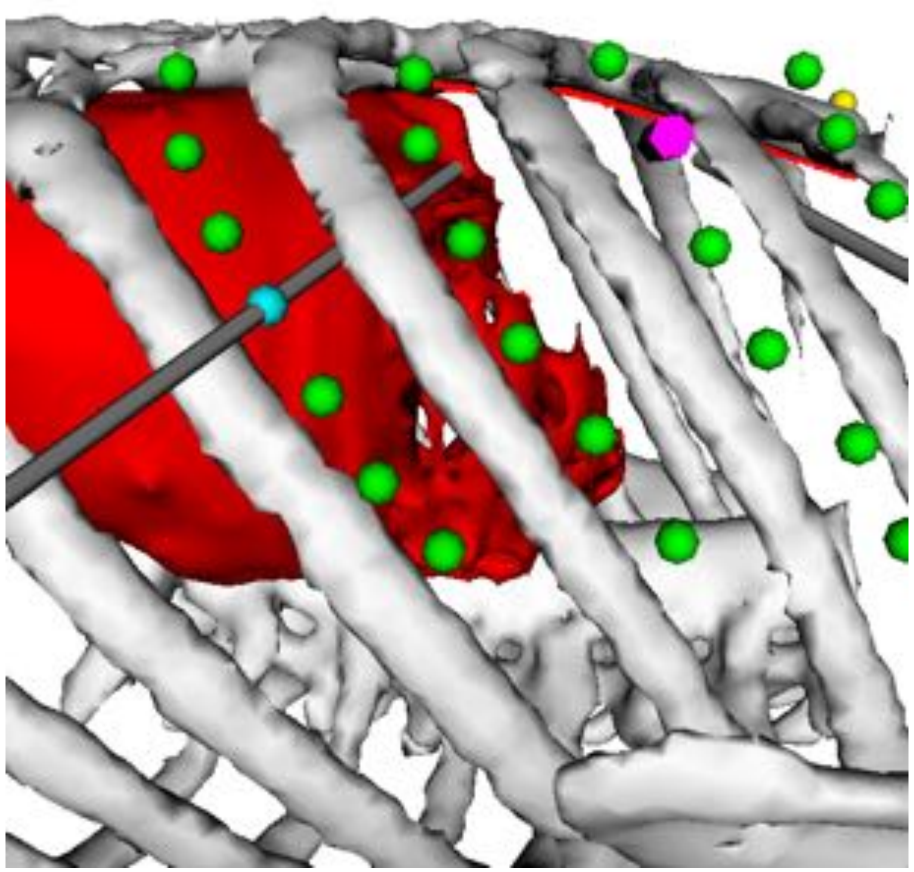
Angle	Angle Weighting Factors, w_{ii}	ψ_{opt} (degrees)	
		LIMA takedown	Anastomosis
θ_r	1.40	60	60
γ_r	1	- 20	45
θ_l	1.40	60	60
γ_l	1	-20	45
φ_e	1.67	7	52
φ_a	1	0	0

Endoscope offset angle $\varphi_o = 30°$.

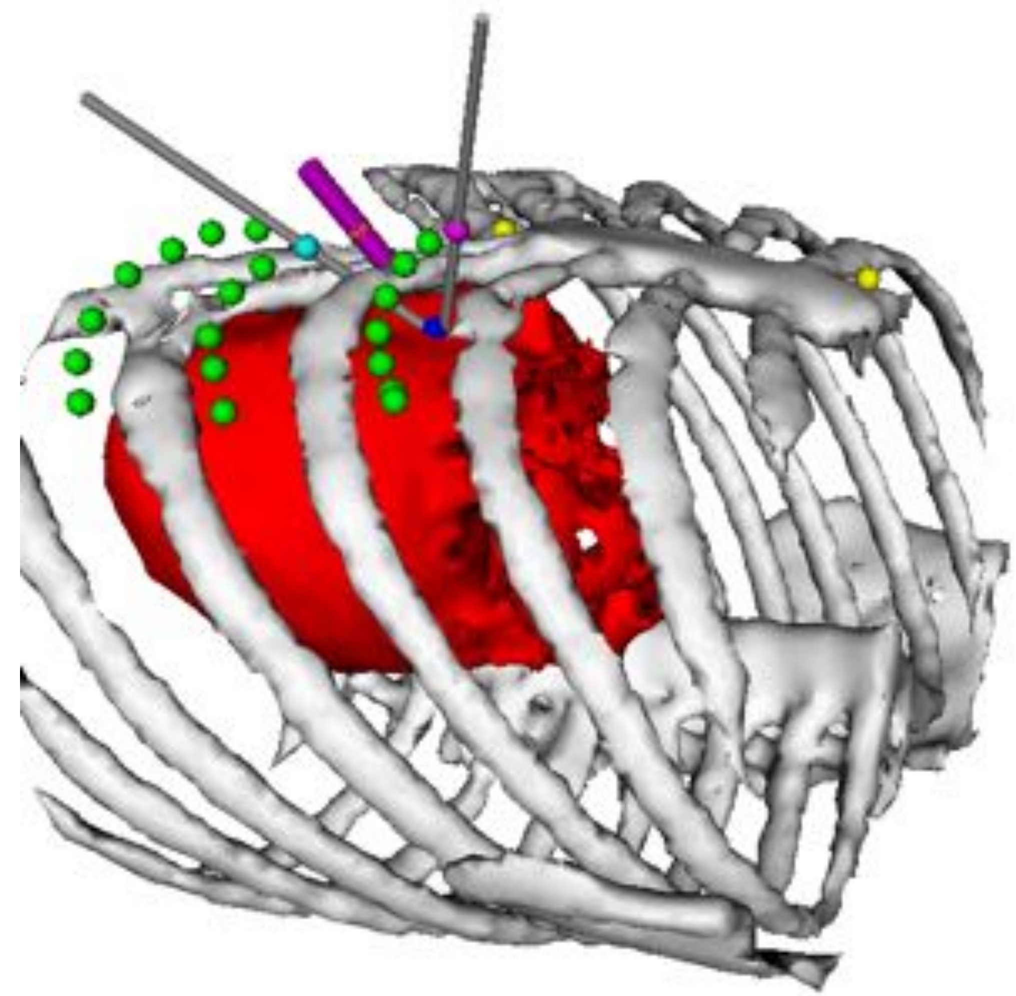
how are optimal angles found?

optimal angles are based on a surgeon's experience in performing CABG

- Instrument angles are task based
- Endoscope angles are viewpoint based



LIMA take-down



Anastomosis

dexterity (quality) metric

sum, over all surgical sites, of the weighted squared "distance" of the instruments and the endoscope from their optimal orientation angles

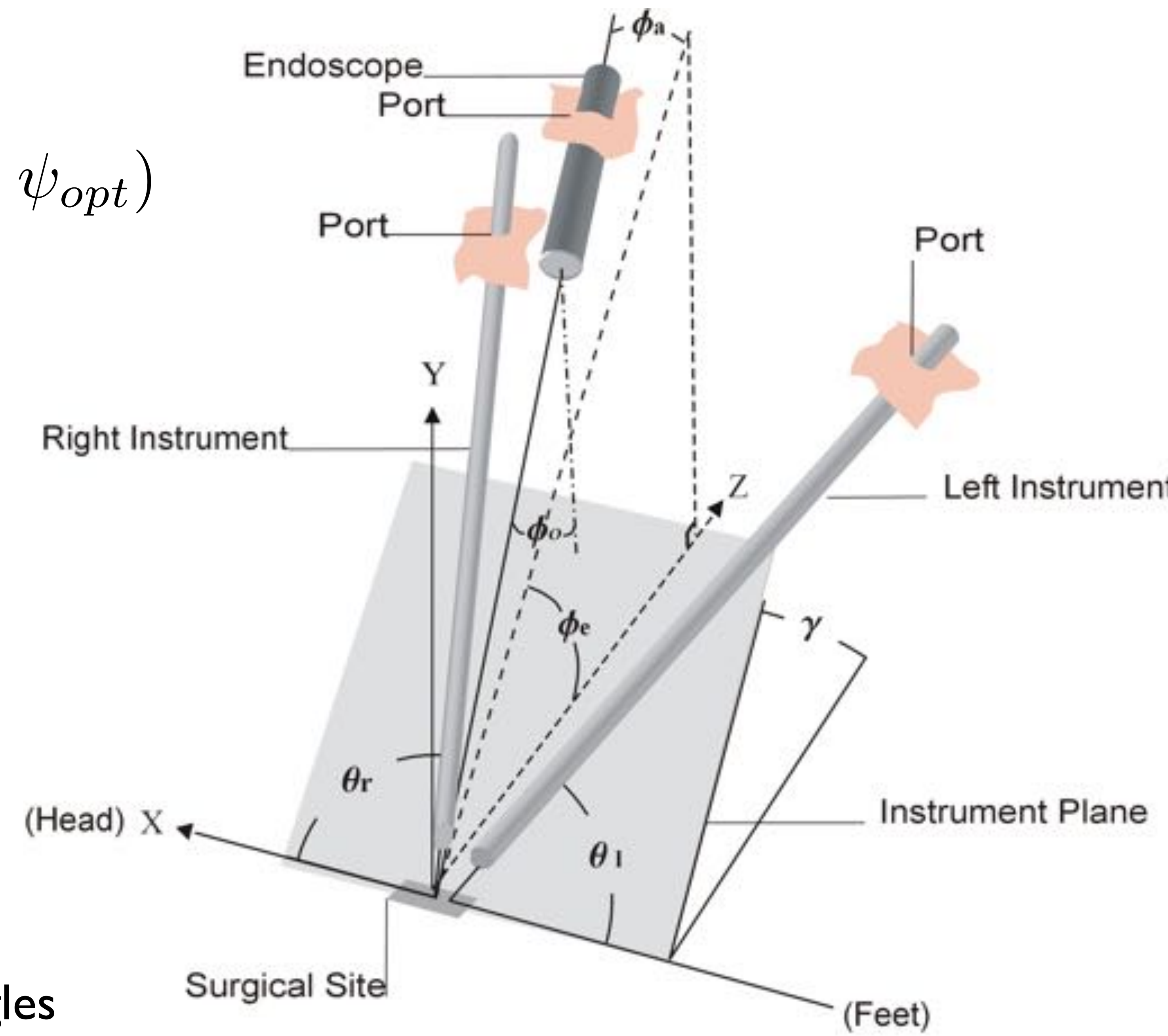
$$J = \sum_{i=l}^{n} K_i(\psi_i - \psi_{opt})^T W(\psi_i - \psi_{opt})$$

W = diagonal weighting matrix to take into account relative importance of different angles

K_i = weighting factor to account for relative importance of different surgical sites

$$\psi_i = (\theta_r, \gamma_r, \theta_l, \gamma_l, \phi_e, \phi_a)^T$$

ψ_{opt} = vector of optimal orientation angles



cost function minimization

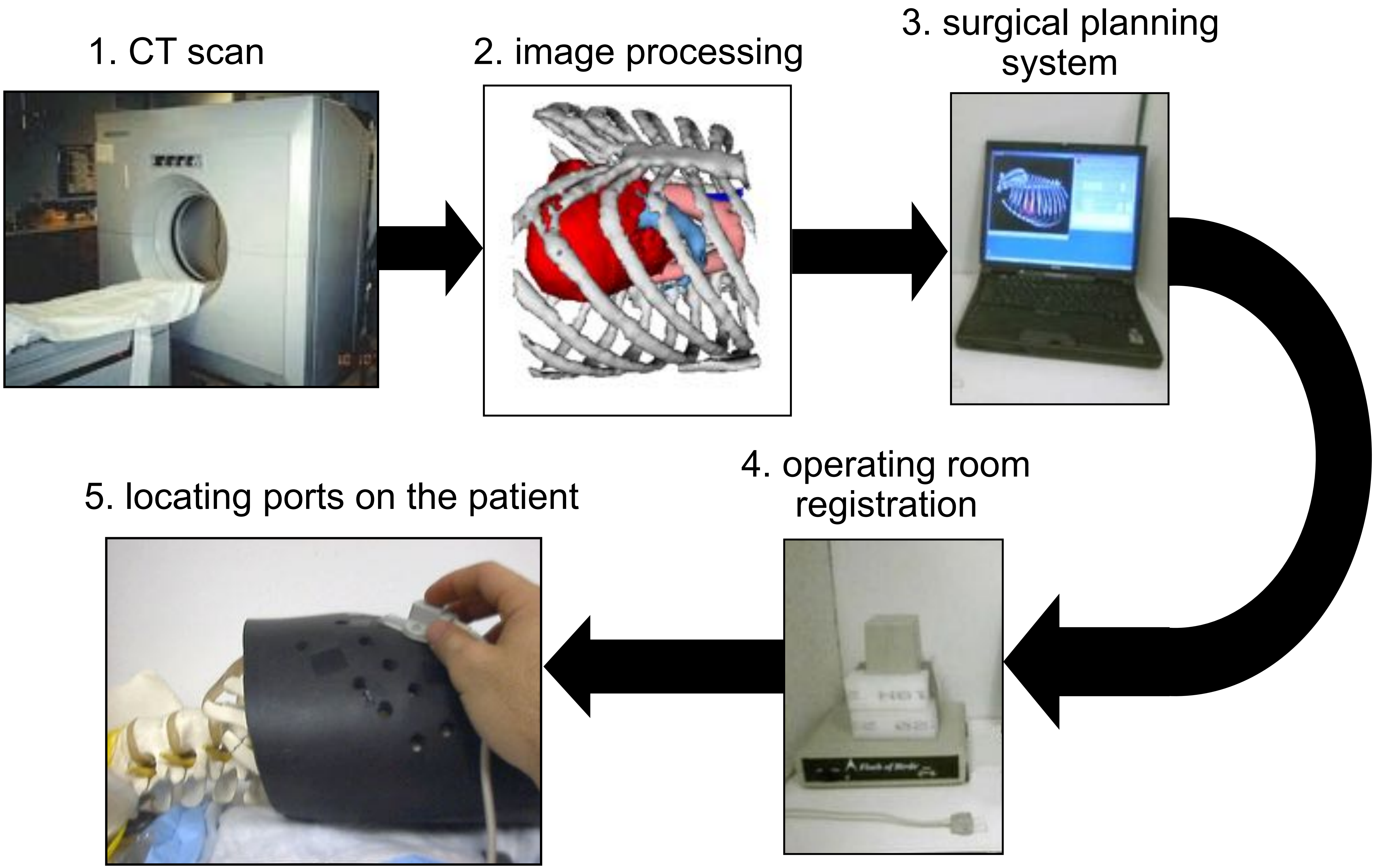
technique used in this case study: brute force!

"the ribs, diaphragm, and other anatomic structures limit candidate port sites to a modest number (< 200). Because the weighting matrix is diagonal, the ranking of each port in the triad is uncoupled; thus, an exhaustive comparison of m feasible ports requires only $3m$ evaluations of [the cost function]"

what are other ways to minimize a cost function?

what might concern you about this general approach?

implementation



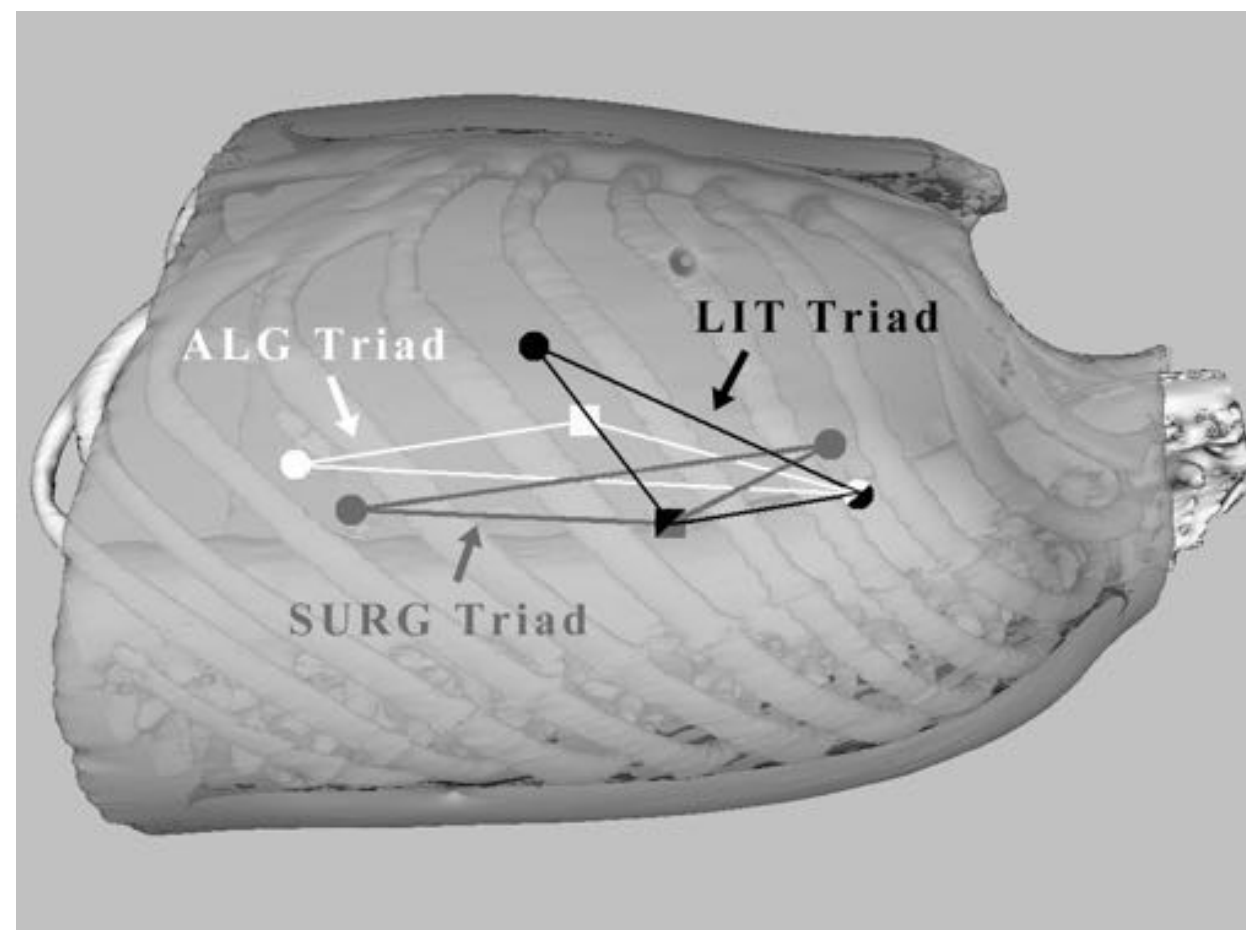
System evaluation

- thorax model: ribs with neoprene skin
- task: vessel dissection
    - 3 mm diameter “vessel” of stiff clay encased in “soft tissue” matrix of modeling dough and then shrink wrapped.
    - three dissections: two at extremes of LIMA takedown and one at site of coronary artery.

system evaluation

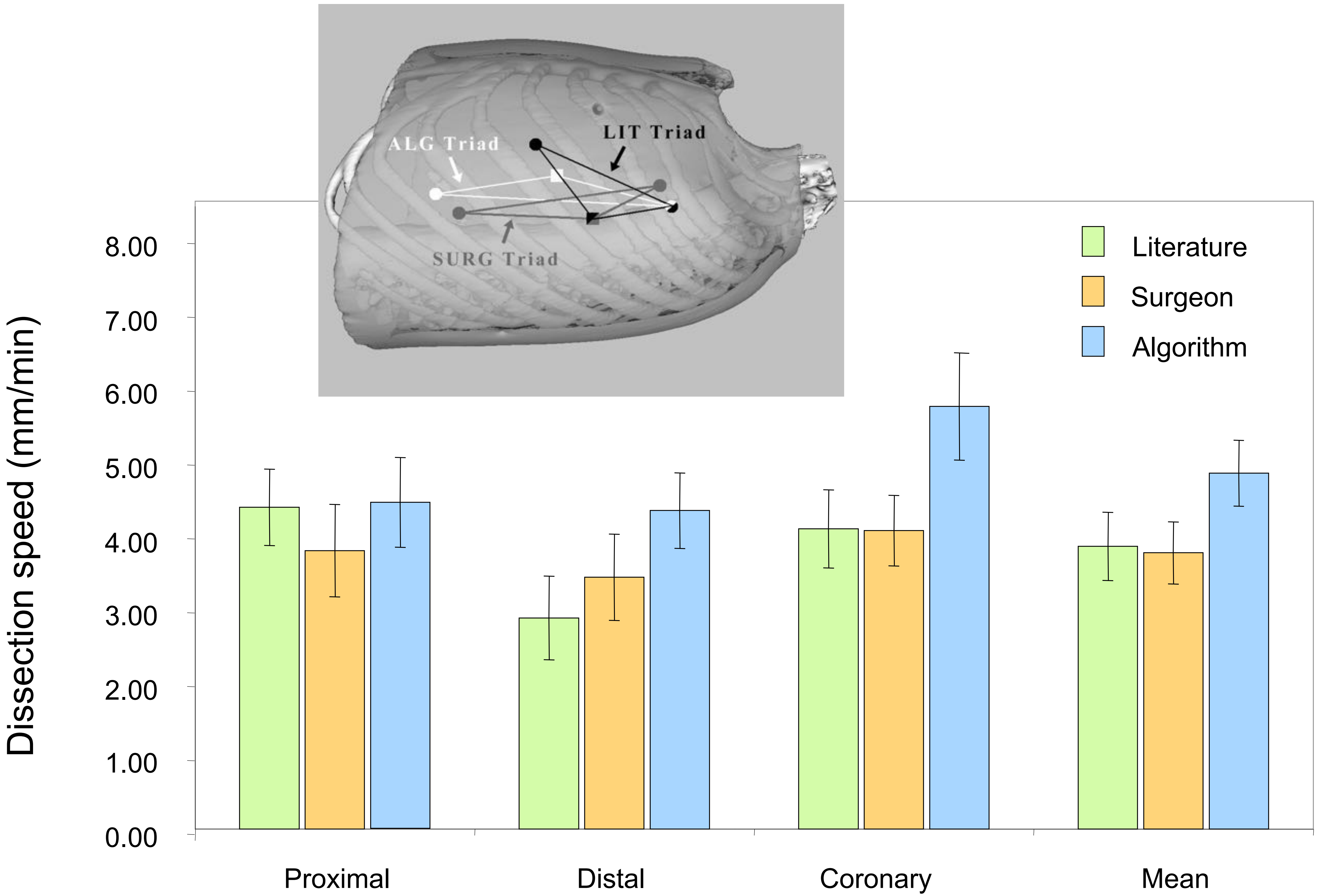
- six staff cardiac surgeons
  (Division of Cardiac Surgery, Massachusetts General Hospital, Boston, MA)
- three sets of ports compared:

1. LIT = template from literature
2. SURG = cardiac surgeons with thorascopic and minimally invasive surgery experience
3. ALG = algorithmic port placement

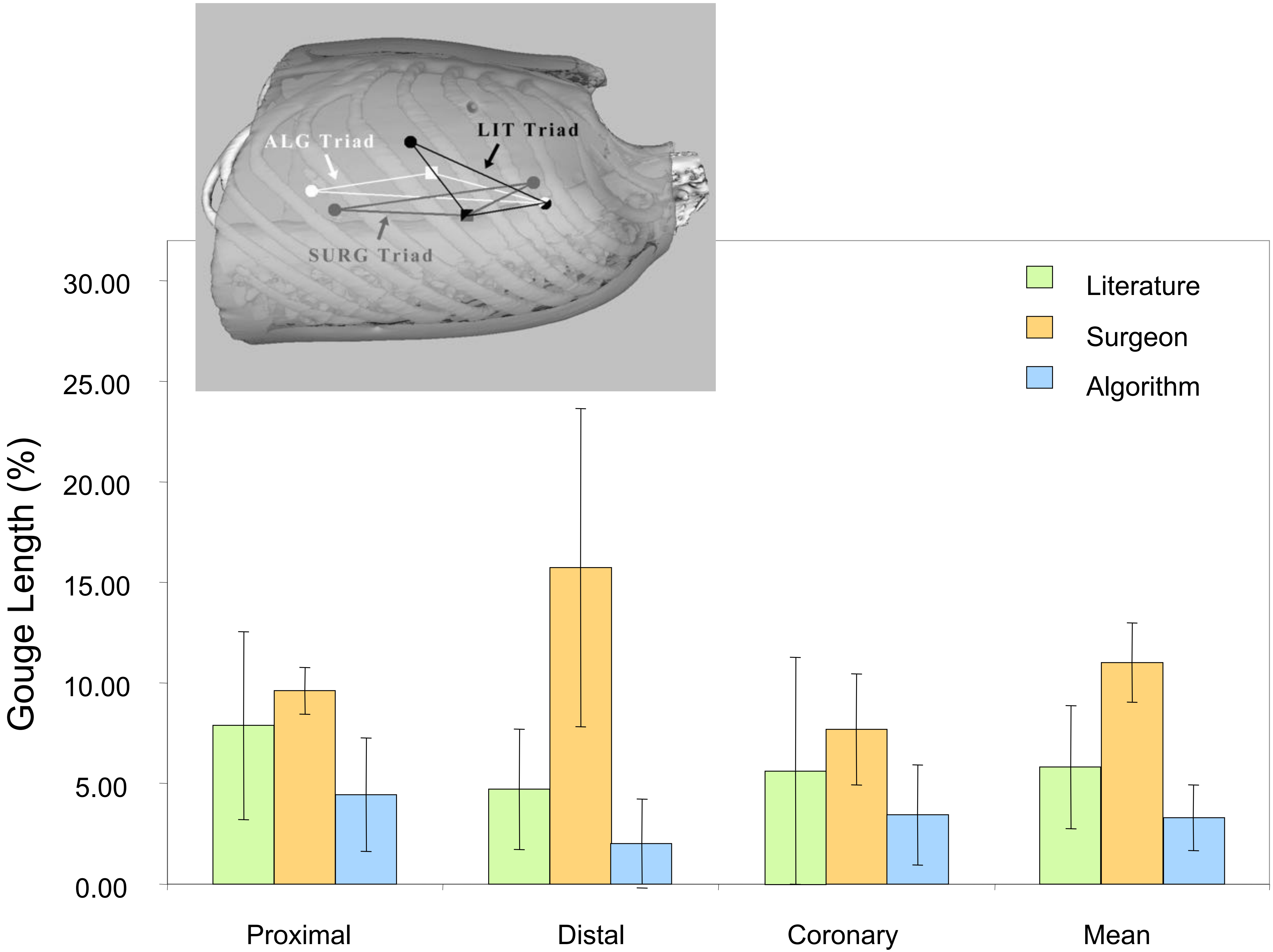


■ = *Endoscope Port*
● = *Instrument Ports*

dissection speed



length of gouges > 1.5 mm deep

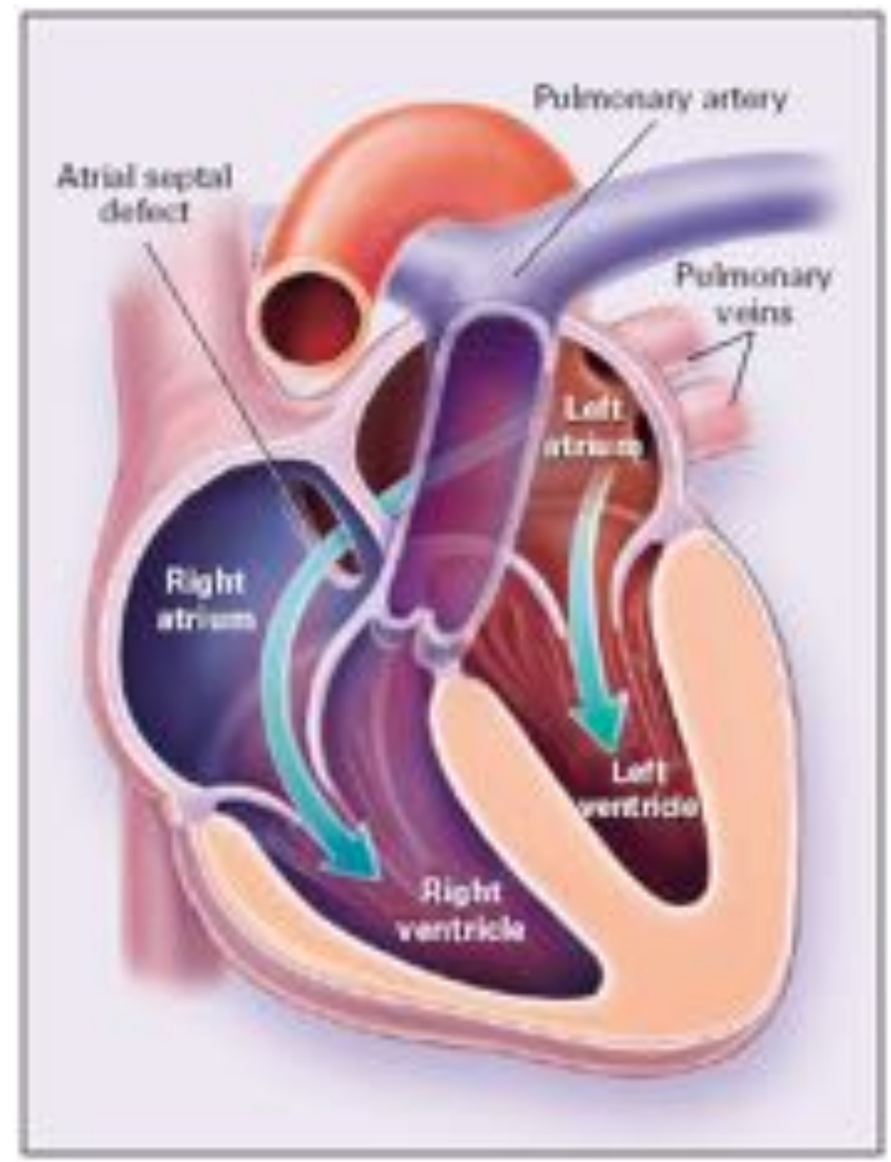


summary

- decoupled robot placement from port placement
- developed a dexterity metric based on optimal orientations
- preliminary in vitro trials
    - dissection speed increased 25%
    - gouge length decreased 50% or more

long-term role of algorithmic port placement

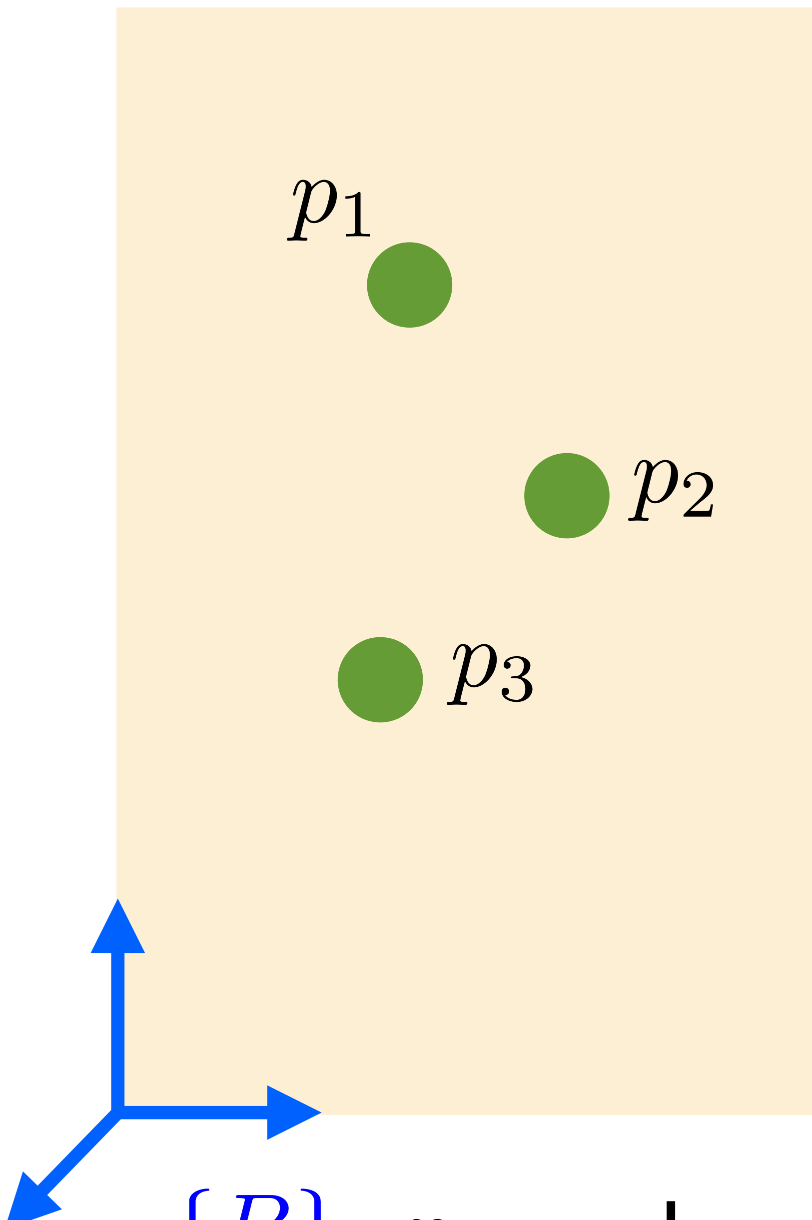
- routine use versus special cases?
  - image library comparison of algorithmic port selections
- development of new procedures
  - e.g., beating heart

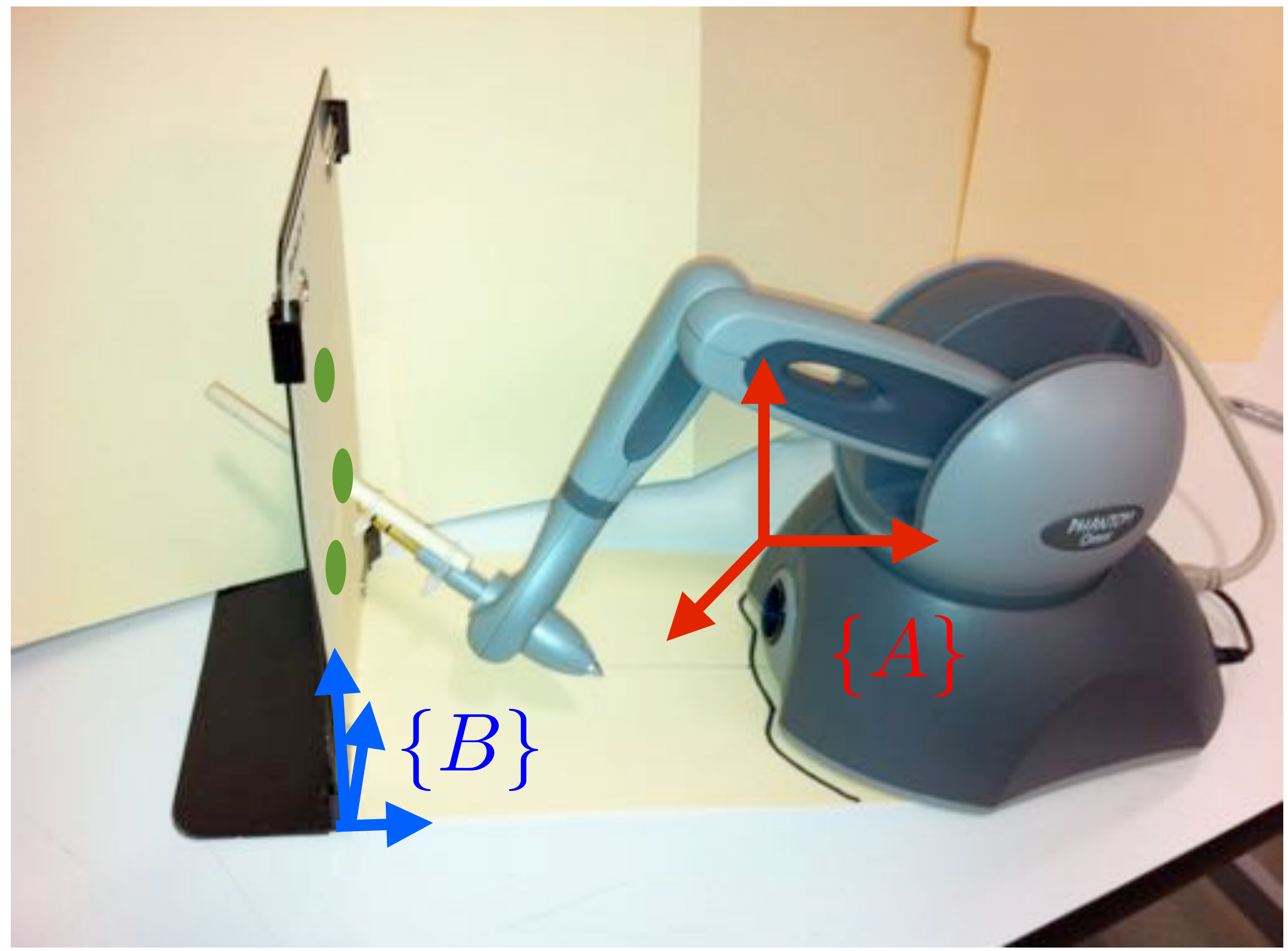


discussion

- what do you think about the method for choosing optimal orientations of the instruments and endoscope?
- what are other ways that port placements could be evaluated?

What you will do in Assignment 5: Phantom Omni and "patient body wall"





$\{B\}$ p_i are known points in the patient frame $\{B\}$

touch patient points with stylus tip to register $\{A\}$ and $\{B\}$

attempt control through different ports and pick the best one