Part 1

Cardiac Surgery

A brief overview and an introduction to Minimally Invasive Cardiac Surgery

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Outline

- History
- Surgical approaches for heart exposure
- The extracorporeal circulation
- Coronary Artery Bypass Grafting
- Valvular surgery
- Endovascular techniques

History

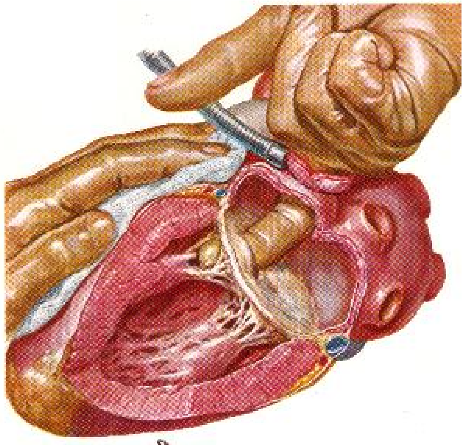
- **First successful heart operation: Rehn, 1896**

  Successful suture of an heart wound

- **Congenital cardiac surgery**
  - Ductus arteriosus: Gross, 1938
  - Coarctation of the aorta: Crafoord, 1944
  - Blalock-Taussig operation: 1944

- **Mitral valvulotomy: Bailey, 1948**

  (first case: Souttar, 1925)



History

- **Indirect revascularization of the heart: Beck, 1930**

  collateral blood flow to ischemic myocardium

- **First cases direct coronary artery surgery: 1960 – 64**

  operations performed on a beating heart

- **First large series of Coronary Artery Bypass Graft patients: Favaloro, Green, 1968**

History

The heart needs to be stopped to repair intracardiac lesions or to improve coronary surgery

- **Cardiac arrest**: irreversible brain damage occurs if circulatory arrest lasts over **3 minutes** in normothermia

- **Two solutions:**

  1) **Hypothermia**: increases the duration of safe cardio-circulatory arrest by decreasing the oxygen consumption

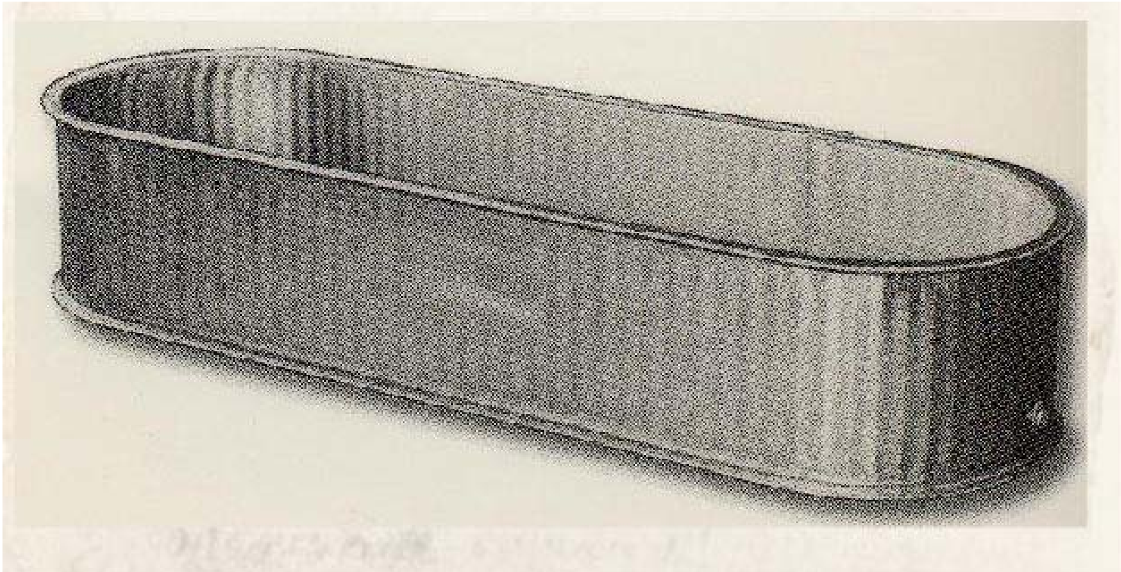
  2) **Heart-lung machine:** replaces the cardiopulmonary function

History

- **Hypothermic technique, surface cooling**: **Lewis, 1952**

Closure of an atrial septal defect in a 5-year-old girl

(five and one-half minutes at 28°C)

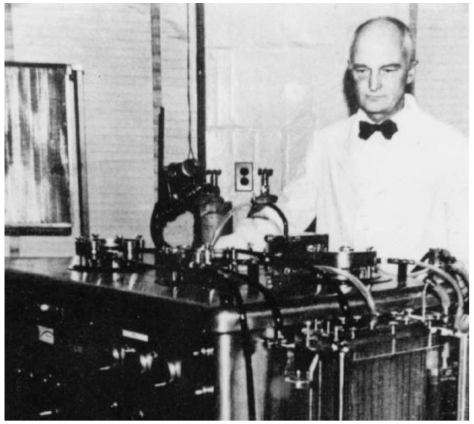


History

- **Heart‑lung machine: Gibbon, 1953**

Closure of an atrial septal defect

in an 18-year-old girl



By the end of 1956, many programs were launched into open heart surgery around the world

*Currently, **more than one million operations** are performed each year under extracorporeal circulation, worldwide*

- **Resurgence of beating heart surgery: Benetti, 1991**
- **First robotic operation of the heart: Carpentier, 1998**

History

Many developments and inventions have been involved in this course:

- Mechanical ventilation
- Defibrillator
- Transfusion
- Heparin
- Antibiotics
- Cardioplegia
- Selective coronary angiography: Sones, 1962
- ...

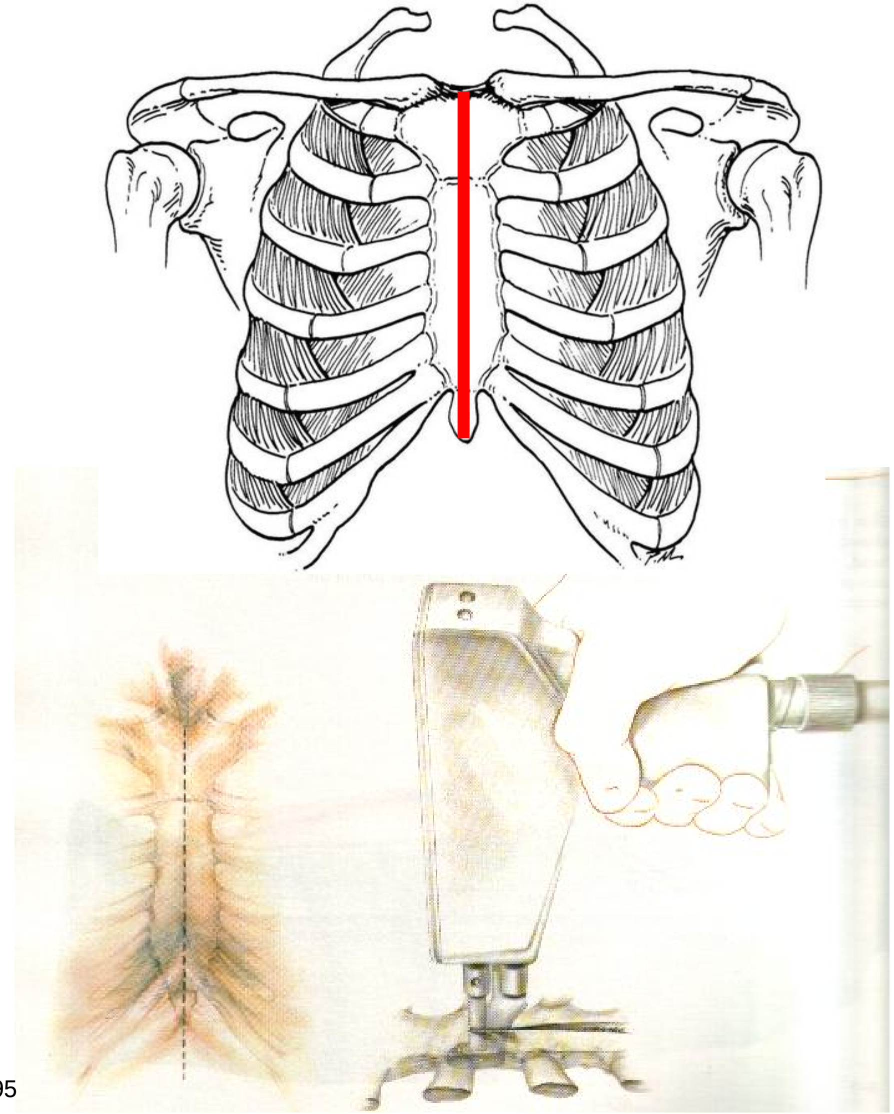
Surgical approaches for heart exposure

Surgical approaches for heart exposure

- Sternotomy
- Thoracotomy
- Minimally invasive cardiac surgery

Sternotomy

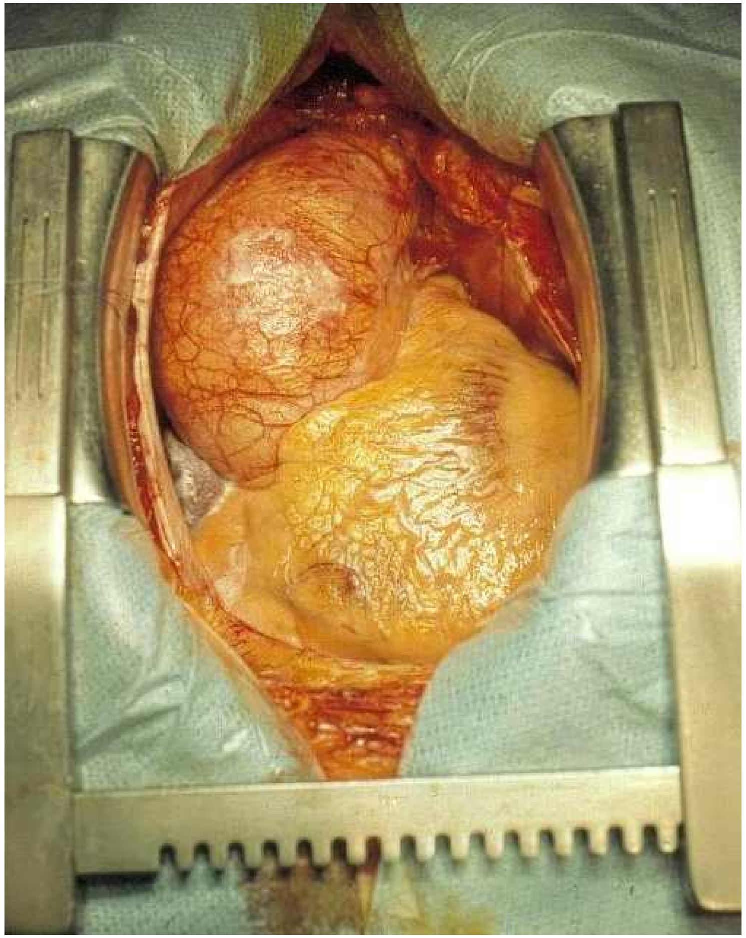
- Sternotomy approach
  - allows almost all cardiac procedures
  - best overall access to the heart
- The sternum is divided with a saw



From : Manual of Cardiac Surgery, Harlan & Starr, Springer-Verlag, New York , 1995

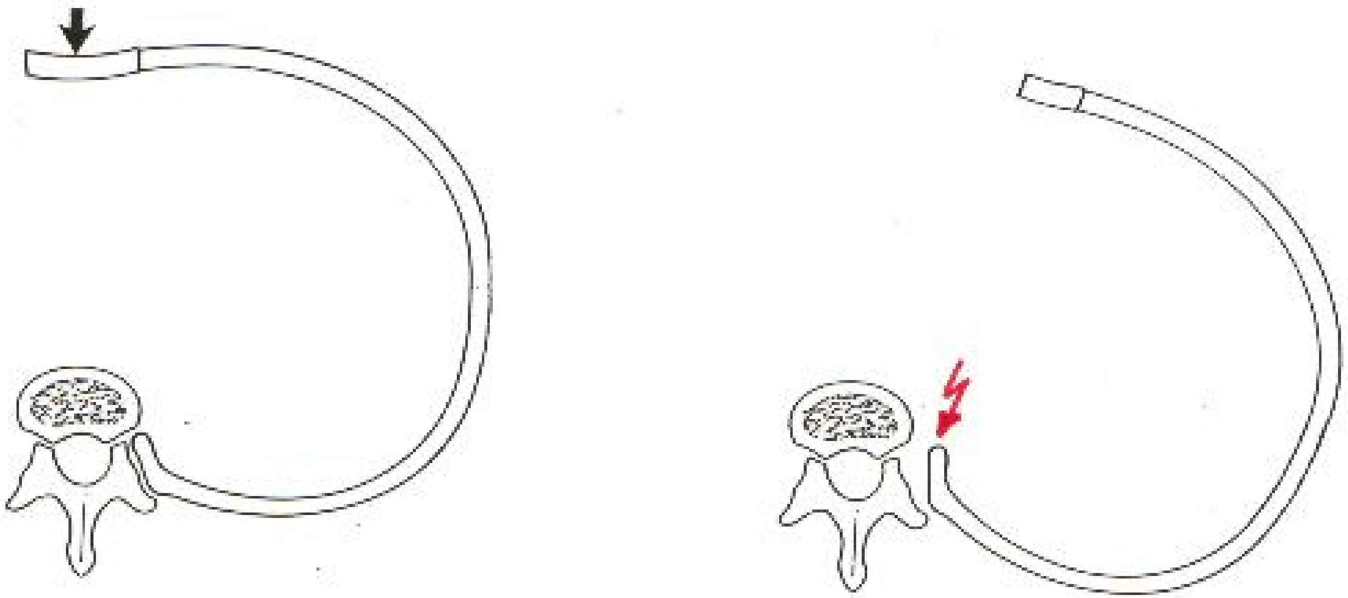
Sternotomy

- A retractor is placed
- The pericardium is incised and sutured to the wound towel, elevating the heart for better exposure



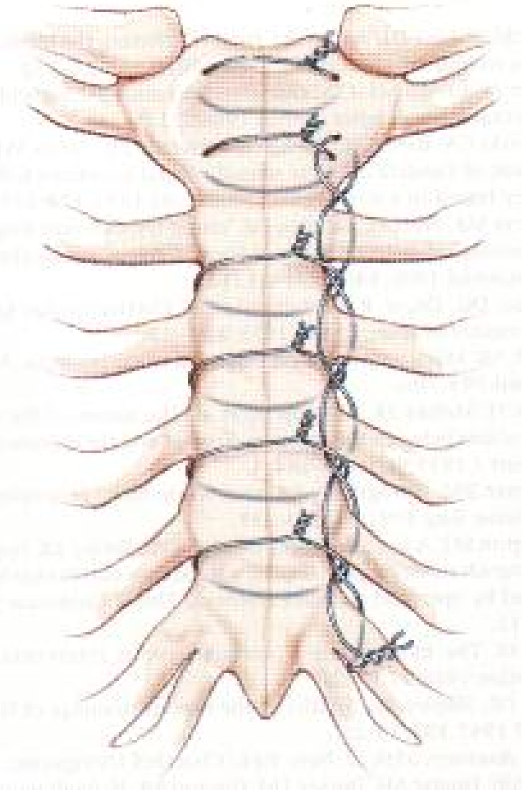
Sternotomy

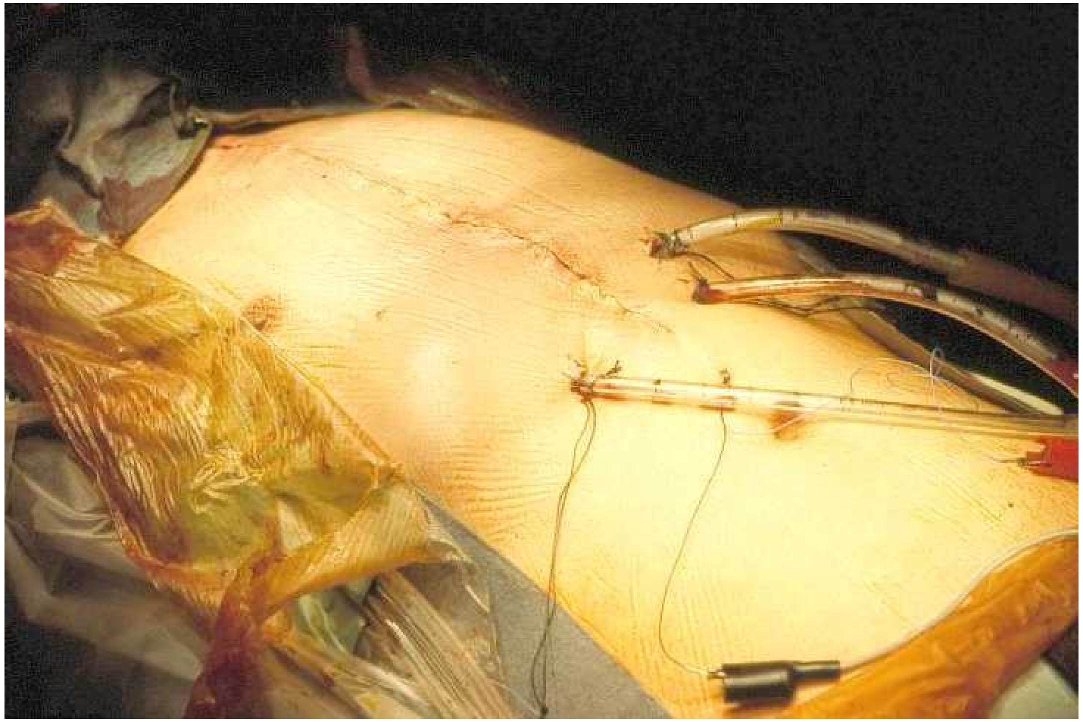
Expension of the retractor is responsible for chest pain and can cause rib fractures



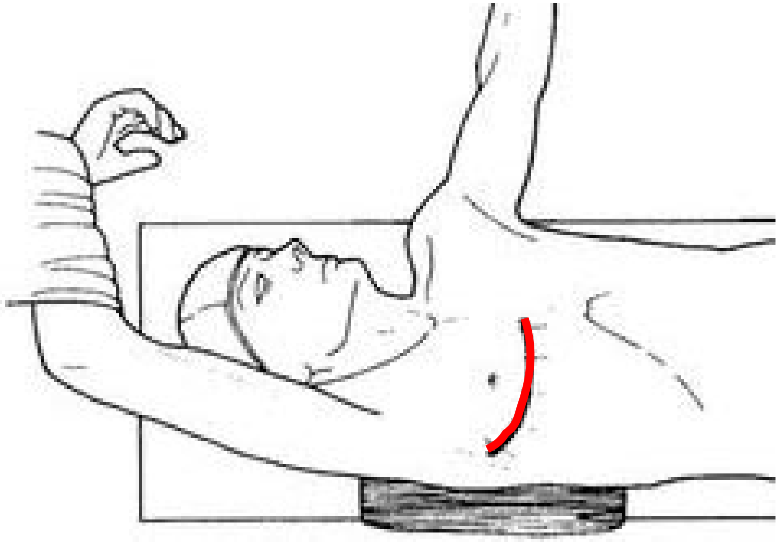
Sternotomy

- Closure

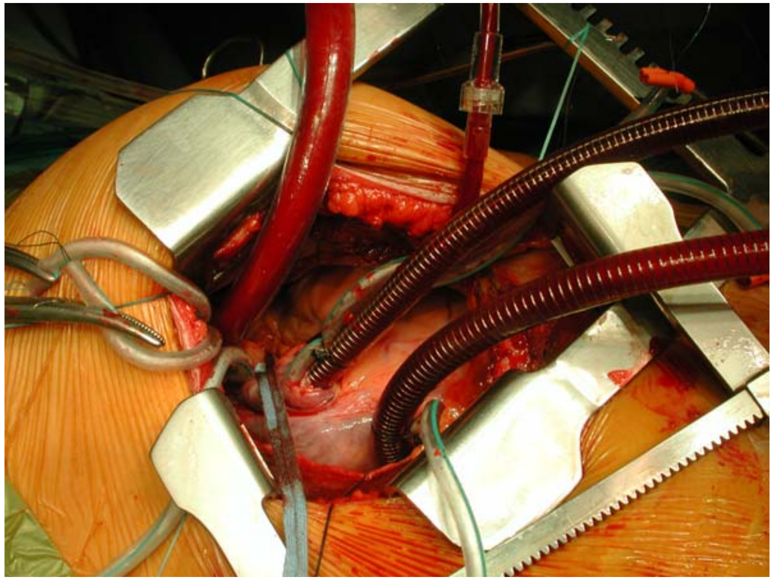


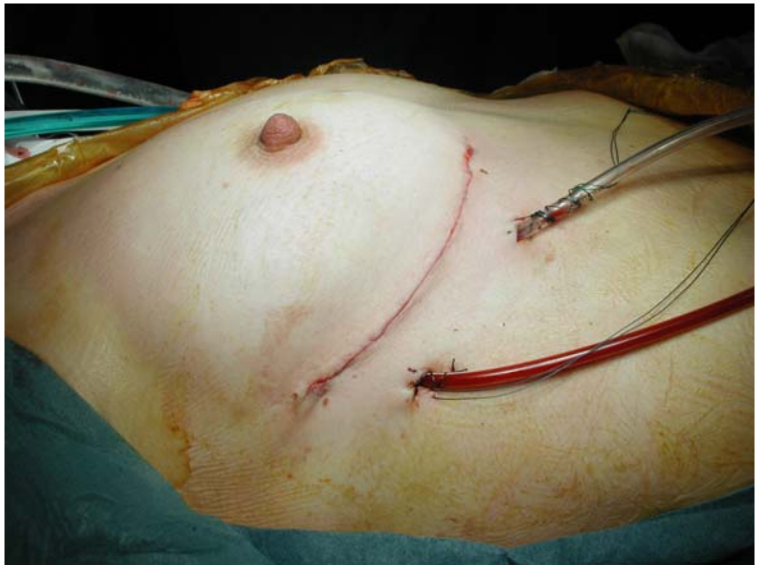


Right anterolateral thoracotomy

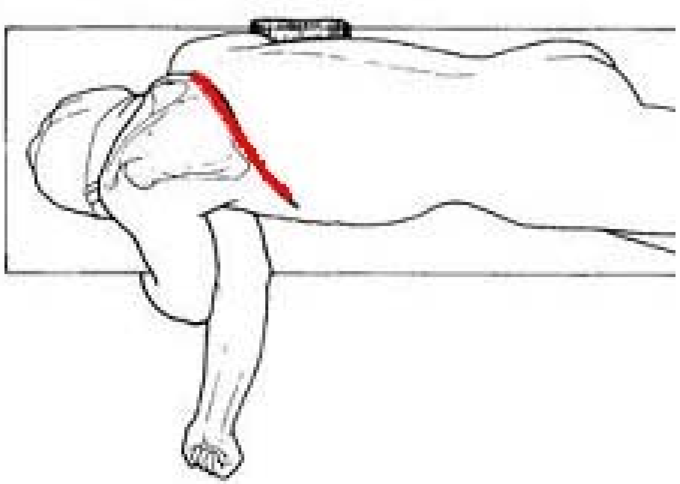


Adapted from: Les thoracotomies, M Noirclerc et al, *in* Traité de Techniques chirurgicales - Thorax : 42-205, Encycl Méd Chir , Elsevier, Paris, 1986





Left posterolateral thoracotomy



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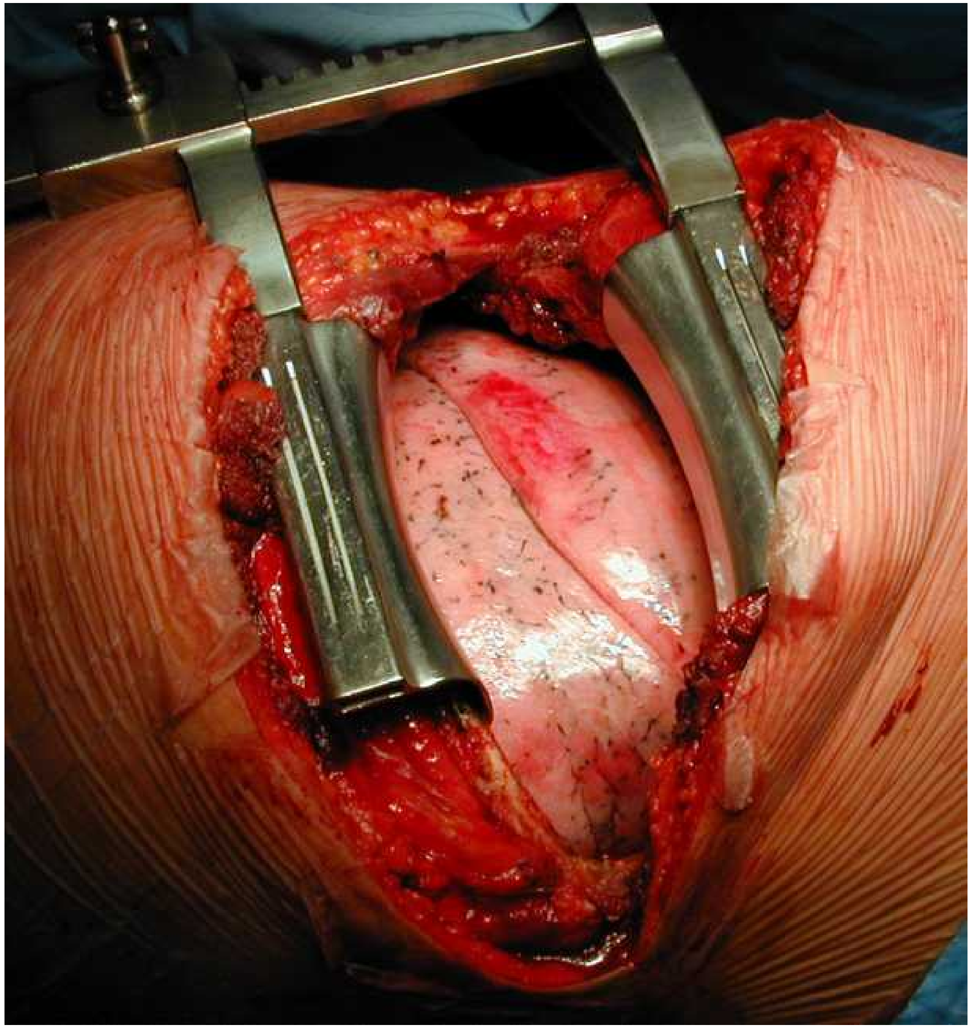
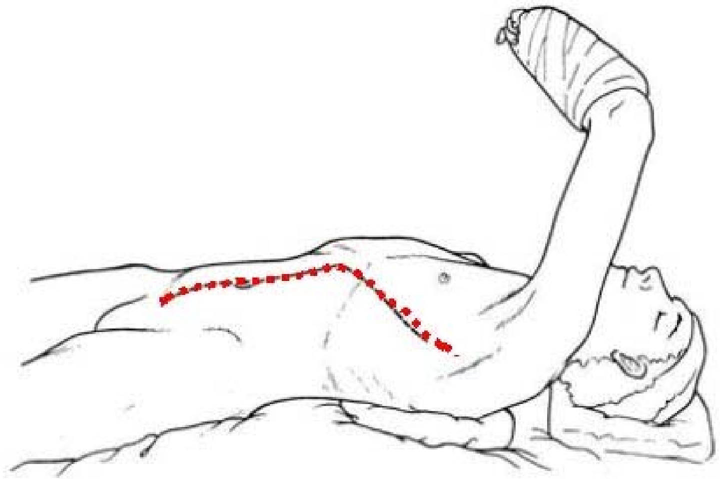


Thoracoabdominal incision



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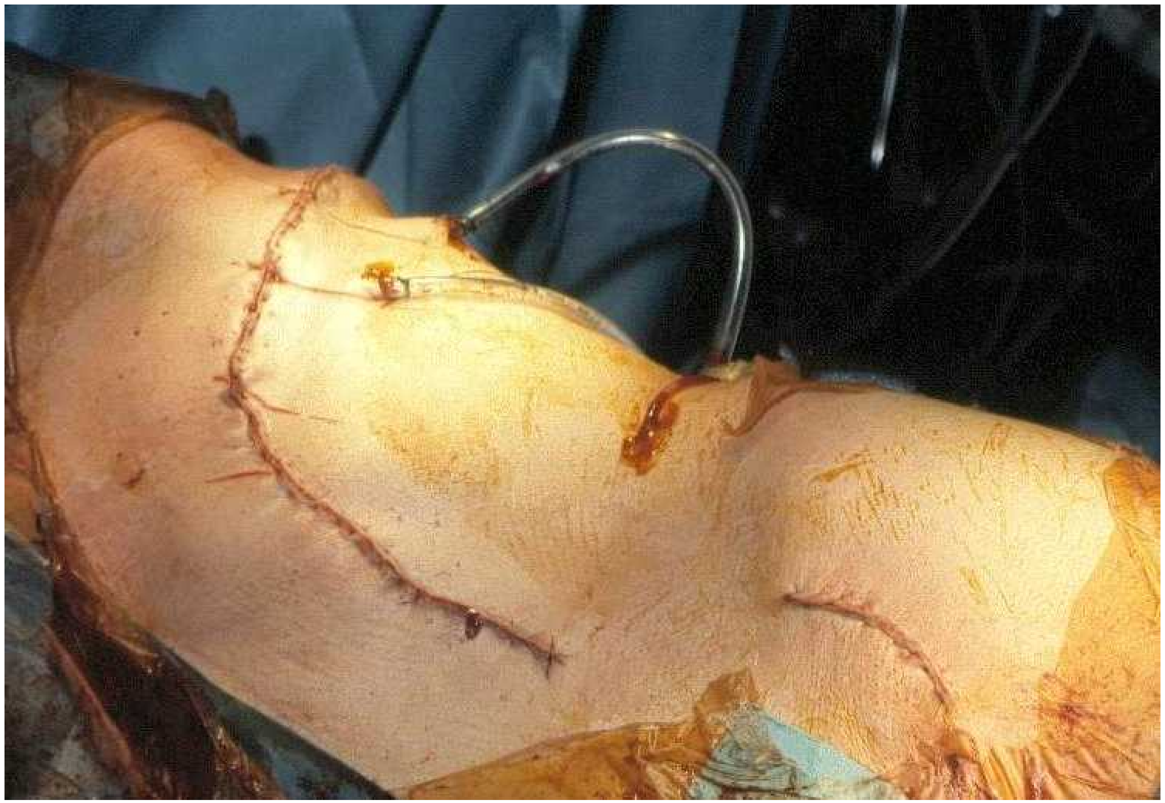
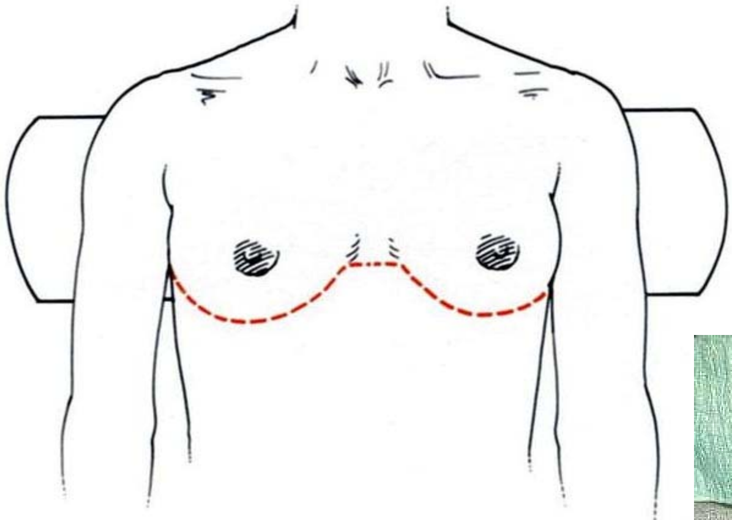


The bilateral transverse thoracosternotomy (clam shell incision)



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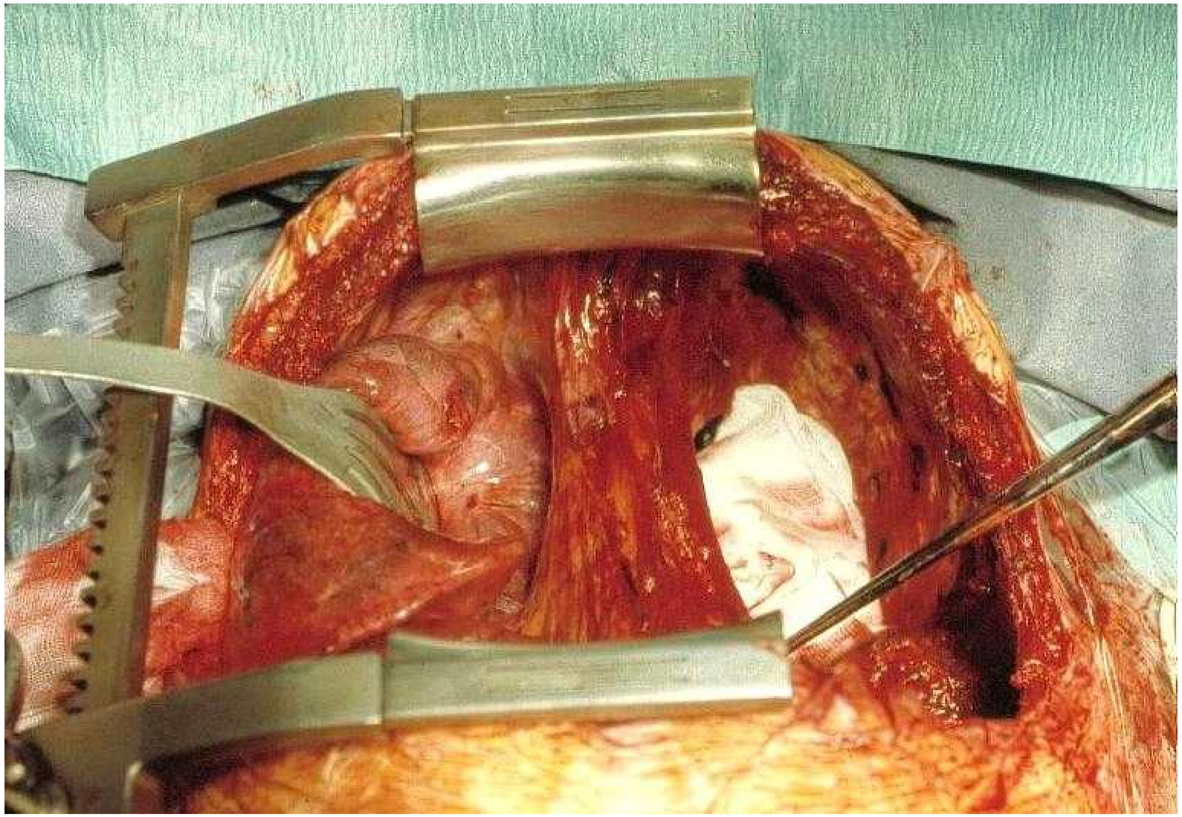
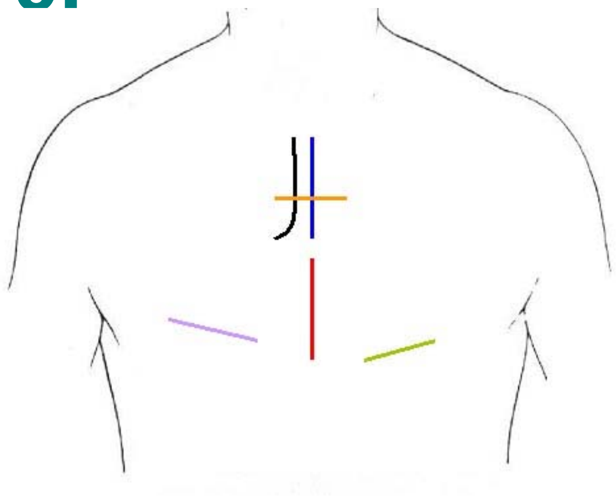


Minimally invasive cardiac surgery

The two major goals of MICS are:

1) To use **smaller incisions**
   - reduce the operative trauma
   - preserve the integrity of the chest
   - more cosmetic



2) To **avoid the extracorporeal circulation**

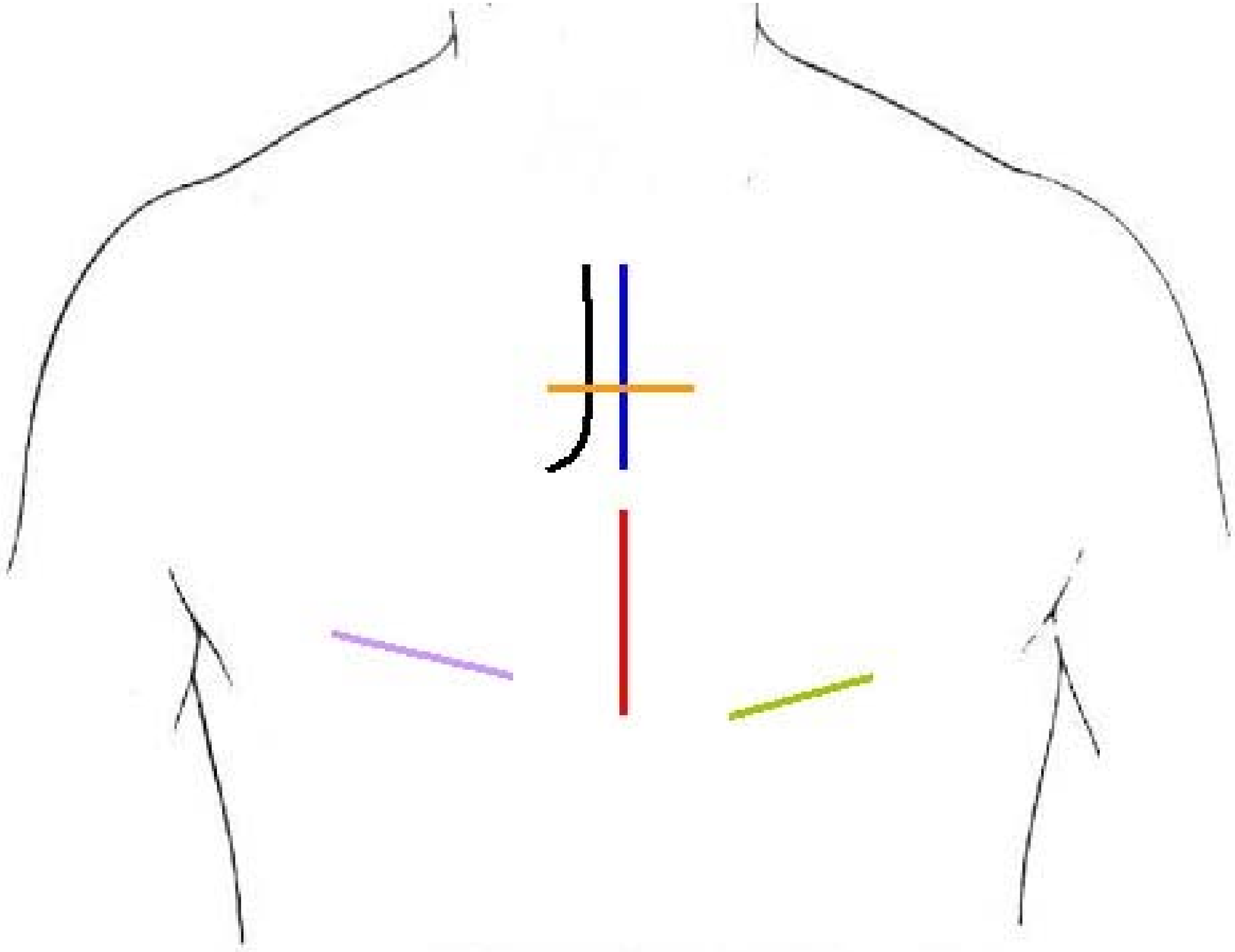
(see latter)

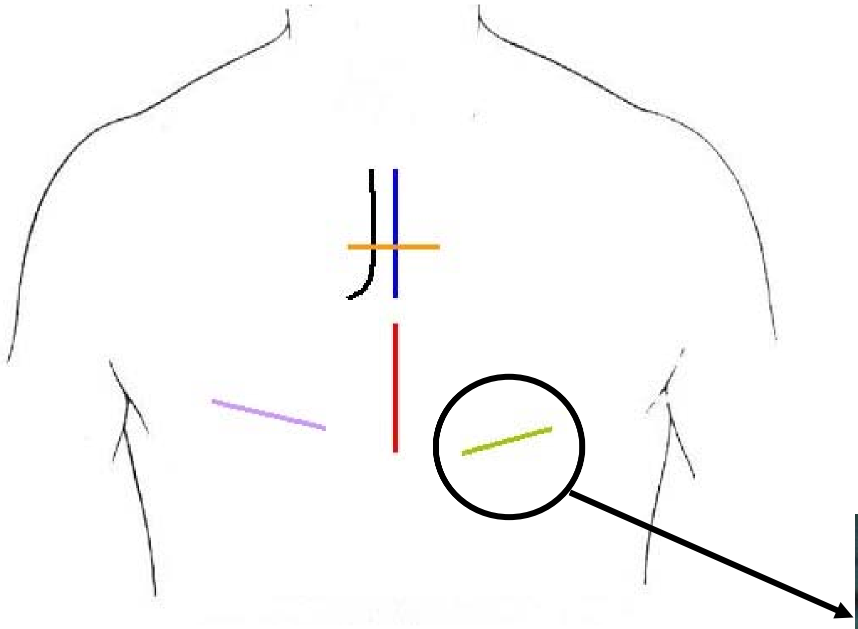
Minimally invasive cardiac surgery

- **MICS remained far behind other specialties:**
  - High quality standard of cardiac surgery
  - Many constraints of cardiac surgery (motion of the heart, limited duration of the induced cardiac arrest)

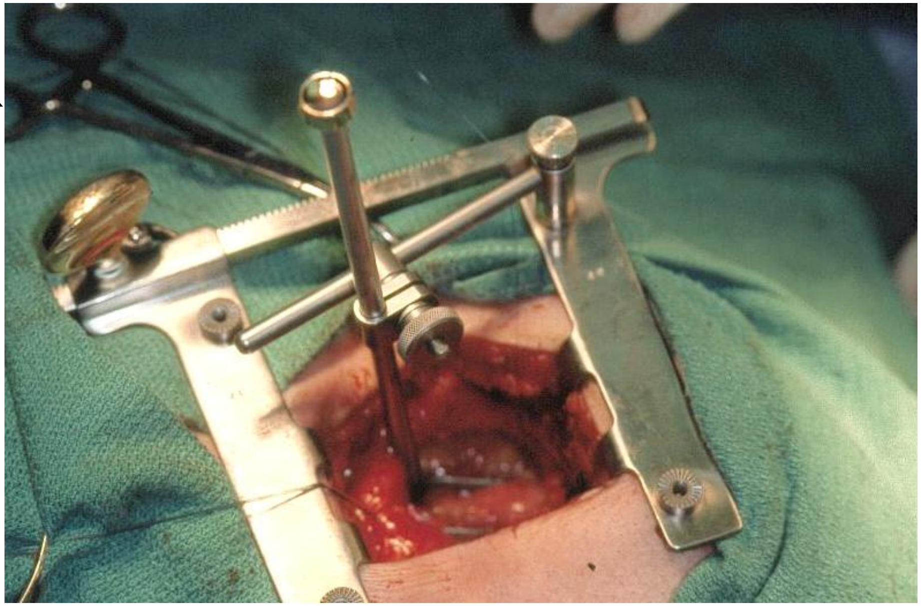
MICS was progressively introduced owing to progress in cardiopulmonary bypass, intracardiac visualization, and instrumentation

Many cardiac surgeons remains very critical of MICS because surgery might be unsafe and/or results less satisfactory

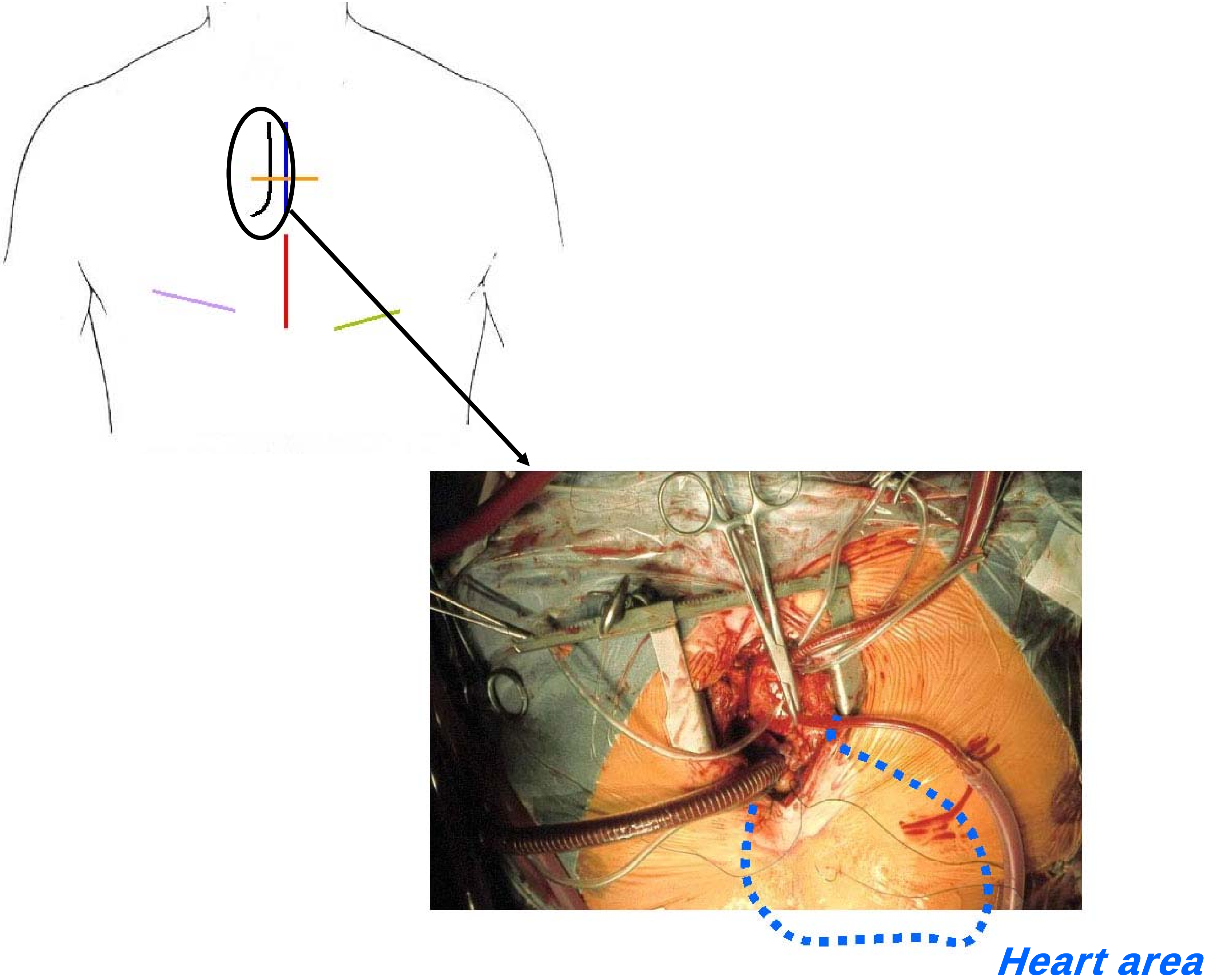




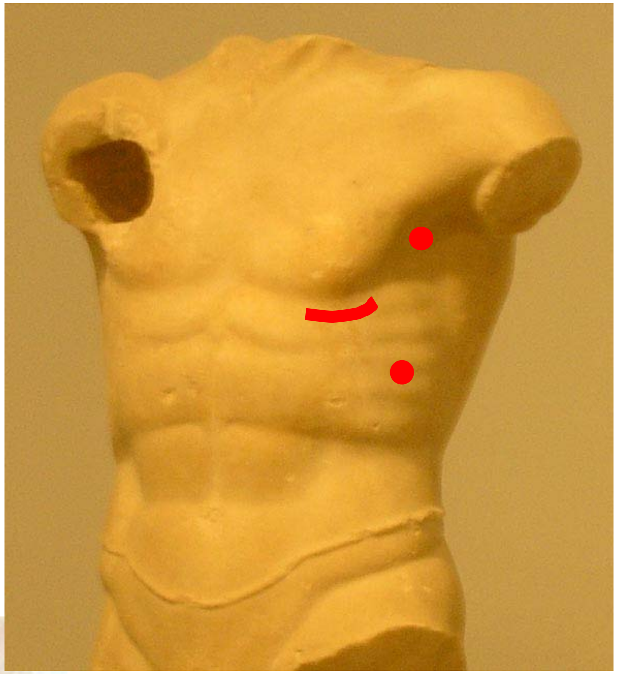
MIDCAB procedure

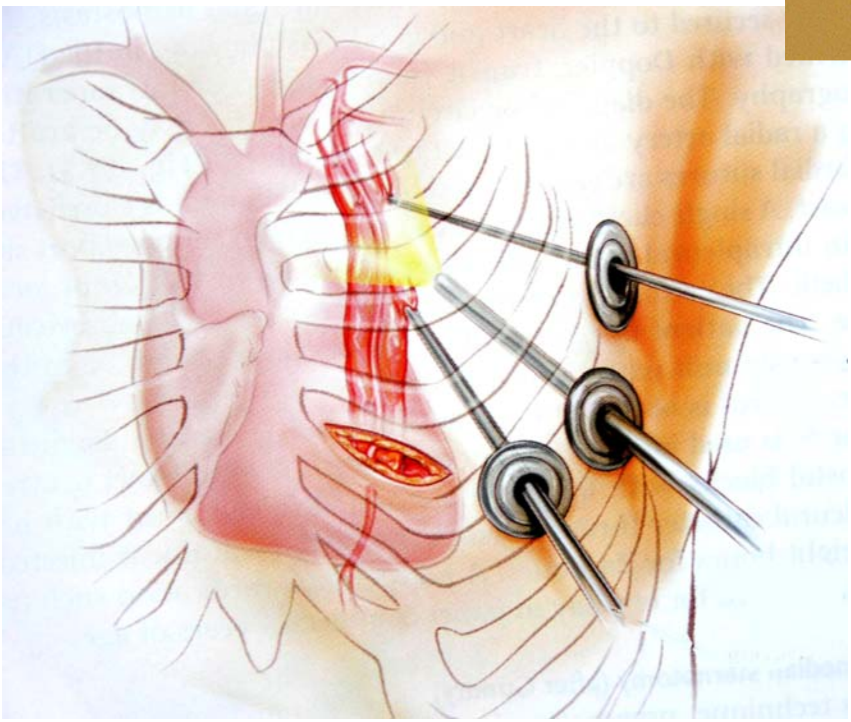


Minimally invasive surgery may be performed under direct vision


Heart area

But true minimally invasive surgery is performed by passing an endoscope and surgical instruments through tiny incisions





Limitations in MICS

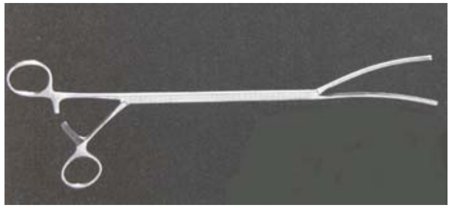
- ***Moving the surgical instruments manually during endoscopic surgery is difficult for many reasons:***
  - Bidimensional visualization
  - Using a long instrument through a tiny incision: fulcrum-effect
  - Fixed port access in the rigid intercostal space
  - Lost of force feedback due to friction
  - Limited DOF (4 + 1) versus the 20 DOF of the human hand
  - Limited ergonomy, operator fatigue & loss of concentration

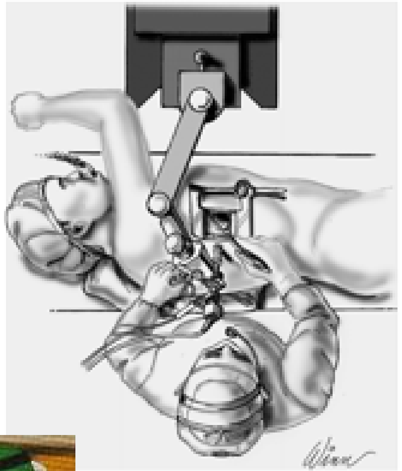
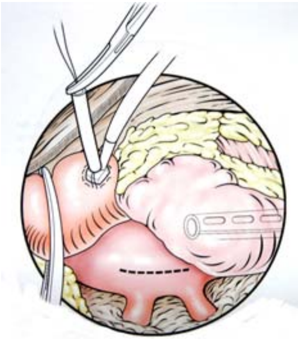
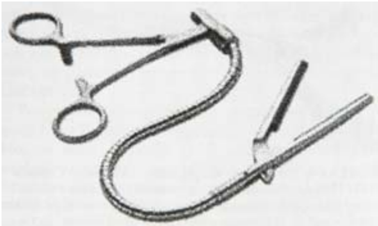
Robotics may solve these problems, at least partially

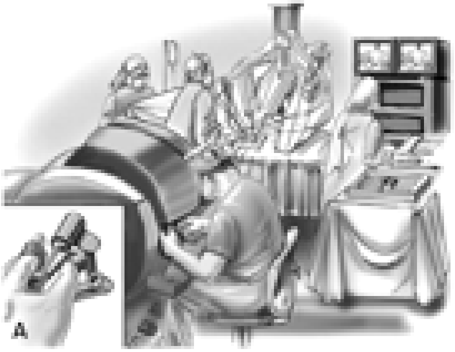
Limitations in MICS

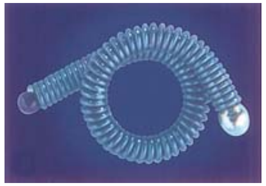
- ***Others limitations and requirements are related to the limited access or vision of the heart:***
  - Monitoring of the operation during conventional technique involves direct observation of the heart: new monitoring technique are required as **Transesophageal Echocardiography**
  - Because of the possible occurrence of a peroperative problem (cardiac arrest, massive hemorrhage), a **conversion** must available at all time
  - Operative techniques are very rigorous and surgeons must be taught through **training programs** and must perform a reasonable number of such operations

Specific tools & instruments







	Time (min)	Quality *	Difficulty **	Anastomotic patency ***
Group I Direct vision Conventional instruments	6.7 +- 0.5	2.8 +- 0.5	1.0 +- 0.0	1.0 +- 0.0
Group II Endoscopic vision Endoscopic instruments	22.4 +- 3.0	1.8 +- 1.0	4.0 +- 0.0	1.5 +- 0.8
Group III Direct vision Endoscopic instruments	21.1 +- 2.1	1.0 +- 0.0	4.0 +- 0.0	1.5 +- 0.55
Group IV Endoscopic vision Conventional instruments	10.5 +- 1.6	2.5 +- 0.55	1.0 +- 0.0	1.0 +- 0.0
Group V Telemanipulation robotic technology	8.87 +- 1.44	2.0 +- 0.0	1.3 +- 0.5	1.0 +- 0.0

** Surgeon's satisfaction with quality of anastomosis at completion : good = 3, fair = 2, poor = 1*

*** Degree of difficulty of anastomosis: easy = 1, somewhat easy = 2, somewhat difficult = 3, difficult = 4*

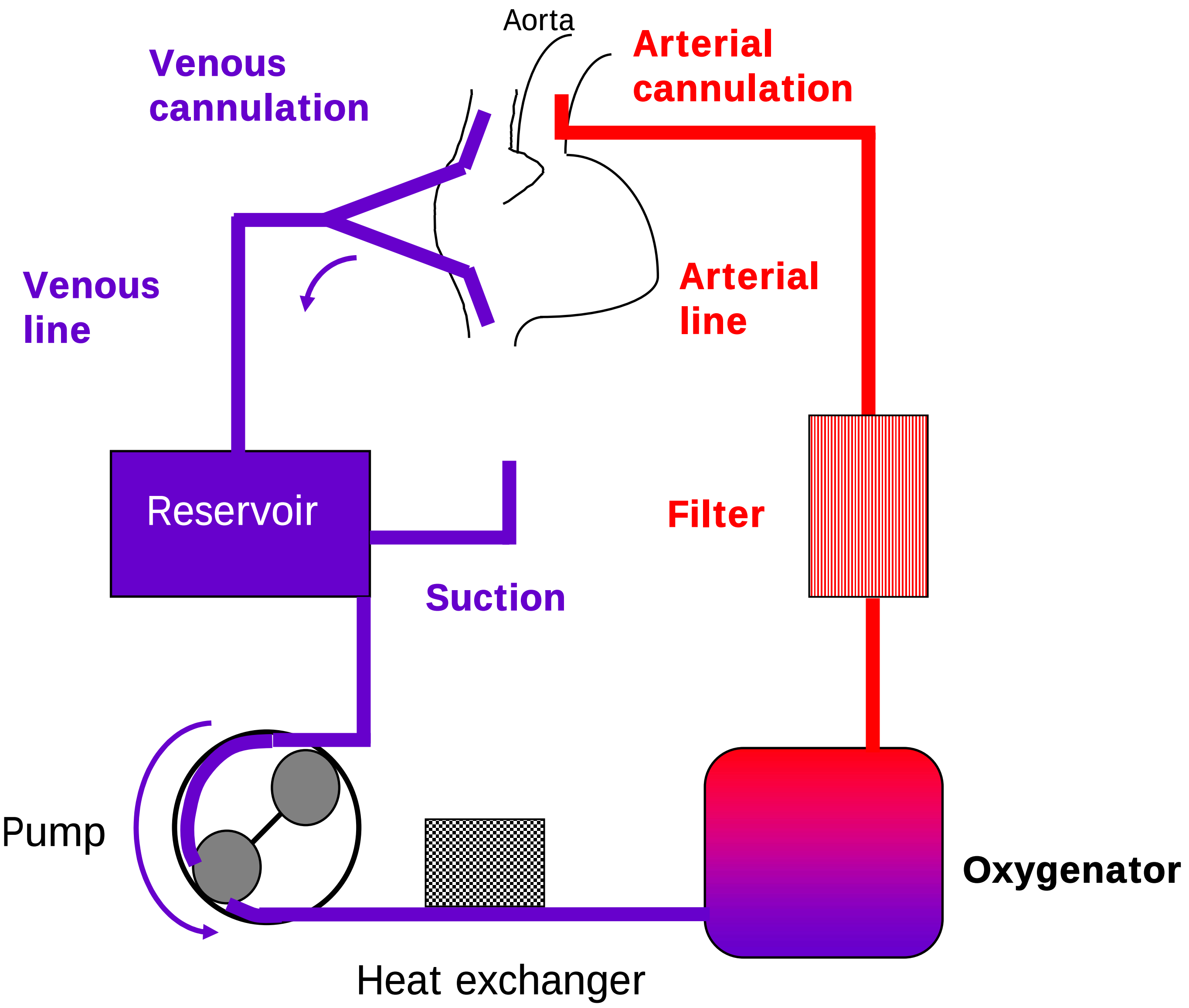
**** Patency of anastomosis : 100 % = 1, 50 % = 2, < 50 % = 3*

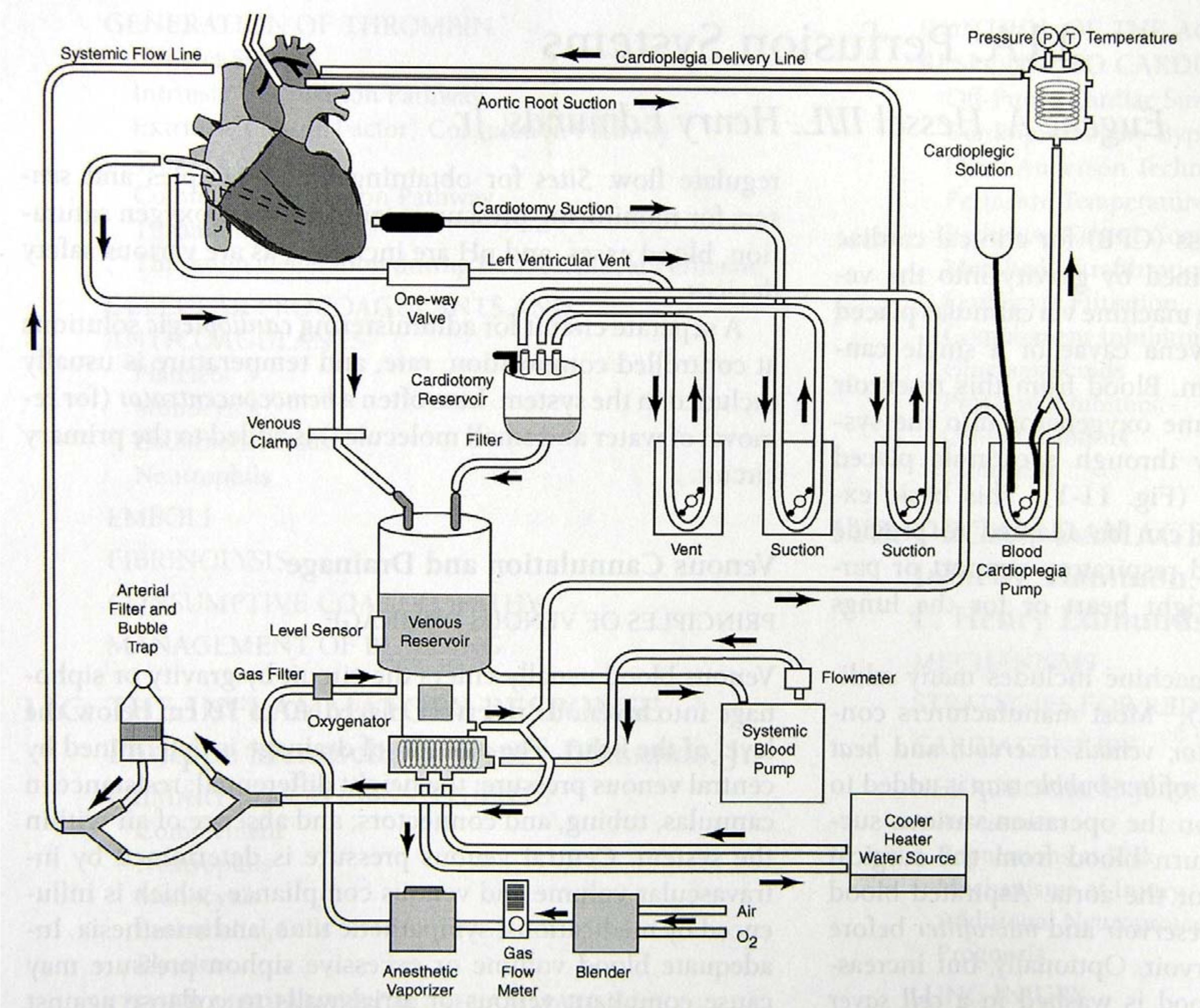
From: Shennib H *et al.* Robotic computer-assisted telemanipulation enhances coronary artery bypass, J Thorac Cardiovasc Surg 1999 Feb;117(2):310-3

Heart-lung machine

The extracorporeal circulation (ECC)

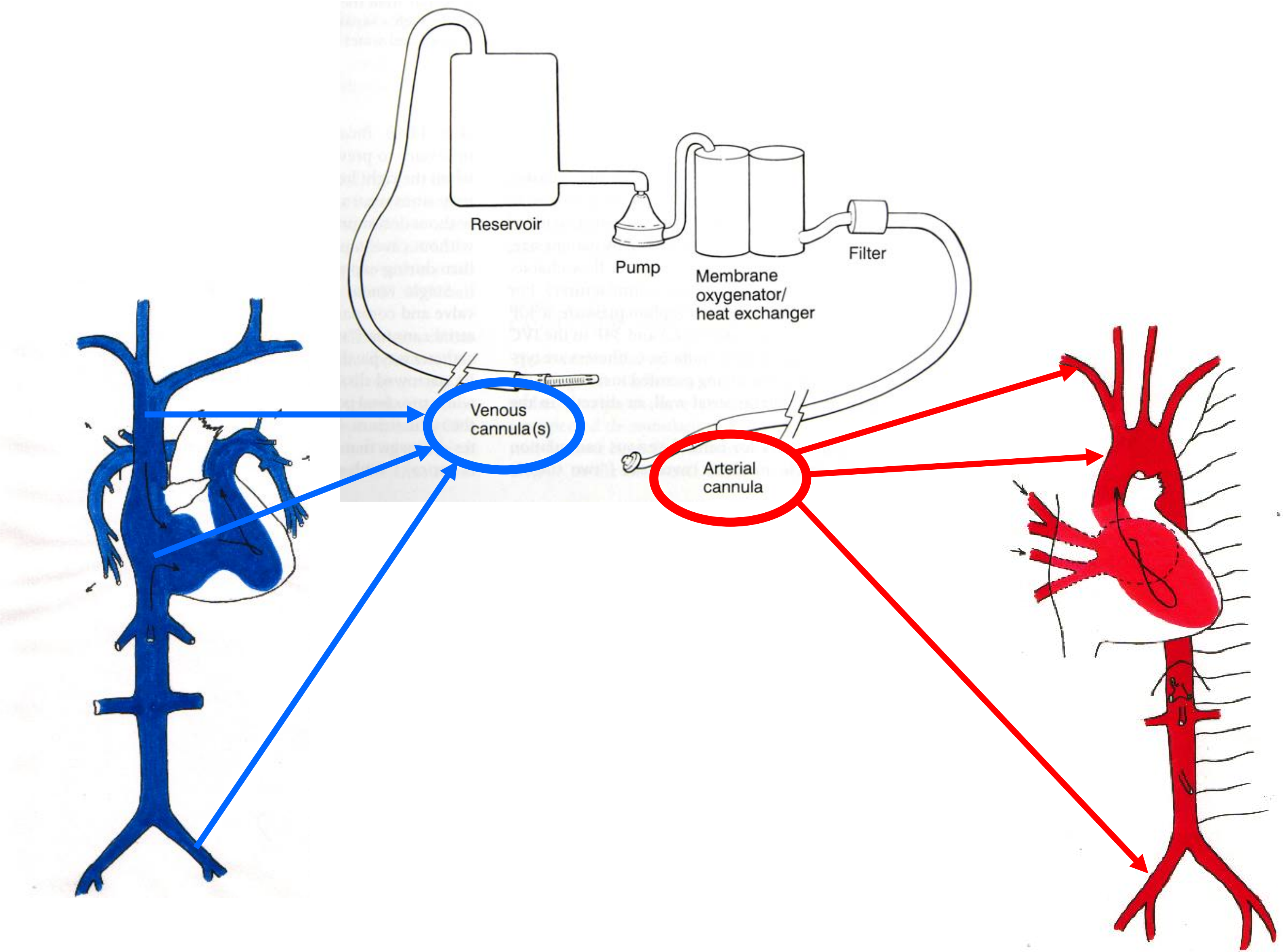
The extracorporeal circulation

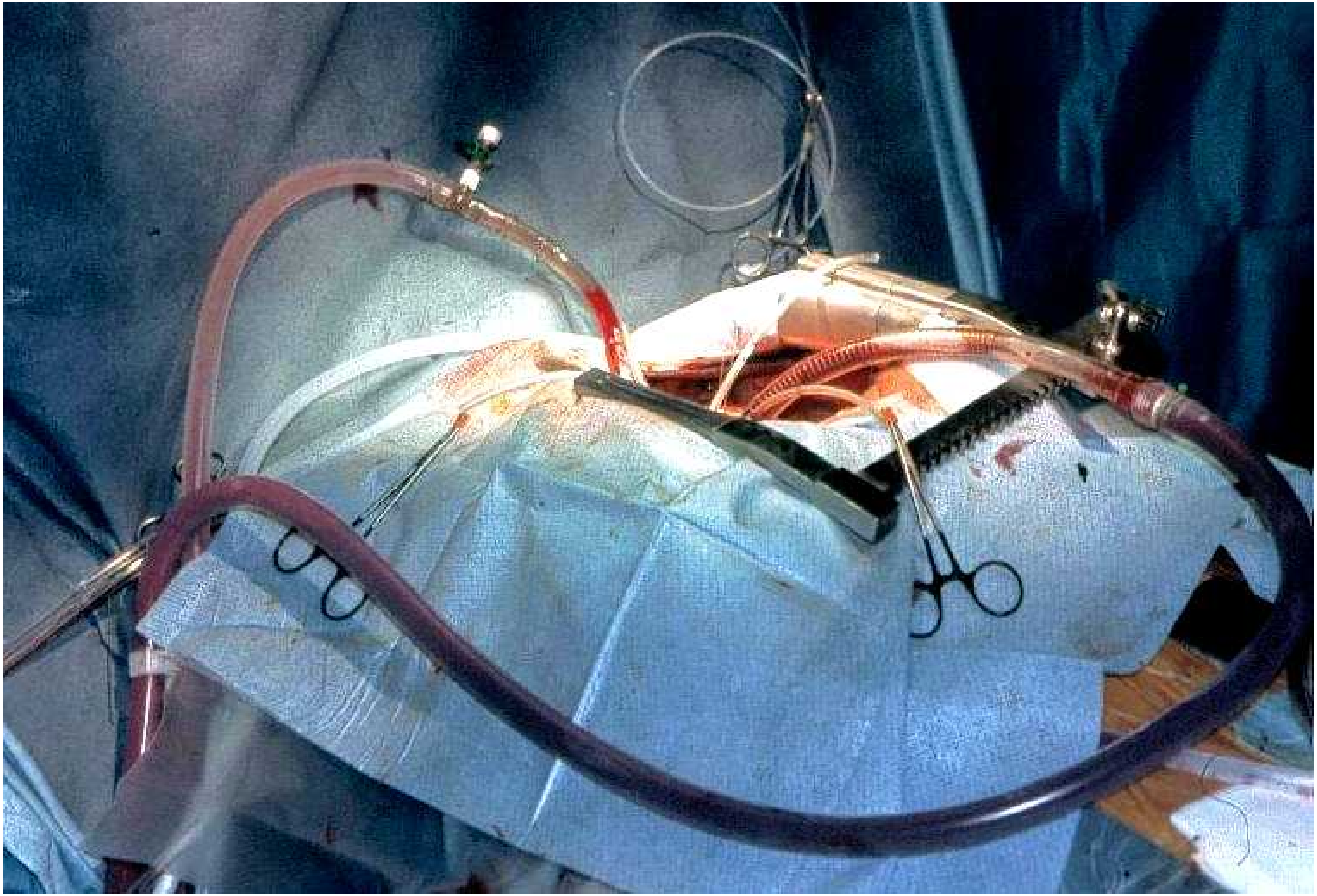


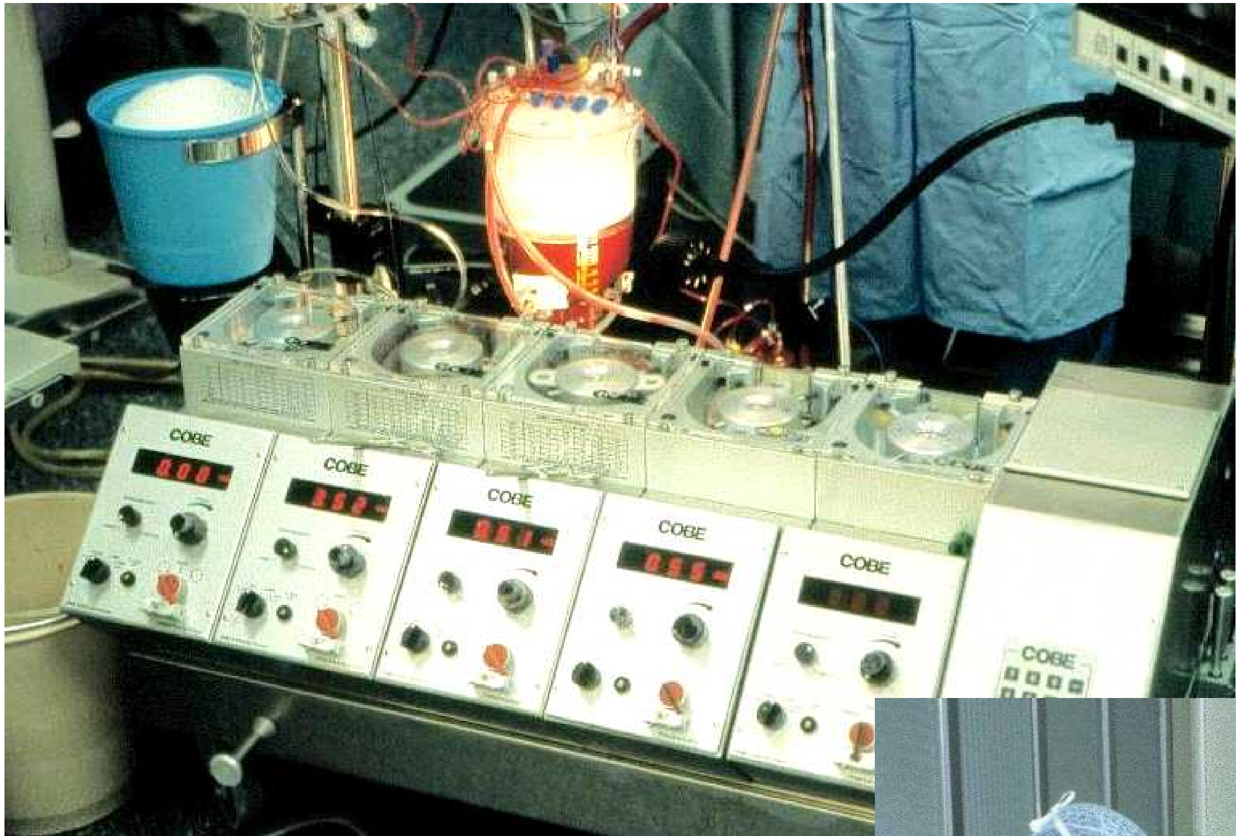


From: Hessel EA II, Edmunds LH Jr, Extracorporeal Circulation: Perfusion Systems,
In: Cohn LH, Edmunds LH Jr, eds, Cardiac Surgery in the Adult, New York: McGraw-Hill, 2003:317338,

Adapted From: Hessel EA II, Edmunds LH Jr, Extracorporeal Circulation: Perfusion Systems, In: Cohn LH, Edmunds LH Jr, eds, Cardiac Surgery in the Adult, New York: McGraw-Hill, 2003:317338,



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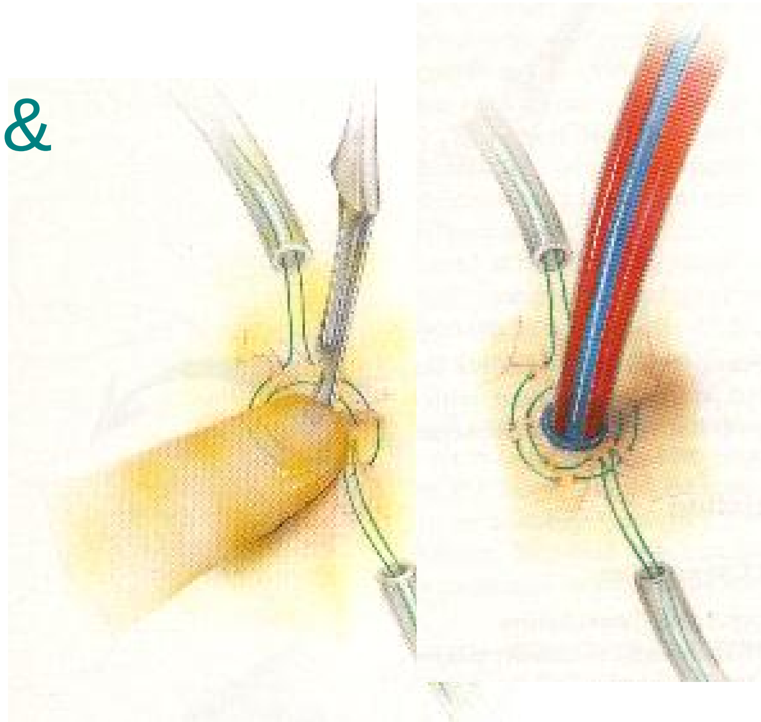
Operation under ECC (1)

- **Sternotomy**
- Opening of the pericardium & exposure of the heart
- Confection of **pursestring**

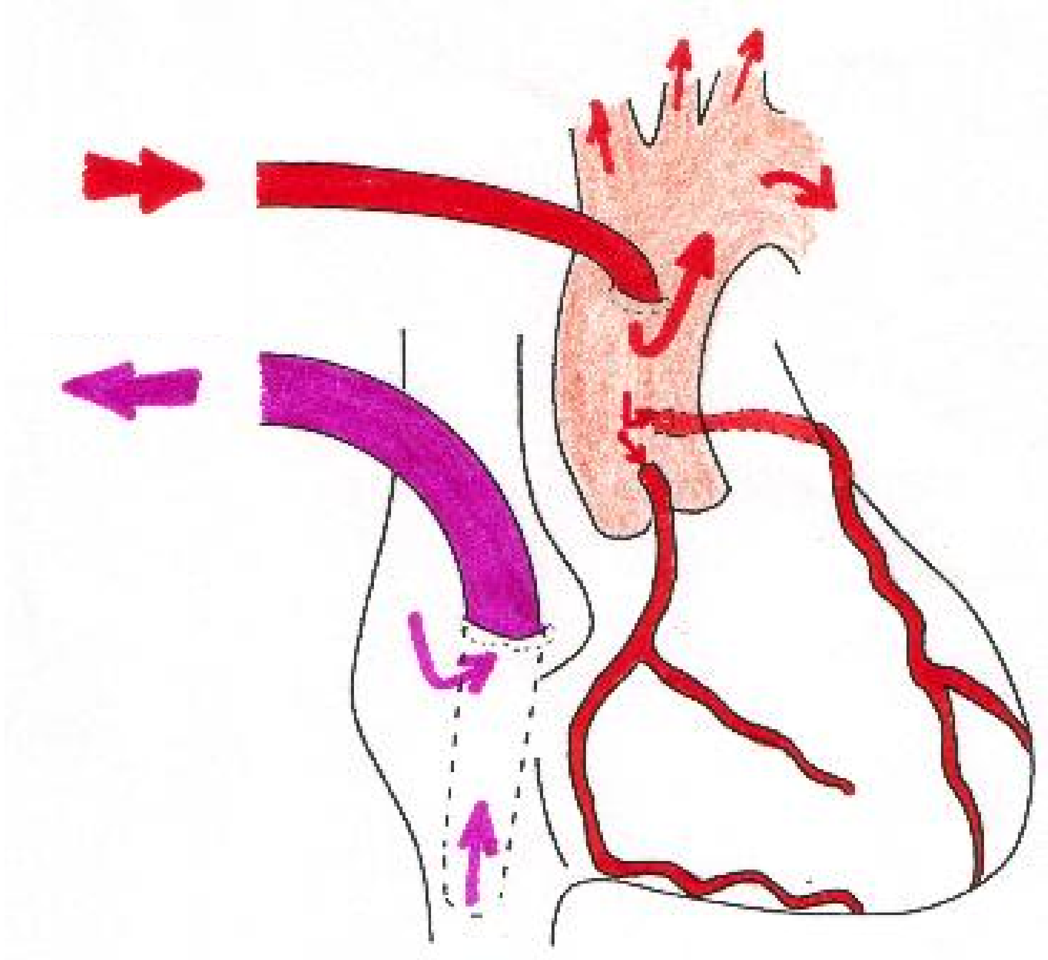


From : Manual of Cardiac Surgery, Harlan & Starr, Springer-Verlag, New York , 1995

- **Heparin:** high dose
- **Cannulation, connections to tubing**

Operation under ECC (2)

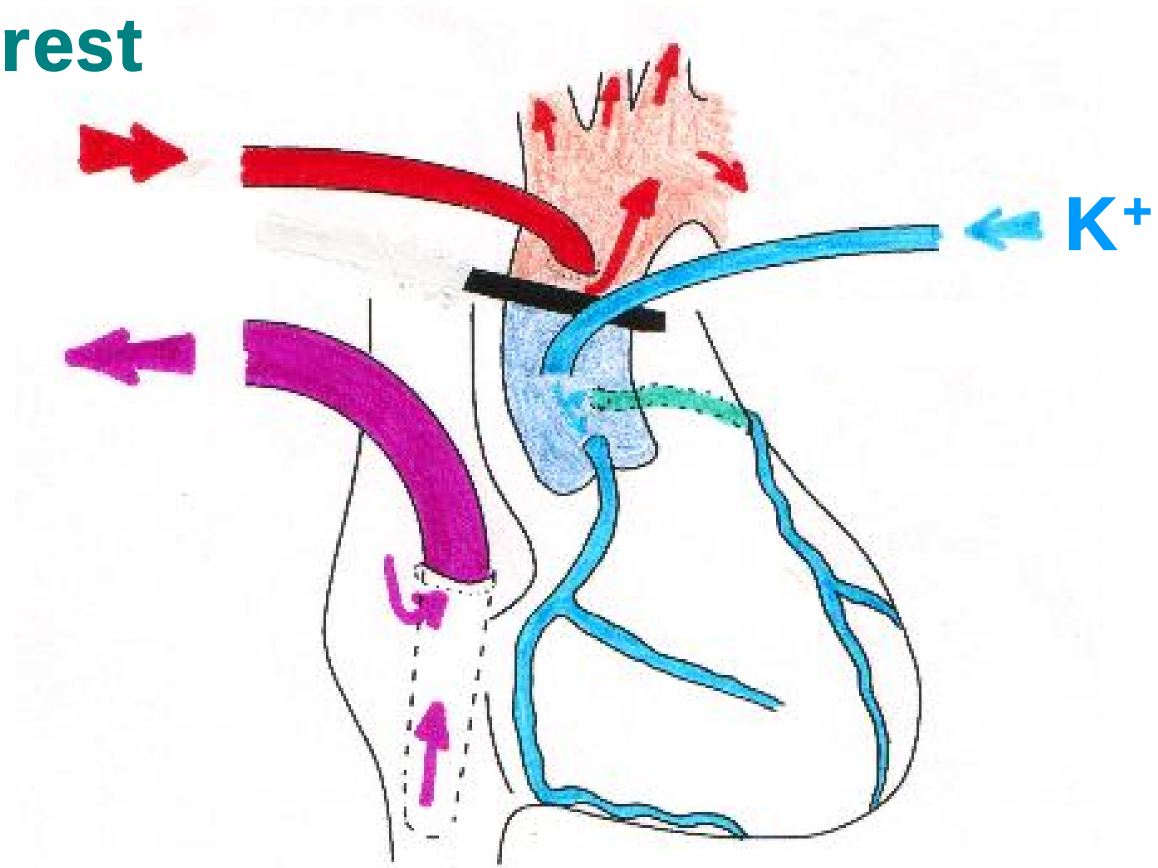
- **Initiation of ECC**



- **Cooling**

Operation under ECC (3)

- **Cardioplegic arrest**



  – Clamping of the aorta
  – K^+ injection into the coronary system:
  « chemical arrest » of the heart » , flaccid heart

Procedure

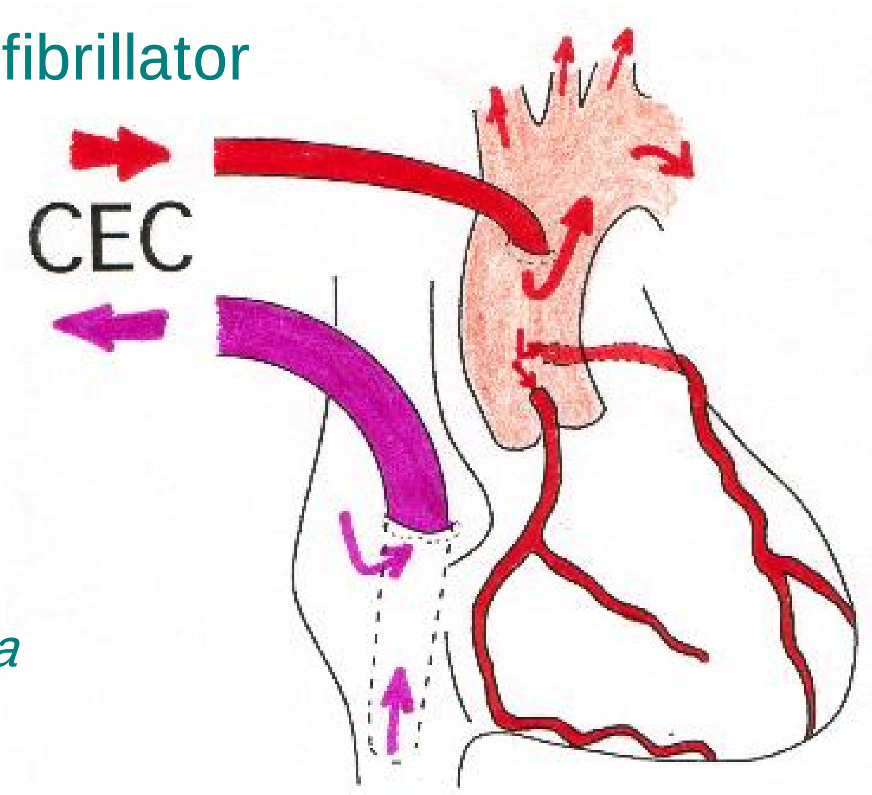
Heart arrested (ECG : no activity)

Lungs deflated

Operation under ECC (4)

- **Release of the aortic clamp**
  - Sinusal rhythm
  - Ventricular fibrillation: defibrillator
  - Block: pace-maker

Sinusal rythm

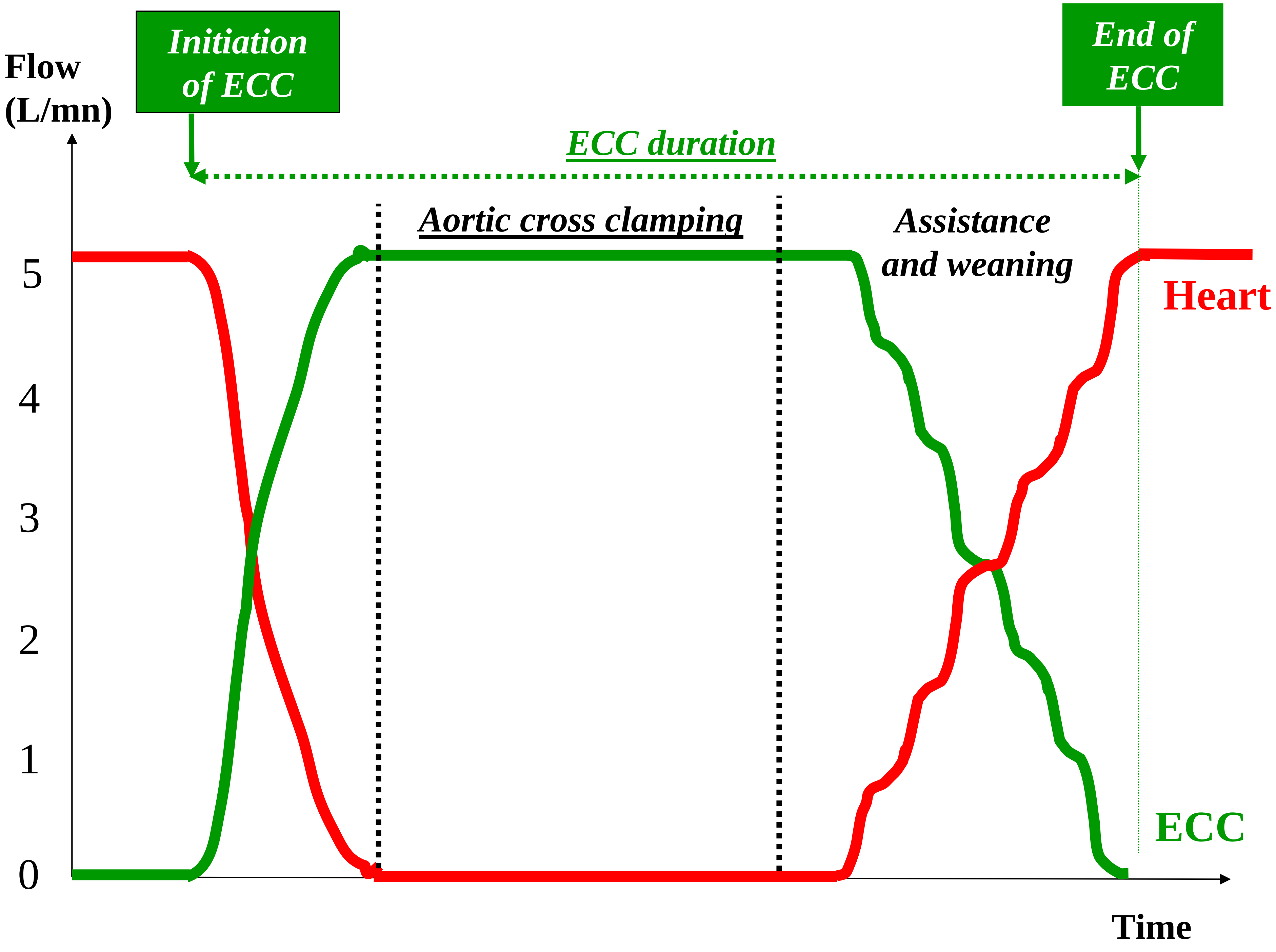


If open-heart surgery
deairing before unclamping the aorta
(air embolization)

Operation under ECC (5)

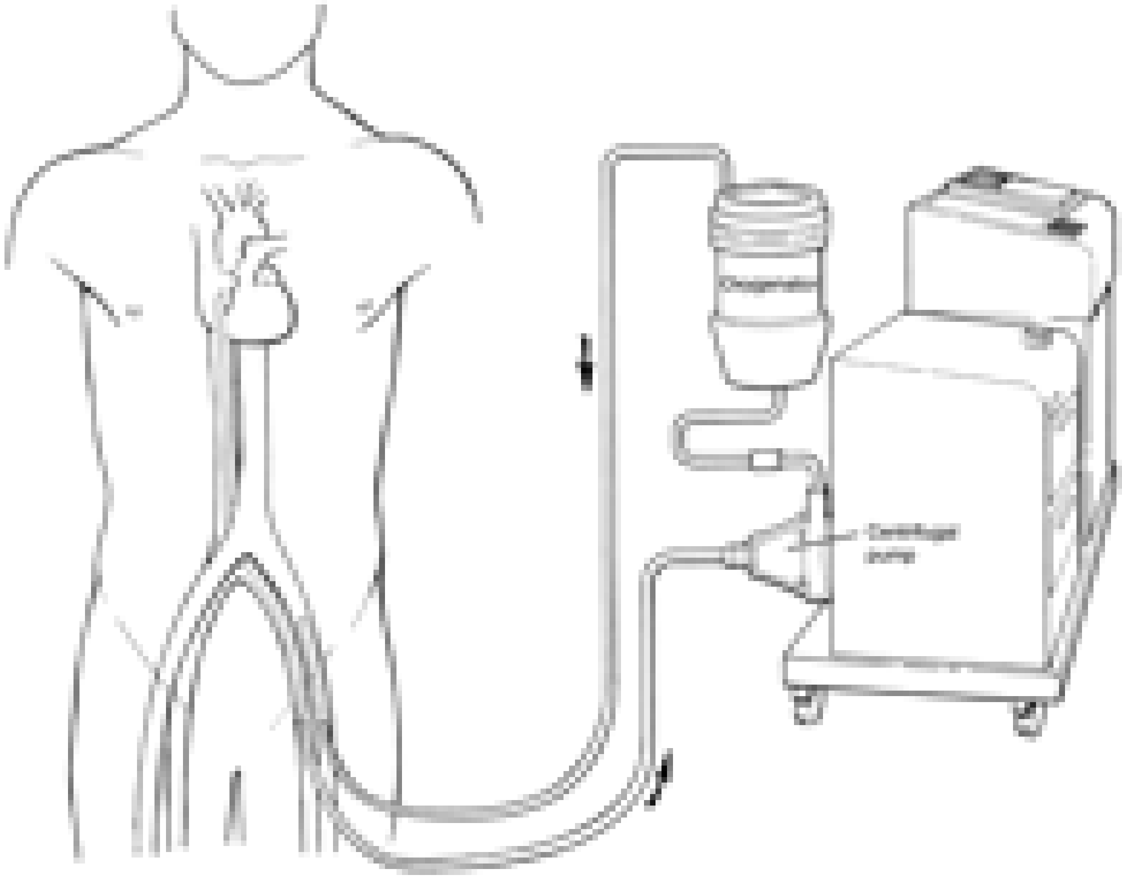
- **Assistance**
  - Recovery of the heart
  - Rewarming
- **ECC discontinuation**

  progressive weaning: transition between ECC and native circulation
- **Once hemodynamic stability is acquired**
  - Remove of cannula
  - Administration of protamine (restoration of coagulation)
- **Drainage**
- **Closure**



Flow (L/mn)
Initiation of ECC
End of ECC
ECC duration
Aortic cross clamping
Assistance and weaning
5
4
3
2
1
0
Heart
ECC
Time

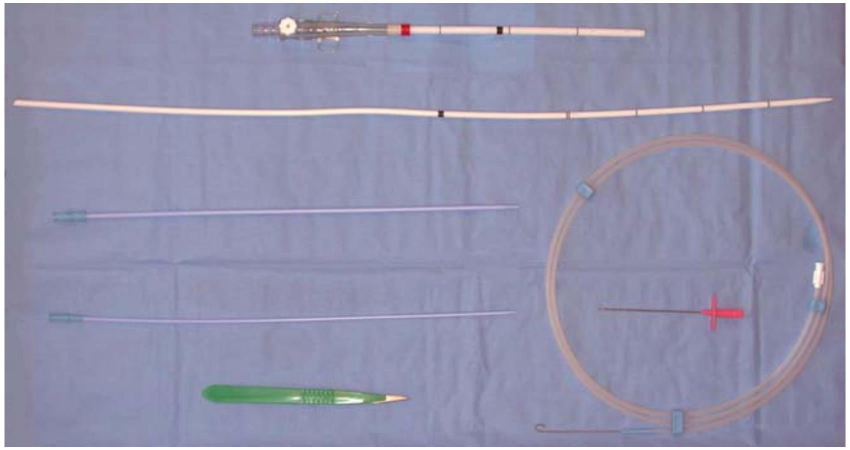
Femoro-femoral ECC

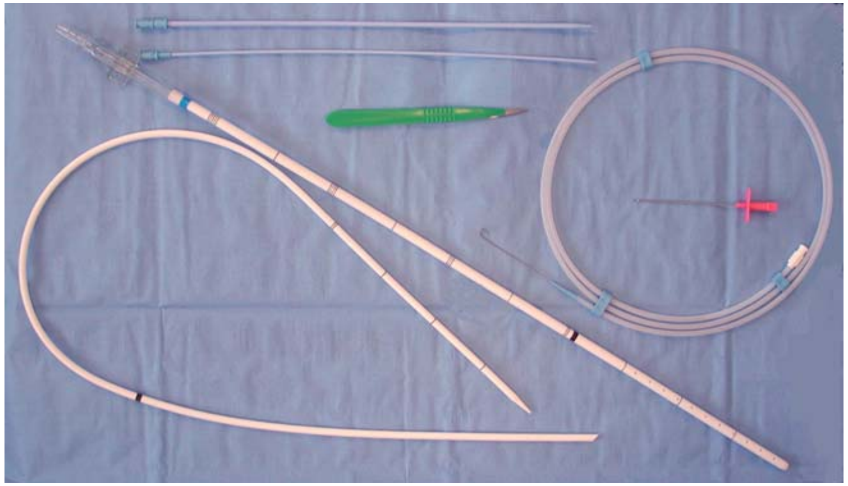


From: Moazami N, McCarthy PM. Temporary Circulatory Support.
In: Cohn LH, Edmunds LH Jr, eds. Cardiac Surgery in the Adult. New York: McGraw-Hill, 2003:495520.

- Open or percutaneous technique

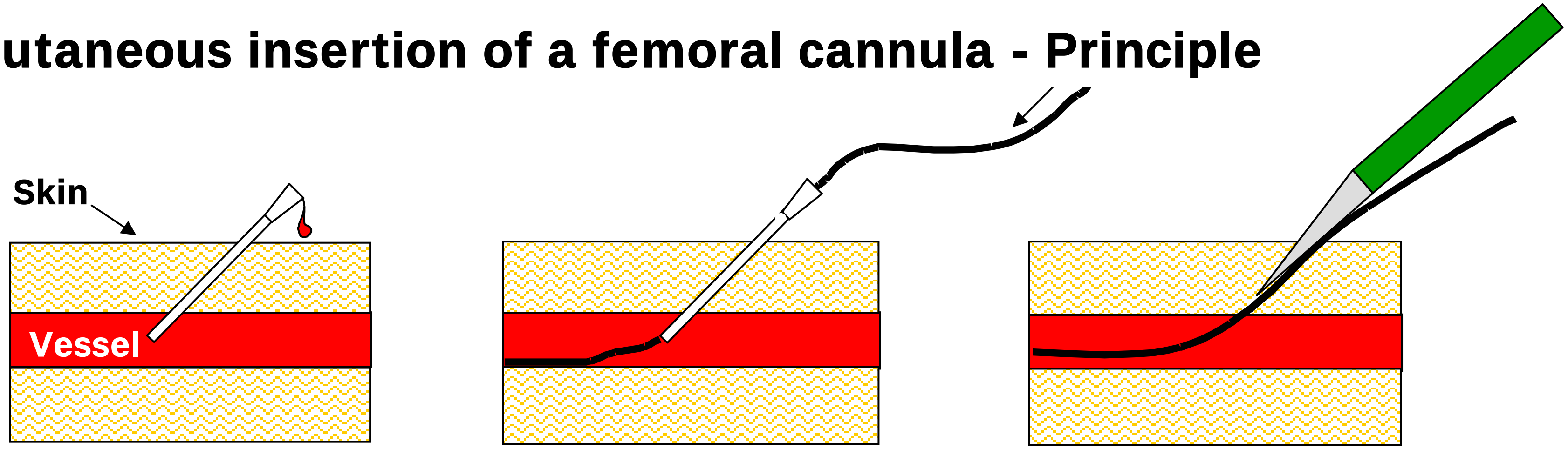
Femoro-femoral ECC





- percutaneous technique

Percutaneous insertion of a femoral cannula - Principle



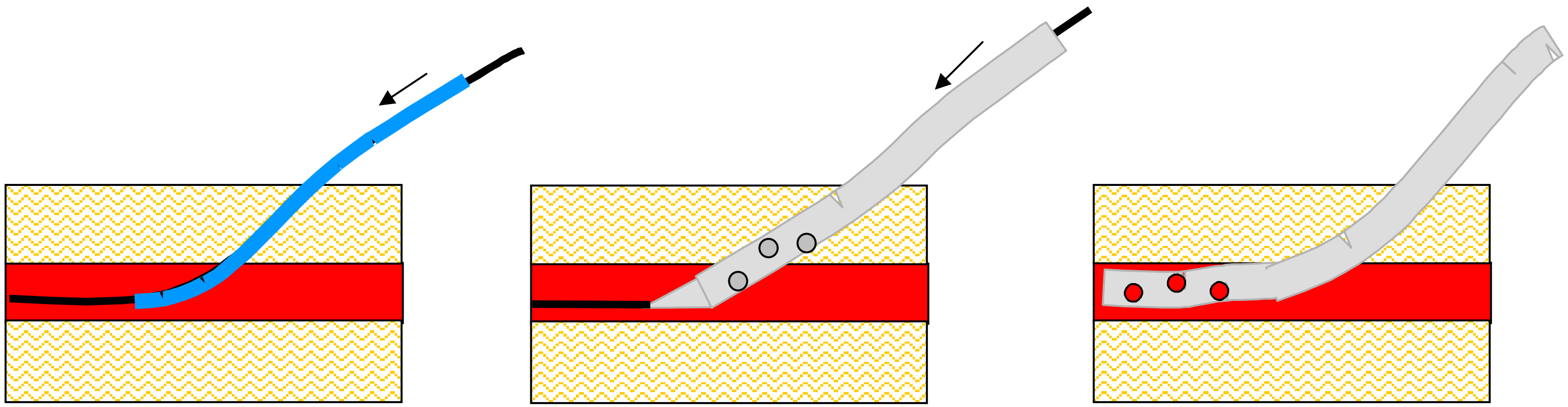
Puncture of the vessel

Guide wire insertion into the vessel

Incision of the skin

Once the guide wire is in the vessel, the cannula can be inserted
Relatively safely

The technique is the same for arterial or venous cannula

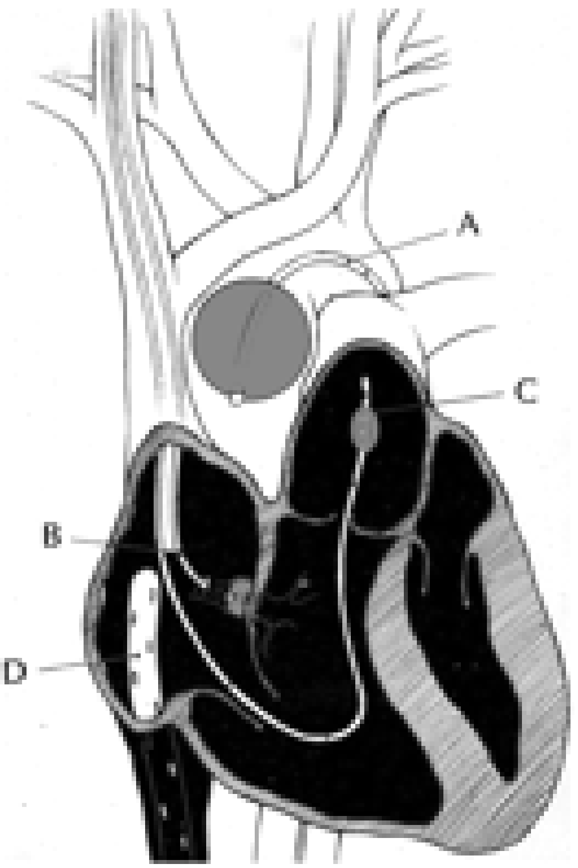


Dilators are inserted into the vessel

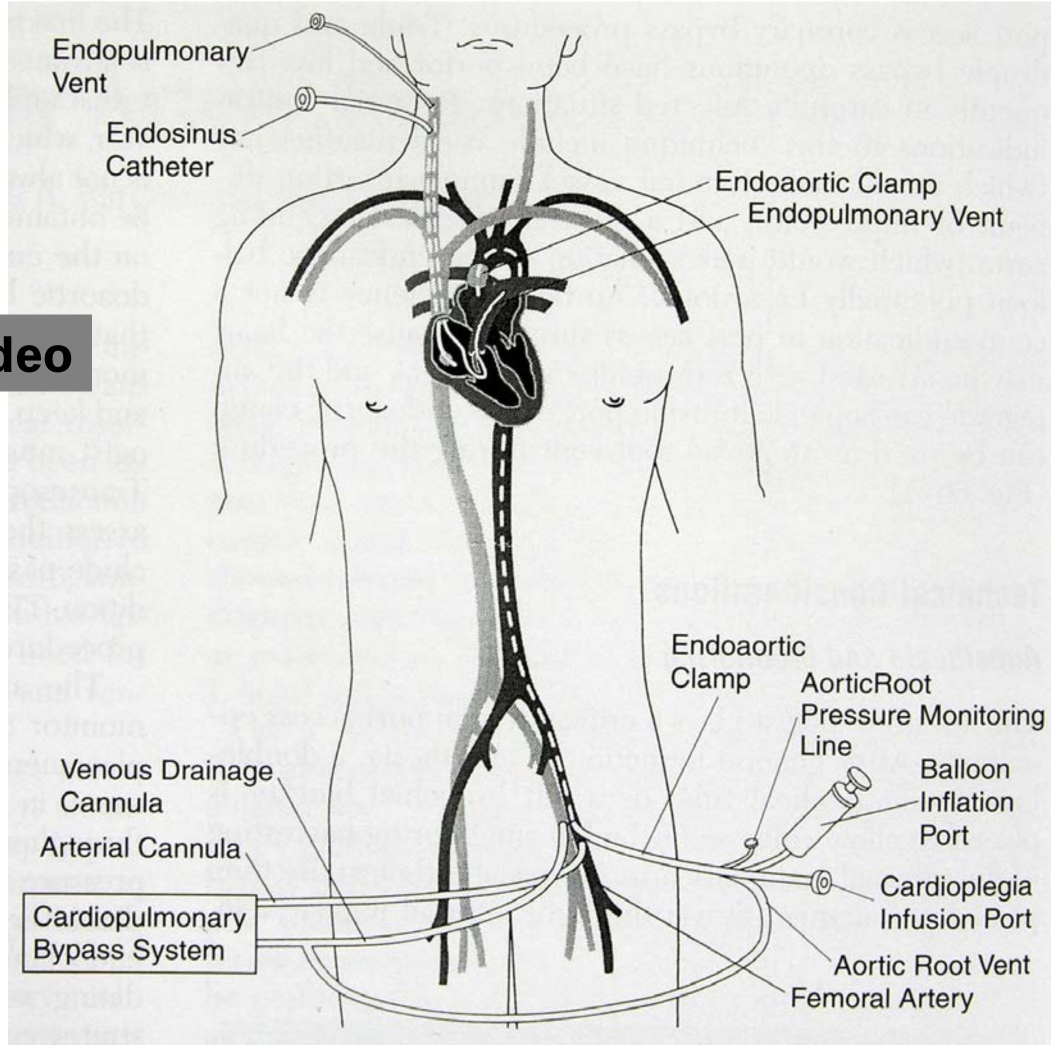
The cannula is inserted into the vessel

cannula in place

Port-Access system

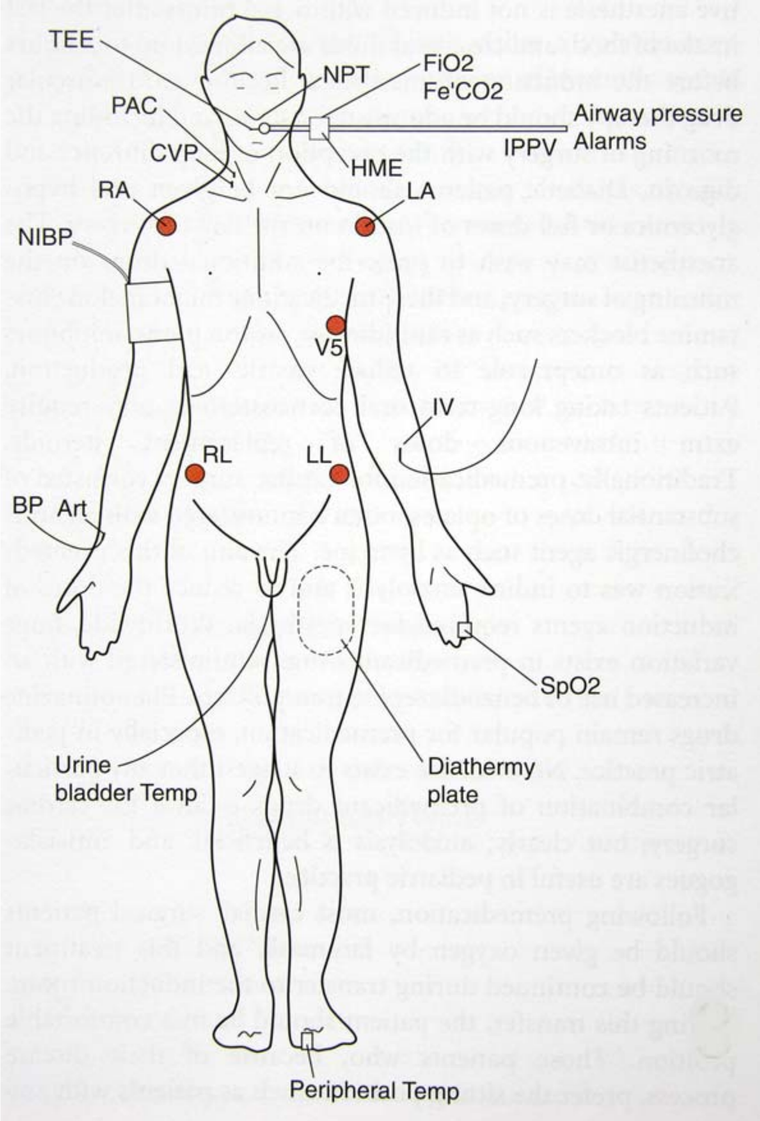


Video

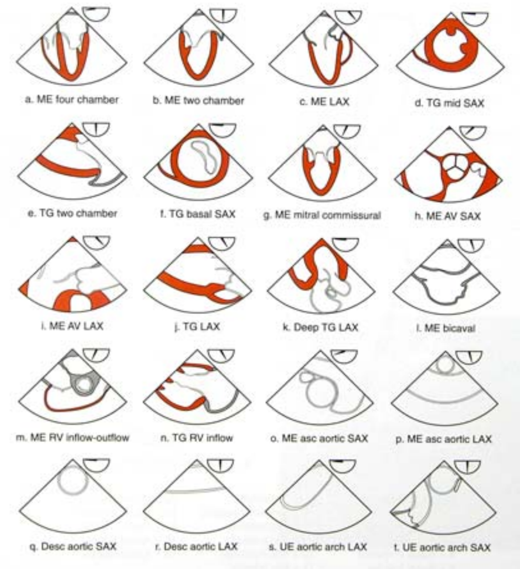


Chitwood WR Jr, Nifong LW. Minimally Invasive and Robotic Valve Surgery. In: Cohn LH, Edmunds LH Jr, eds. Cardiac Surgery in the Adult. New York: McGraw-Hill, 2003:10751092.

Equipment - Monitoring



ECG and hemodynamic monitoring



Transesophageal echocardiography monitoring

Preoperative imaging

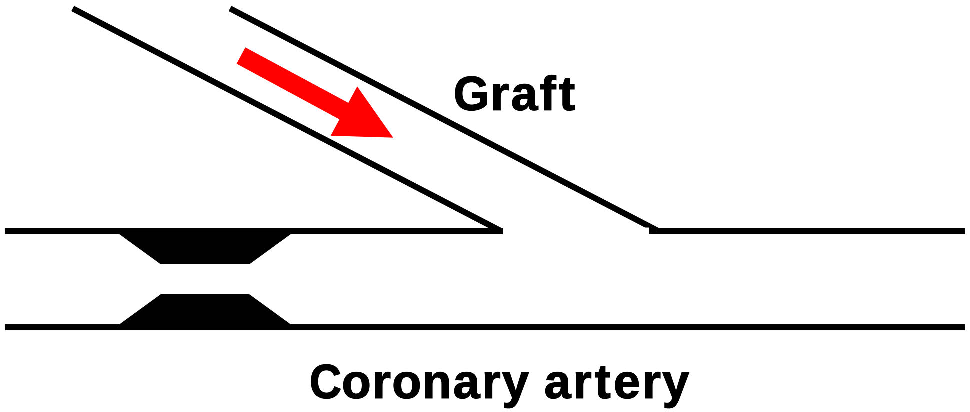
- Coronarography Video
- Echocardiography Video
- CT-scan
- MRI

Coronary surgery

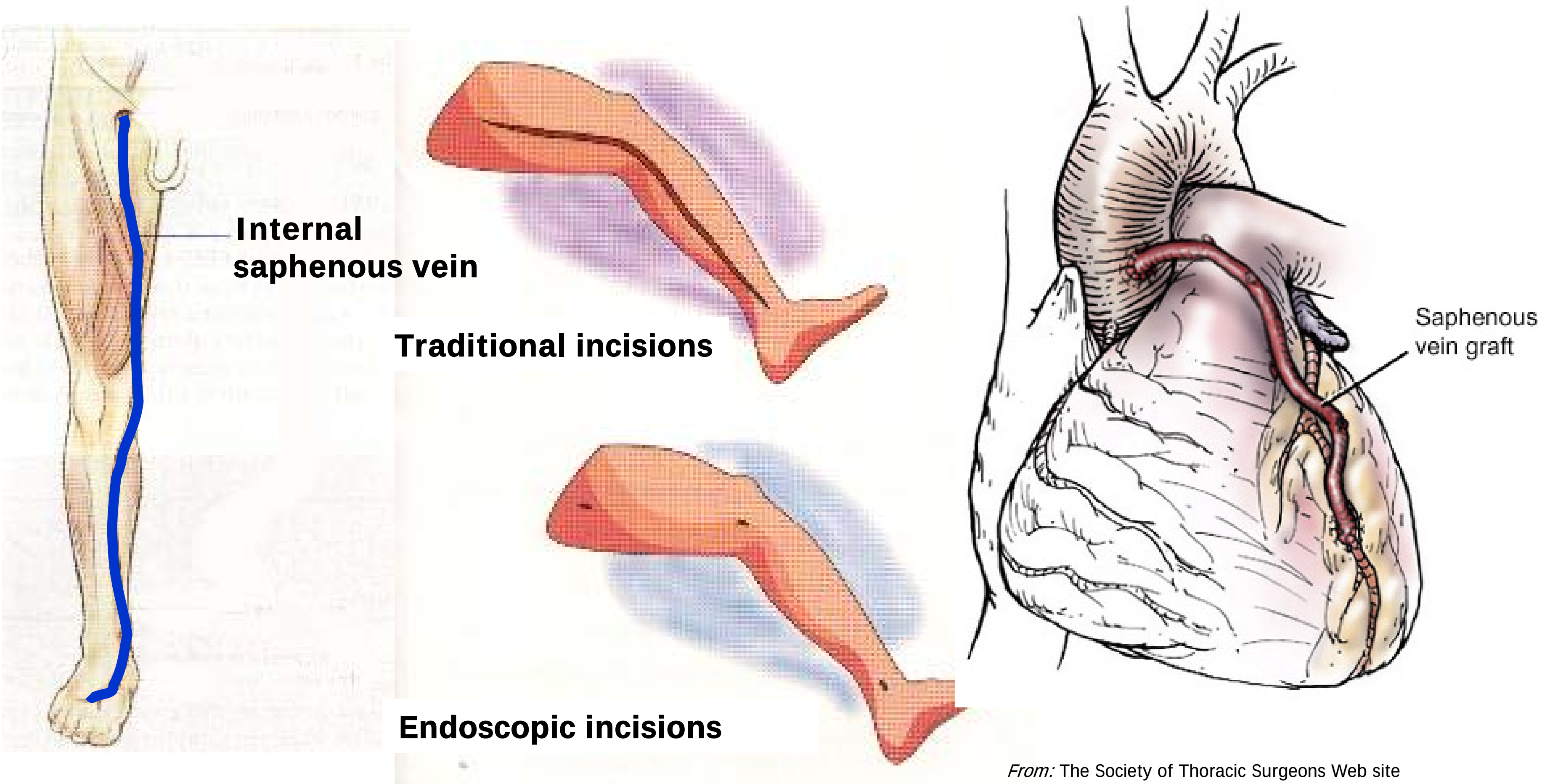
Coronary Artery Bypass Grafting (CABG)

What is a CABG ?

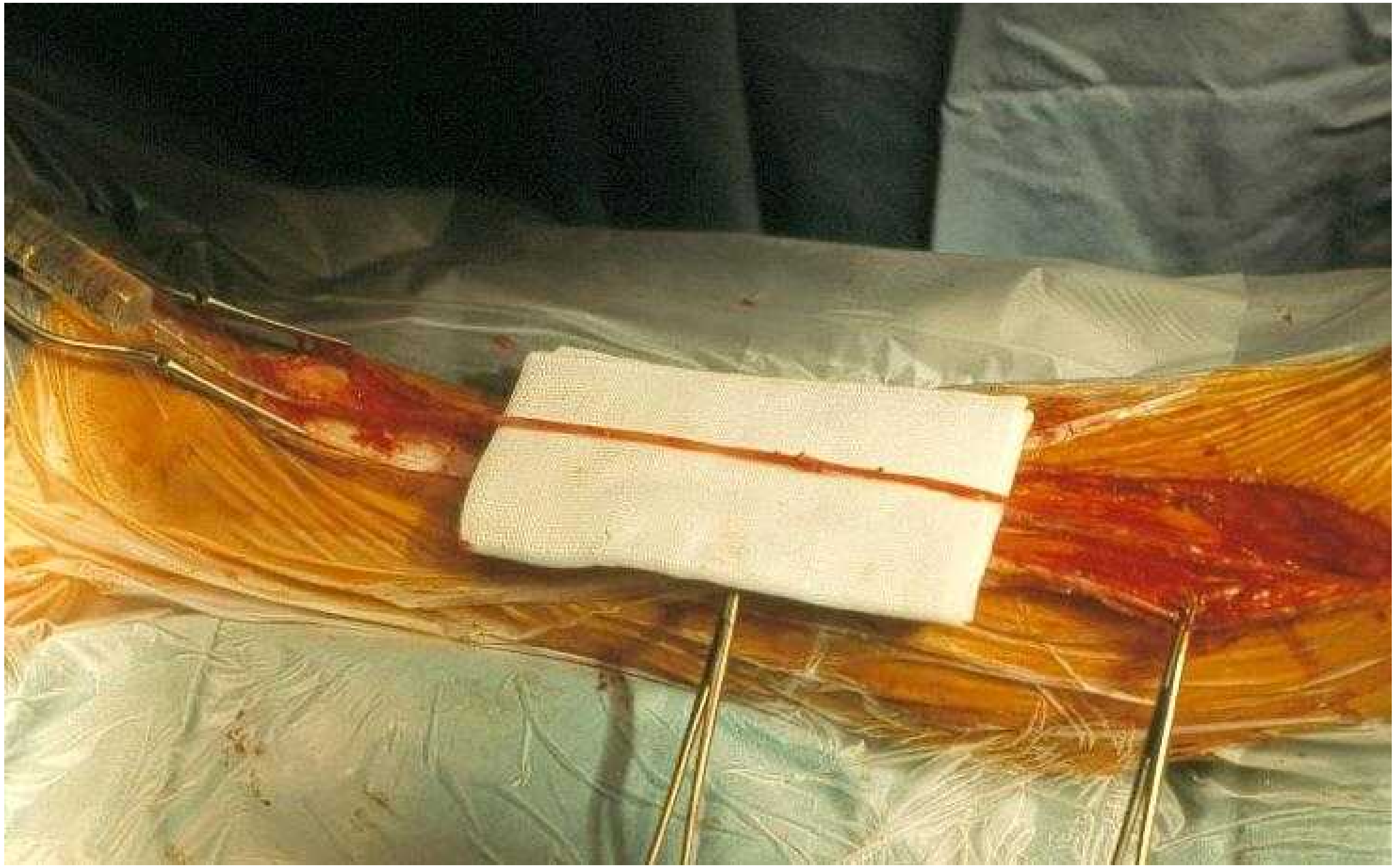
- A vascular graft is sutured to the coronary artery beyond the stenosis



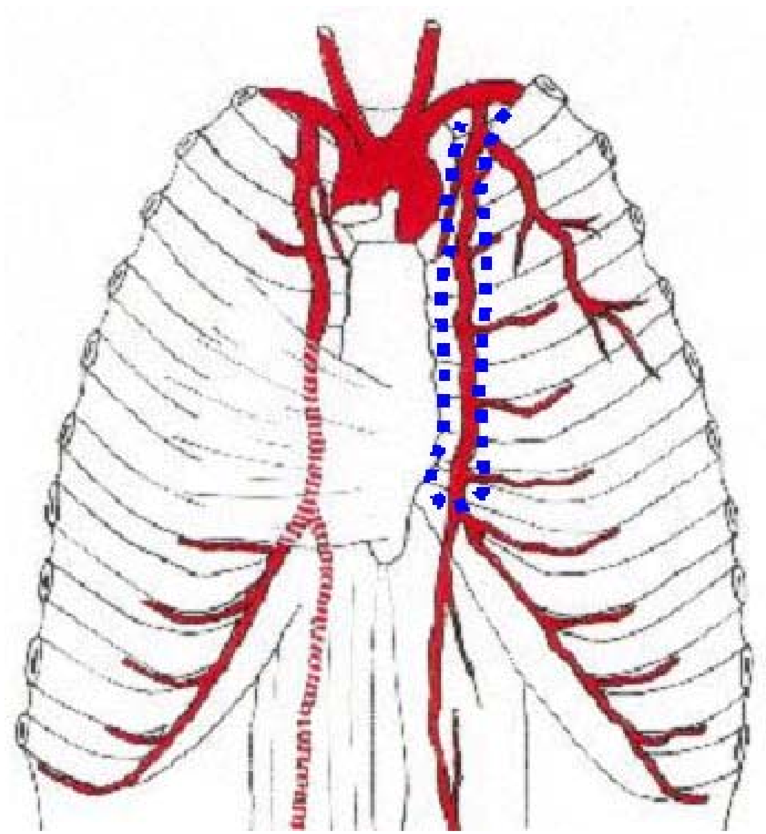
Saphenous vein graft

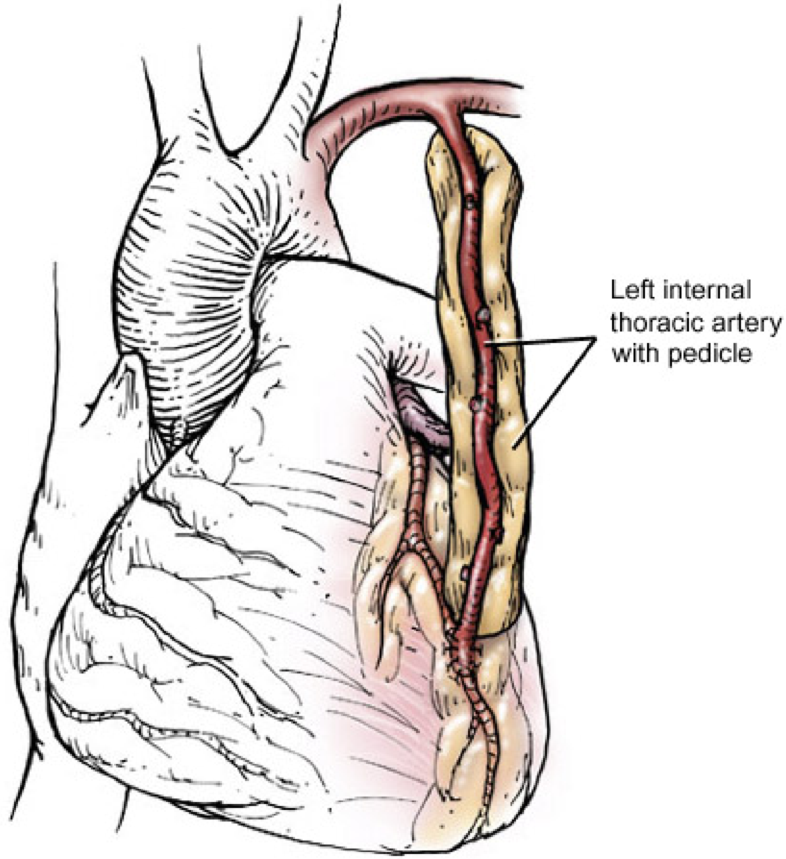


From: The Society of Thoracic Surgeons Web site
http://www.sts.org

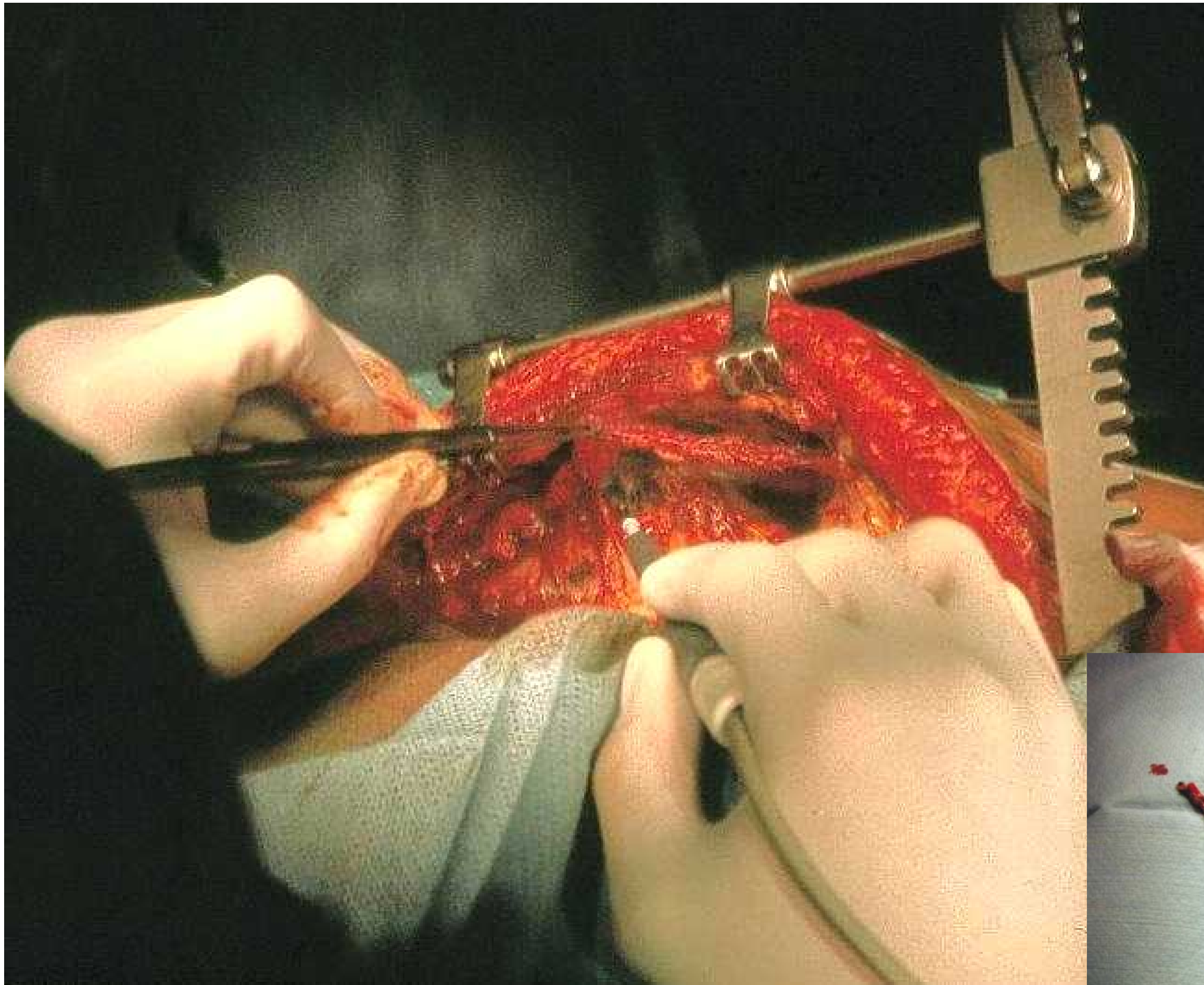
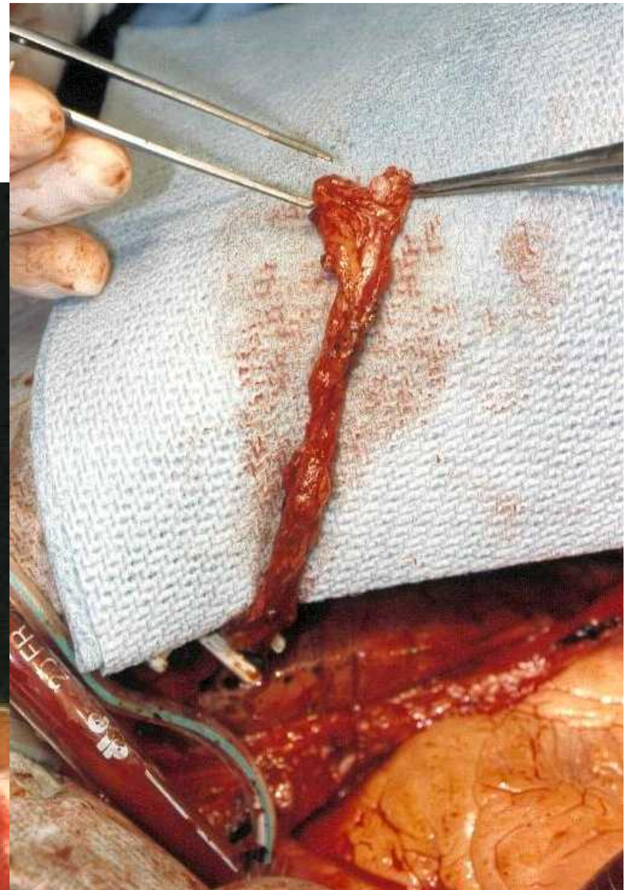
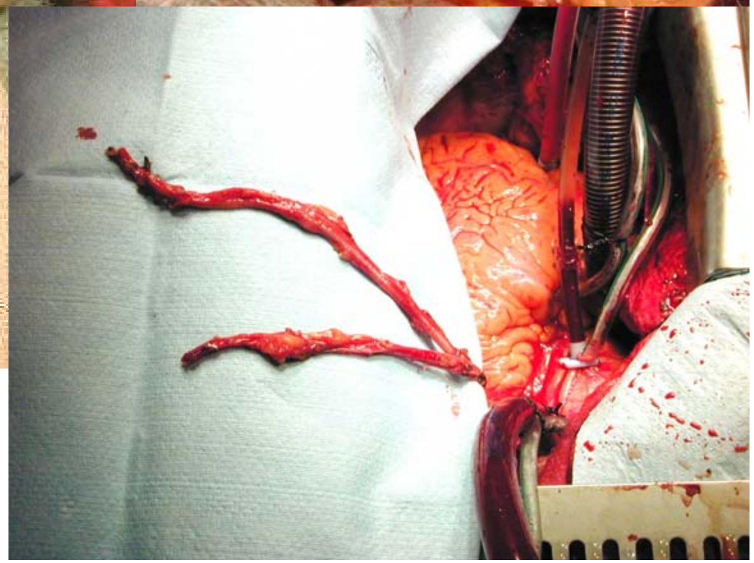


Internal thoracic artery graft

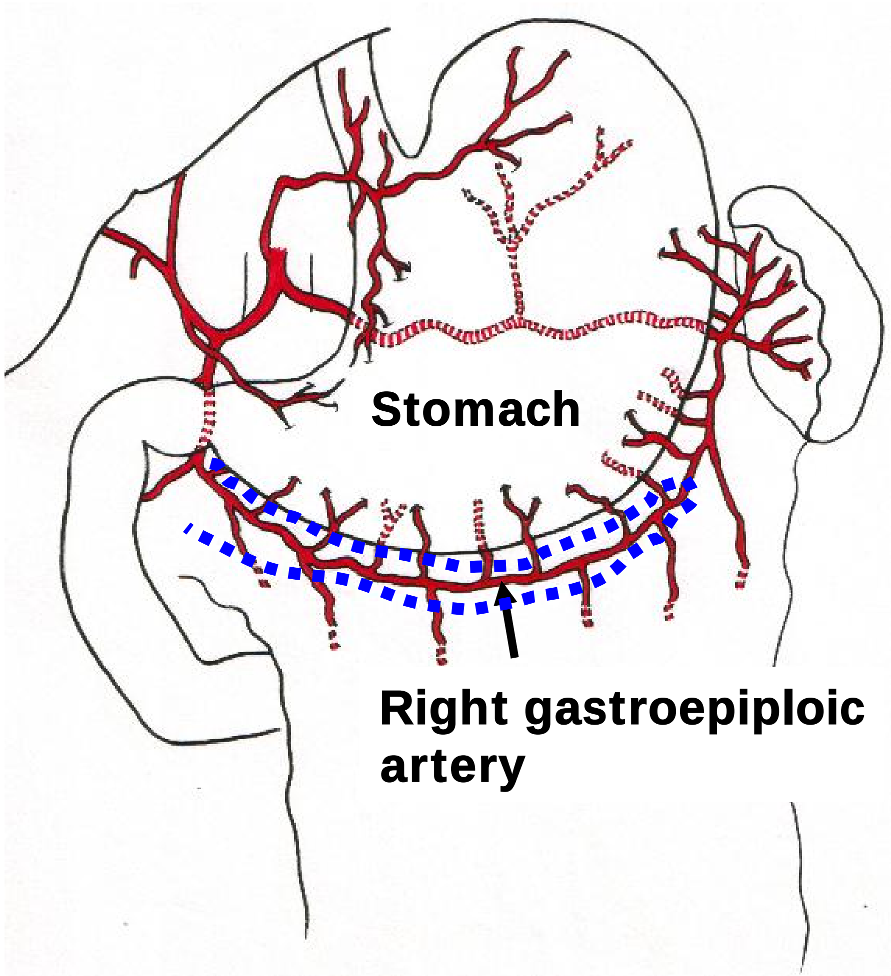




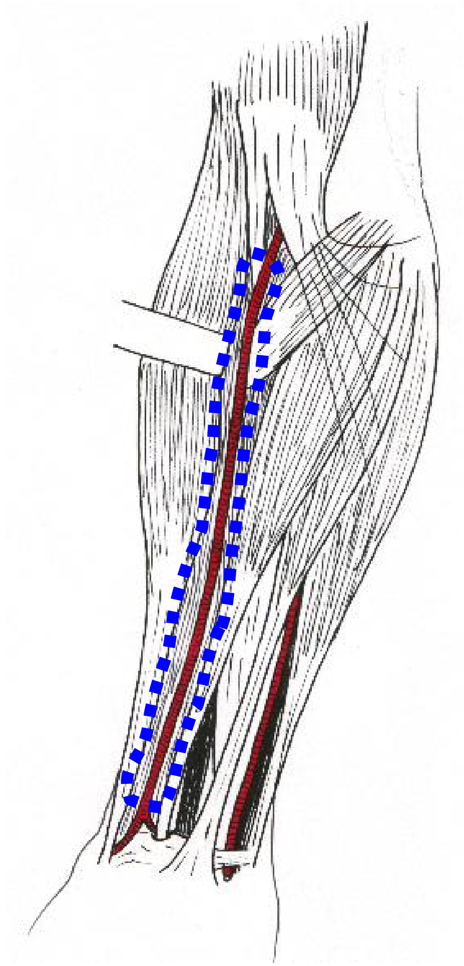
From: The Society of Thoracic Surgeons Web site
http://www.sts.org

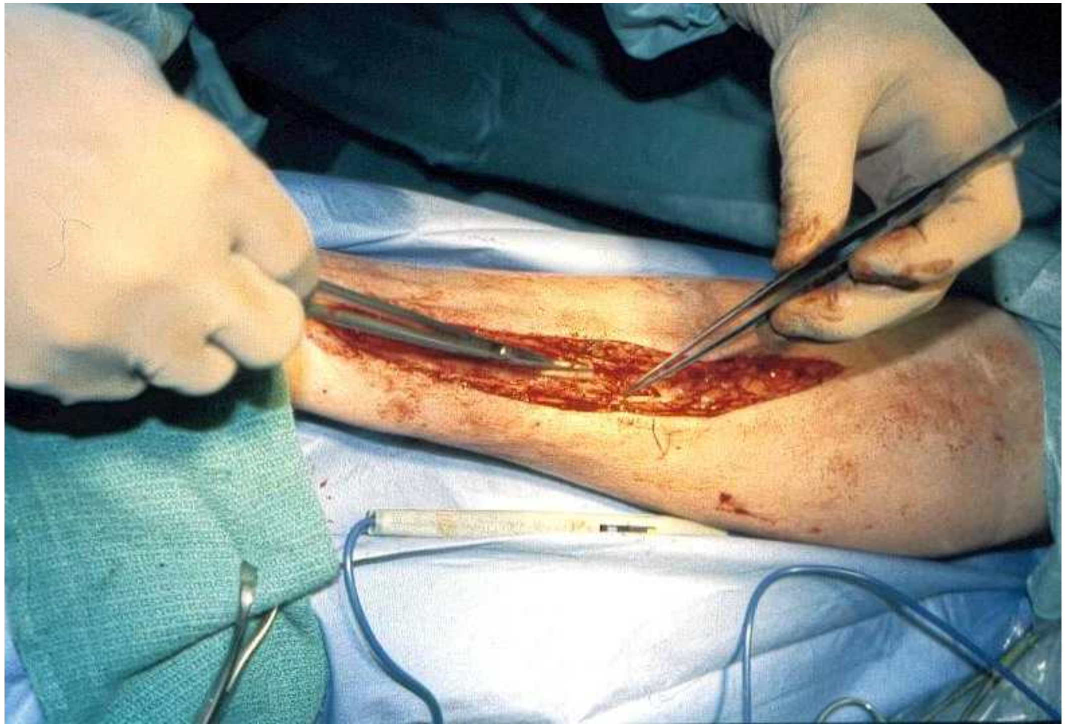
Other arterial grafts



Other arterial grafts

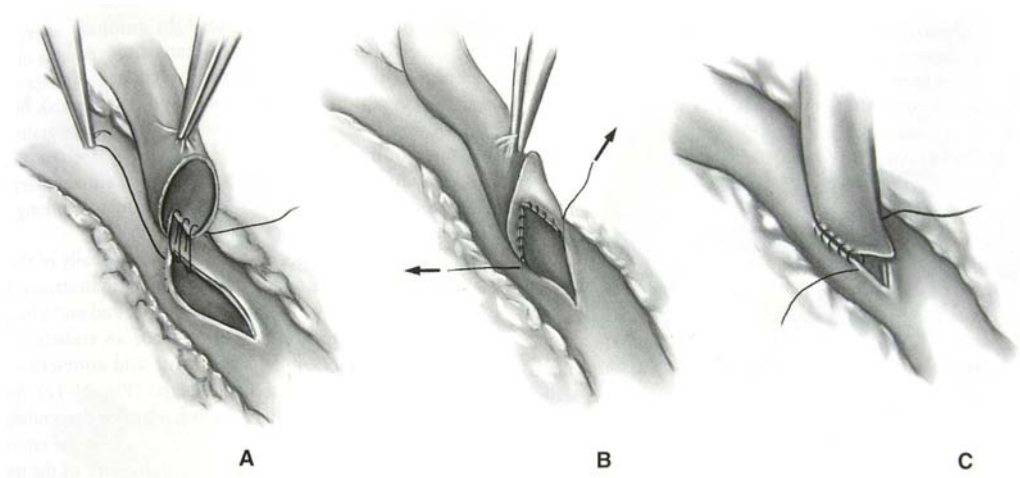


Radial artery

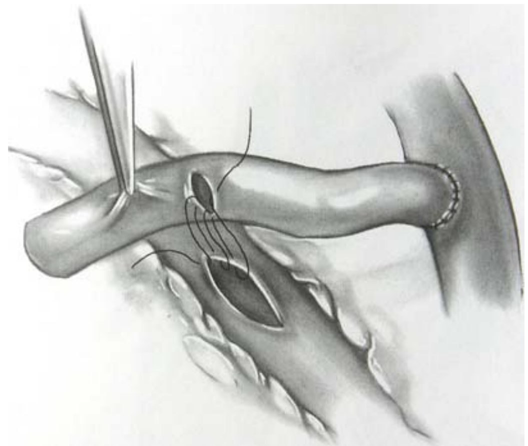


Coronary anastomosis

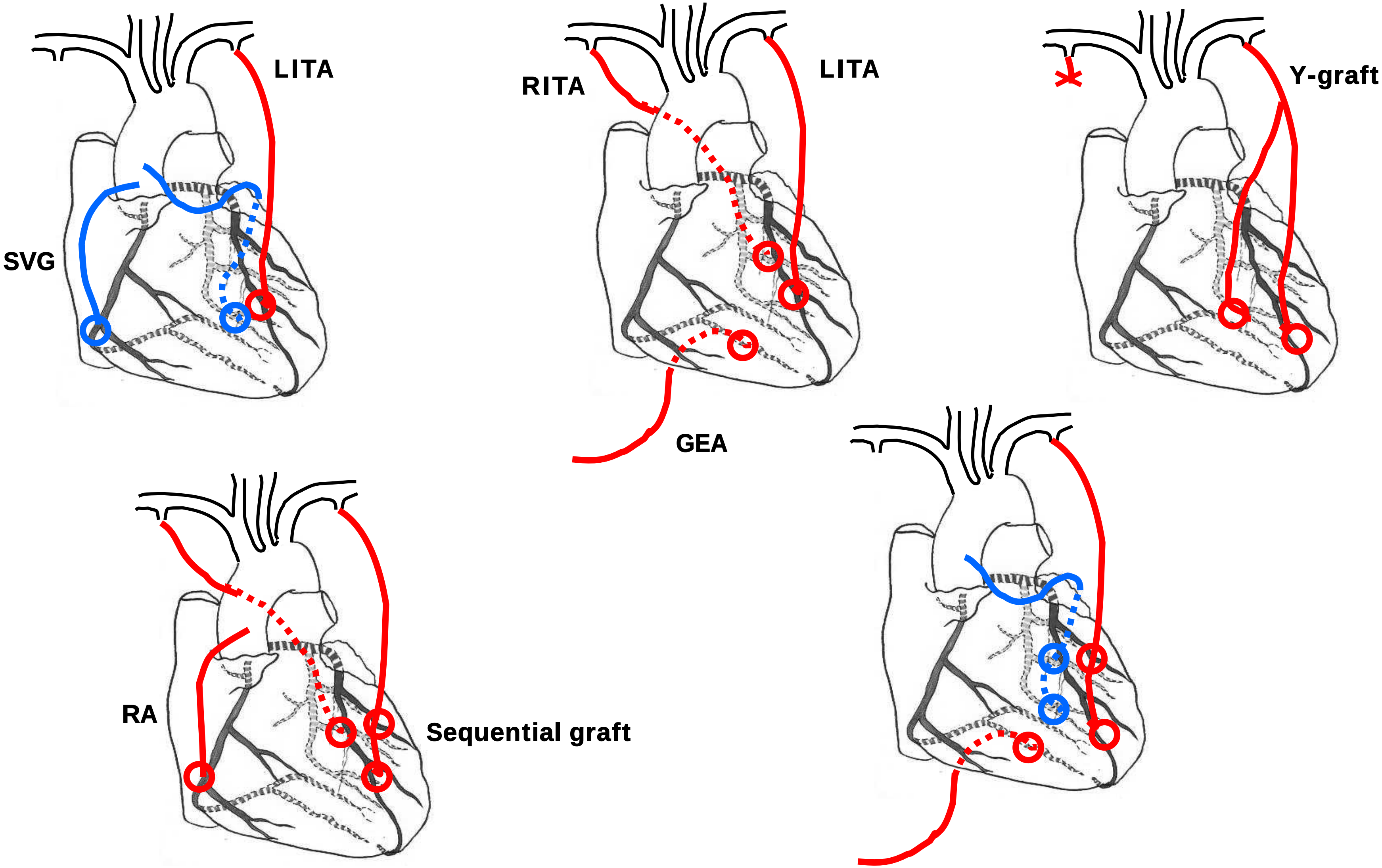
Distal anastomosis



Sequential anastomosis



From: Woo YJ, Gardner TJ, Myocardial Revascularization with Cardiopulmonary Bypass,
In: Cohn LH, Edmunds LH Jr, eds, Cardiac Surgery in the Adult, New York: McGraw-Hill, 2003:581607,



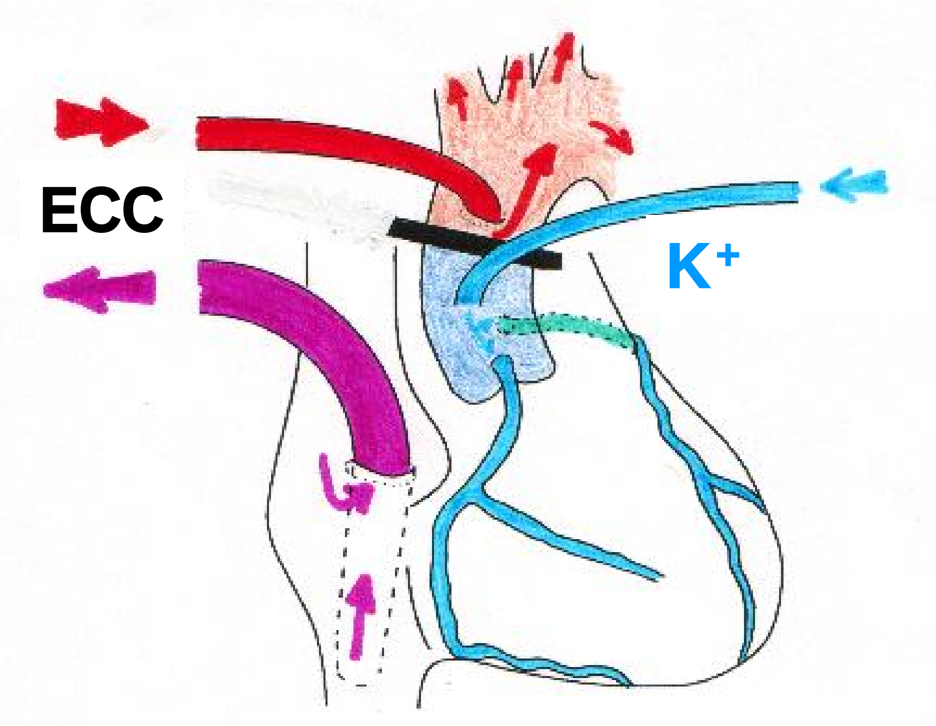
Some example of CABG

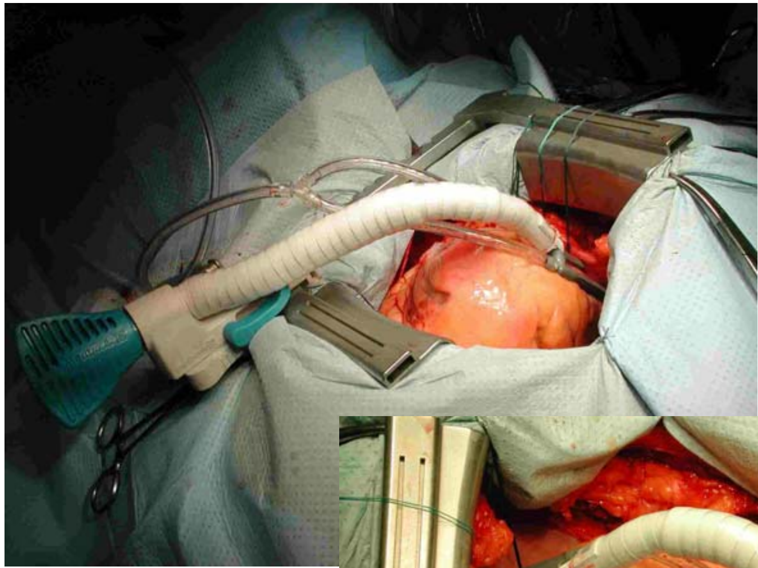
Various combinations are possible

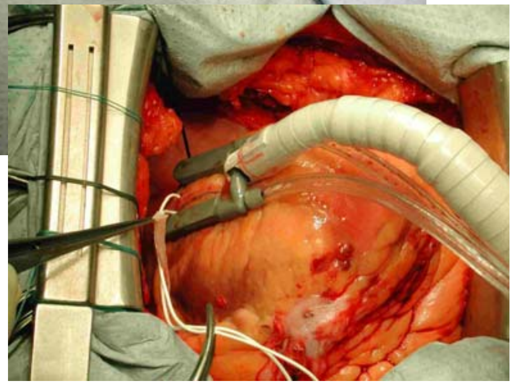
Arterial graft must be favored

LITA: left internal thoracic artery
RITA: right internal thoracic artery
GEA: gastroepiploic artery
SVG: saphenous vein graft
RA: Radial artery

CABG – Operative technique







Under ECC with cardioplegia

Video

Beating-heart surgery (without ECC)

Video

Cardiac motion of an epicardial beacon

From: Borst et al, J Am Coll Cardiol 1996;27:1356-64

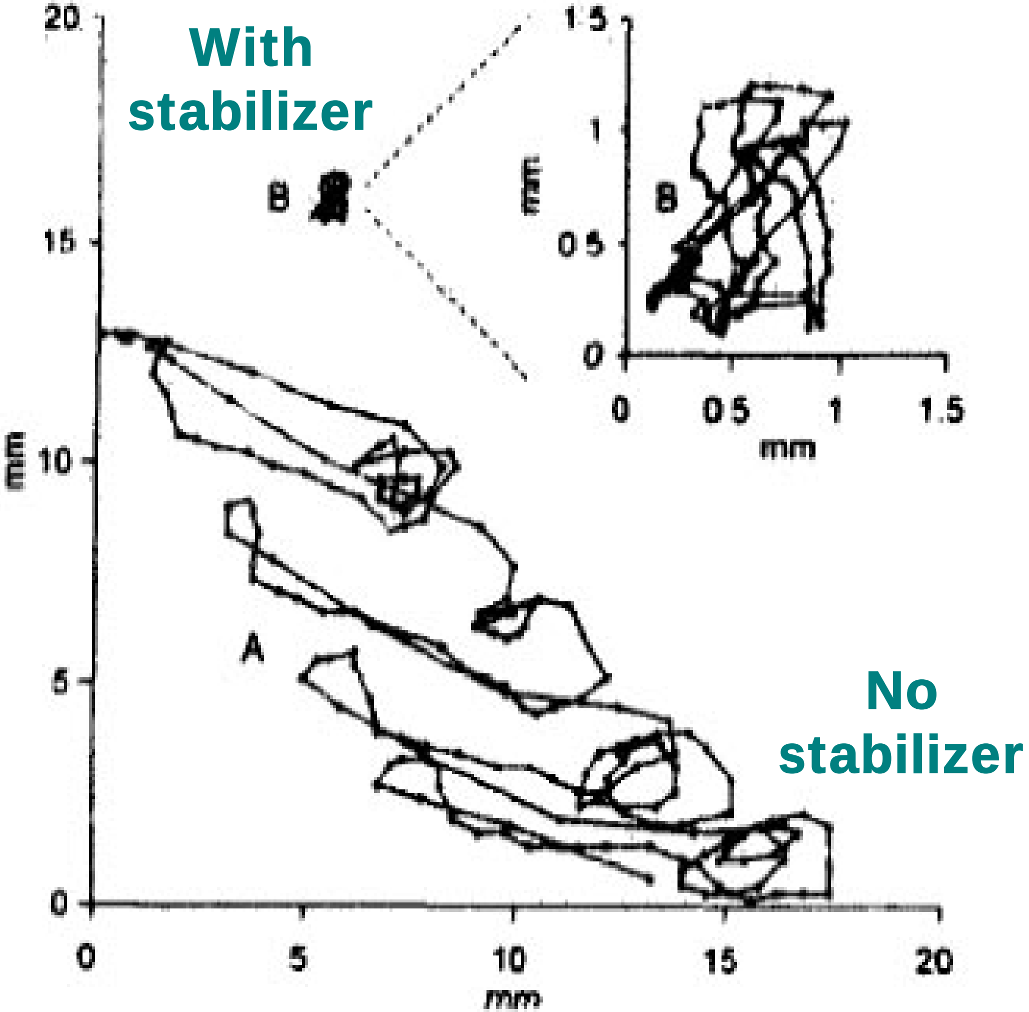


Figure 2. Example of two-dimensional epicardial beacon motion in the obtuse marginal area during an open-chest procedure. Beacon motion is depicted during one half respiratory cycle when the heart is unrestrained (A) and when it is immobilized locally by the encircling Octopus (B). The **inset** shows a magnification of the residual cardiac motion (B). The Octopus limited cardiac wall motion to about 1 × 1 mm. Data points are plotted at 20-ms intervals.

Valvular surgery

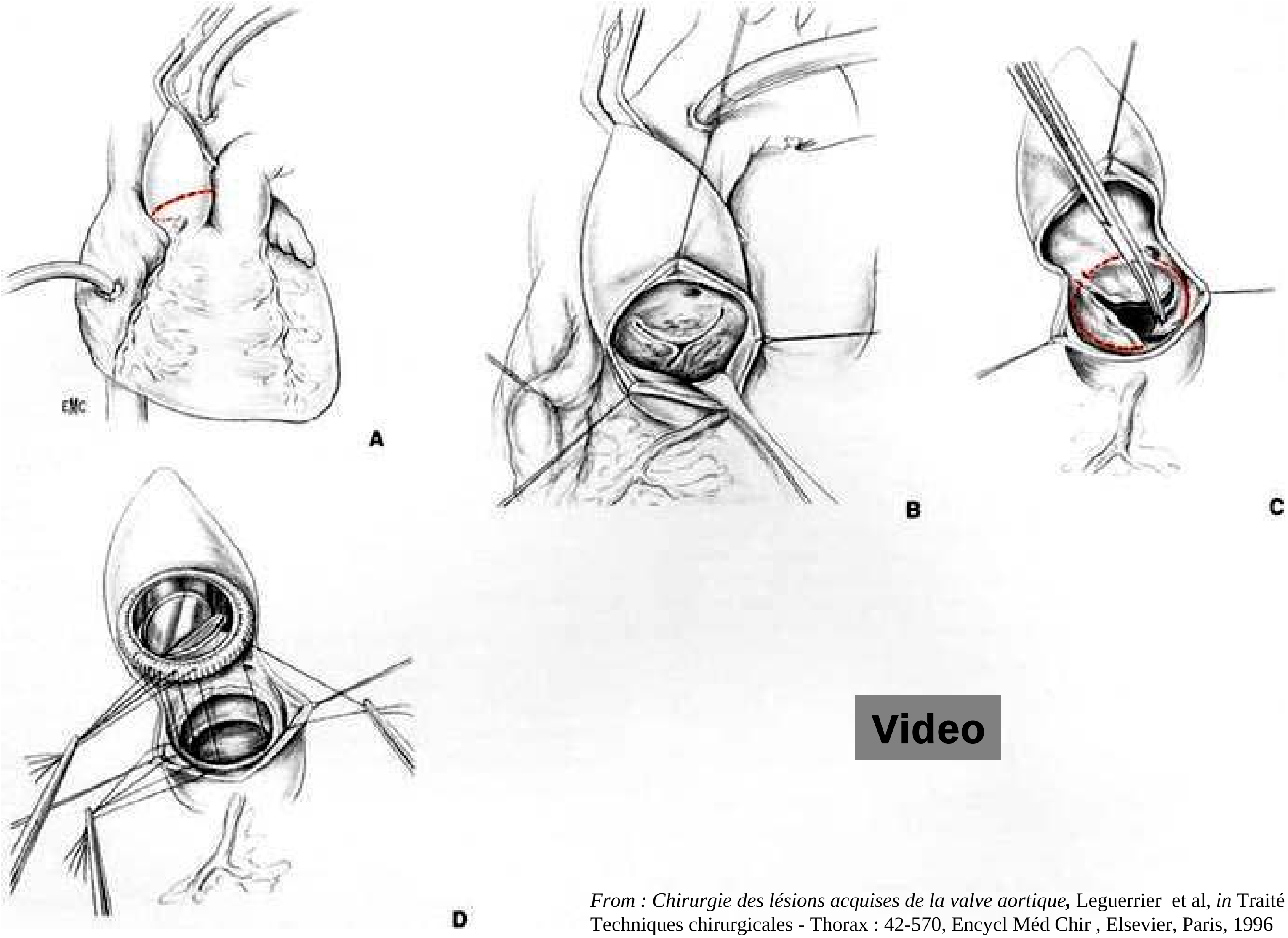
Generality

In adult, valvular surgery is mostly used for the aortic valve and mitral valve

Repair must be favored because of a higher valve prosthesis morbidity

- **Aortic valve**
  - Aortic valve replacement: most cases
  - Valvuloplasty: some cases
- **Mitral valve**
  - Valvuloplasty: most cases
  - Mitral valve replacement if valvuloplasty is impossible

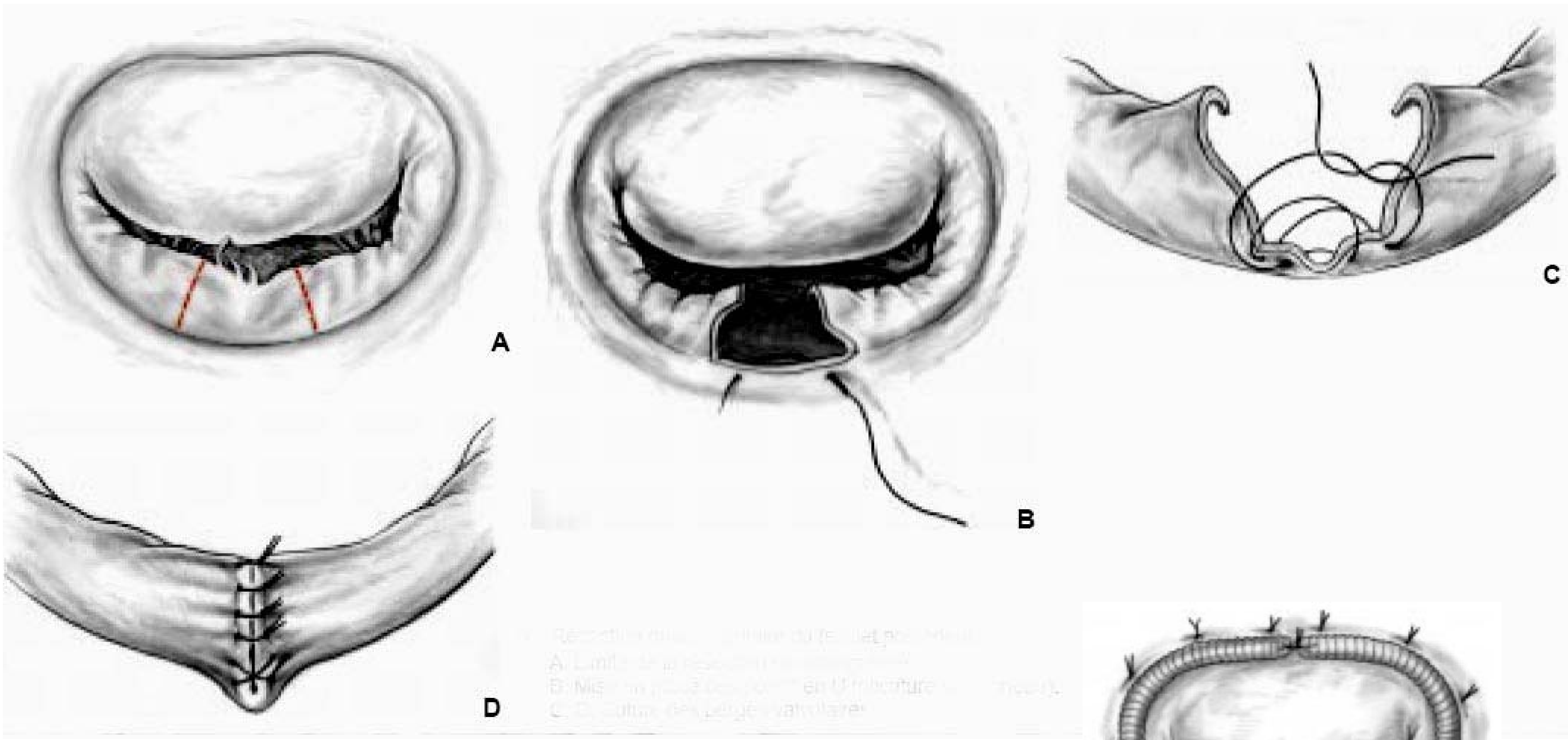
Aortic valve replacement

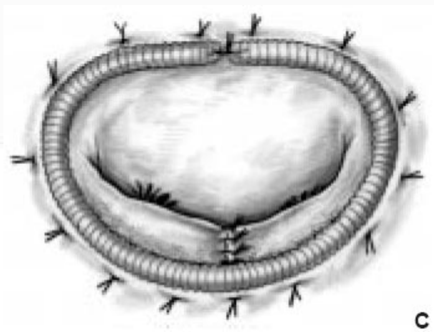


Video

*From : Chirurgie des lésions acquises de la valve aortique***,** Leguerrier et al, *in* Traité de Techniques chirurgicales - Thorax : 42-570, Encycl Méd Chir , Elsevier, Paris, 1996

Mitral valve repair

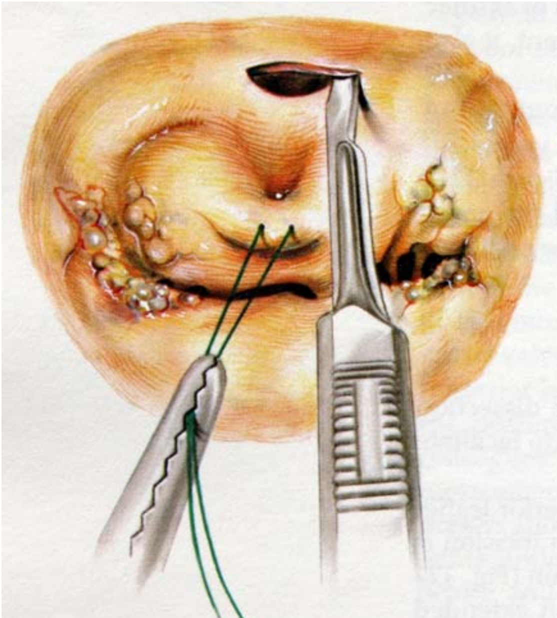




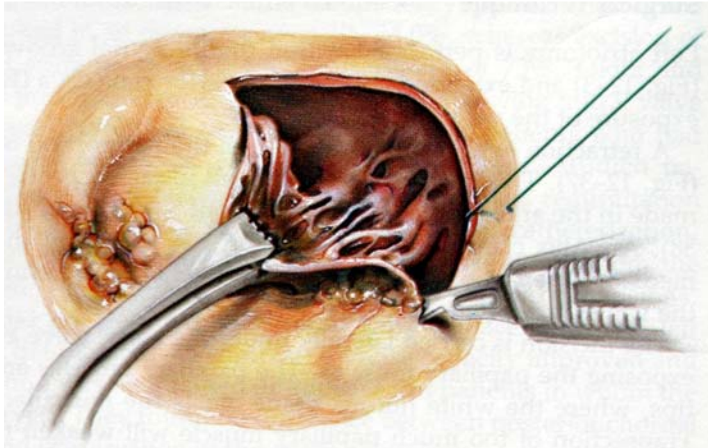
Video

*From : Chirurgie des lésions acquises de la valve mitrale (II)***,** Fuzellier et al, *in* Traité de Techniques chirurgicales - Thorax : 42-531, Encycl Méd Chir , Elsevier, Paris, 1999

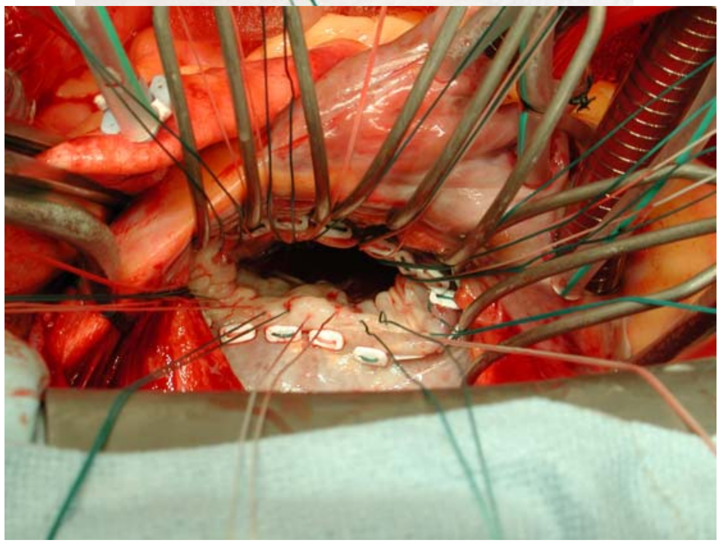
Mitral valve replacement

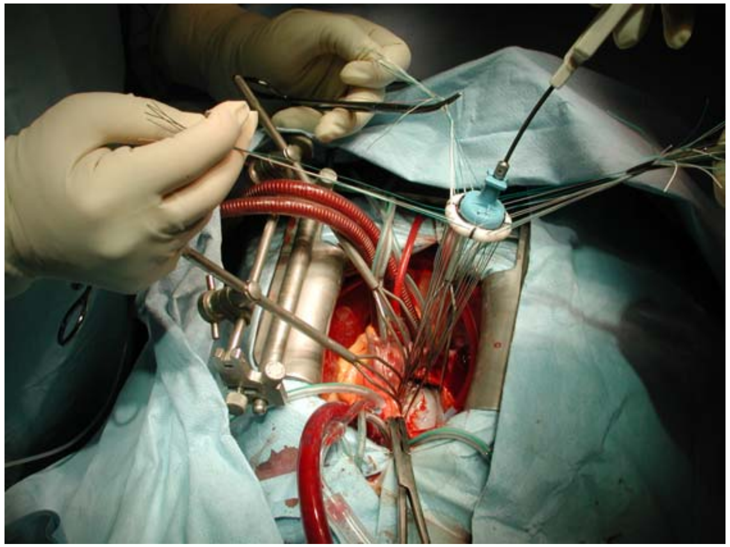


Video

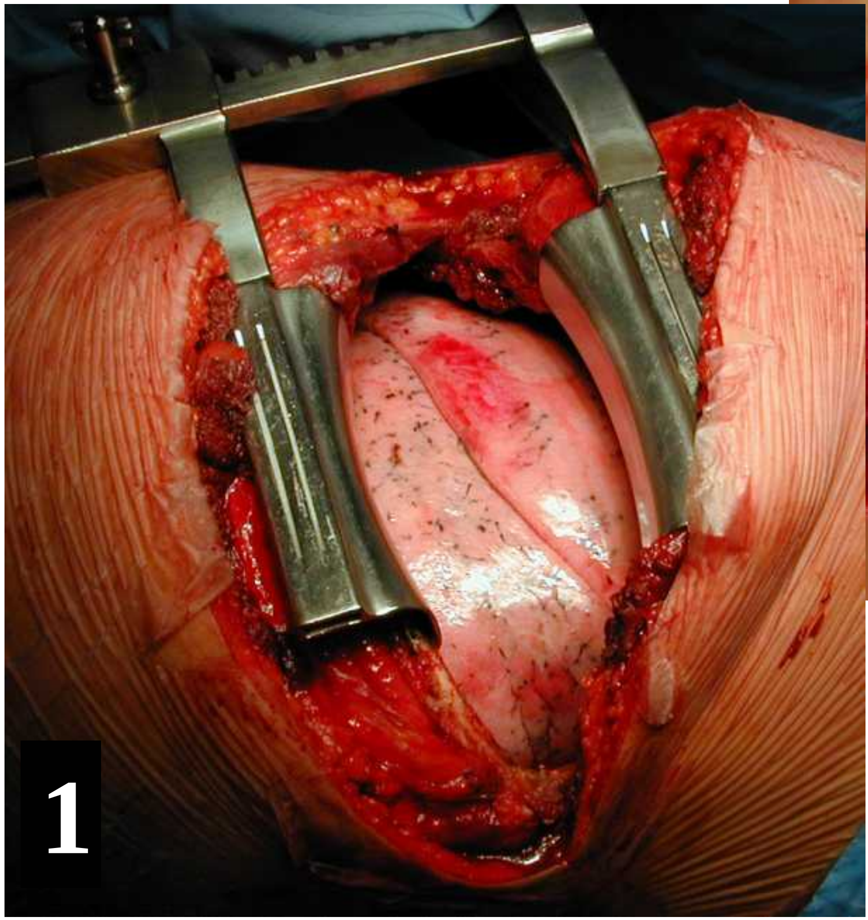


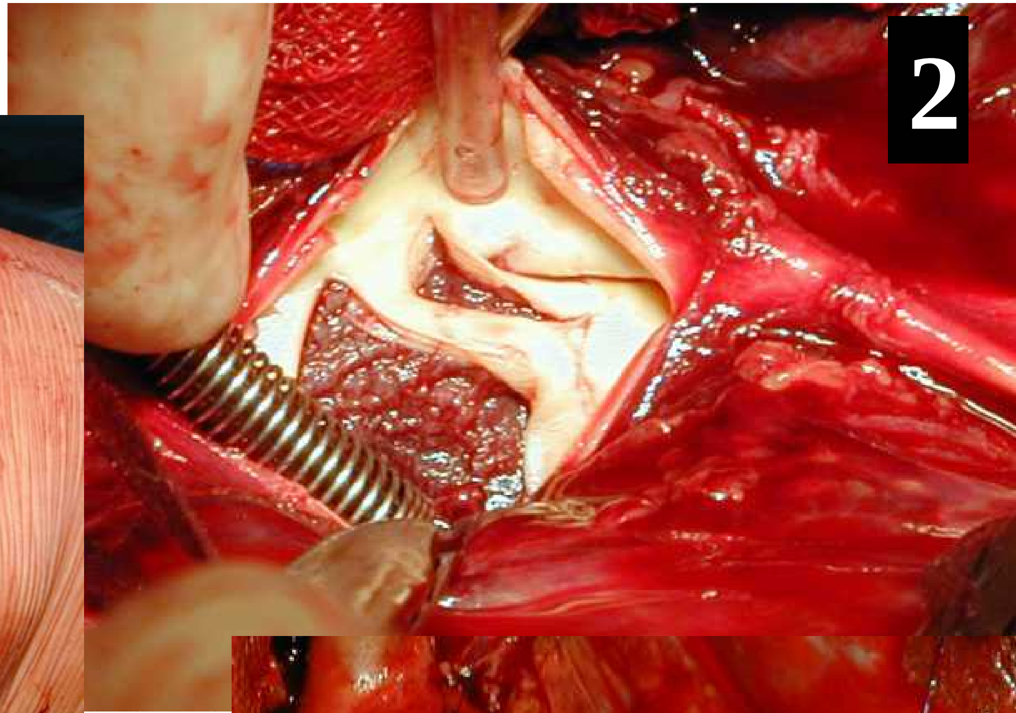
From : Manual of Cardiac Surgery, Harlan & Starr, Springer-Verlag, New York , 1995

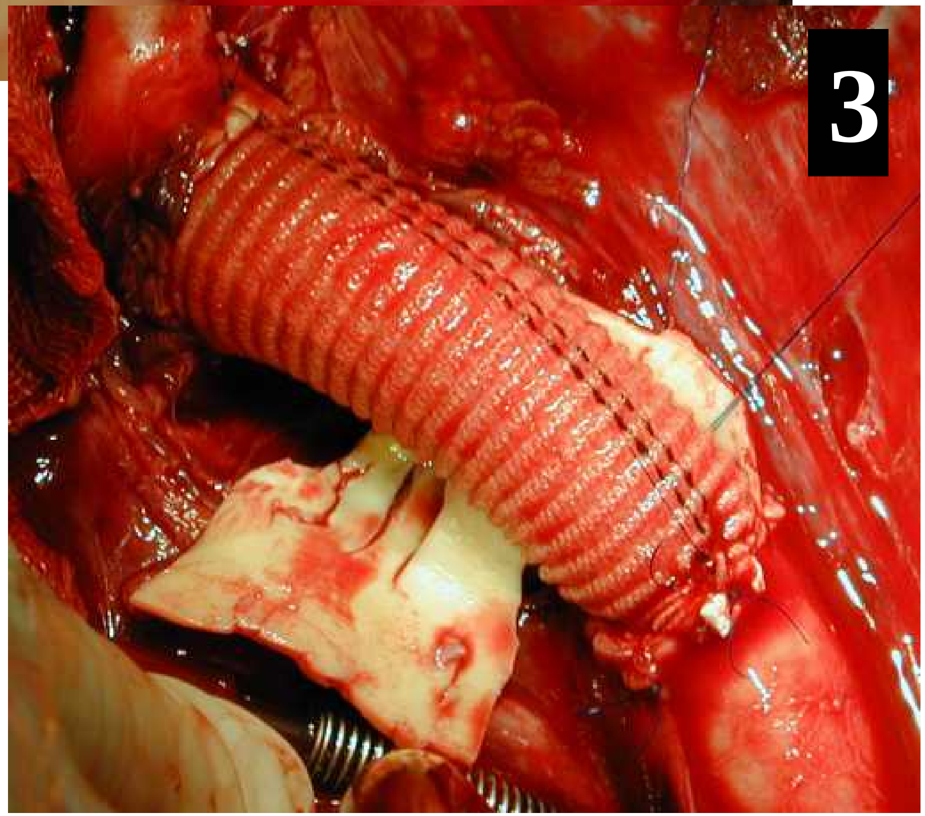




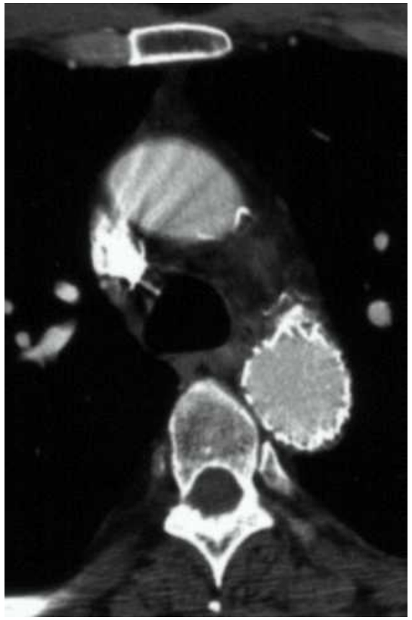
Endovascular techniques







Open technique



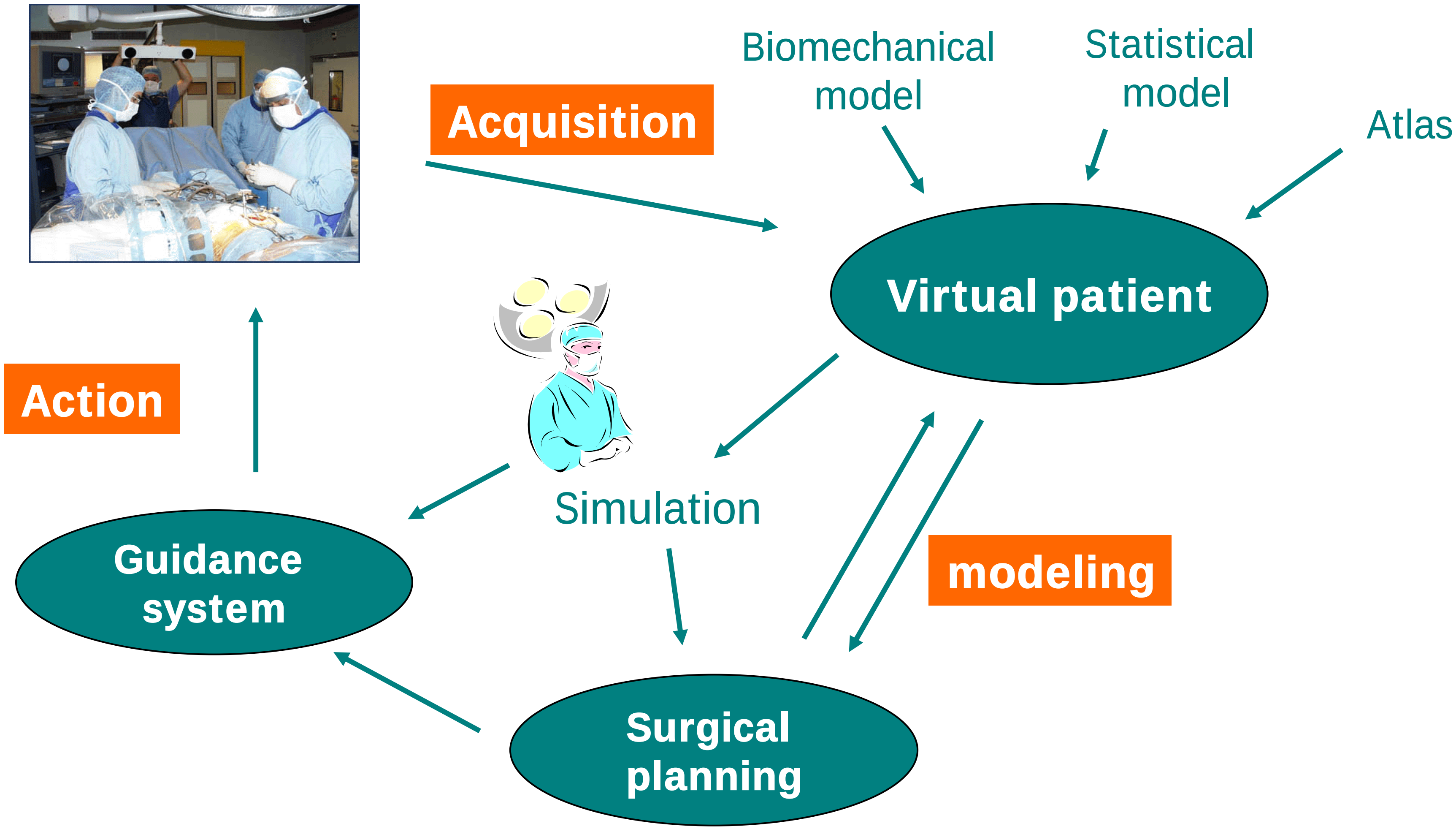
Endoaortic prosthesis

Video

Part 2

Introduction to Computer Assisted Medical Intervention in Cardiac Surgery

Computer Assisted Medical Intervention



Introduction

Motion of the heart

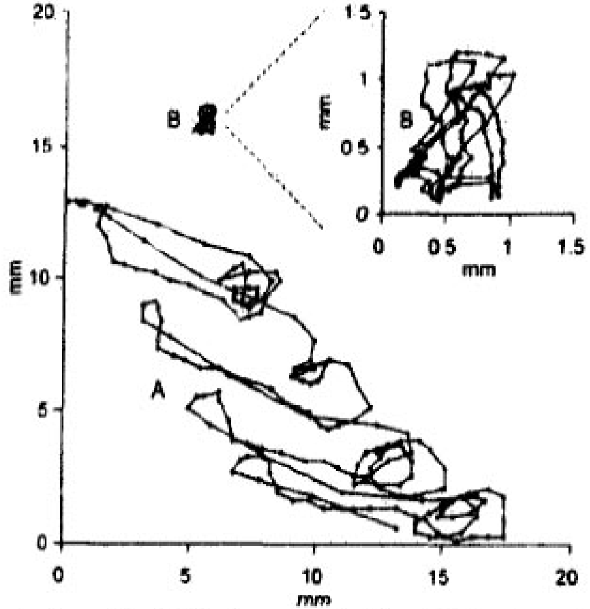
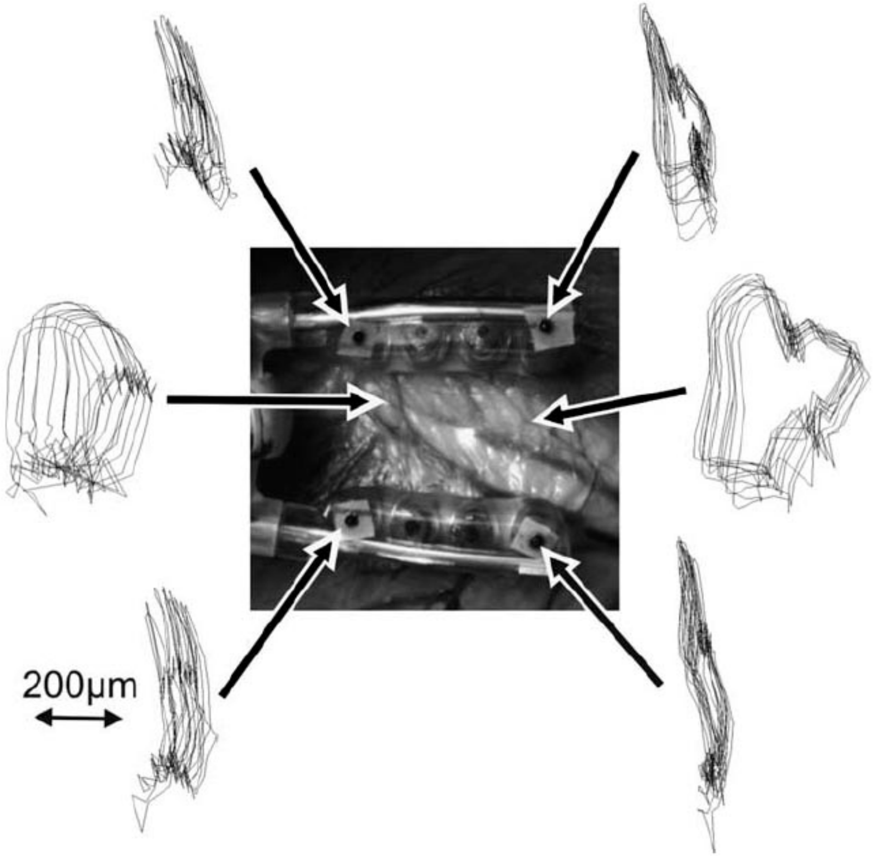


Figure 2. Example of two-dimensional epicardial beacon motion in the obtuse marginal area during an open-chest procedure. Beacon motion is depicted during one half respiratory cycle when the heart is unrestrained (**A**) and when it is immobilized locally by the encircling Octopus (**B**). The **inset** shows a magnification of the residual cardiac motion (**B**). The Octopus limited cardiac wall motion to about 1 × 1 mm. Data points are plotted at 20-ms intervals.

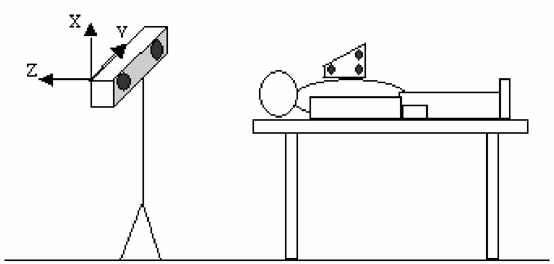


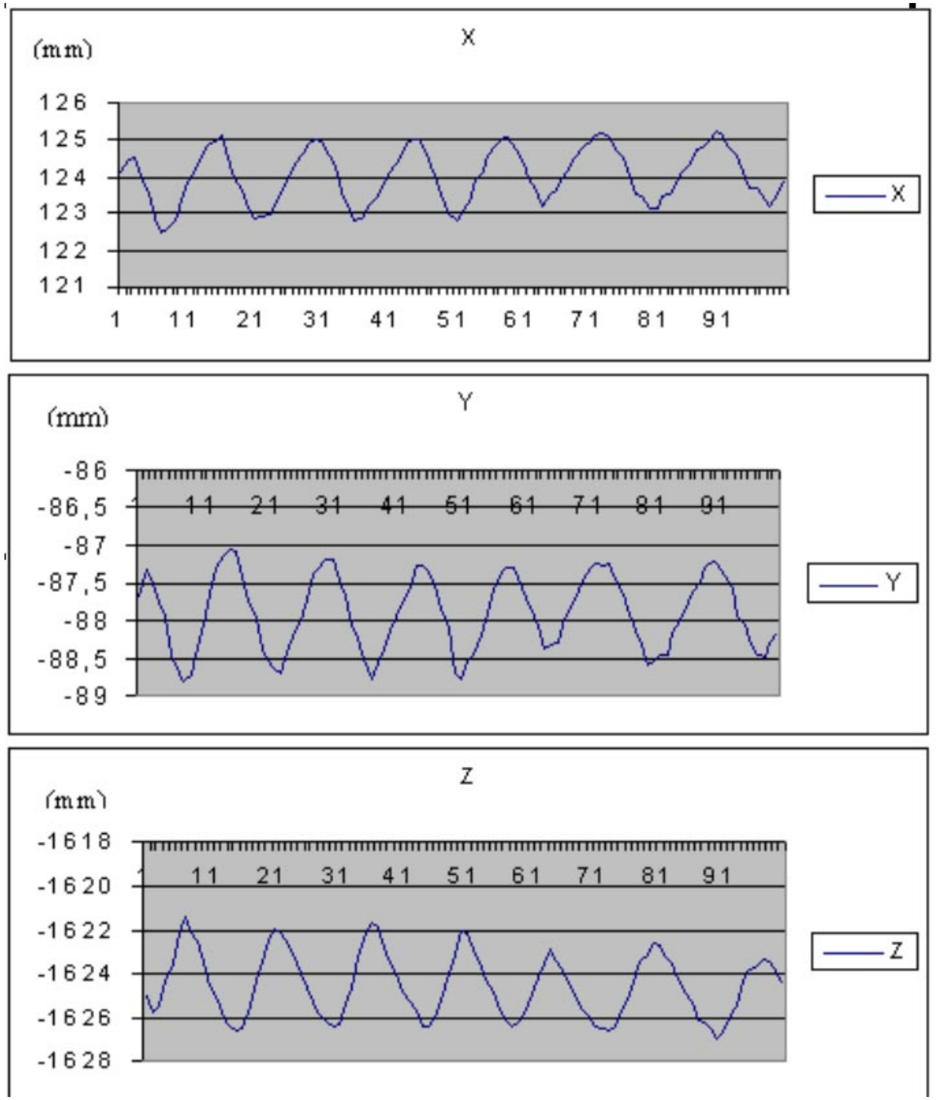
From: Borst et al, J Am Coll Cardiol 1996;27:1356-64

Ph. Cattin et al. / European Journal of Cardio-thoracic Surgery 25 (2004) 786–790

Introduction

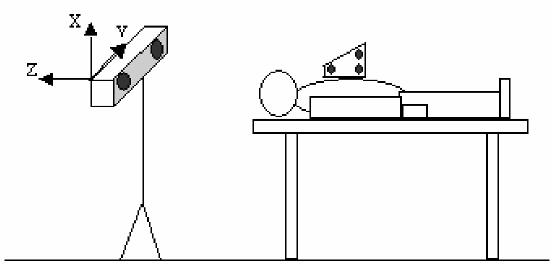
Motion of the chest during normal respiration

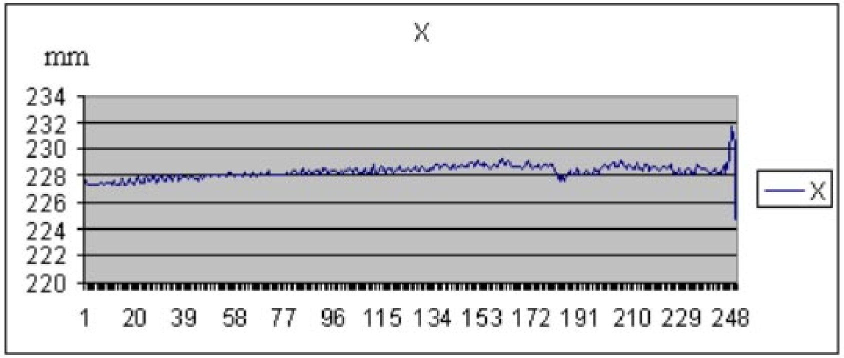


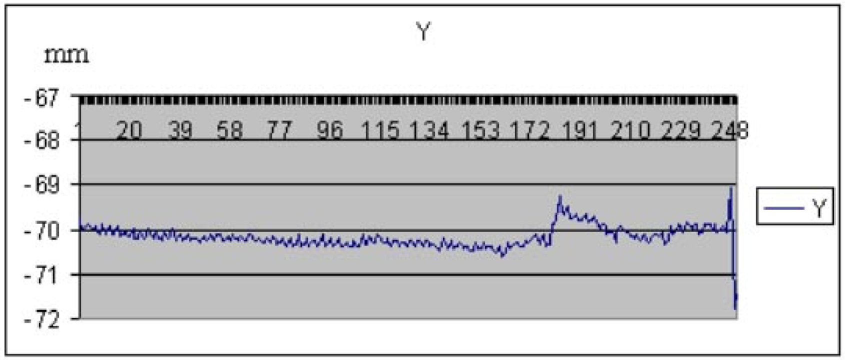


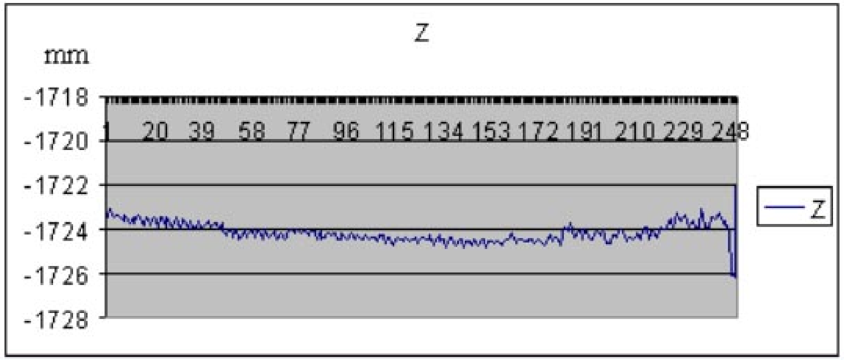
Introduction

Motion of the chest during apnea



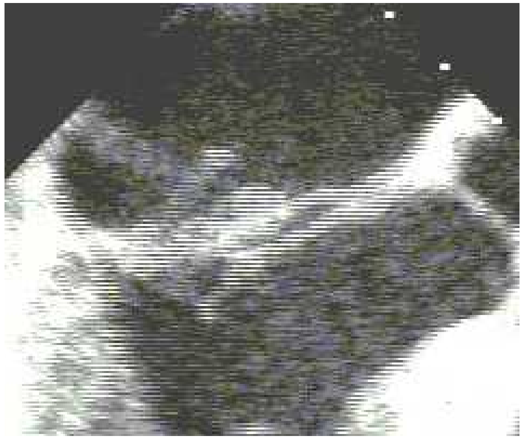


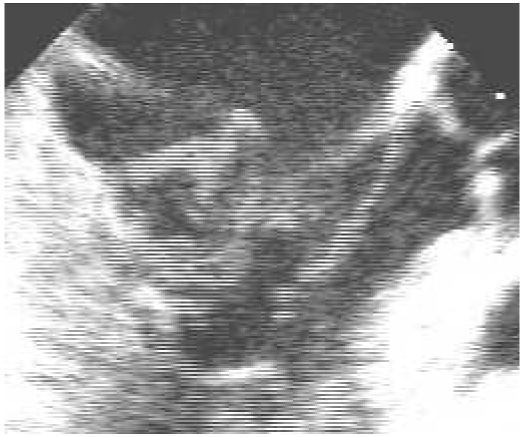




Introduction

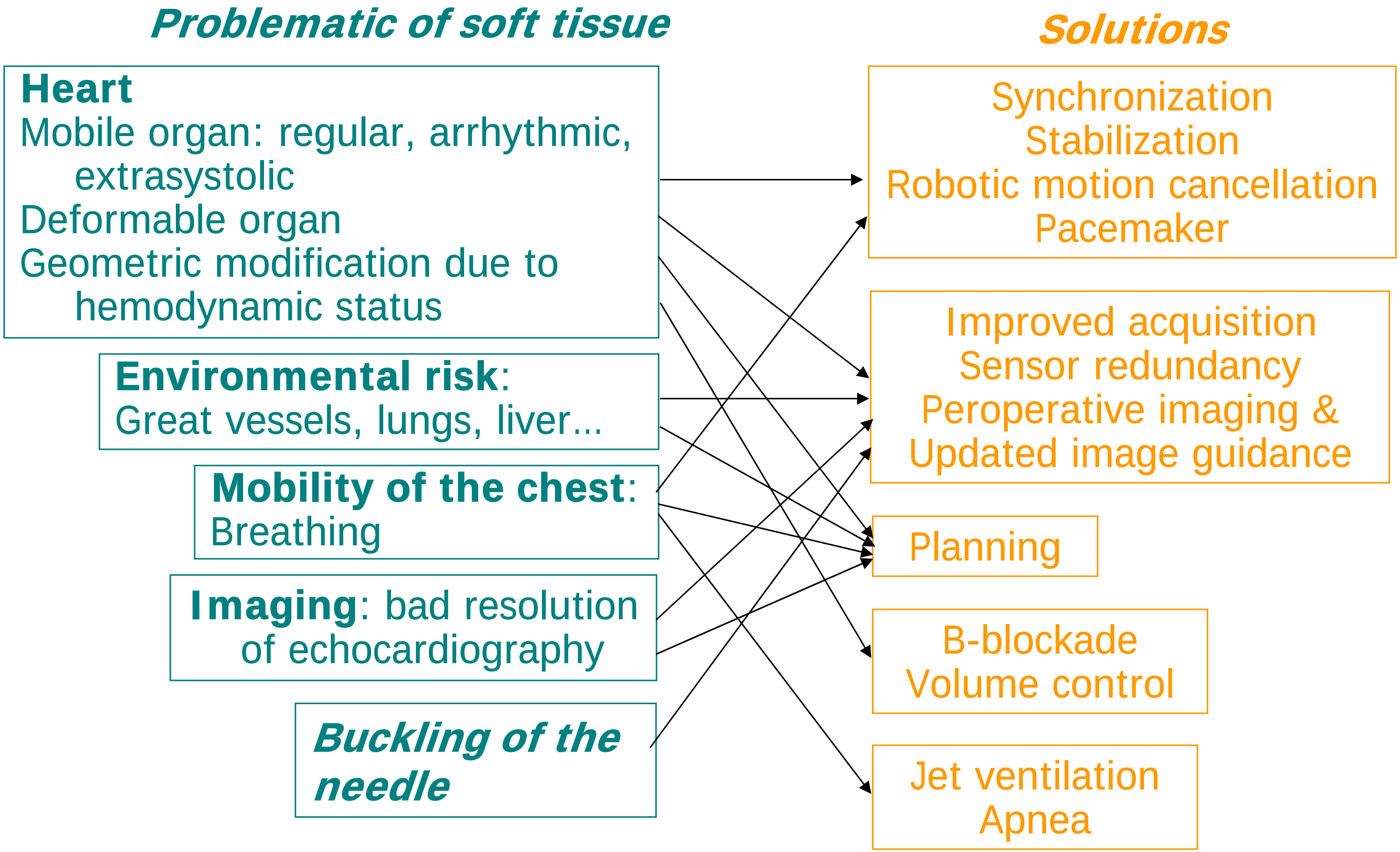
Problems of echography





Video

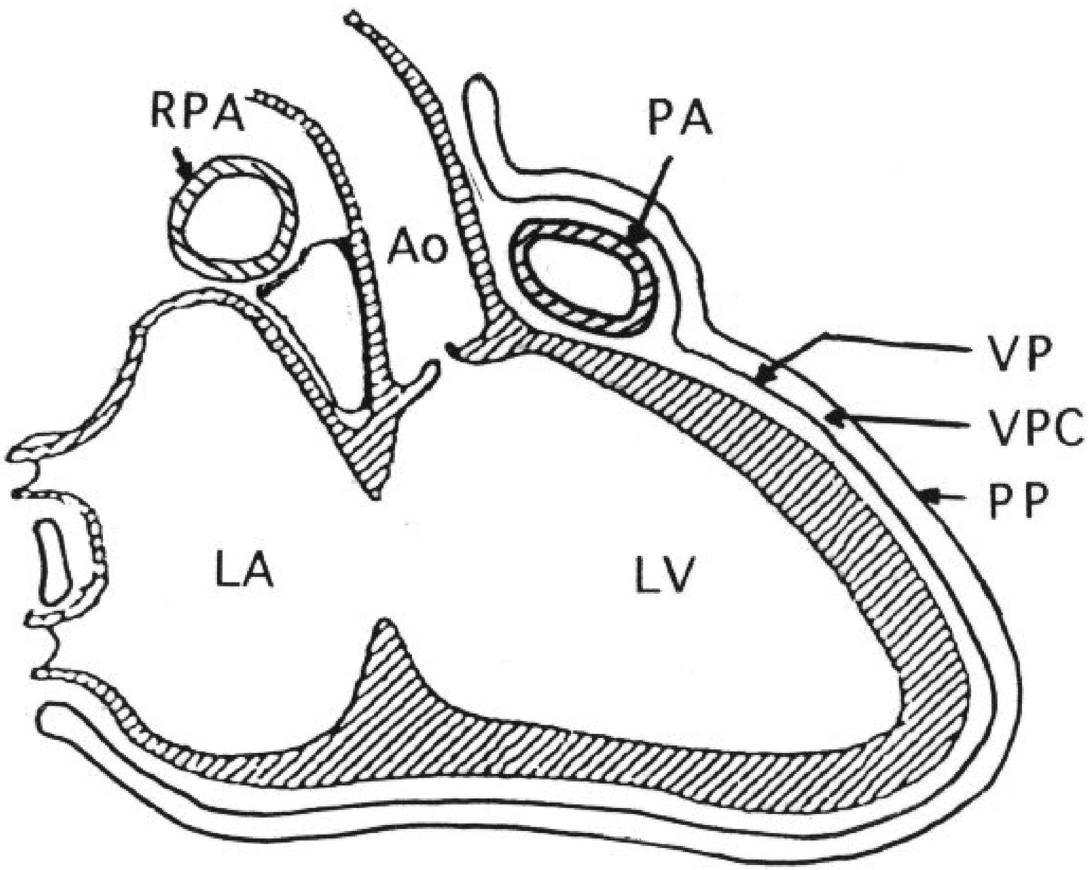
Problematic of CAMI in cardiac surgery



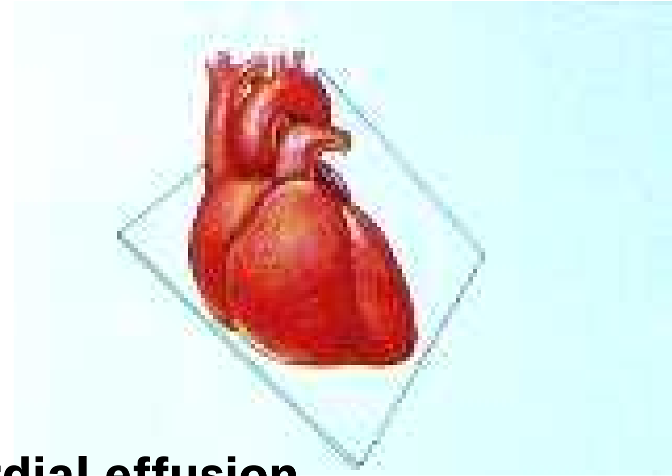
CASPER

Computer ASsisted

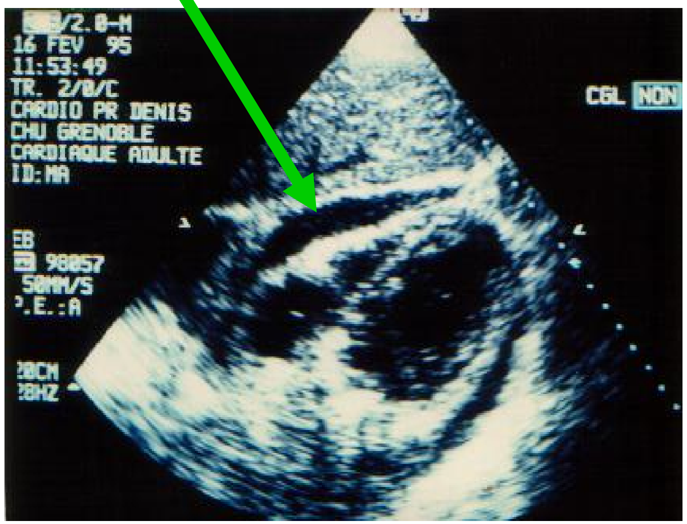
PERicardiocentesis

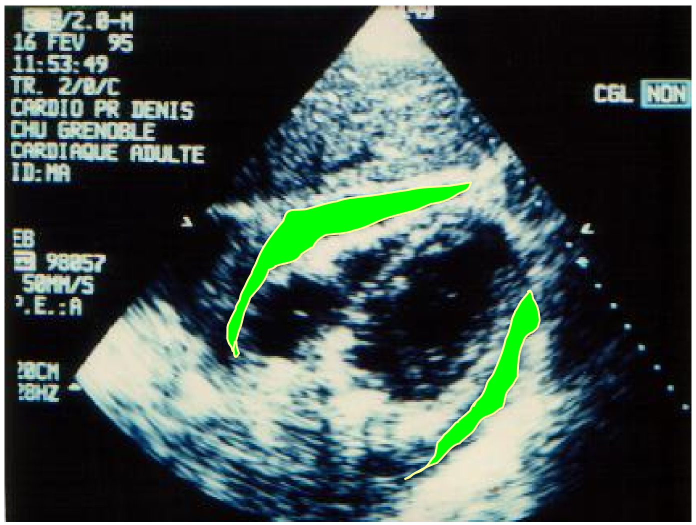

RPA
Ao
PA
VP
VPC
PP
LA
LV

Classical pericardiocentesis (1)

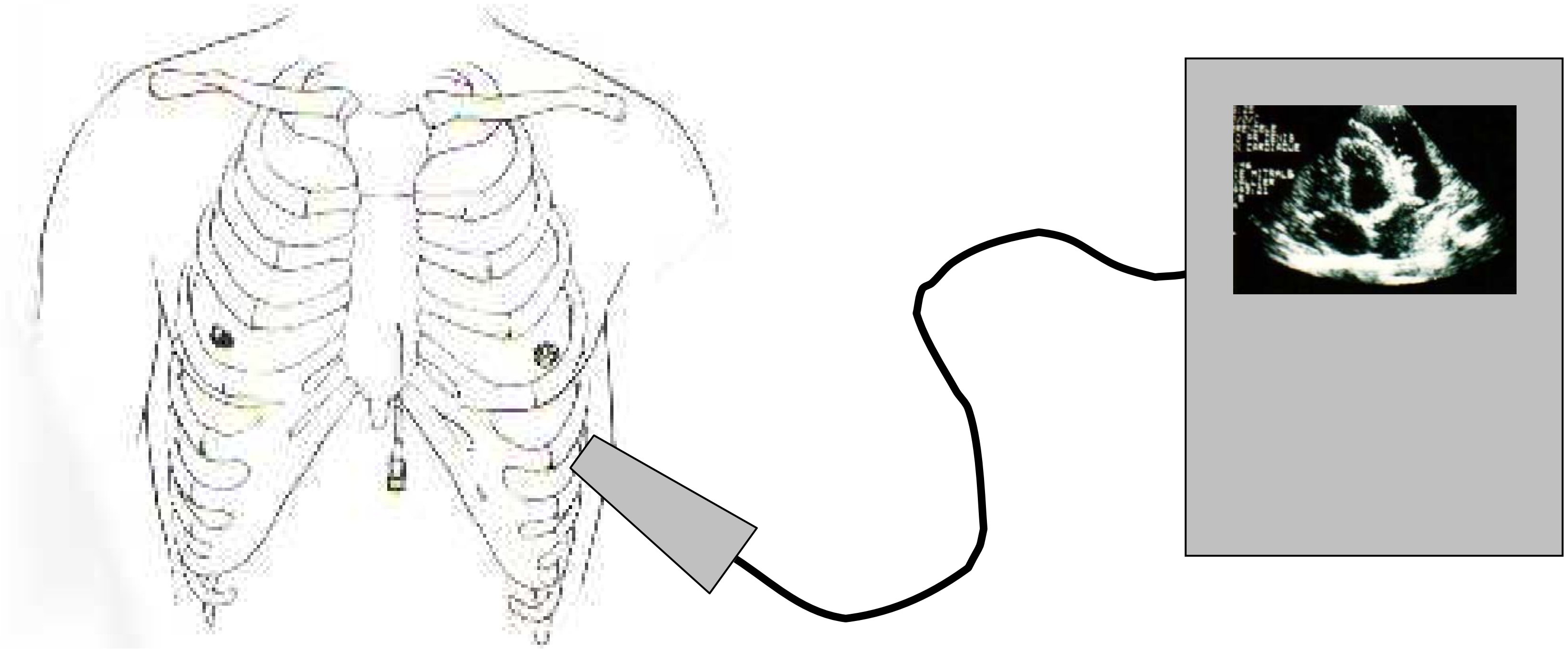


Pericardial effusion

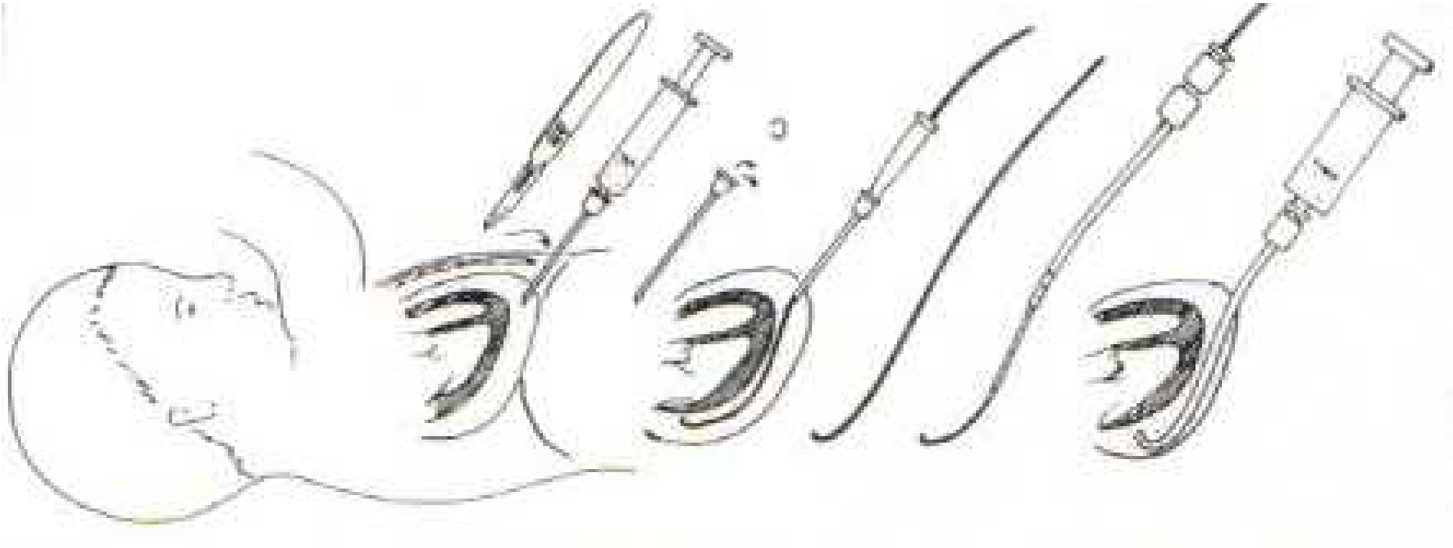




Classical pericardiocentesis (2)



Classical pericardiocentesis (3)



Operator-dependant technique

difficult and often blind

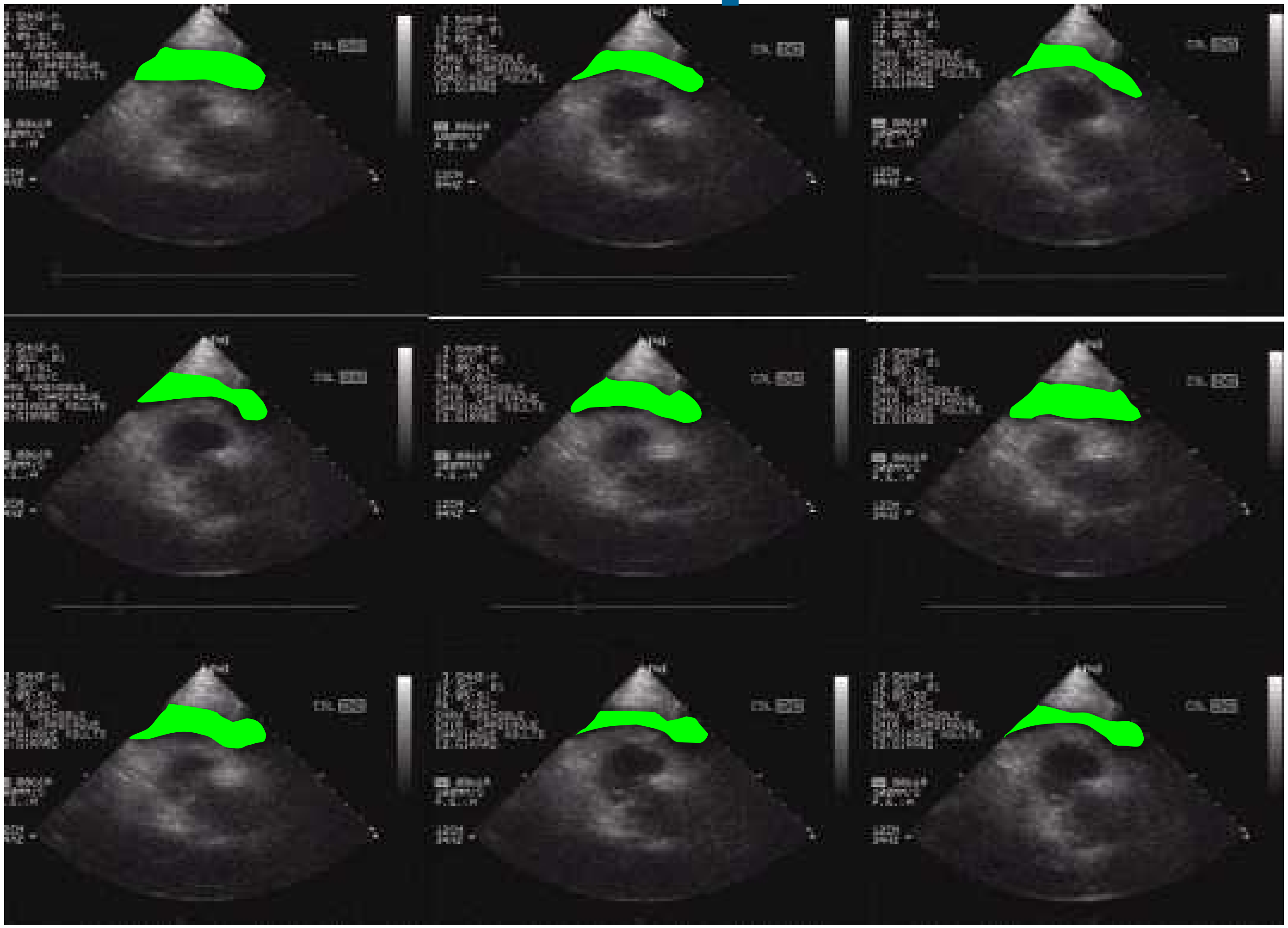
risk of failure or accidental puncture of organs

A computer assisted system could enhance this procedure

CASPER - Principle

Echocardiography

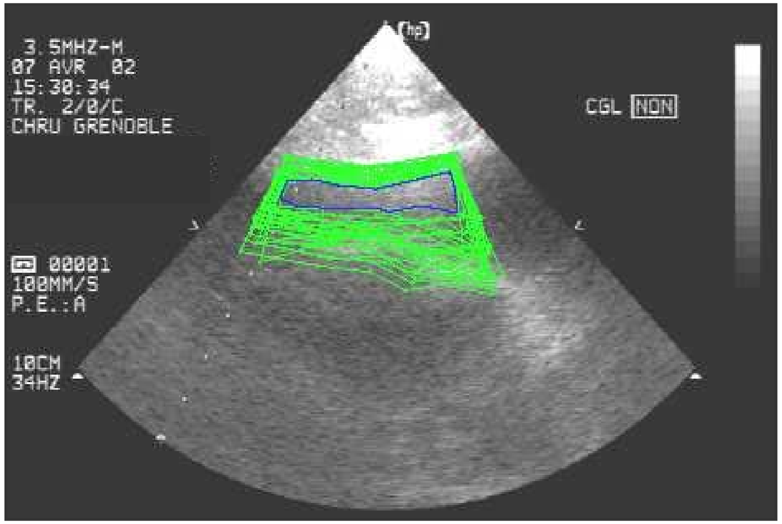
CASPER - Principle



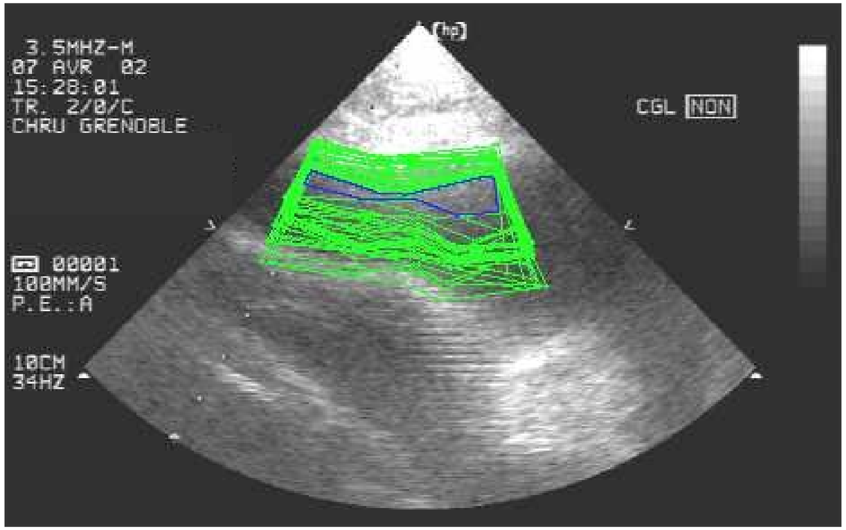
The problem of the heart motion may be solved by finding a stable target along the course of the cardiac cycle, the "stable region"

CASPER - Principle

- **Problem of mobility**
  - Heart: modeling « stable region »
  - Respiration: apnea, alarm of displacement

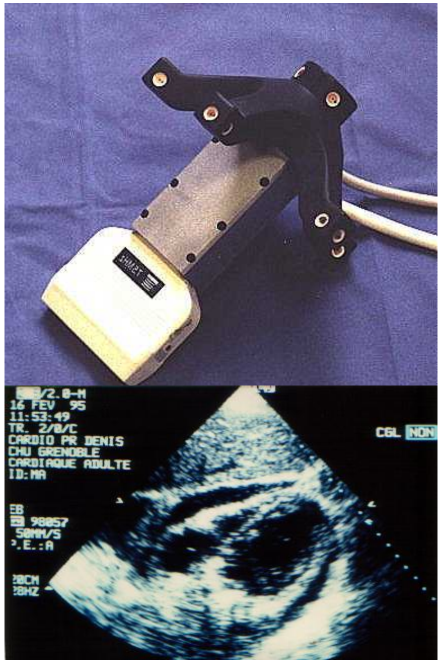


apnea

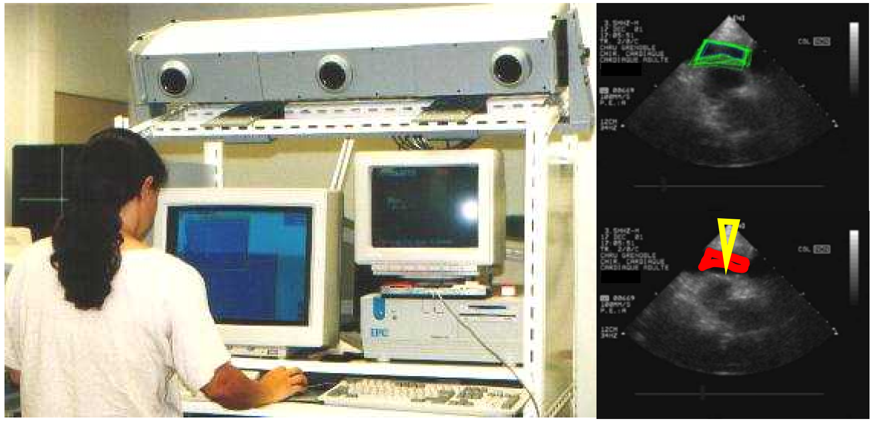


normal respiration

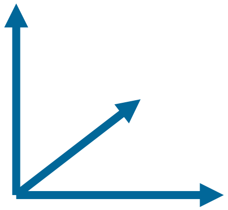
CASPER - Principle



Perception



modeling



Puncture

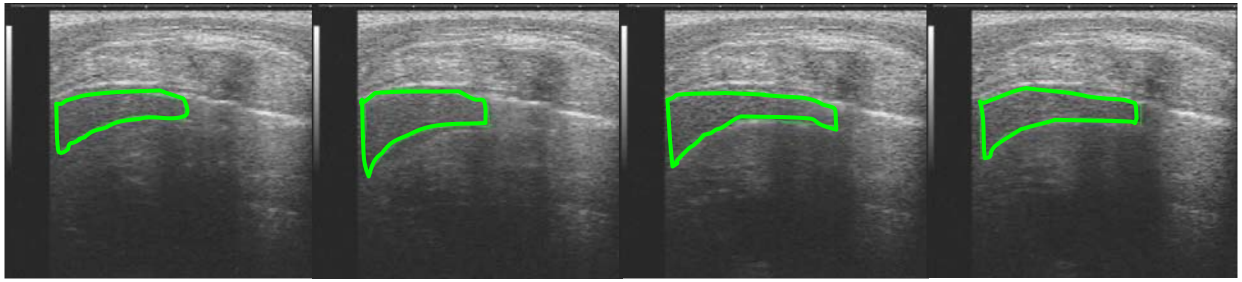
CASPER - Method

- **Perception**
  - Selection of the best view & choice of the region of interest
  - Acquisition of a set of images : 20 to 30 images

CASPER - Method

- **Modeling (1)**
  - average plane: a "**referential plane**" is computed

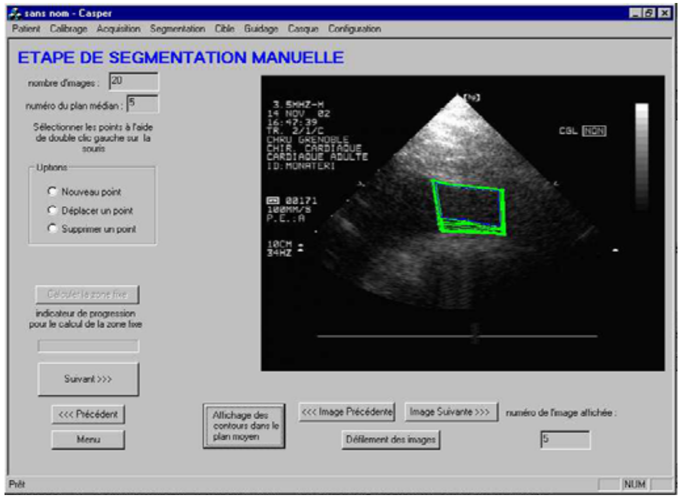
  the behavior of the effusion will be modeled in this plane

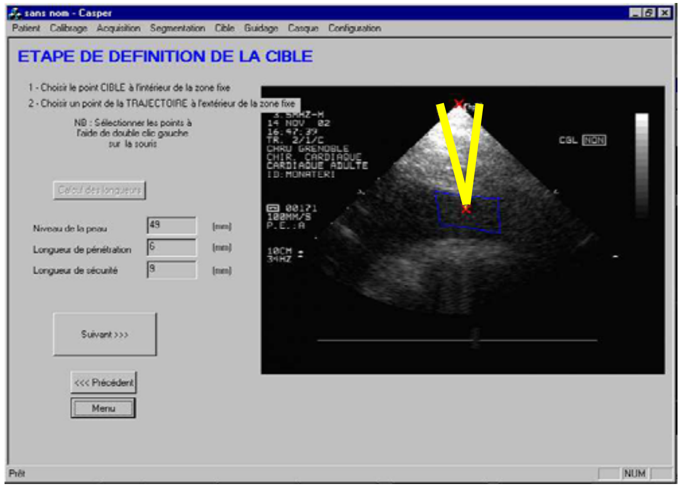


- The zone of interest is **manually segmented** on each image

CASPER - Method

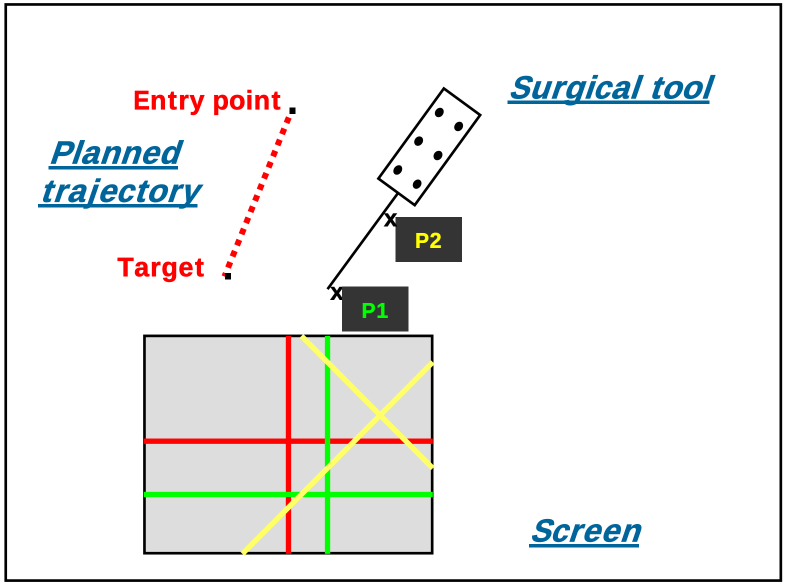
- **modeling (2)**
  - the **stable region** is computed by intersection: safe target along the cardio-respiratory movement
  - the surgeon defines the **trajectory** for the needle so that it will avoid anatomical structures



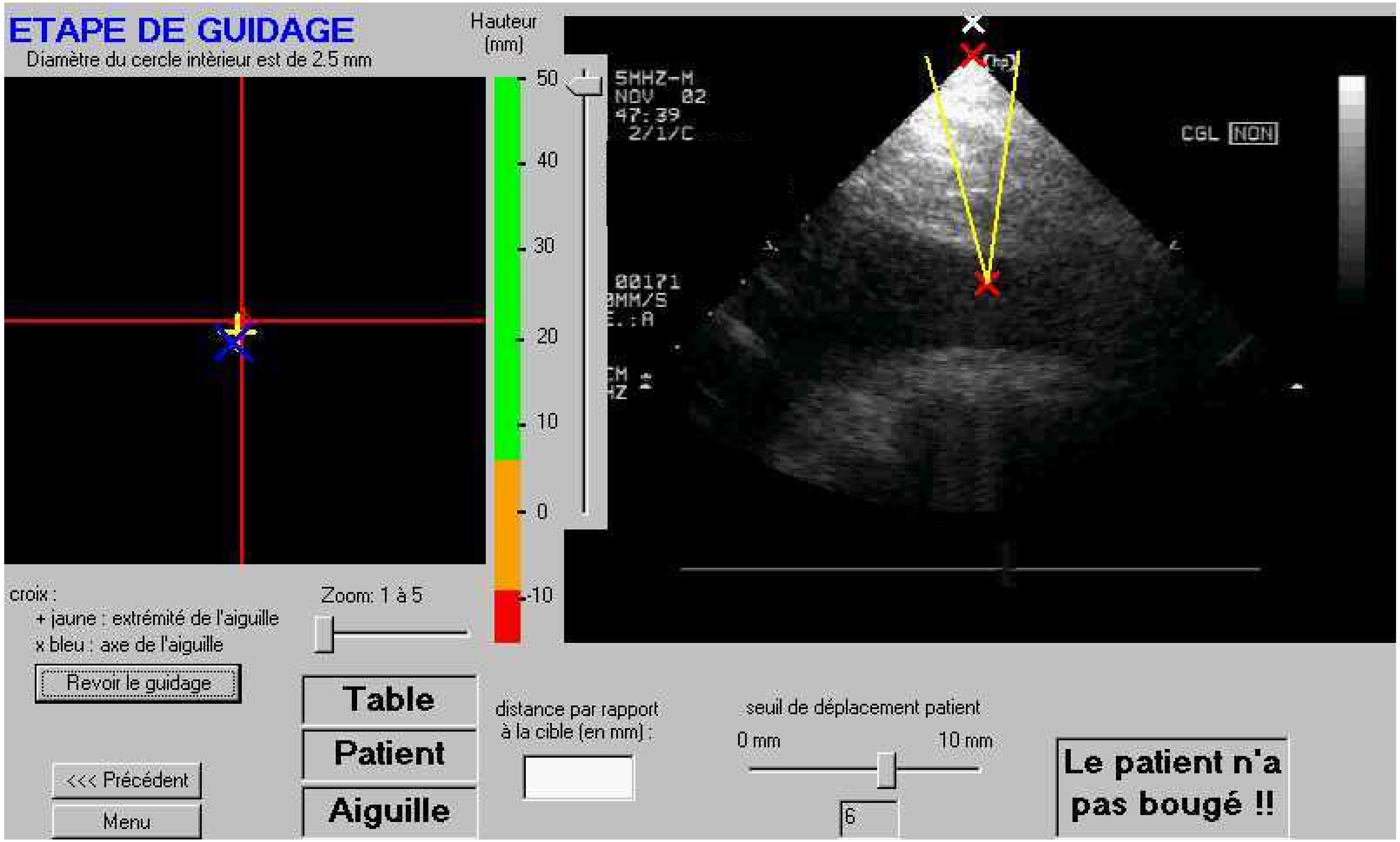


CASPER - Method

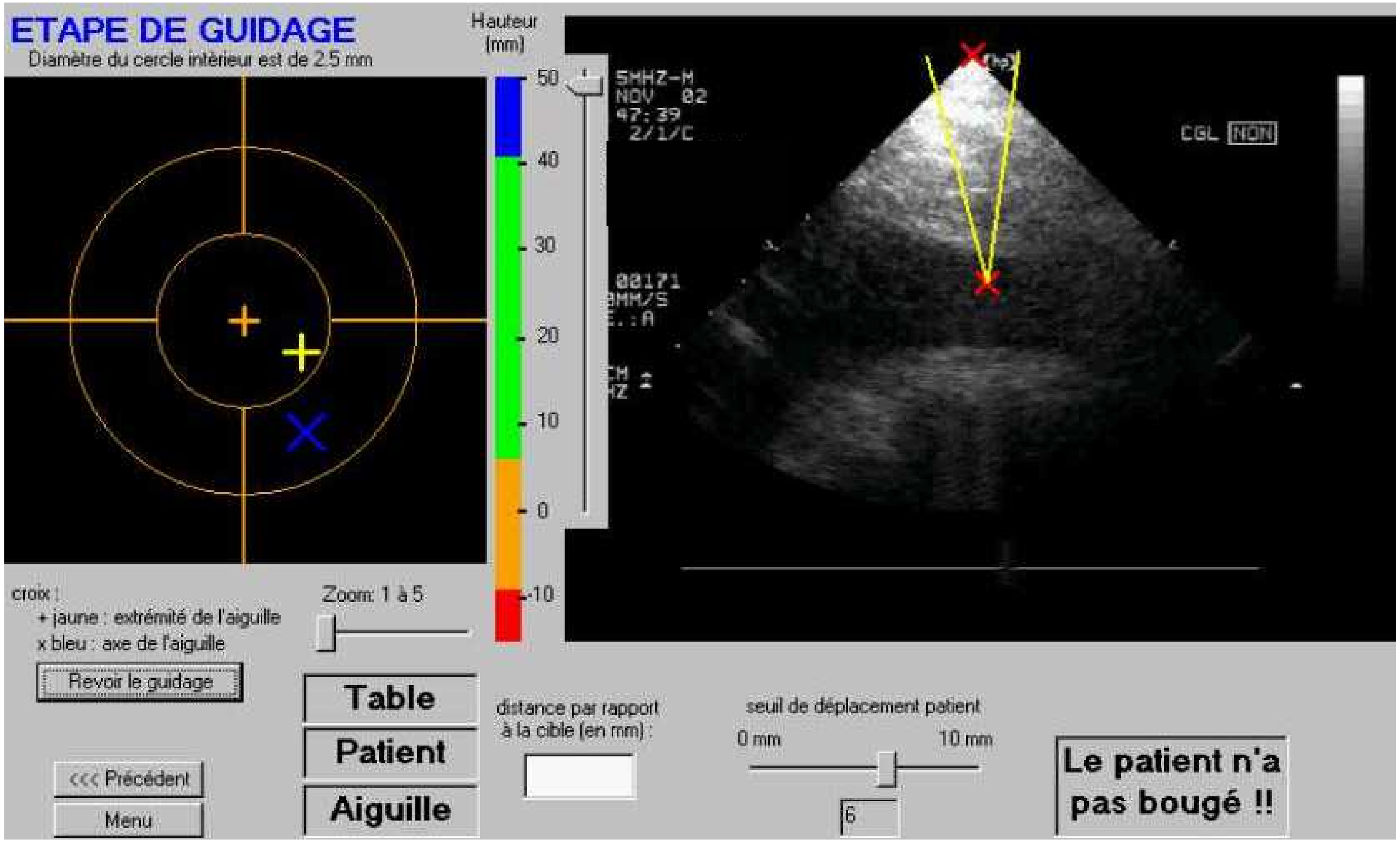
- **Puncture**
  - The surgeon is assisted by a **passive guidance system** based on super-imposed crosses on the user interface



It is a real time surgical tool guidance



ETAPE DE GUIDAGE
Diamètre du cercle intèrieur est de 2.5 mm
Hauteur (mm)
50
40
30
20
10
0
-10
5MHZ-M
NOV 02
47:39
2/1/C
CGL NON
00171
croix :
+ jaune : extrémité de l'aiguille
x bleu : axe de l'aiguille
Zoom: 1 à 5
Revoir le guidage
Table
Patient
Aiguille
distance par rapport à la cible (en mm) :
seuil de déplacement patient
0 mm
10 mm
6
<<< Précédent
Menu
Le patient n'a pas bougé !!


ETAPE DE GUIDAGE
Diamètre du cercle intérieur est de 2.5 mm
Hauteur (mm)
50
40
30
20
10
0
-10
croix :
+ jaune : extrémité de l'aiguille
x bleu : axe de l'aiguille
Revoir le guidage
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Menu
Table
Patient
Aiguille
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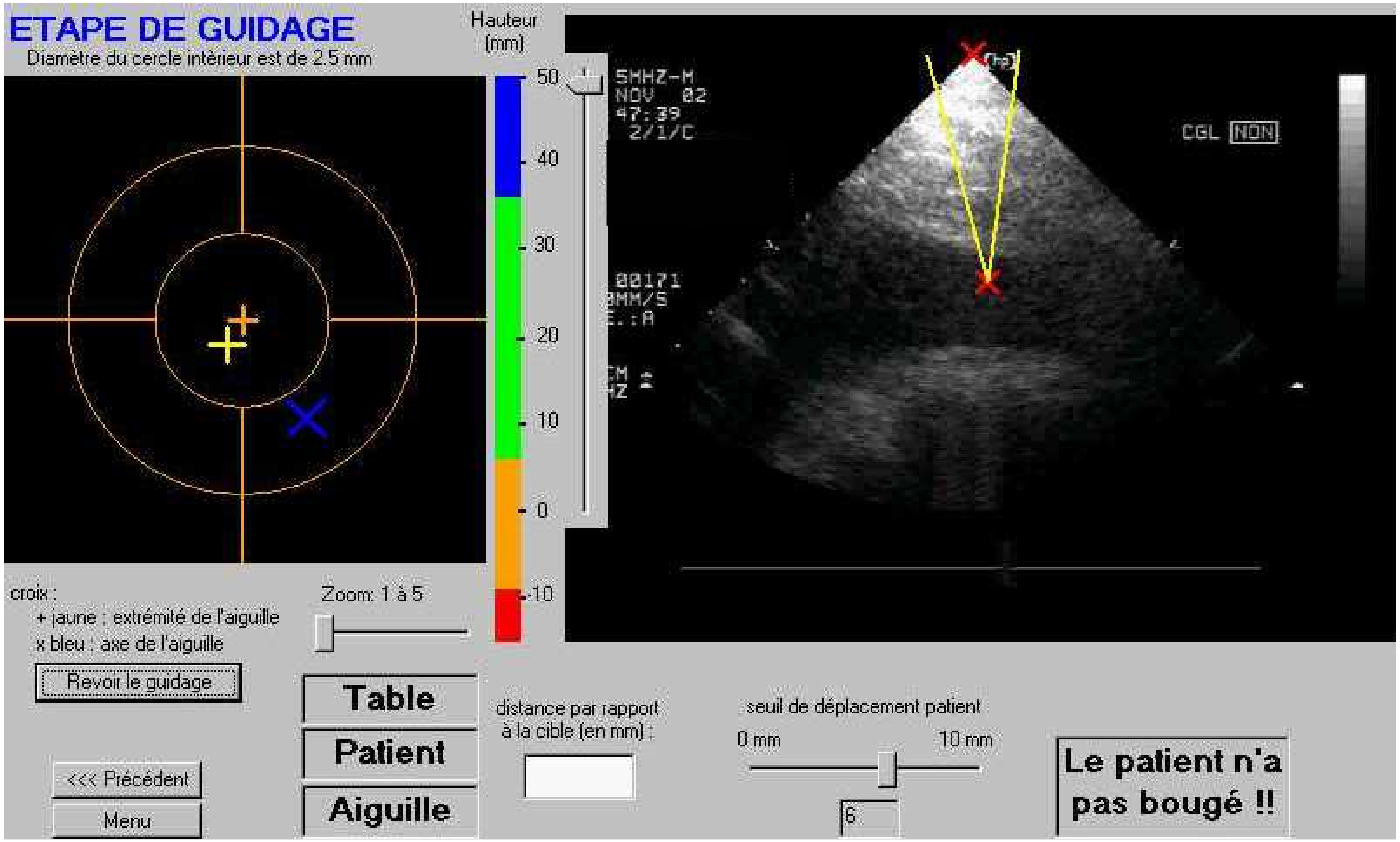
seuil de déplacement patient
0 mm
10 mm
6
Le patient n'a pas bougé !!
5MHZ-M
NOV 02
47:39
2/1/C
CGL NON


ETAPE DE GUIDAGE
Diamètre du cercle intérieur est de 2.5 mm
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20
10
0
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croix :
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Revoir le guidage
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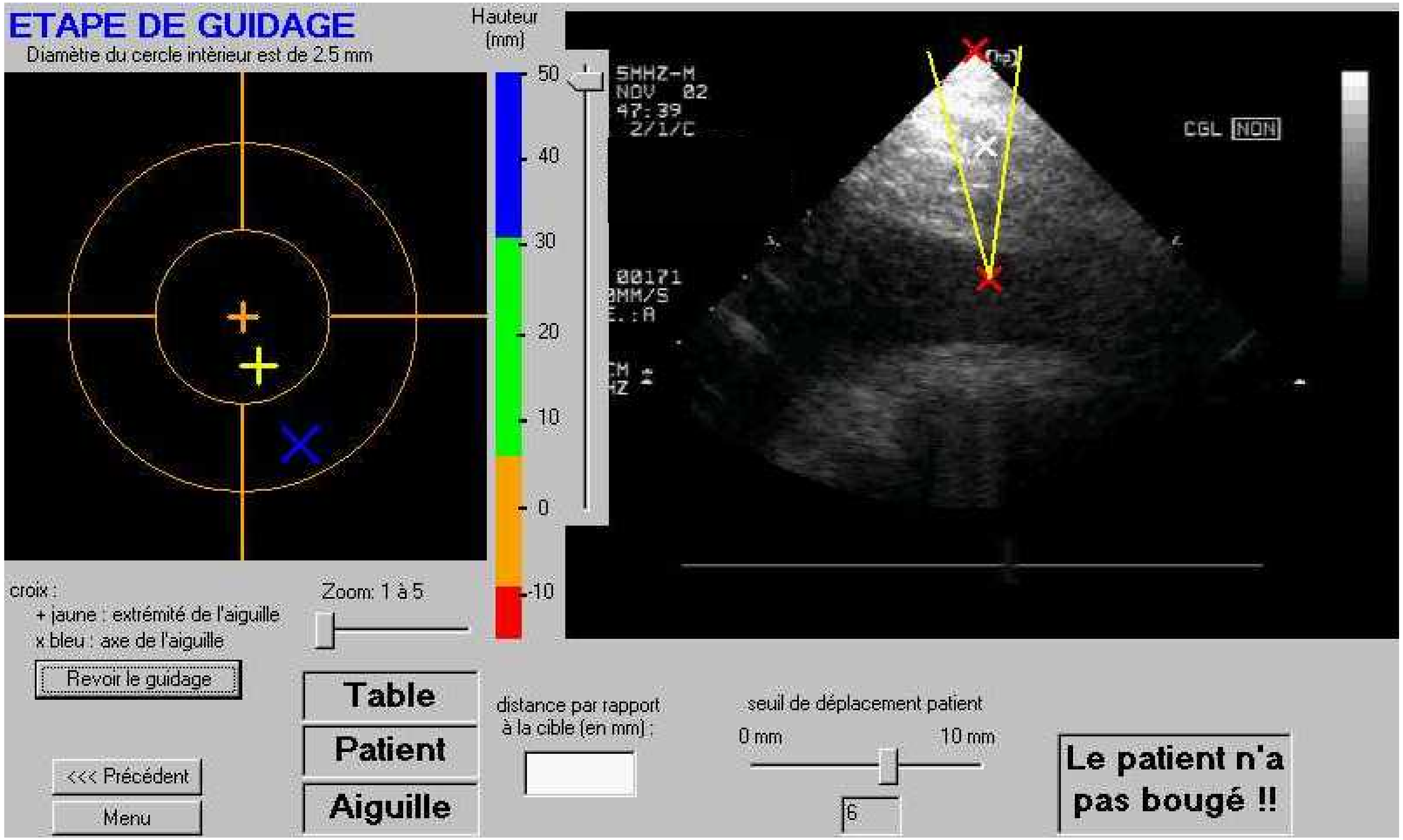
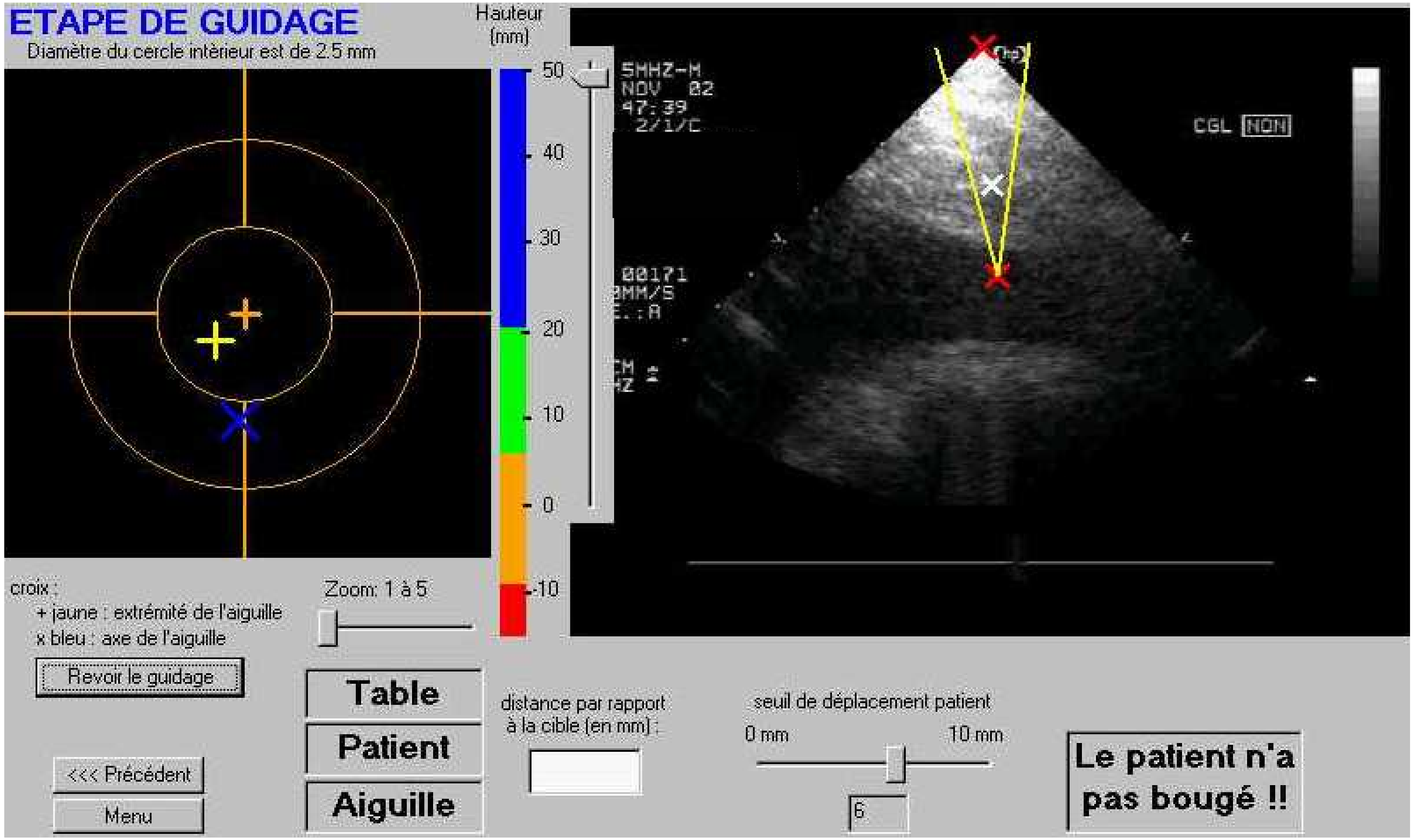
seuil de déplacement patient
0 mm
10 mm
6
<<< Précédent
Menu
Le patient n'a pas bougé !!


ETAPE DE GUIDAGE
Diamètre du cercle intérieur est de 2.5 mm
Hauteur (mm)
50
40
30
20
10
0
-10
5MHZ-M
NOV 02
47:39
2/1/C
CGL NON
croix :
+ jaune : extrémité de l'aiguille
x bleu : axe de l'aiguille
Revoir le guidage
Zoom: 1 à 5
Table
Patient
Aiguille
distance par rapport à la cible (en mm) :
seuil de déplacement patient
0 mm
10 mm
6
Le patient n'a pas bougé !!
<<< Précédent
Menu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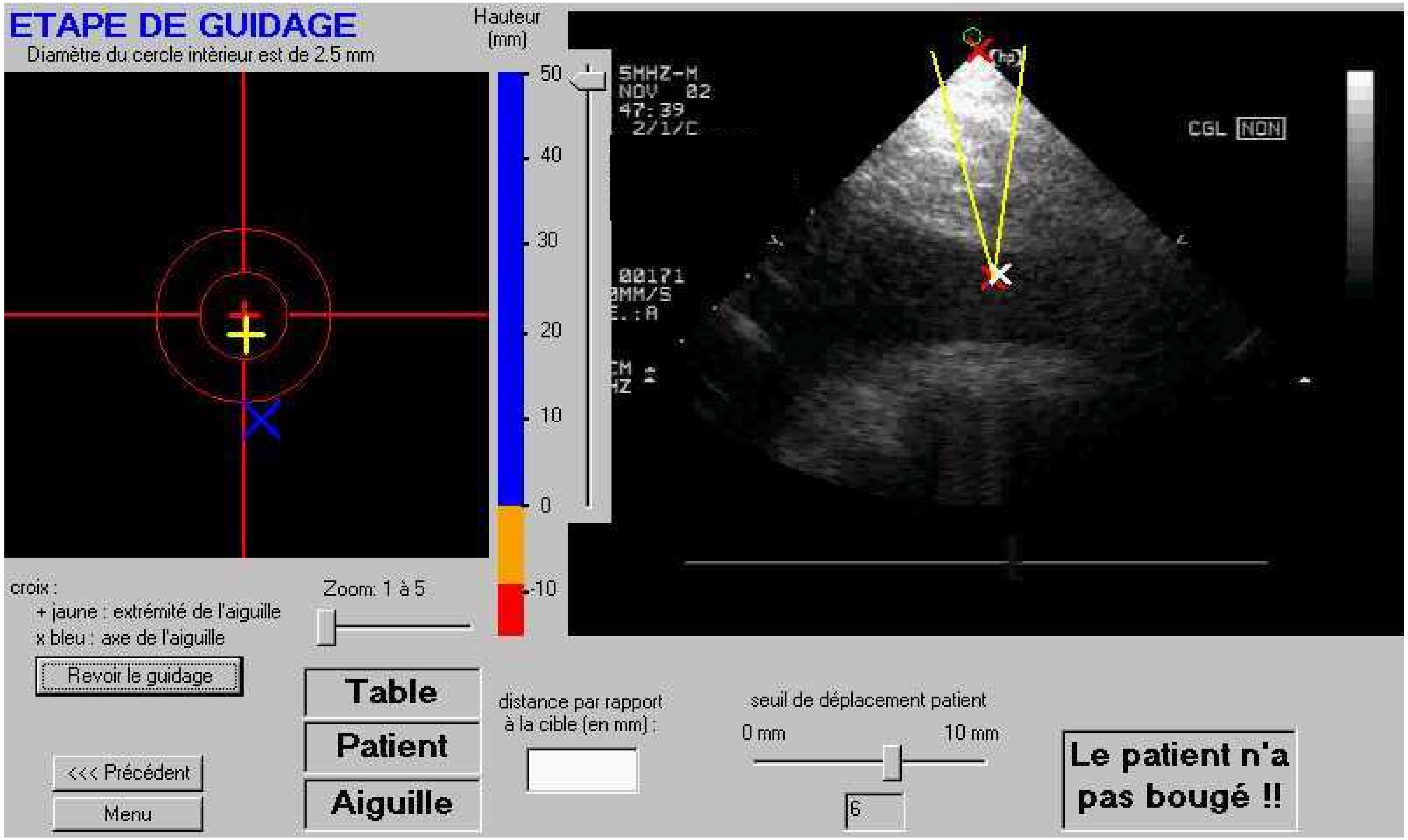
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Menu
Le patient n'a pas bougé !!

CASPER - Results

- In vivo validation was performed on a porcine model with an accuracy of at least 2.5mm

Chavanon et al. Accurate guidance for percutaneous access towards a specific target in soft tissues. Preclinical study of computer assisted pericardiocentesis. *J Laparoendosc Adv Surg Tech* 1999;9:259-66.

- A phase of improvement have been implemented

Chavanon et al. Computer guided pericardiocentesis : experimental results and clinical perspectives. *Herz* 2000;25:761-768

- A successful procedure was performed on a patient

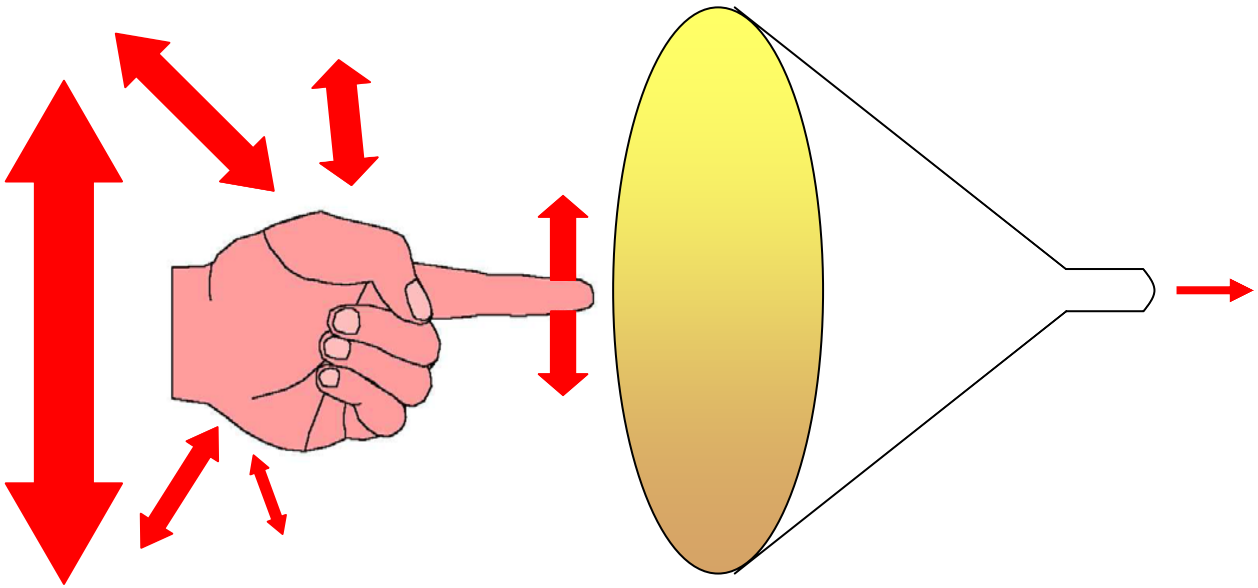
Marmignon et al. CASPER, a Computer ASsisted PERicardial puncture system. First clinical results. *Comput Aid Surg (in press)*

CASPER - Comments

- The assessment of accuracy is problematic: virtual target
- The precision is limited by many factors :
  - a strict immobility is required between acquisition and puncture
  - deformability of soft tissue (echography & puncture)
  - precision of the localizer
  - quality of calibration (echographic probe & needle)
  - precision of computing
  - quality of modeling
    - lost of information: size of the images set (cardiac & respiratory cycle)
    - segmentation accuracy
  - difficulties in performing the puncture
    - deformability of soft tissue, buckling of the needle
    - tiredness of the operator, lost of concentration
- Heaviness of the procedure
- Learning curve

CASPER - Perspectives

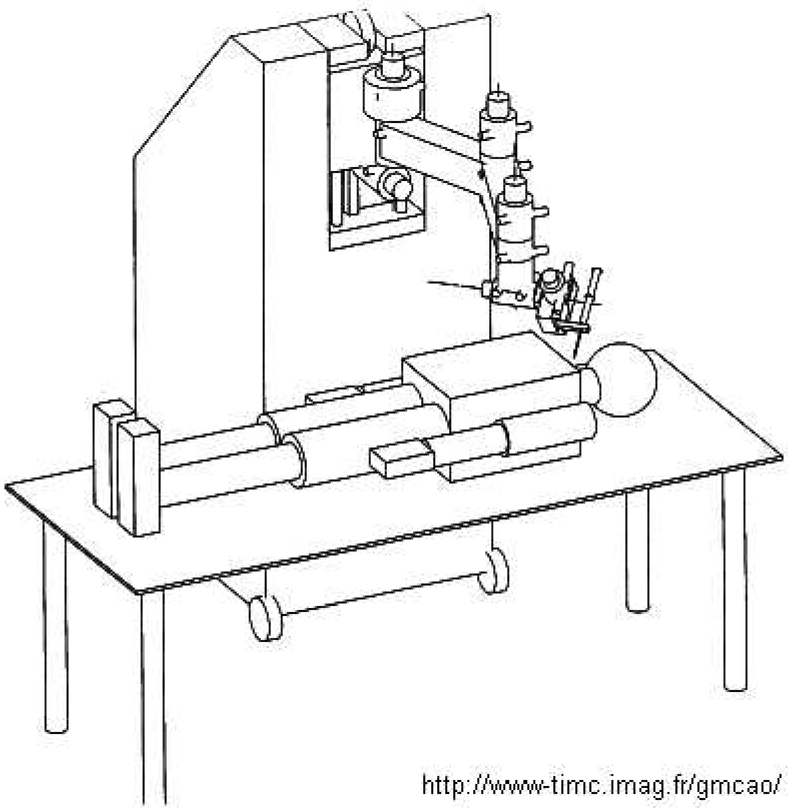
CASPER - Perspectives



PADyC

Passive Arm with Dynamic Constraint

CASPER - PADyC



The surgeon is free to propose any direction of motion to the arm
The system filters these moves to keep only those which are compatible with the pre-planned task

CASPER - PADyC

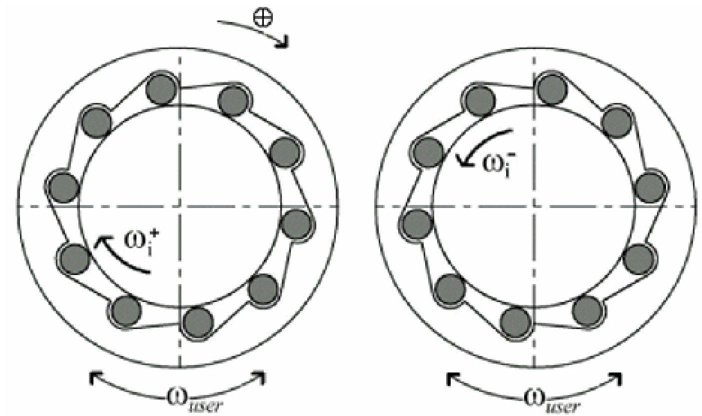
- Passive arm with dynamic constraint
  - Purely passive device
  - Each encoded joint is equipped with a patented mechanism:

2 freewheels mounted in opposition and

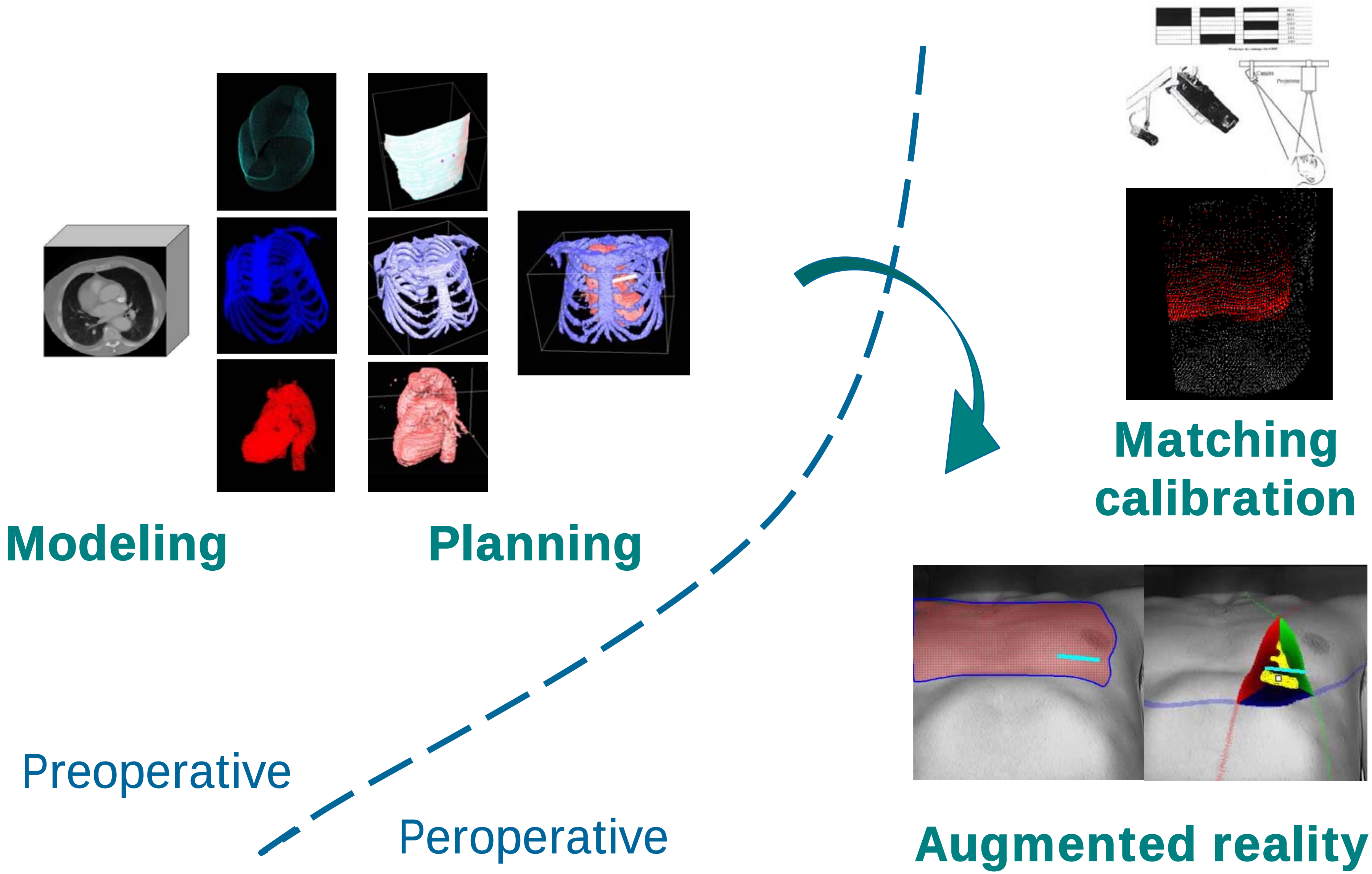
2 electrical motors: clutch or unclutch the freewheels independently

In each joint there are 4 possible functions:

- F1 : joint can be moved in forward and backward directions
- F2 : joint can be moved in forward direction only
- F3 : joint can be moved in backward direction only
- F4 : joint cannot be moved



Preoperative planning in MICS



Conclusions