Computer Vision Assisted Robotic Surgery
Motion Compensation for Beating Heart Surgery

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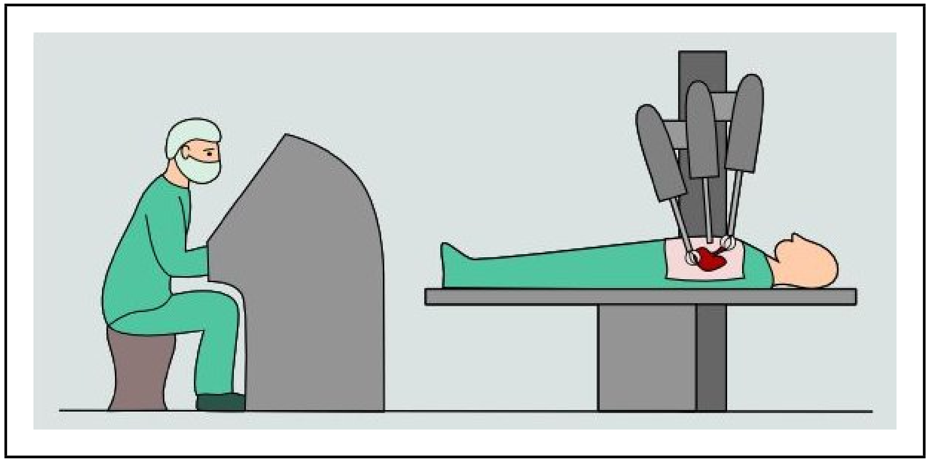
Minimally Invasive Robotic Surgery (MIRS)

- Telemanipulation systems for minimally invasive (or keyhole) surgery
- Master-slave concept
  - Master side: Surgeon controls robotic arms that hold the endoscopic devices at the slave side
  - Slave side: Operation is performed through a few small incisions by remote controlled endoscopic instruments



- Benefits of minimal invasiveness: Small incisions → less trauma and bleeding & lower risk of infection → quicker recovery, improved cosmetic effect
- MIRS should overcome limitations of conventional keyhole surgery (loss of depth of field & the normal eye-hand-target axis, restricted possibilities to manipulate tools)

The *da Vinci*® Surgical System

- Commercially available system from *Intuitive Surgical Inc.*, Sunnyvale, CA, USA
- Development started in 1995, clinical use since 1999
- More than 60 *da Vinci* systems currently used in Europe and 300 worldwide

Source: Intuitive Surgical

Master console:

- Ergonomically designed console to control the robotic arms
- High-resolution 3D binocular display of the operative field

Control unit:

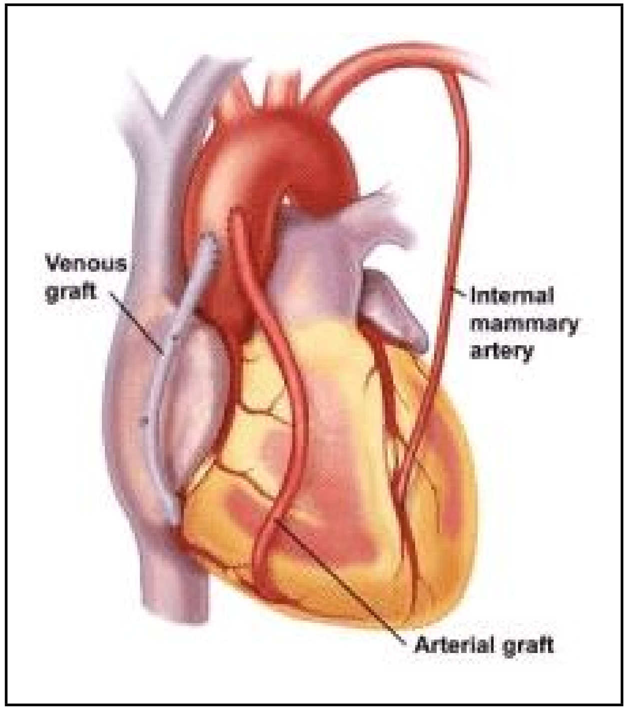
- Computer tower comprises main computer hardware
- External display, video electronic equipment, insufflator for pneumoperitoneum, ...

Patient side cart (slave):

- 3 or 4 robotic arms with 7 degrees of freedom
- Stereoendoscope: 2 separate telescopes for 3D vision

Coronary Artery Bypass Surgery on the Beating Heart

- Coronary artery disease: Obstructed coronary arteries → limited blood supply to heart muscle → heart attack
- Coronary artery bypass (CAB) surgery: Other arteries or veins are grafted from aorta to coronary arteries to bypass the obstructed area
- CAB surgery is the most often performed cardiac procedure (up to 75 %)
- Usually performed on arrested heart using cardiopulmonary bypass (CPB, or heart-lung-machine) by open surgery
- A number of complications associated with CPB (systemic inflammatory response syndrome,...)



Source: www.cvtsc.com

- **Possibility to avoid CPB and sternotomy with telemanipulation systems for minimally invasive surgery → totally endoscopic operation on the beating heart**
- Problems: Limited space, lack of tactile feedback, motion of the heart

Objective

The overall objective is to synchronize the movements of the robotic arms with the motion of the beating heart in such way that the surgeon can operate as on an arrested heart.

Subproblems:

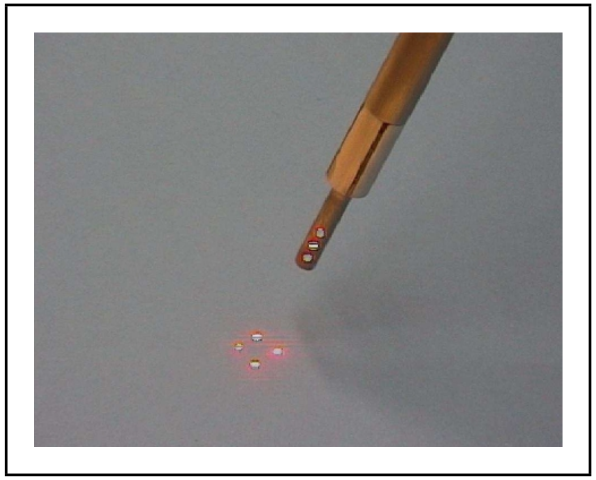
- Assessment of the heart motion
- Adaption of the movements of the robotic arms with surgical tools to that motion
- Stabilization of the view of the surgical scene

Focus on visual estimation of the heart motion.

State of the Art

Existing approaches include

- Non-visual assessment of the heart motion using sonomicrometry
- Visual assessment of the heart motion with or without artificial markers
- Integration of ECG signals for motion prediction



Optical Marker (Source: [1])

Issues comprise

- Accuracy of motion tracking
- Occlusion of the heart surface by surgical tools
- Handling of arrhythmic heartbeats
- Real-time capability of tracking and robotic control

We intend

- to estimate the heart motion from stereo endoscopic images,
- not to use artificial, physical or optical markers,
- not to apply additional devices

[1] J. Gangloff, R. Ginhoux, M. De Mathelin & J. Soler, "Model predictive control for compensation of cyclic organ motions in teleoperated laparoscopic surgery", IEEE Trans. on Control Systems Technology 2006, 2006, 14, 235-246

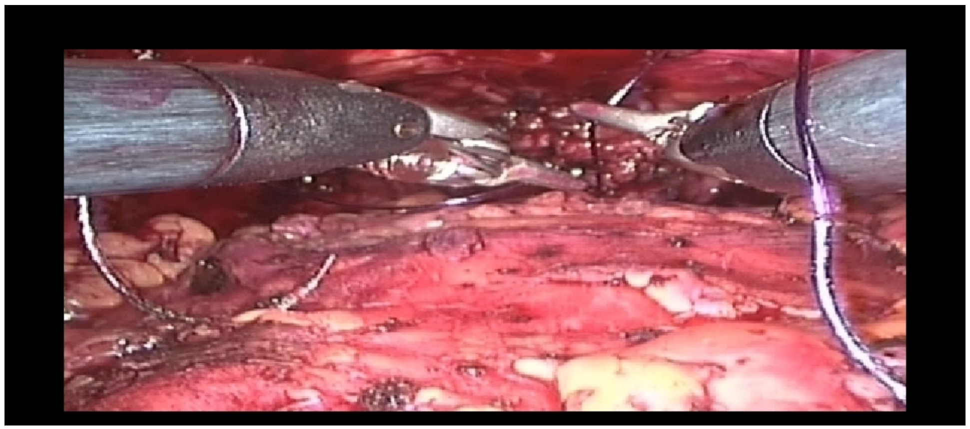
Preliminary Experiments (1)

Tracking of a point on the organ surface (here not on the heart):

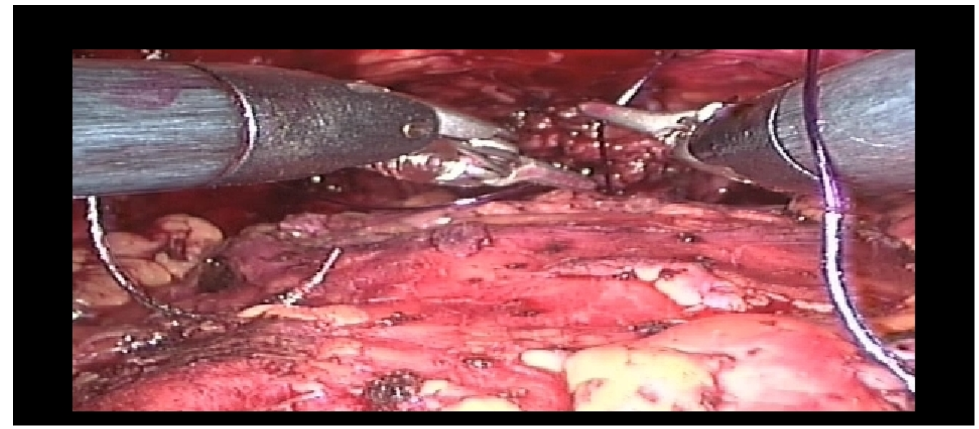
K. Zimmermann, J. Matas & T. Svoboda, "Tracking by an Optimal Sequence of Linear Predictors", to appear 2007.

Preliminary Experiments (2)

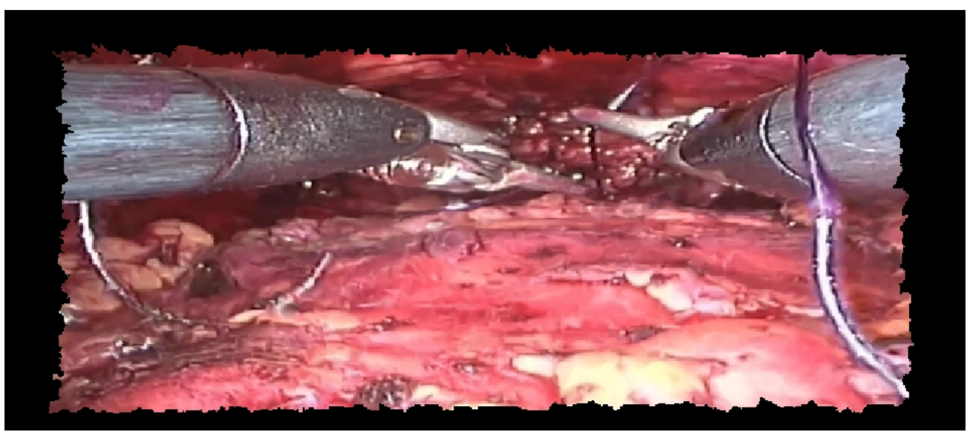
Warping one image to another (here not on the heart):



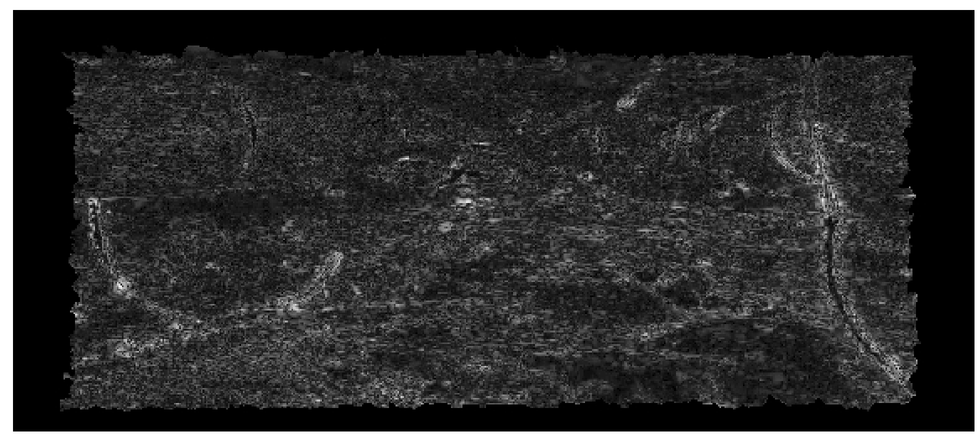
Original image 1



Original image 2



Warped image 1 to image 2



Differences between warped image 1 and original image 2 (higher intensities indicate bigger differences)

A. Shekhovtsov, I. Kovtun & V. Hlaváč, "Efficient MRF Deformation Model for Non-Rigid Image Matching", Proceedings of the 2007 IEEE Computer Society Conference on Computer Vision and Pattern Recognition, 2007.

Thank you for your attention.

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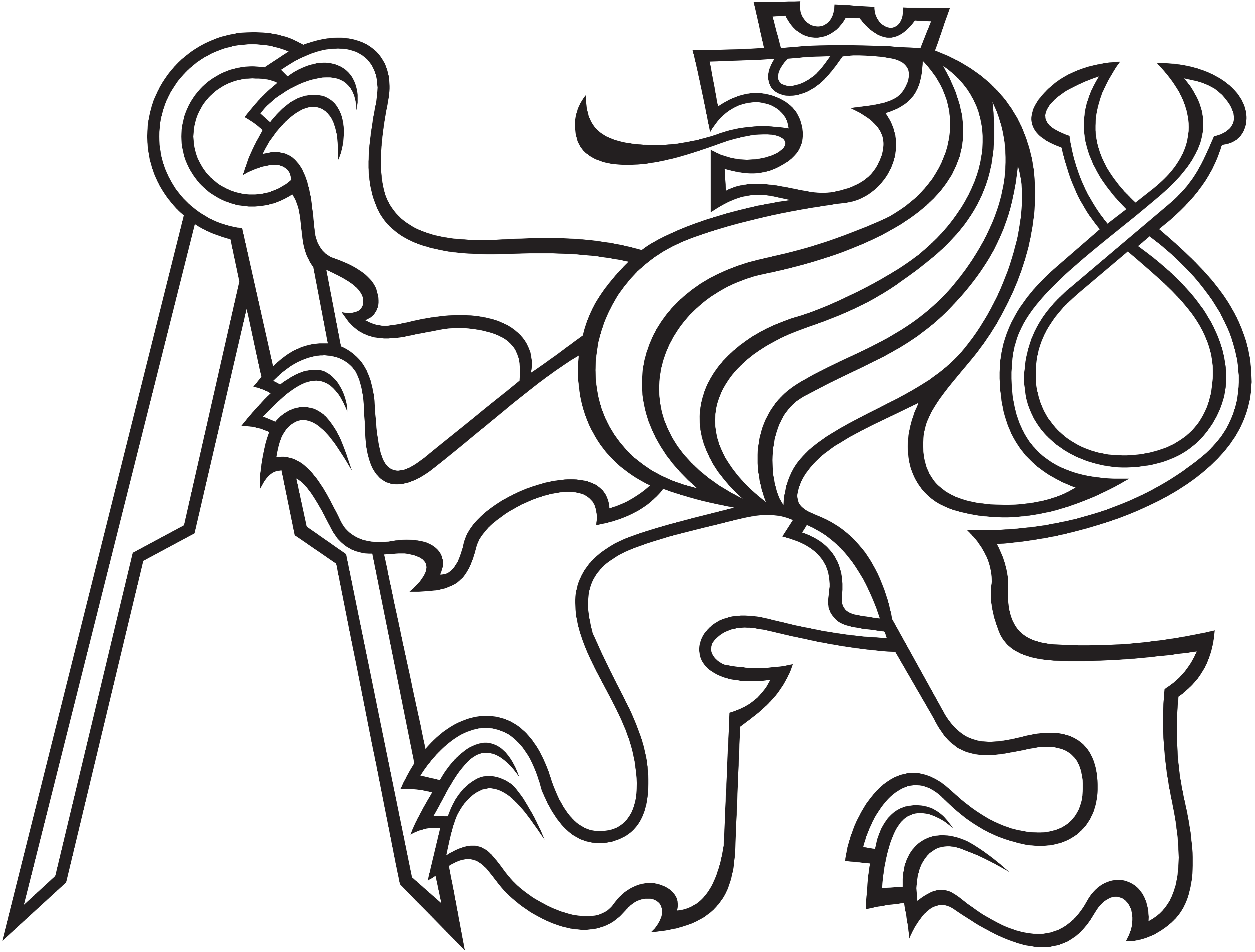

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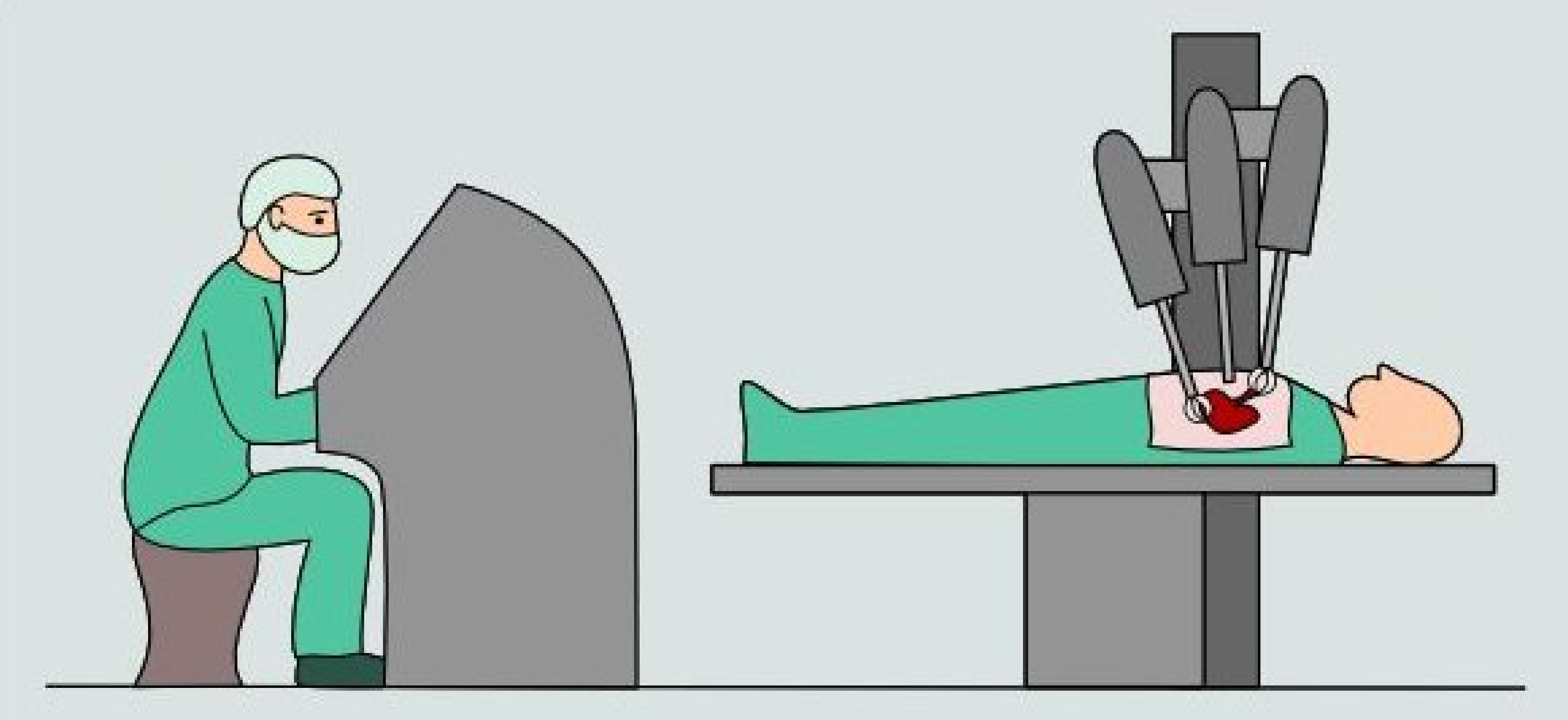

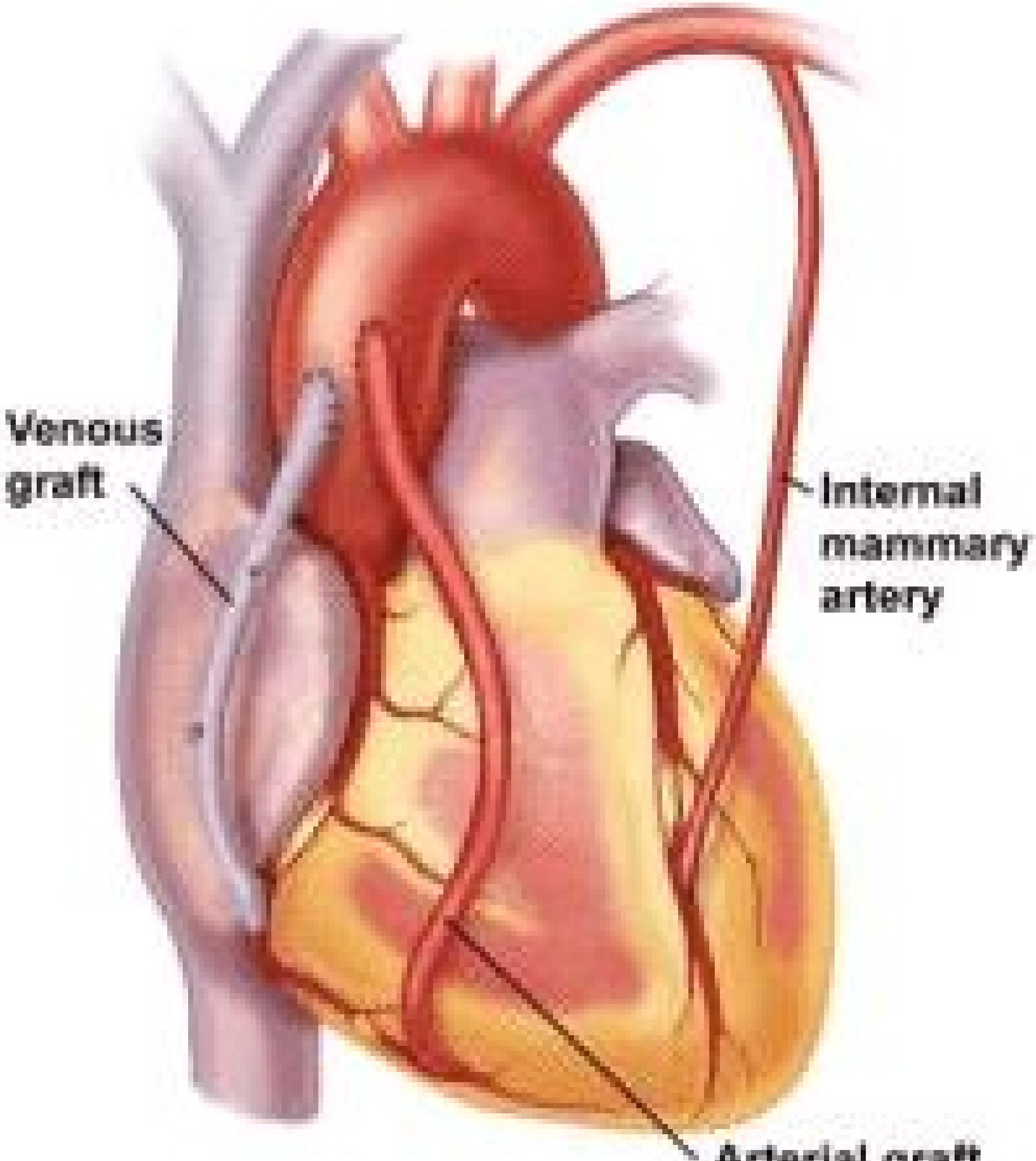

Venous graft
Internal mammary artery
Arterial graft