THEORY & TECHNIQUES OF COUNTERPULSATION THERAPY
CARDIOSAVE

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Course Description

- A four hour program designed for health care professionals with a sound understanding of hemodynamics who will be directly responsible for the care of patients requiring IABP therapy
- Comprised of theoretical, clinical and technical considerations for a patient requiring IABP therapy

Behavioral Objectives

At the conclusion of this program, the participants will be able to:

- Describe the two physiological effects achieved by the mechanics of inflation and deflation of the IAB as it relates to the cardiac cycle illustrated by an augmented arterial pressure waveform
- Identify four indications and three contraindications for IABP therapy
- Delineate the major clinical complications associated with IABP therapy
- Discuss operation and troubleshooting of the MAQUET IABP

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Program Overview

- Introduction
- Overview of Cardiac Performance
- IAB Catheter Sizing & Placement
- Theory of Counterpulsation
- Timing & Timing Errors
- Triggers
- Factors Affecting Diastolic Augmentation
- 15 Minute Break
- Indications/Contraindications
- Side Effects & Complications/Patient Assessment
- Technical Aspects – IAB/IABP
- Hands-on/Troubleshooting
- Q & A – Wrap Up

OVERVIEW OF CARDIAC PERFORMANCE

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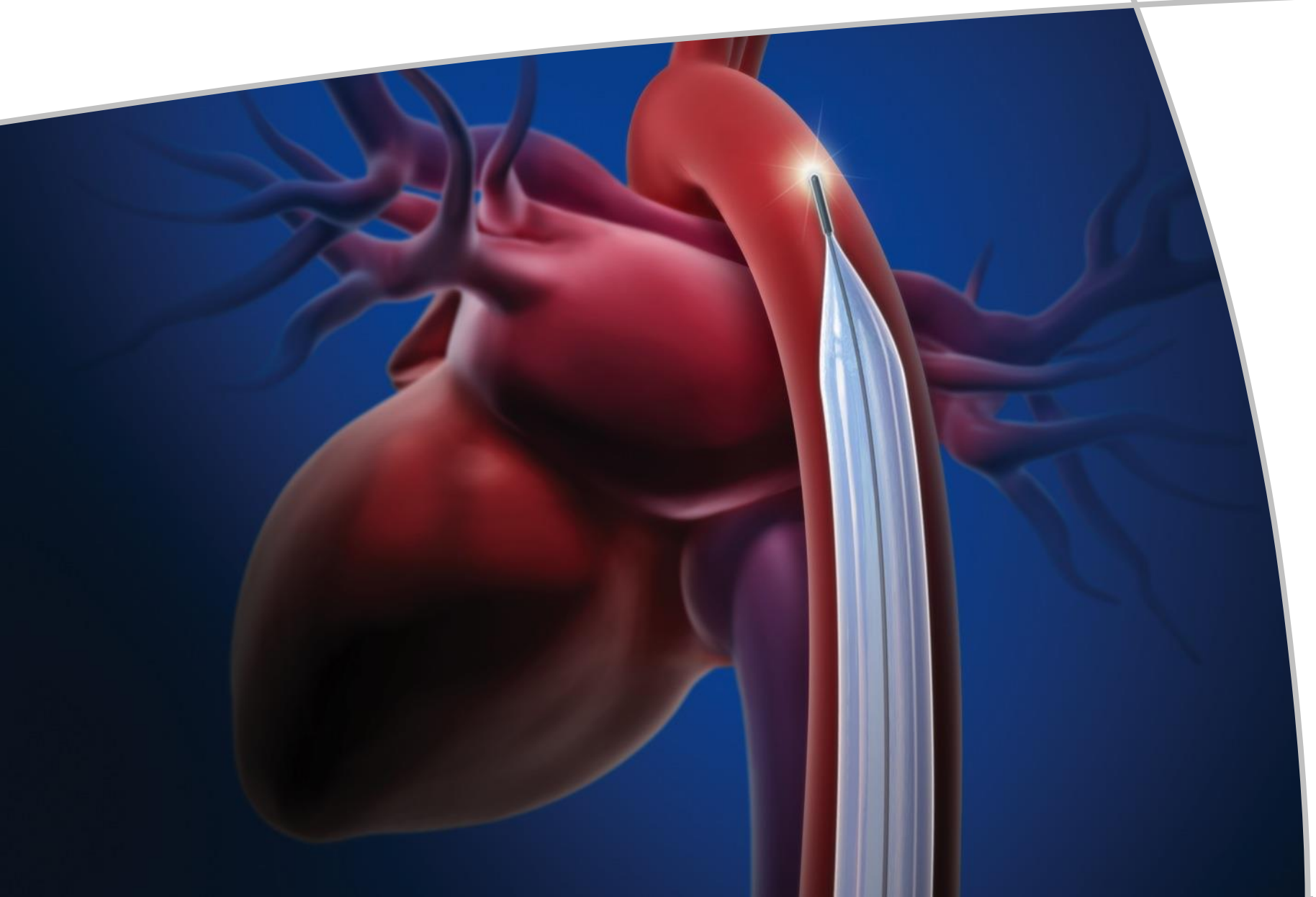

OVERVIEW OF CARDIAC PERFORMANCE

- Coronary perfusion
  - Coronary artery anatomy
  - Diastolic time/pressure
- Oxygen extraction
  - Hemoglobin & PaO_2
- Heart rate
- Afterload
- Preload
- Contractility

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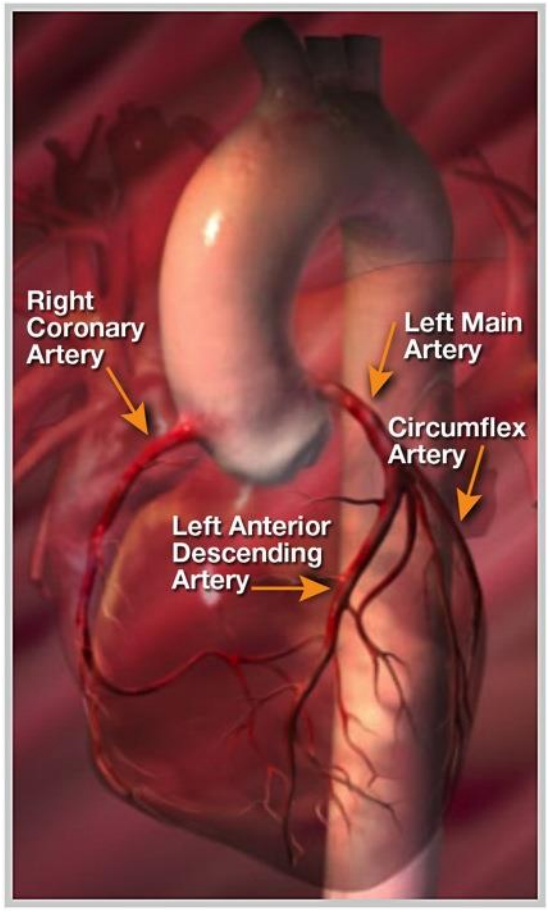
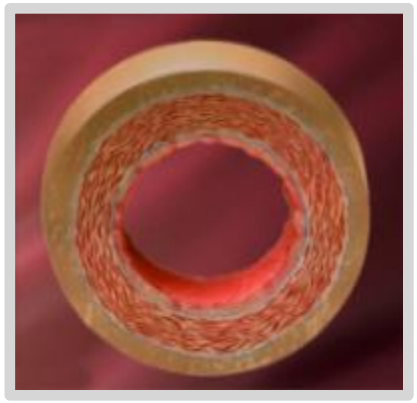
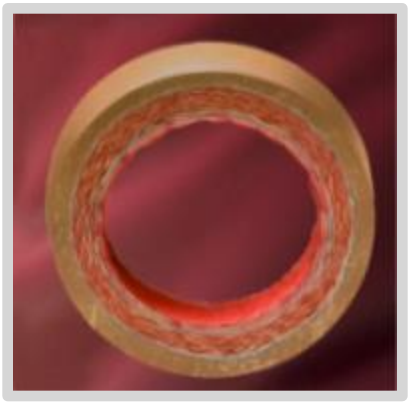
Oxygen Supply - Coronary Anatomy



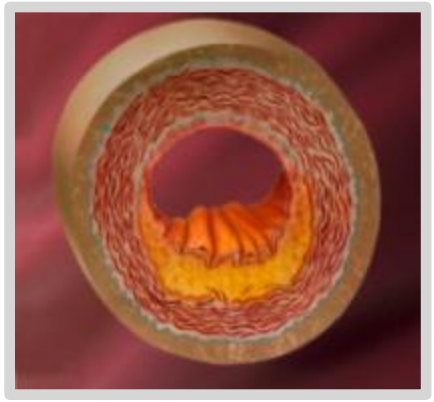
Coronary Arteries



Normal



Autoregulation



70% or < occlusion

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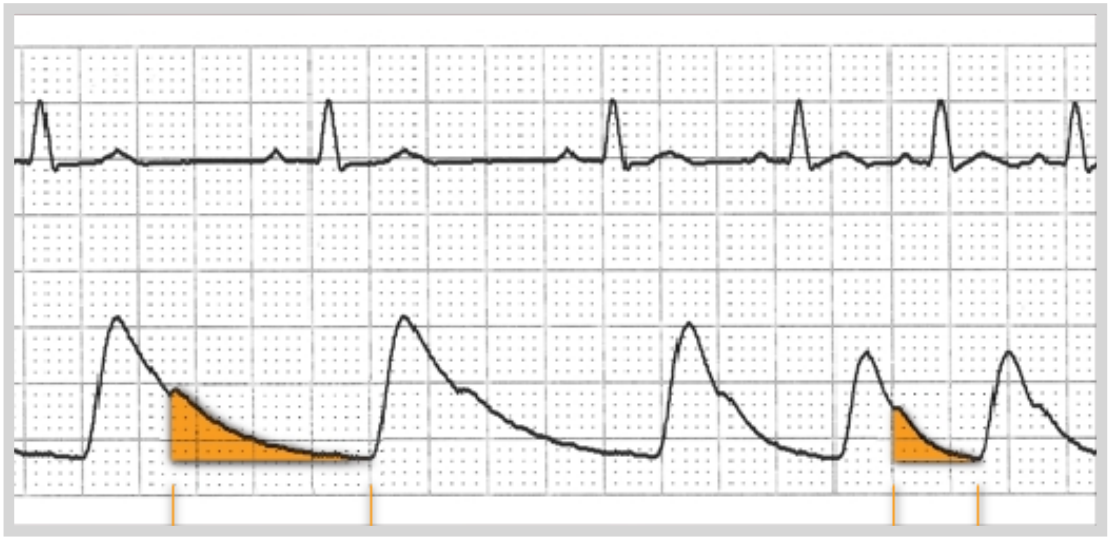
Oxygen Supply - Diastolic Time/Pressure



Diastolic Phase
60 BPM

Diastolic Phase
130 BPM

- Decreased diastolic filling time = decreased stroke volume
- Decreased diastolic pressure = decreased myocardial oxygen supply

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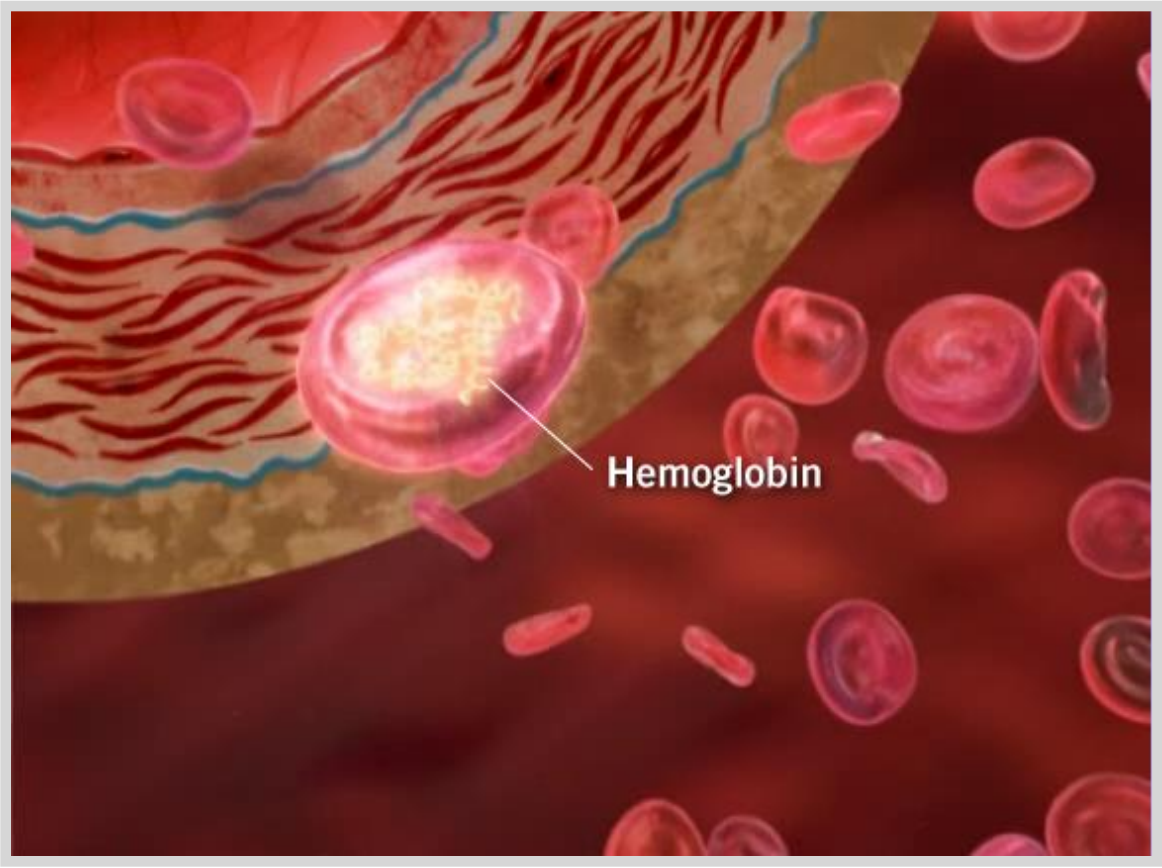
Oxygen Supply - Hgb & PaO_2



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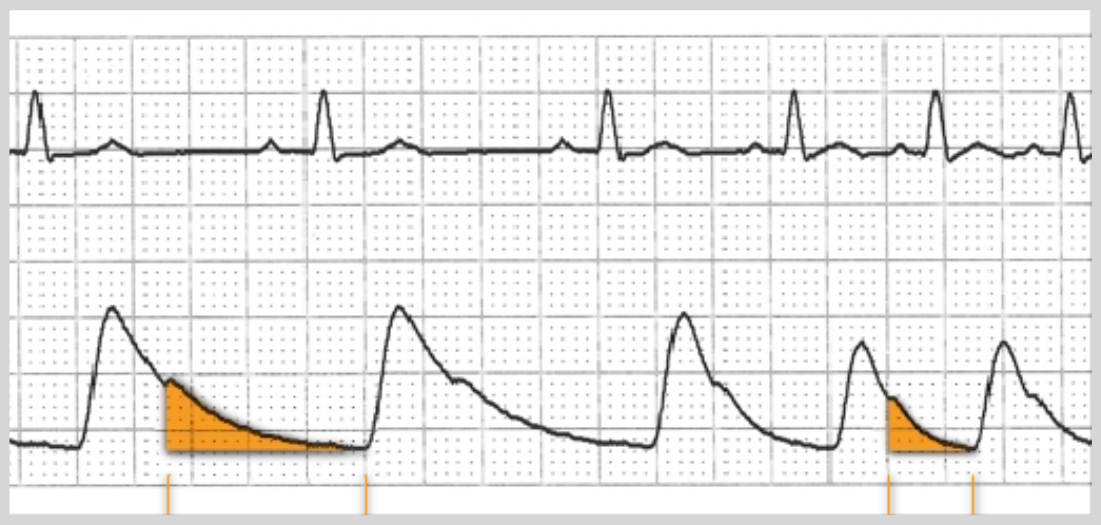
Oxygen Demand - Heart Rate



Diastolic Phase
60 BPM

Diastolic Phase
130 BPM

- Increased heart rate = increased demand for myocardial oxygen

Oxygen Demand - Afterload (Left Side)

Resistance left ventricle has to overcome to eject blood from heart

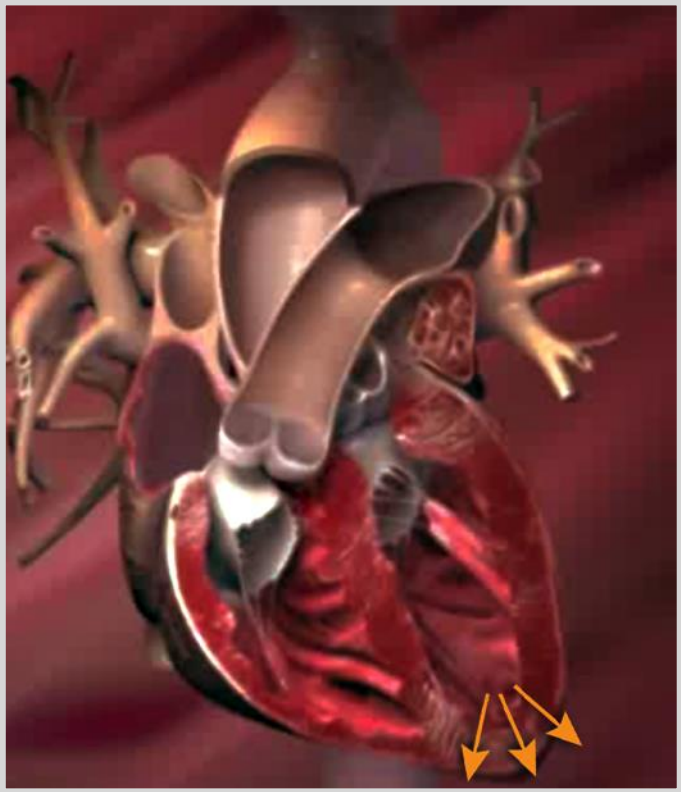
- Measured by Systemic Vascular Resistance (SVR)
  - Normal values: 900 - 1400 dynes/s/cm^{-5}

Klein DG. AACN Procedure Manual for Critical Care. 6th Edition 2011; 578-579

Oxygen Demand - Preload (Left Side)

Volume of blood in left ventricle at end of diastole, creating a “stretch” in muscle fibers

- Measured by Pulmonary Artery Wedge Pressure (PAWP)
  – Normal values: 4-12mmHg



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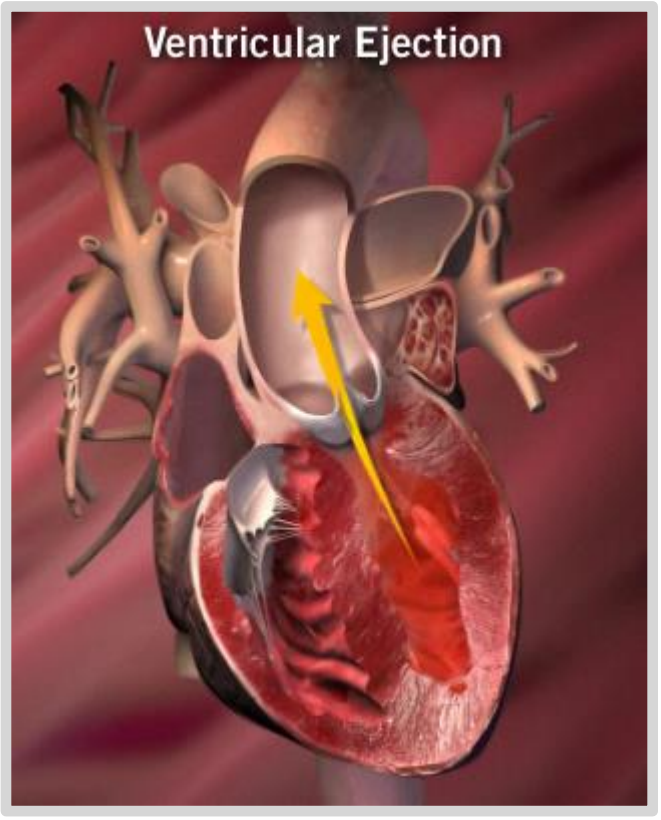
Oxygen Demand - Contractility

Ability of muscle fibers to contract in order to eject blood into the circulation

- Measured by Ejection Fraction (EF)
  - Normal values: 60% - 75%



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IAB CATHETER SIZING & PLACEMENT

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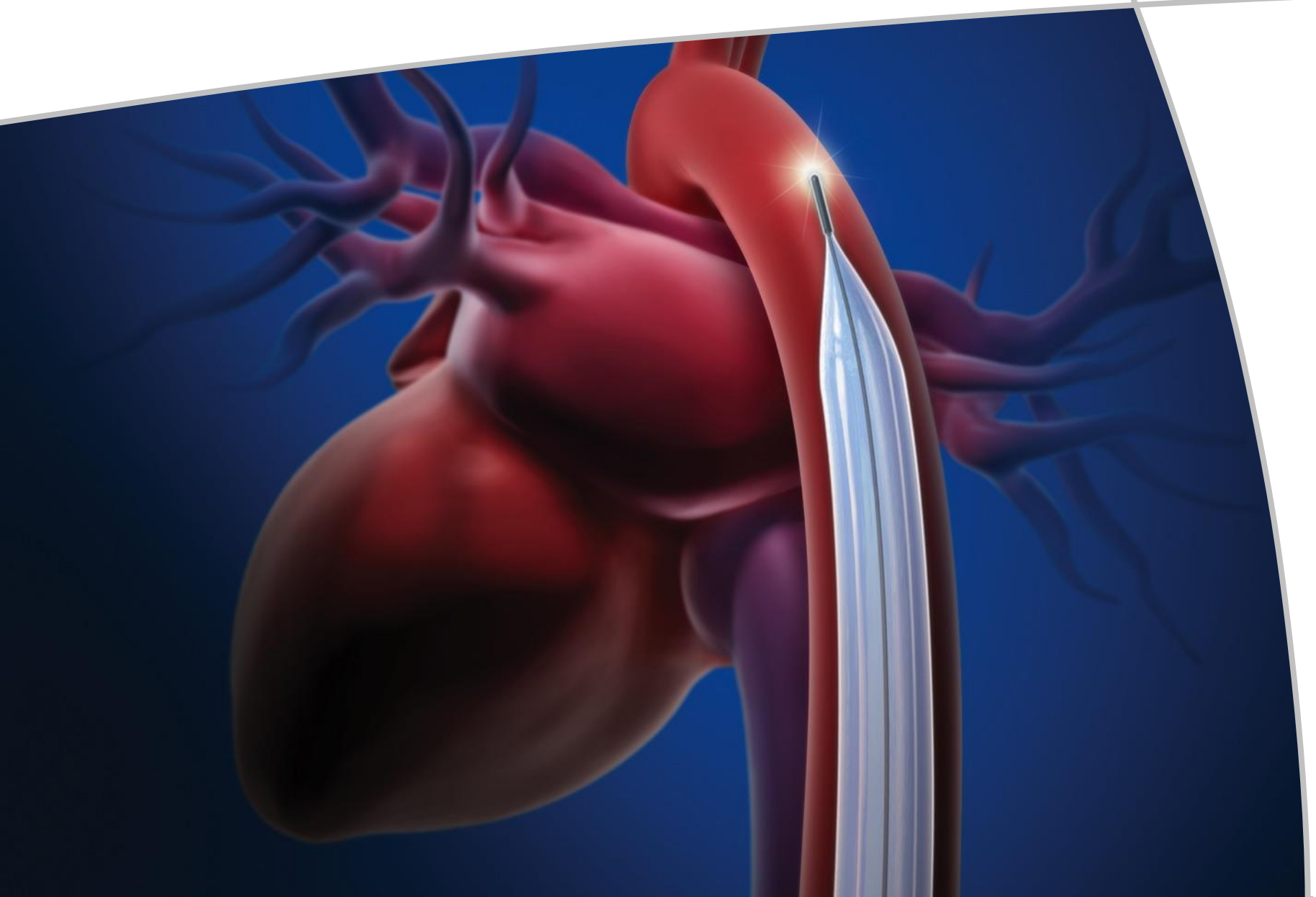

IAB CATHETER SIZING & PLACEMENT

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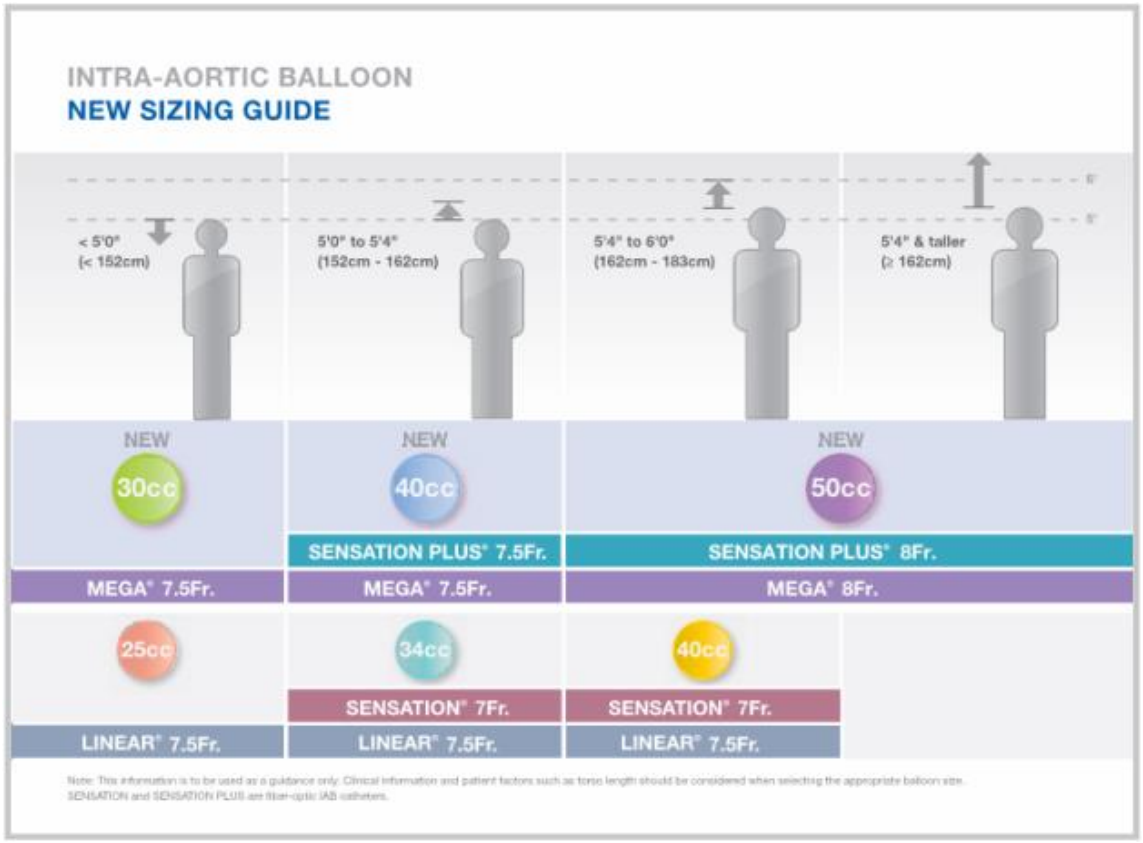
Intra-Aortic Balloon
New Clinical Reference Sizing Guide



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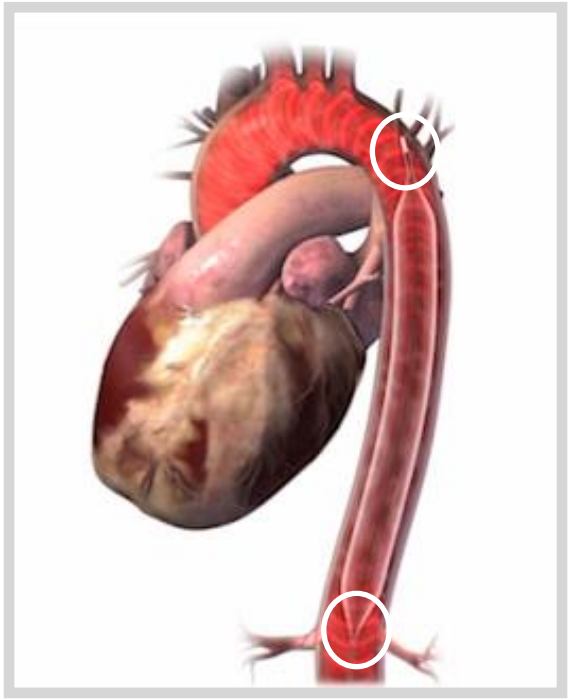
Proper placement of IAB catheter

- Tip of IAB catheter
  - Positioned approximately 1 to 2cm distal to the left subclavian artery
- Base of balloon
  - Positioned above renal arteries



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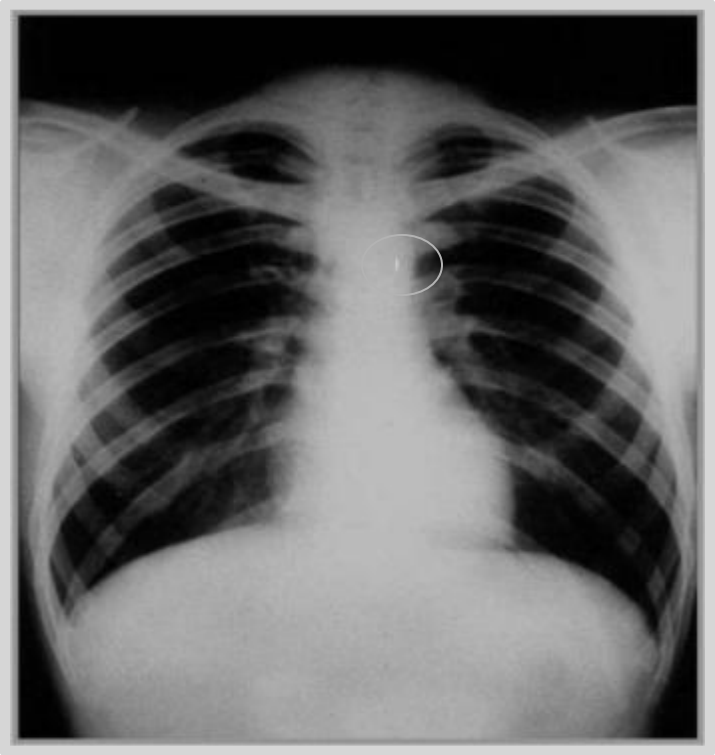
Verification of proper placement



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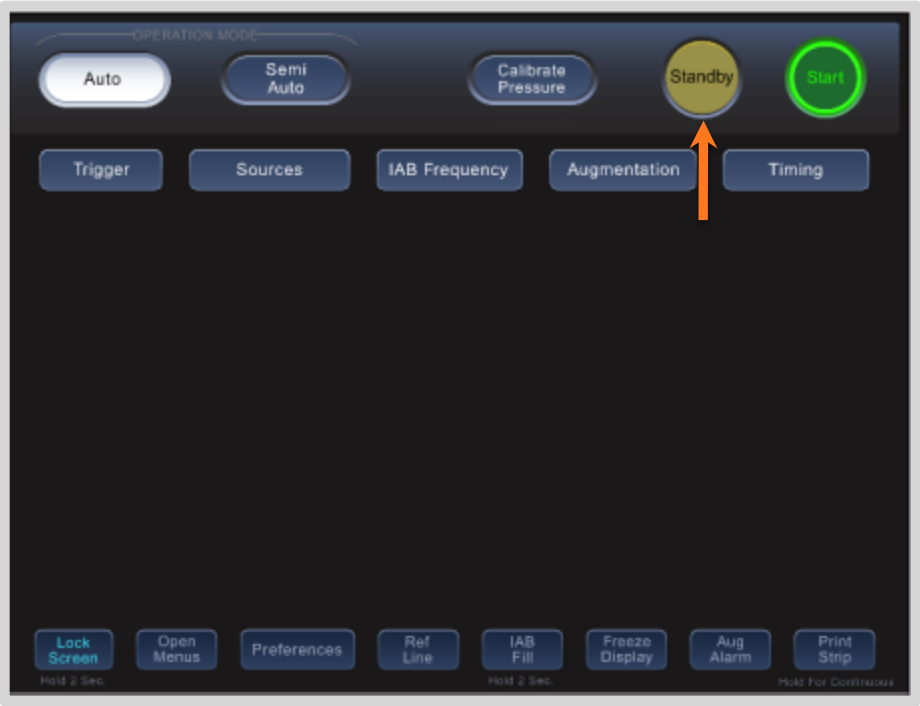
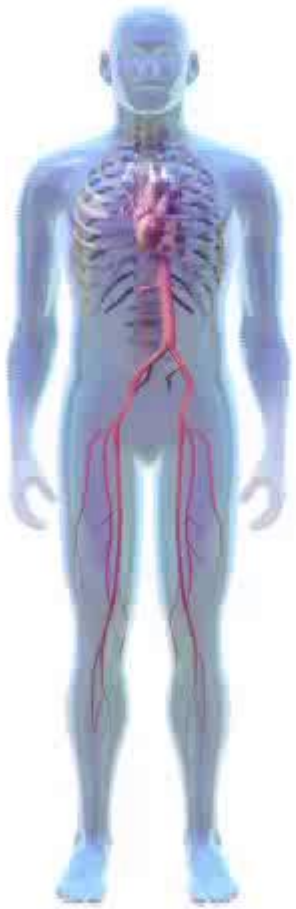
Important tips to remember

- Whenever possible, use fluoroscopy
- If fluoroscopy is not used, a CXR should be taken as soon as possible after insertion to identify placement
- Place IABP in Standby when obtaining CXR to enhance visualization of IAB tip



IAB CATHETER SIZING & PLACEMENT



THEORY OF COUNTERPULSATION

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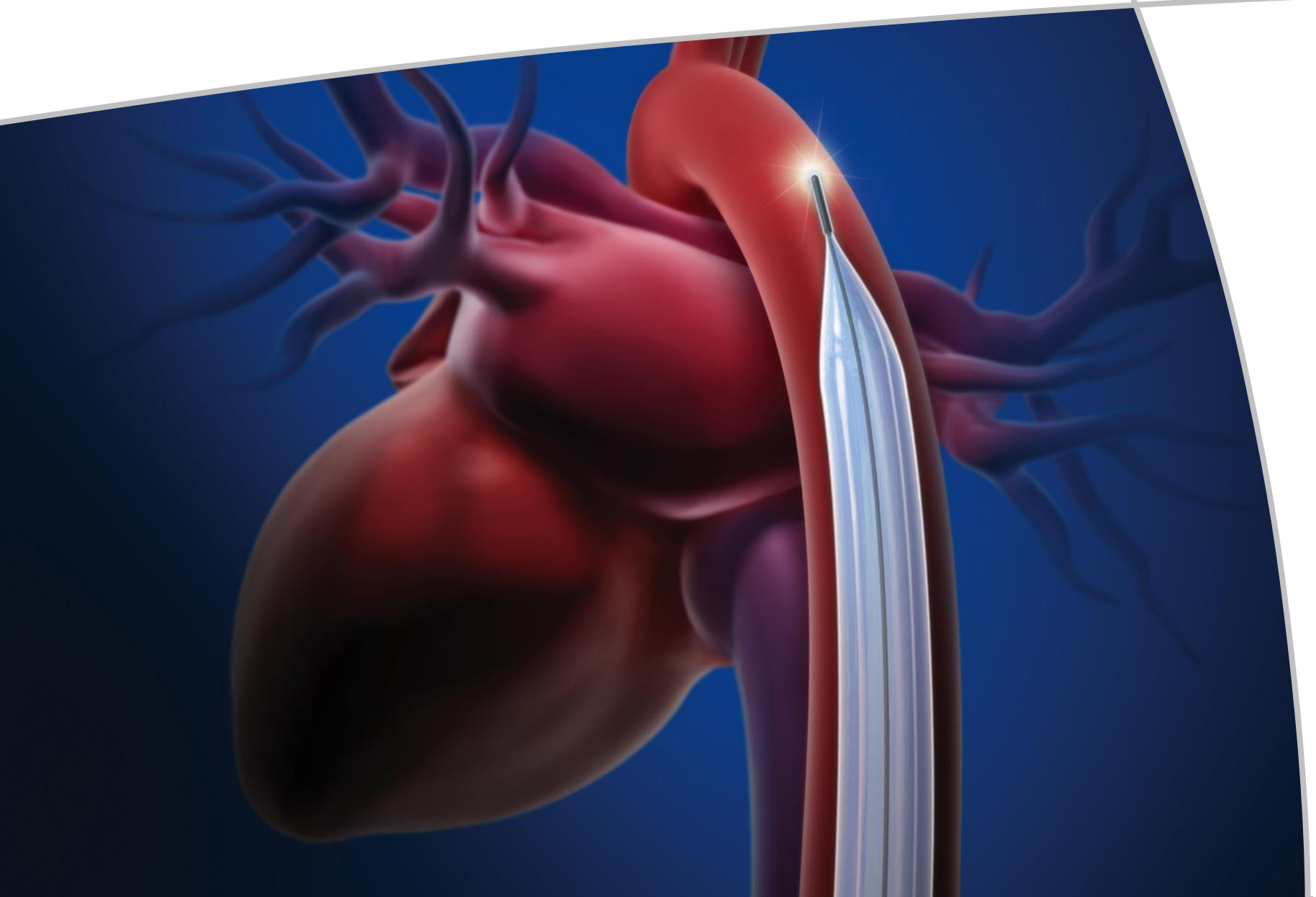
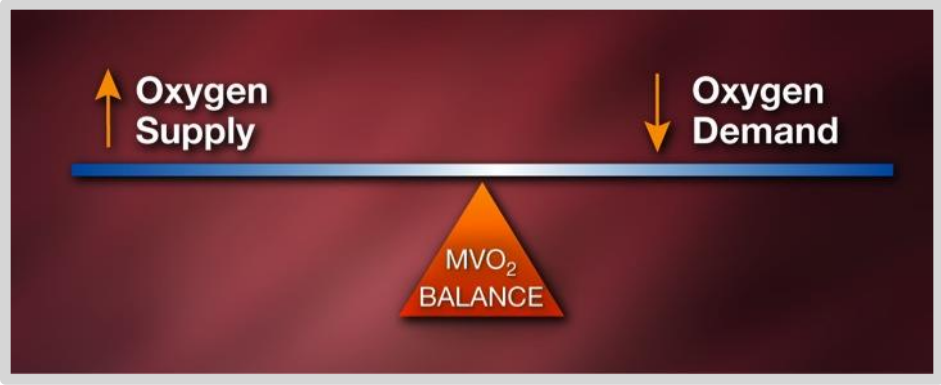


THEORY OF COUNTERPULSATION

Primary Goal of IABP Therapy



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IAB Inflation:
Increases supply of oxygen to myocardium

How it works

- Balloon inflates at onset of diastole (when aortic valve closes)
- Displaces blood, causing an increase in aortic pressure (known as augmentation)

Benefits

- Increases coronary artery perfusion
- Increases mean arterial pressure

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IAB Deflation:
Decreases demand for oxygen by left ventricle

How it works

- Balloon deflates just prior to systolic ejection (before aortic valve opens)
- Results in a rapid decrease in aortic pressure

Benefits

- Decreases afterload
- Decreases cardiac workload
- Increases cardiac output

THEORY OF COUNTERPULSATION

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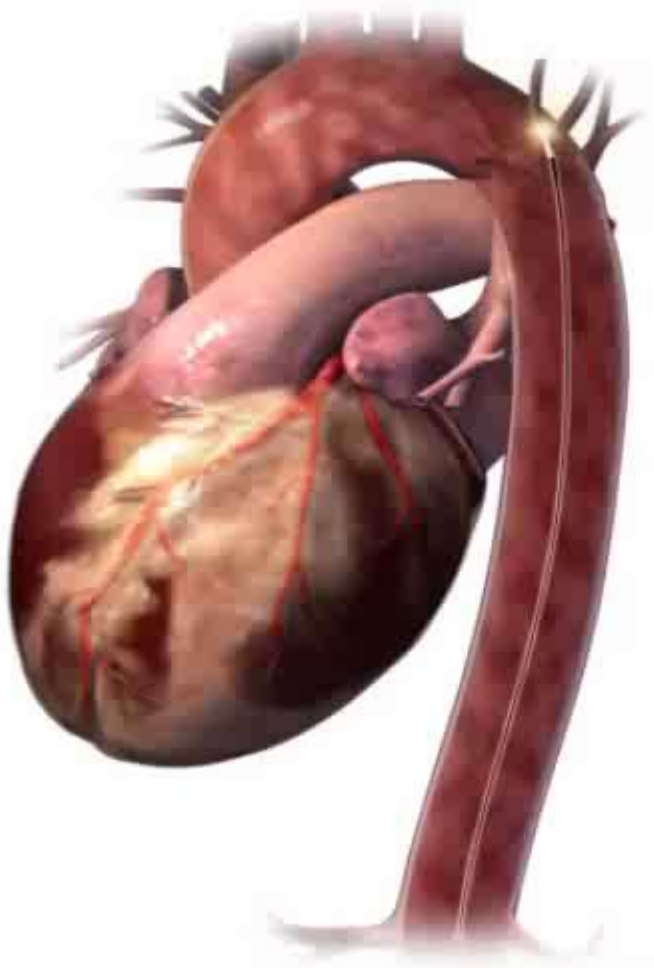

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What are the effects of IABC therapy on the following?

- Coronary perfusion ↑
- Cardiac output ↑
- Heart rate ↓
- PAWP ↓
- SVR ↓
- Systolic BP ↓
- Diastolic pressure with balloon inflation ↑
- End diastolic BP ↓
- MAP ↑
- Systemic perfusion (neurologic, respiratory, renal, vascular) ↑

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Review Questions

1. The IAB inflates when the aortic valve **closes**
2. The IAB deflates just before the aortic valve **opens**
3. The IAB is inflated during which phase of the cardiac cycle? **diastole**
4. The IAB is deflated during which phase of the cardiac cycle? **systole**
5. The main benefit of inflation is **increased myocardial oxygen supply**
6. The main benefit of deflation is **decreased myocardial oxygen demand**

TIMING & TIMING ERRORS

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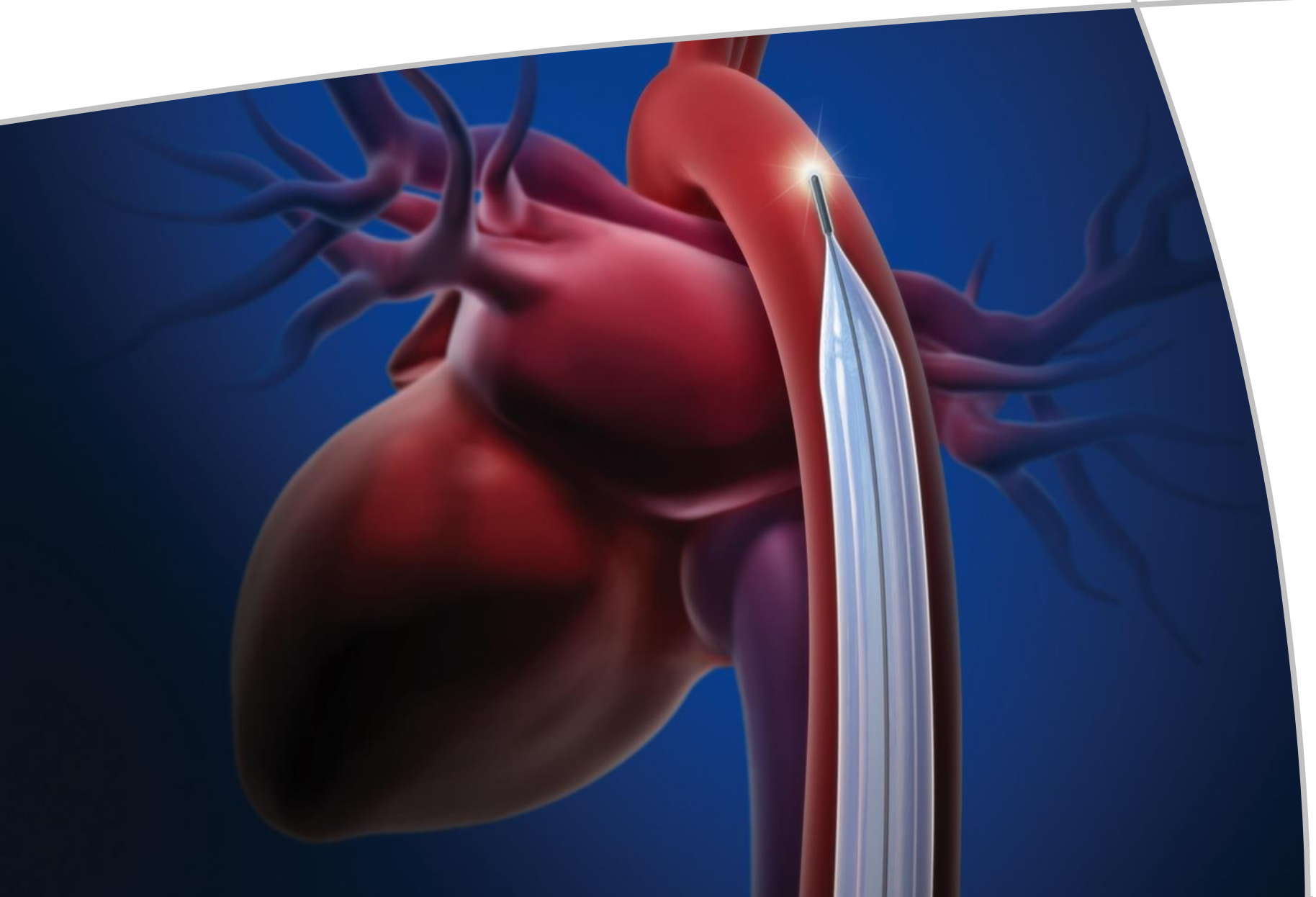

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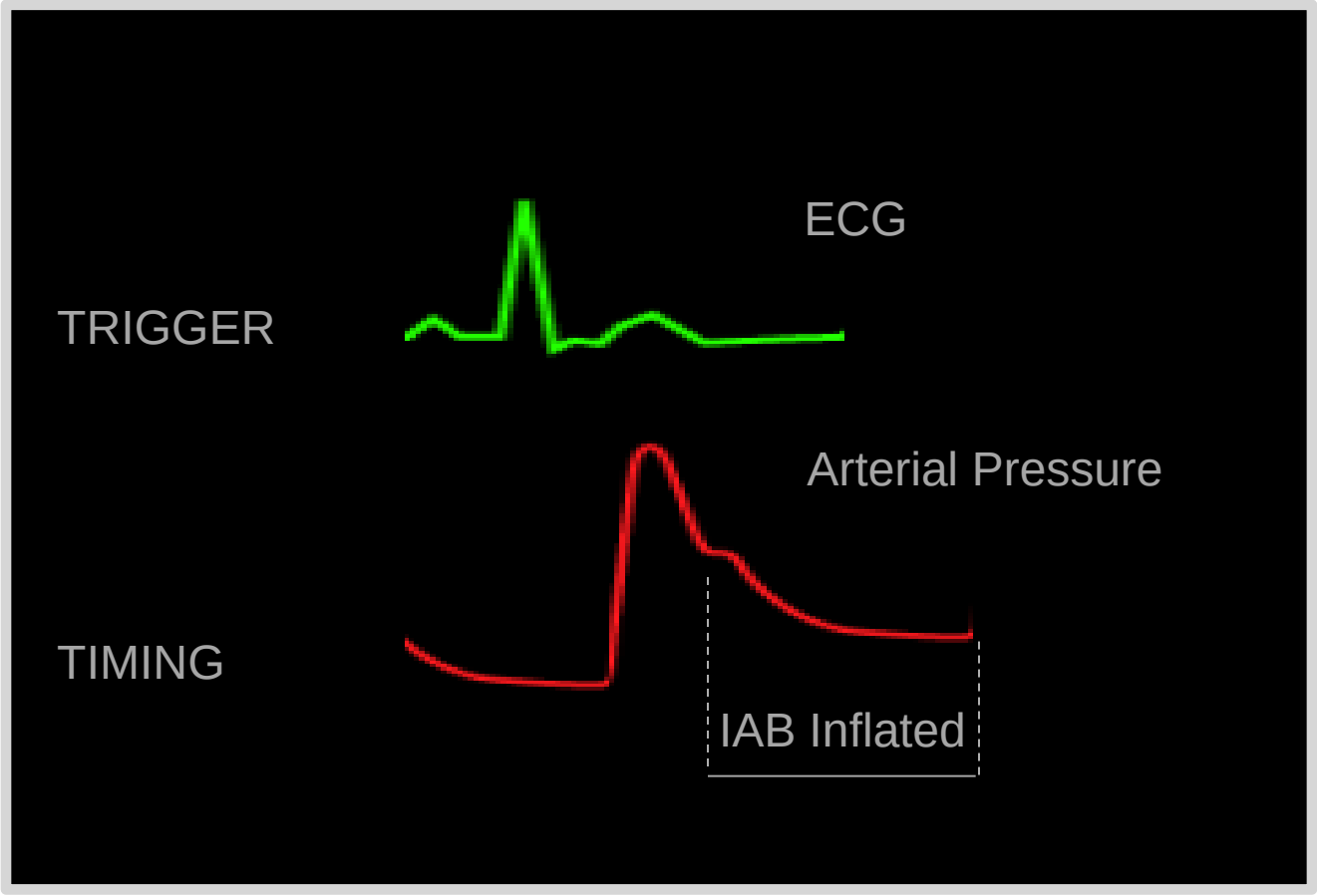
Synchronization with the cardiac cycle



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Timing Assessment

A: Unassisted End Diastolic Pressure

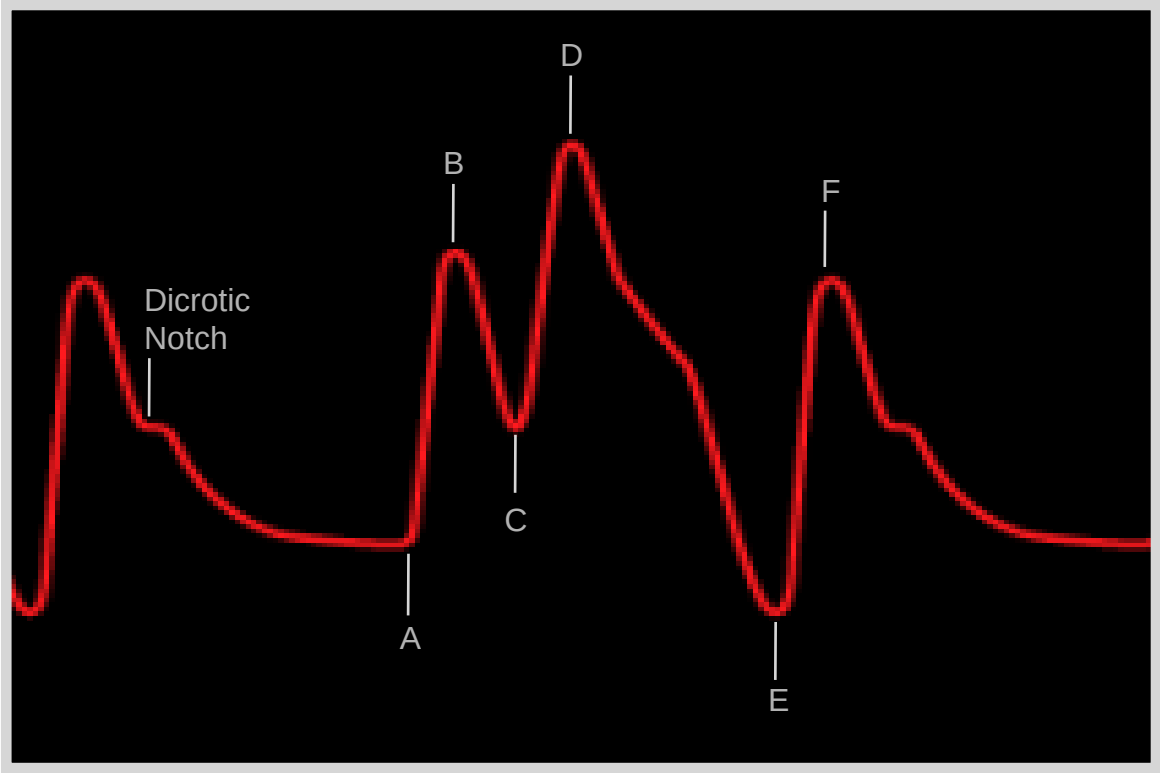
B: Unassisted Systole

C: IAB Inflation

D: Diastolic Augmentation

E: Assisted End Diastolic Pressure

F: Assisted Systole



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Timing

Refers to the positioning of inflate and deflate points on the arterial pressure waveform

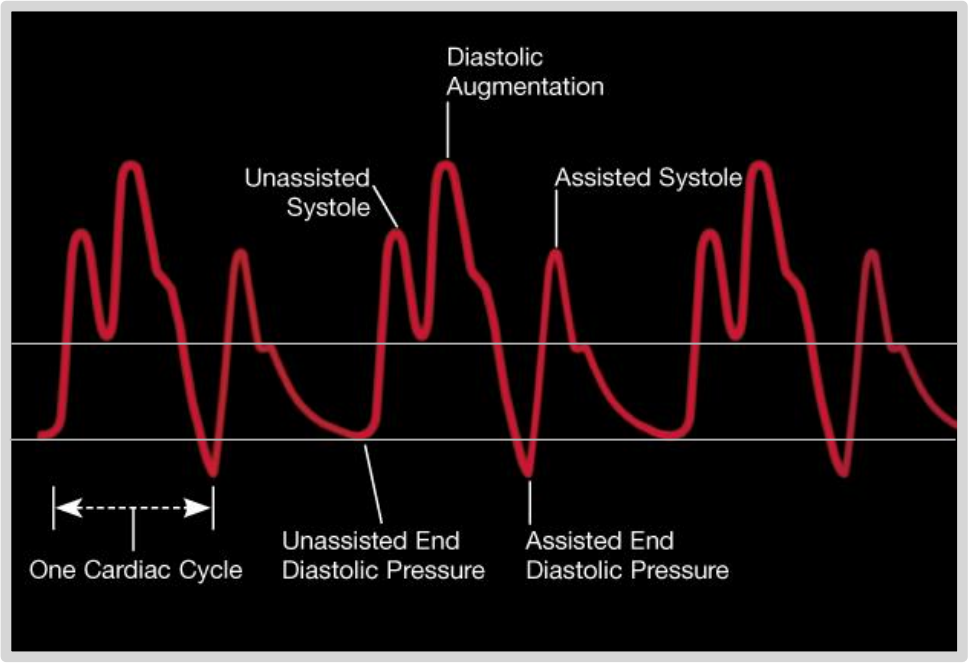
Proper IABP Timing

Inflation

- Occurs at the dicrotic notch
- Appears as a sharp “V”
- Ideally diastolic augmentation rises above systole

Deflation

- Occurs just prior to systolic ejection
- Results in a reduction in assisted end diastolic pressure
- Results in a reduction in assisted systolic pressure



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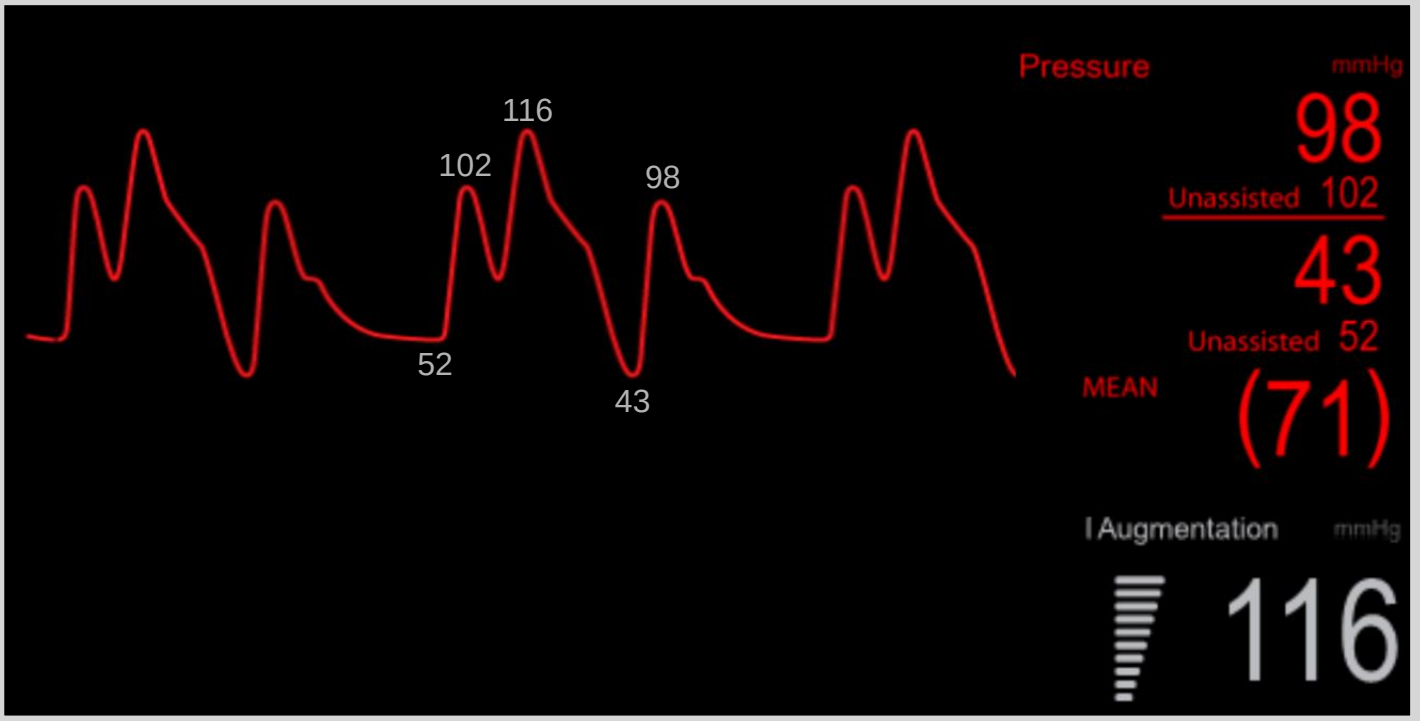
Timing Assessment



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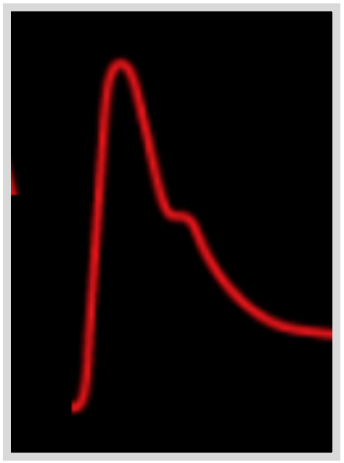
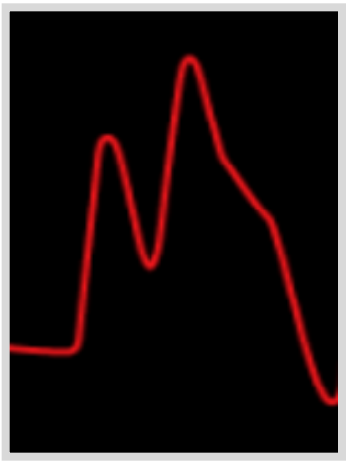
Mean arterial pressure - MAP

Normal arterial mean pressure



- MAP = $\frac{[(2 \times \text{diastolic}) + \text{systolic}]}{3}$

IAB assisted arterial mean pressure



- Augmentation increases mean pressure by increasing pressure and time under the curve
- The pump samples the BP every 4 msec on the pressure waveform = MAP

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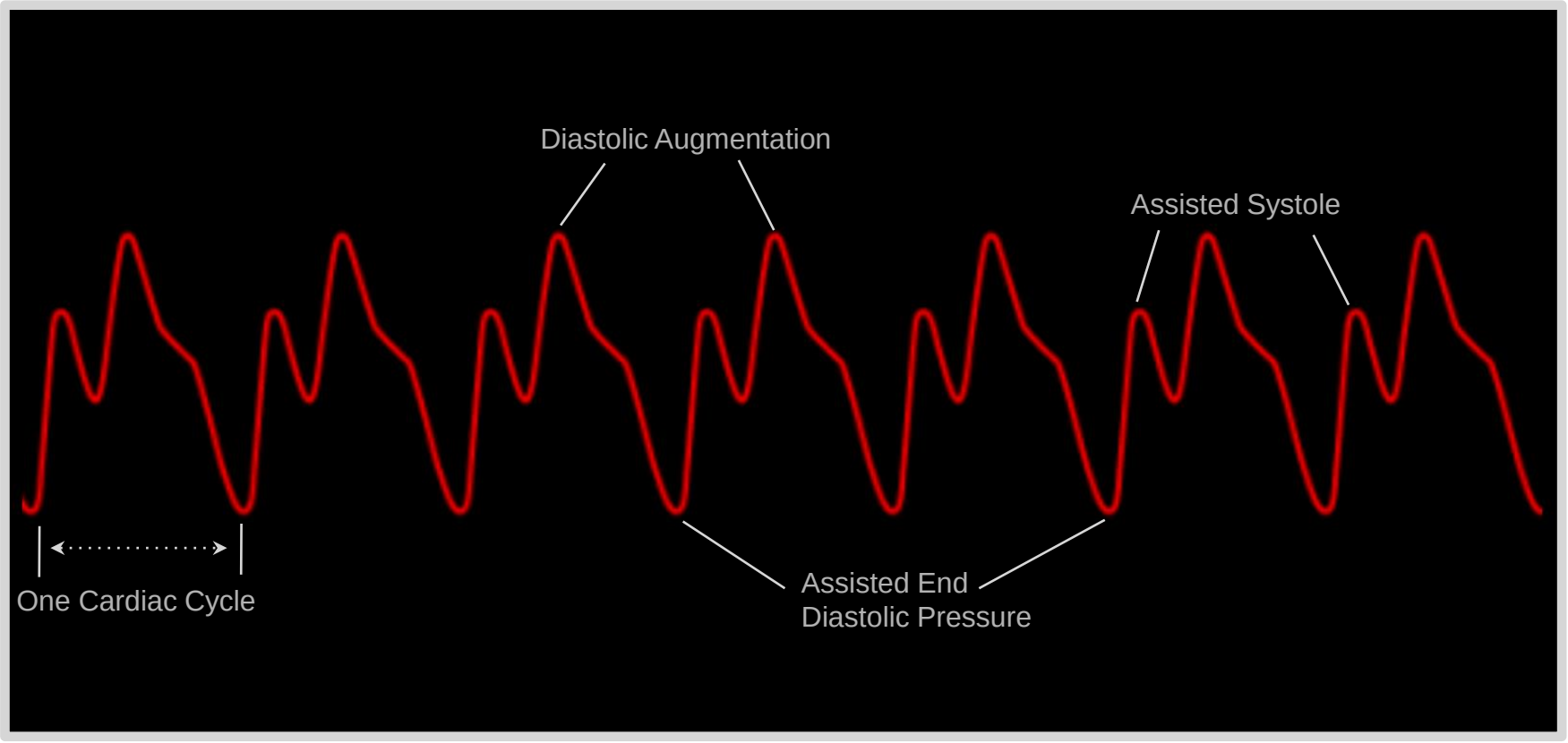
1:1 Frequency



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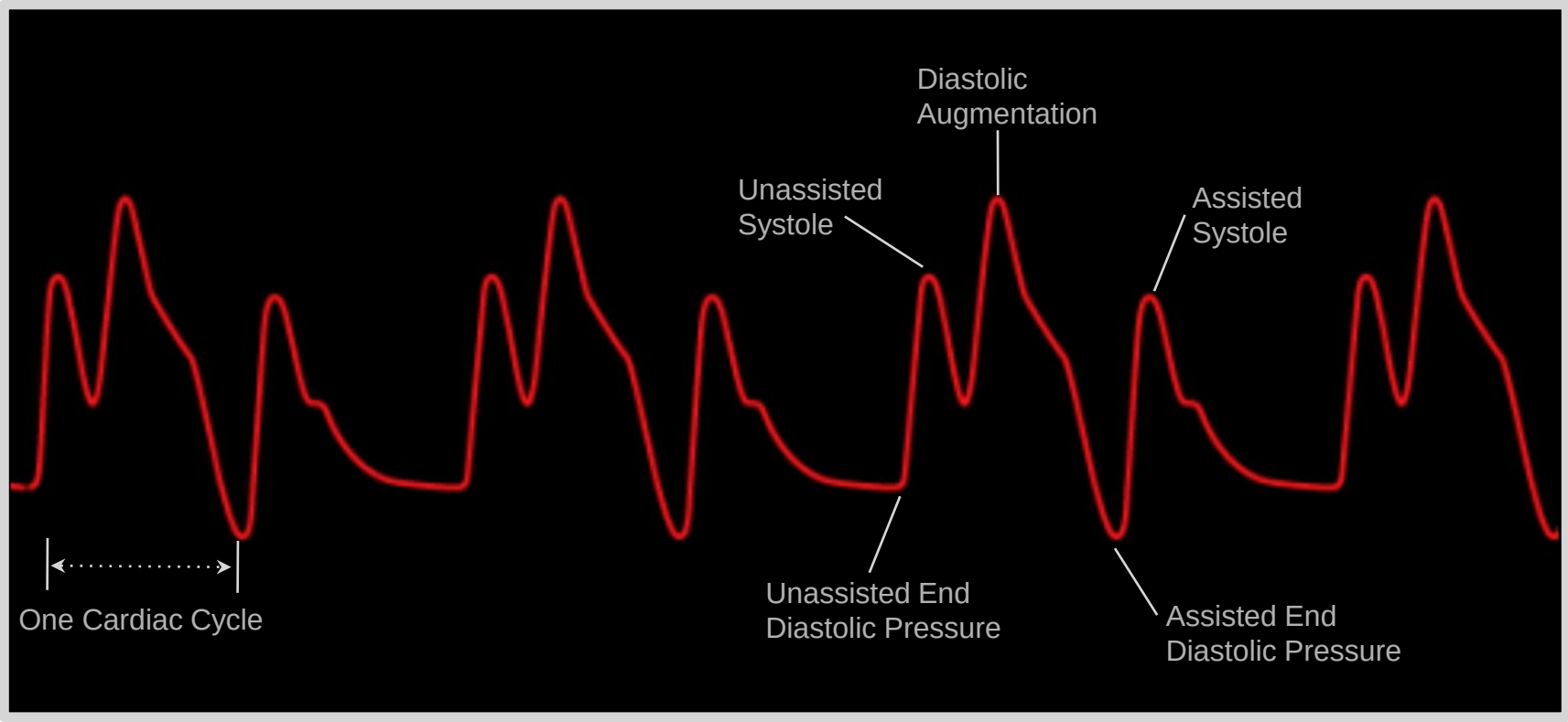
1:2 Frequency



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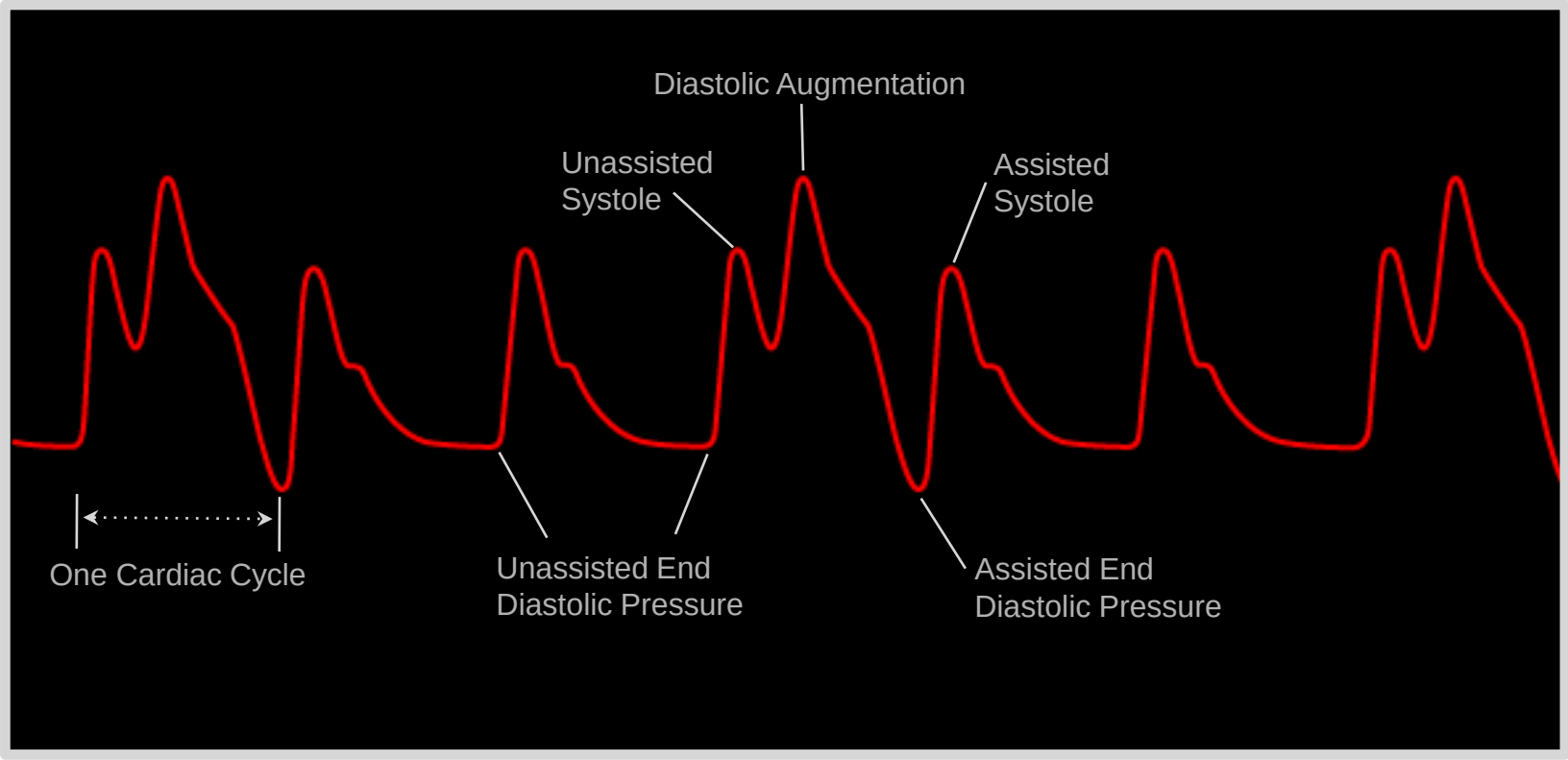
1:3 Frequency



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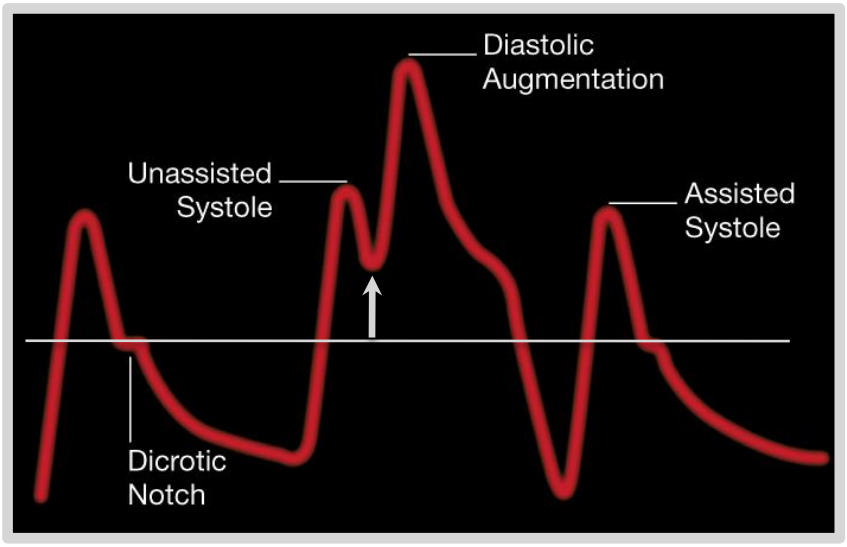
Timing Error – Early Inflation

Inflation of IAB prior to aortic valve closure

Waveform Characteristics

- Inflation of IAB prior to dicrotic notch
- Diastolic augmentation encroaches onto systole (may be unable to distinguish)



Physiologic Effects

- Potential premature closure of aortic valve
- Potential increase in LVEDV/LVEDP/PCWP
- Increased left ventricular wall stress or afterload
- Aortic regurgitation
- Increased MVO_2 demand

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Timing Error – Late Inflation

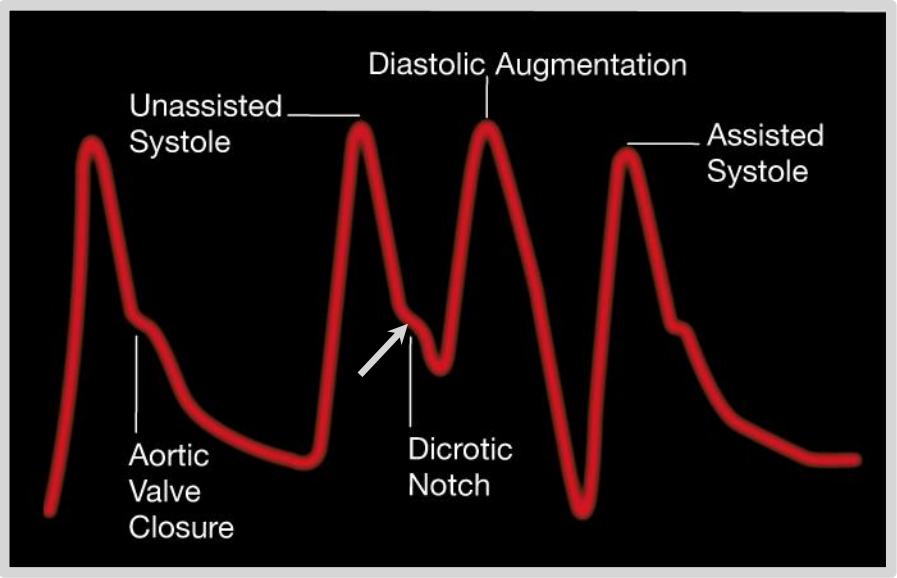
Inflation of IAB markedly after closure of aortic valve

Waveform Characteristics

- Inflation of IAB after dicrotic notch
- Absence of sharp “V”
- Sub-optimal diastolic augmentation

Physiologic Effects

- Sub-optimal coronary artery perfusion



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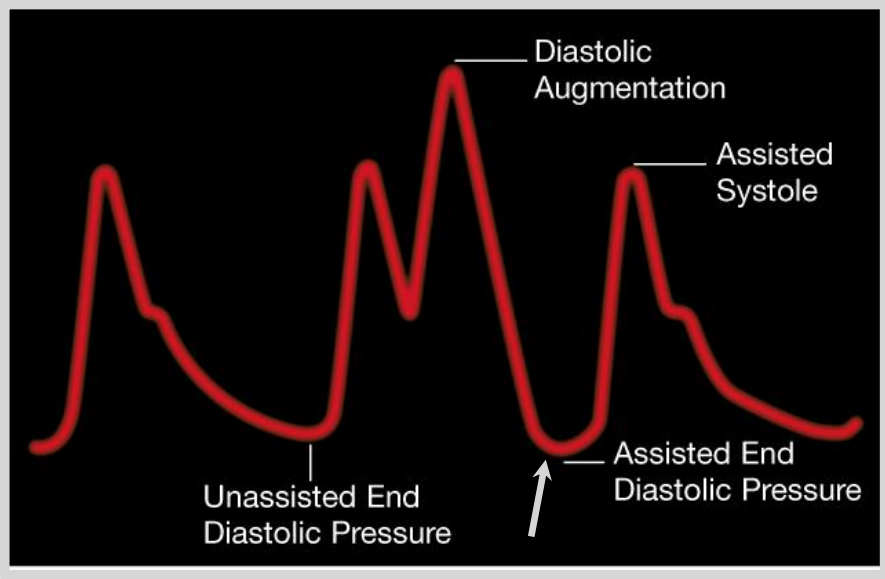
Timing Error – Early Deflation

Premature deflation of IAB during diastolic phase

Waveform Characteristics

- Deflation of IAB is seen as a sharp drop following diastolic augmentation
- Sub-optimal diastolic augmentation
- Assisted end diastolic pressure may be equal to or less than unassisted end diastolic pressure
- Assisted systolic pressure may rise



Physiologic Effects

- Sub-optimal coronary perfusion
- Potential for retrograde coronary and carotid blood flow, which may result in angina
- Sub-optimal afterload reduction
- Increased MVO_2 demand

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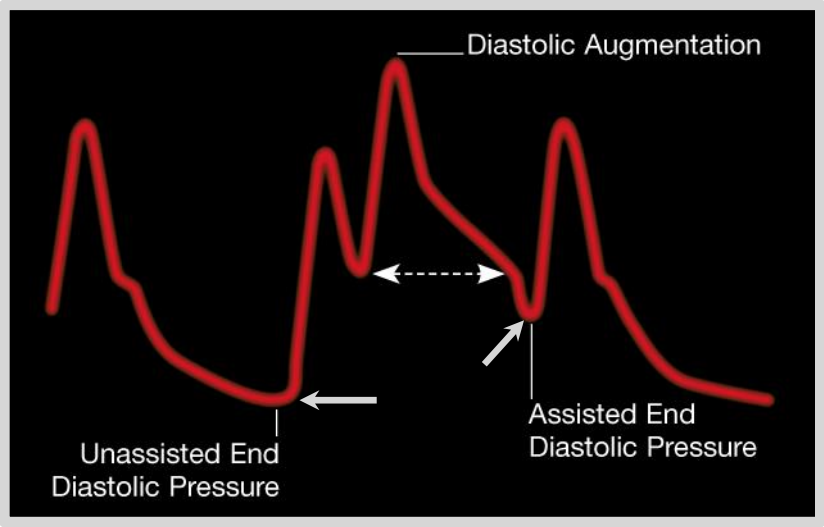
Timing Error – Late Deflation

Deflation of IAB after aortic valve has opened

Waveform Characteristics

- Assisted end diastolic pressure may be equal to or higher than unassisted end diastolic pressure
- Rate of rise of assisted systole is prolonged
- Diastolic augmentation may appear widened



Physiologic Effects

- Afterload reduction is essentially absent
- Increased MVO_2 consumption due to left ventricle ejecting against a greater resistance and a prolonged isovolumetric contraction phase
- IAB may impede left ventricular ejection and increase afterload

TRIGGERS

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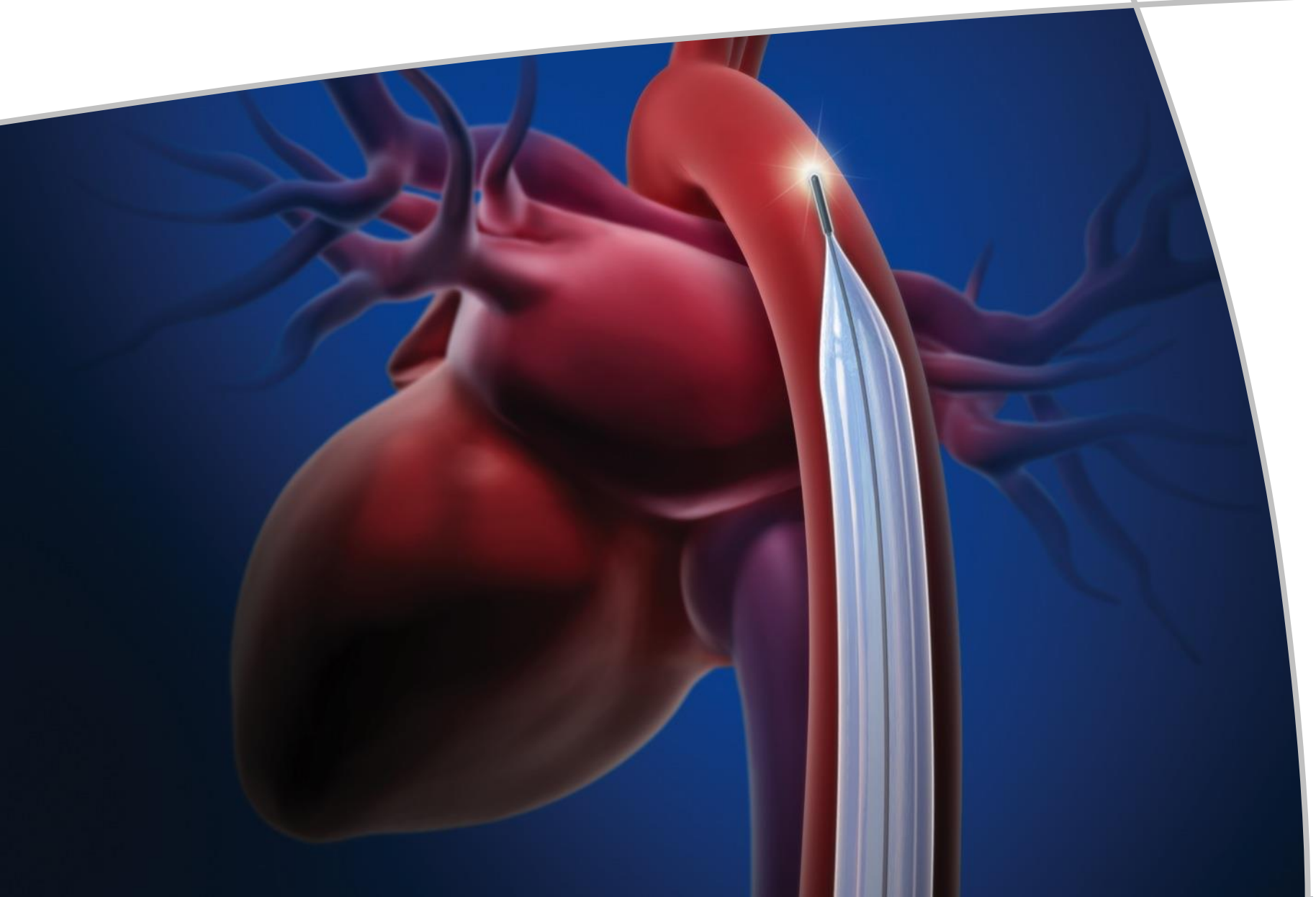

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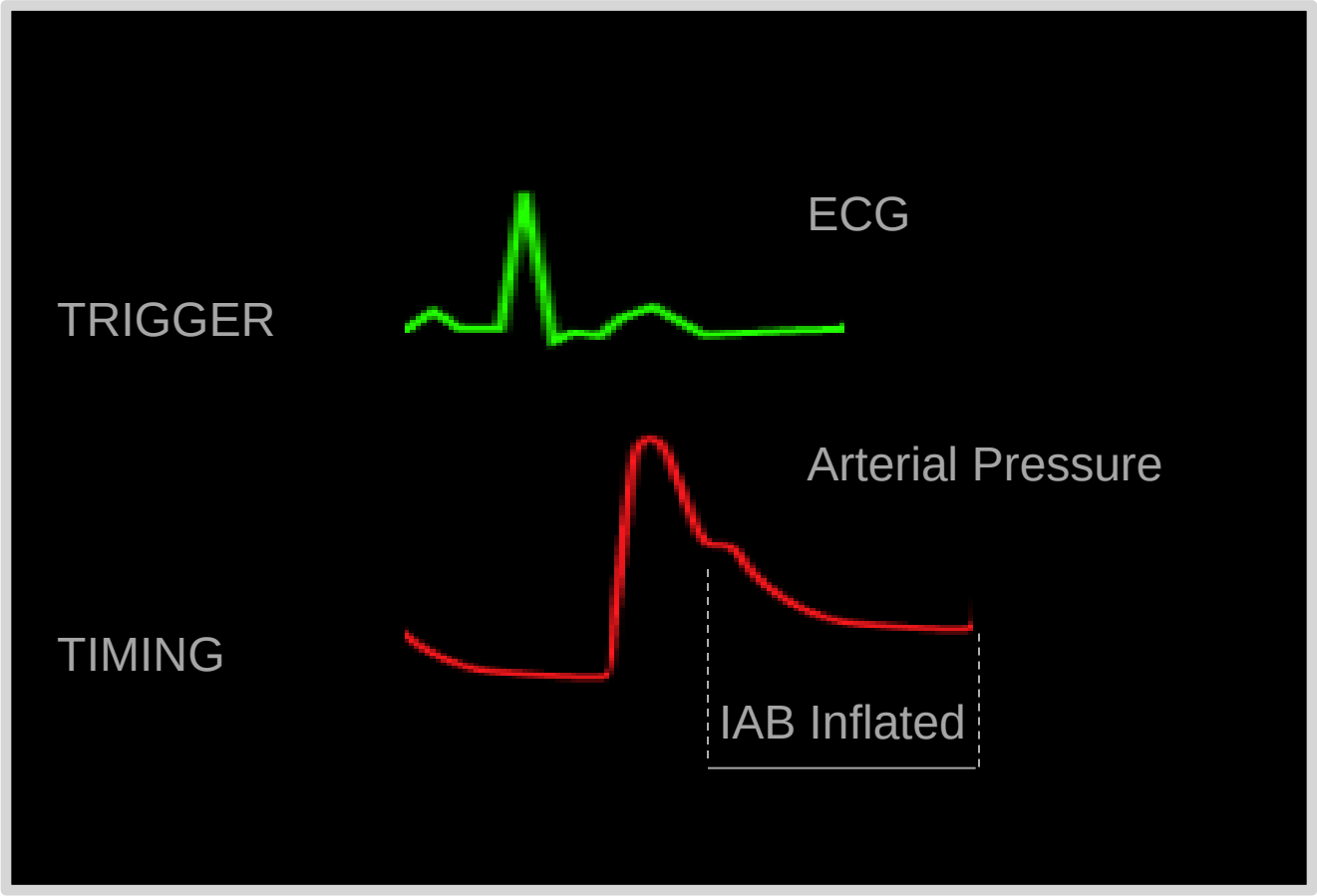
Synchronization with the cardiac cycle



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Trigger

- A Trigger is the signal that MAQUET IABP uses to identify the beginning of the next cardiac cycle
- When MAQUET IABP recognizes the trigger event, it will deflate the balloon if not already deflated

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ECG Trigger

Trigger Event

- **R-Wave**

Applications

- Preferred trigger (must have reliable R-Wave)
- Recommended for patients with arrhythmias
- Recommended for paced rhythms (demand or asynchronous pacing)

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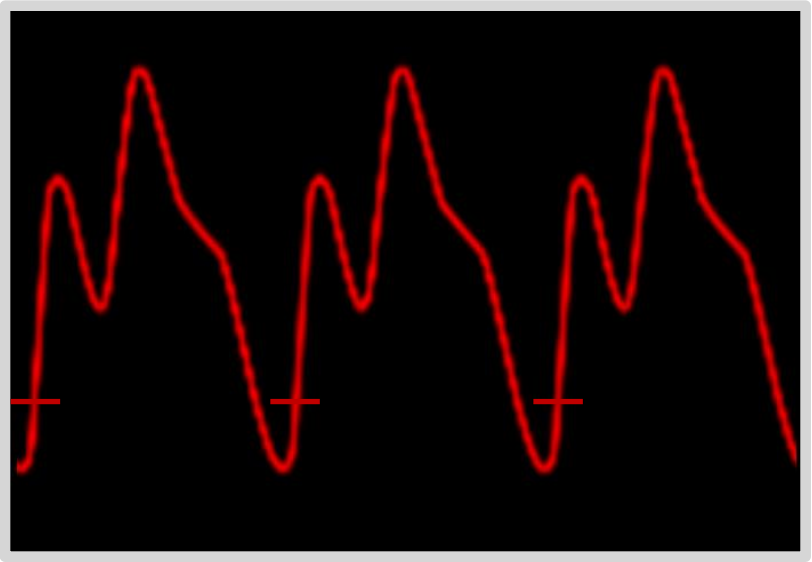
Pressure Trigger

Trigger Event

- **Systolic upstroke of arterial waveform**

Applications

- Backup trigger when ECG trigger is not appropriate
- Reoccurring ECG artifact
- Electrocautery interference in OR
- Low voltage R-Wave
- Cardiac arrest/CPR



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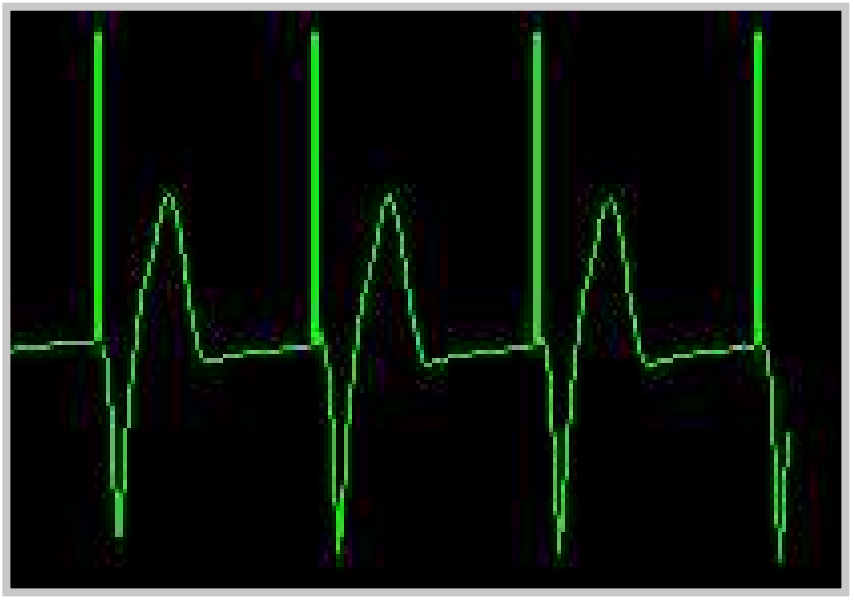
Pacer V/A-V

Trigger Event

- **Ventricular pacer spike**

Applications

- Used with V or AV paced rhythms
- Used when 100% paced and NO reliable R-Wave
- Low voltage R-Wave
- Only available in Semi-Auto operation mode



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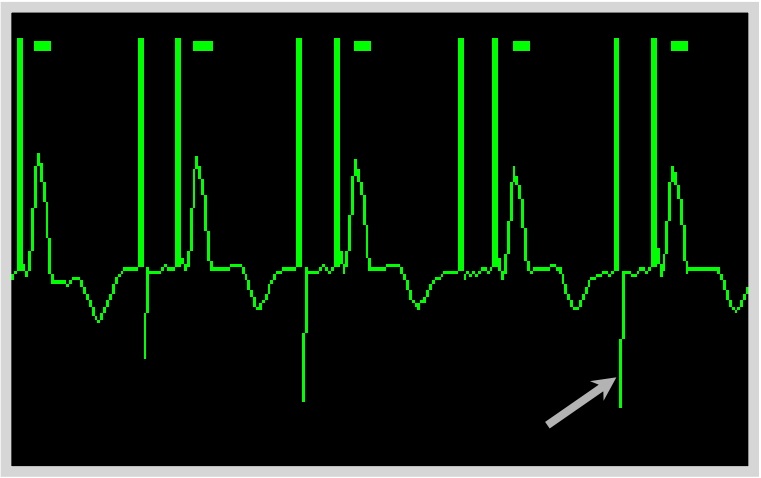
Pacer A

Trigger Event

- **R-Wave**

Applications

- If pacer tails are present, they can cause the IABP to trigger inappropriately on the pacer tail, instead of the R-Wave (in ECG trigger)
- Primarily used in open heart patients who have a temporary atrial pacemaker
- Never use Pacer A trigger in the presence of a ventricular paced rhythm
- Only available in Semi-Auto operation mode



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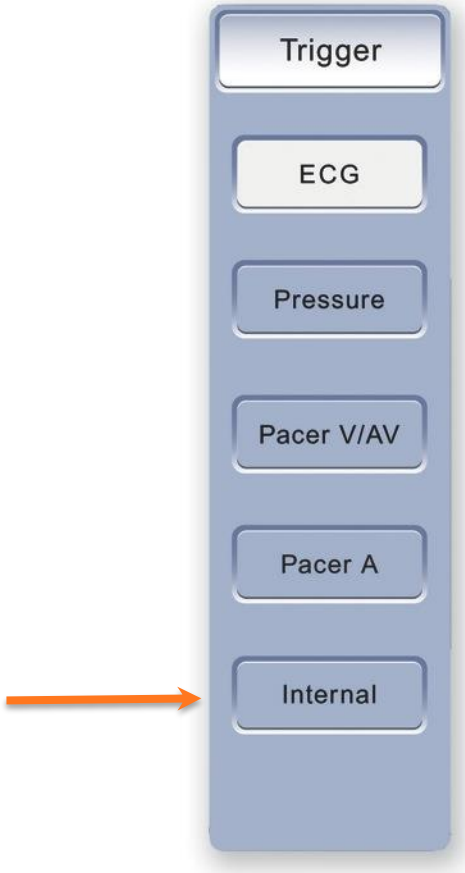
Internal Trigger

Trigger Event

- **Asynchronous**
- Balloon inflates/deflates at a set rate of 80 BPM
- Internal rate is adjustable

Applications

- Only use when patient is not generating a cardiac output on their own
- Cardiac arrest
- Cardiopulmonary bypass
- Only available in Semi-Auto operation mode



FACTORS AFFECTING DIASTOLIC AUGMENTATION

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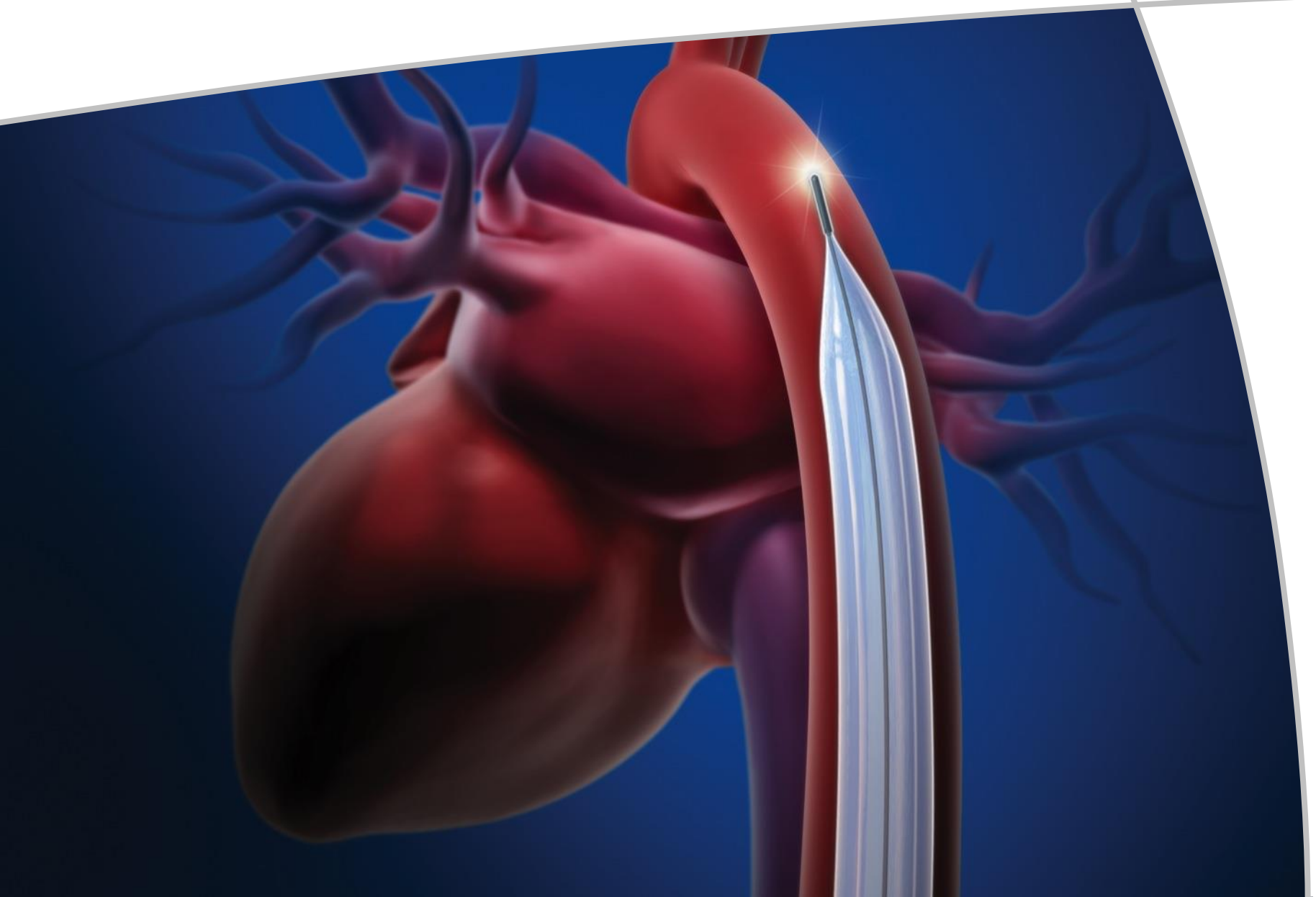
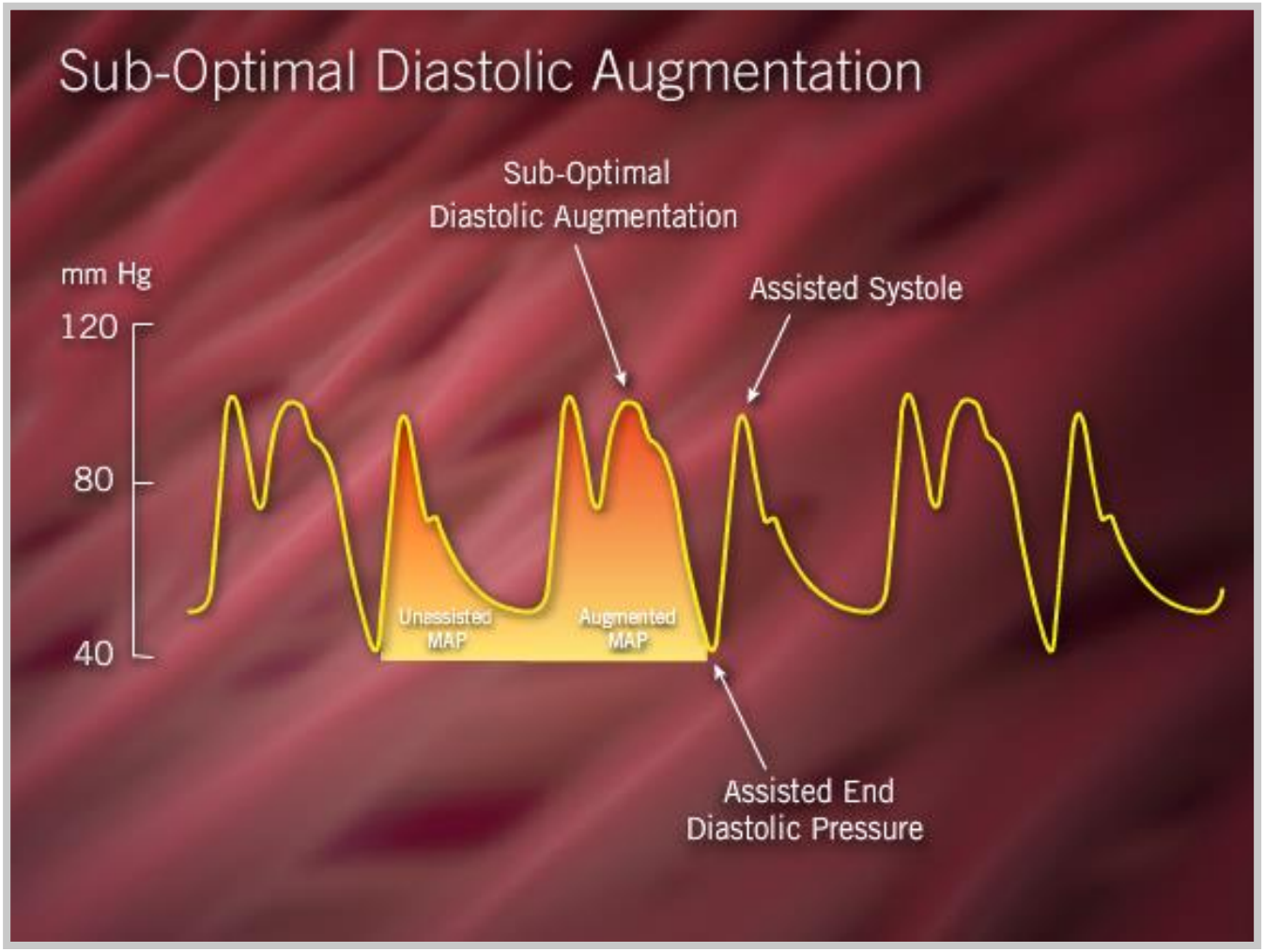


FACTORS AFFECTING DIASTOLIC AUGMENTATION



FACTORS AFFECTING DIASTOLIC AUGMENTATION

Patient Hemodynamics

- Heart rate
- Stroke volume
- Mean arterial pressure
- Systemic vascular resistance

FACTORS AFFECTING DIASTOLIC AUGMENTATION

IAB Catheter

- IAB in sheath
- IAB not unfurled
- IAB position
- IAB size
- Kink in IAB catheter
- IAB leak
- Low helium concentration

FACTORS AFFECTING DIASTOLIC AUGMENTATION

Intra-aortic Balloon Pump

- Timing

  - Late inflation

  - Early deflation

- Position of the IAB augmentation control

BREAK TIME

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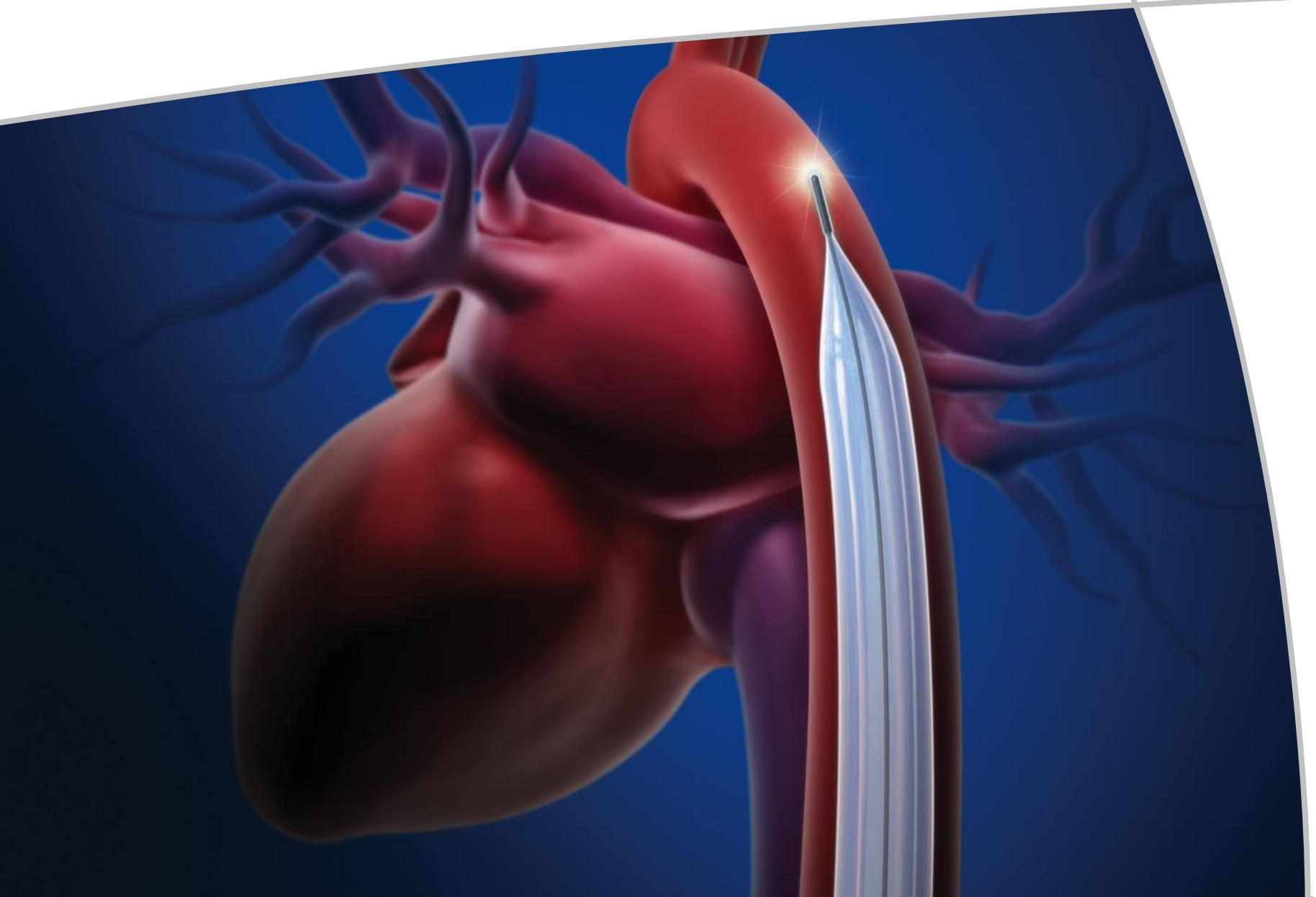

INDICATIONS/CONTRAINDICATIONS

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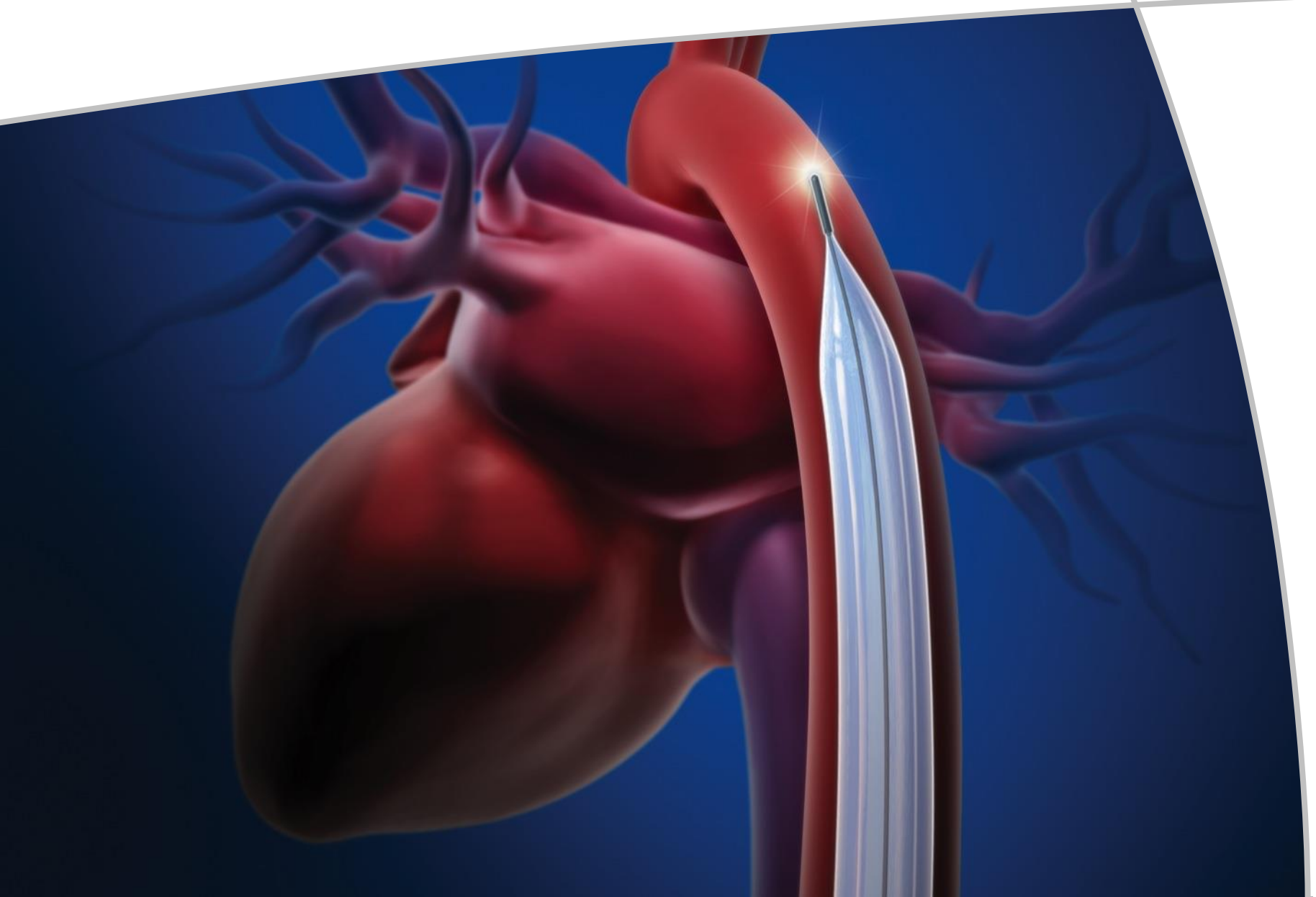

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Indications

1. Refractory unstable angina
2. Impending infarction
3. Acute MI
4. Refractory ventricular failure
5. Complications of acute MI
6. **Cardiogenic shock**
7. **Support for diagnostic, percutaneous revascularization, and interventional procedures**
8. Ischemia related intractable ventricular arrhythmias
9. 9Septic Shock
10. Intra-operative pulsatile flow generation
11. Weaning from bypass
12. Cardiac support for non-cardiac surgery
13. **Prophylactic support in preparation for cardiac surgery**
14. Post surgical myocardial dysfunction/ low cardiac output syndrome
15. Myocardial contusion
16. Mechanical bridge to other assist devices
17. Cardiac support following correction of anatomical defects

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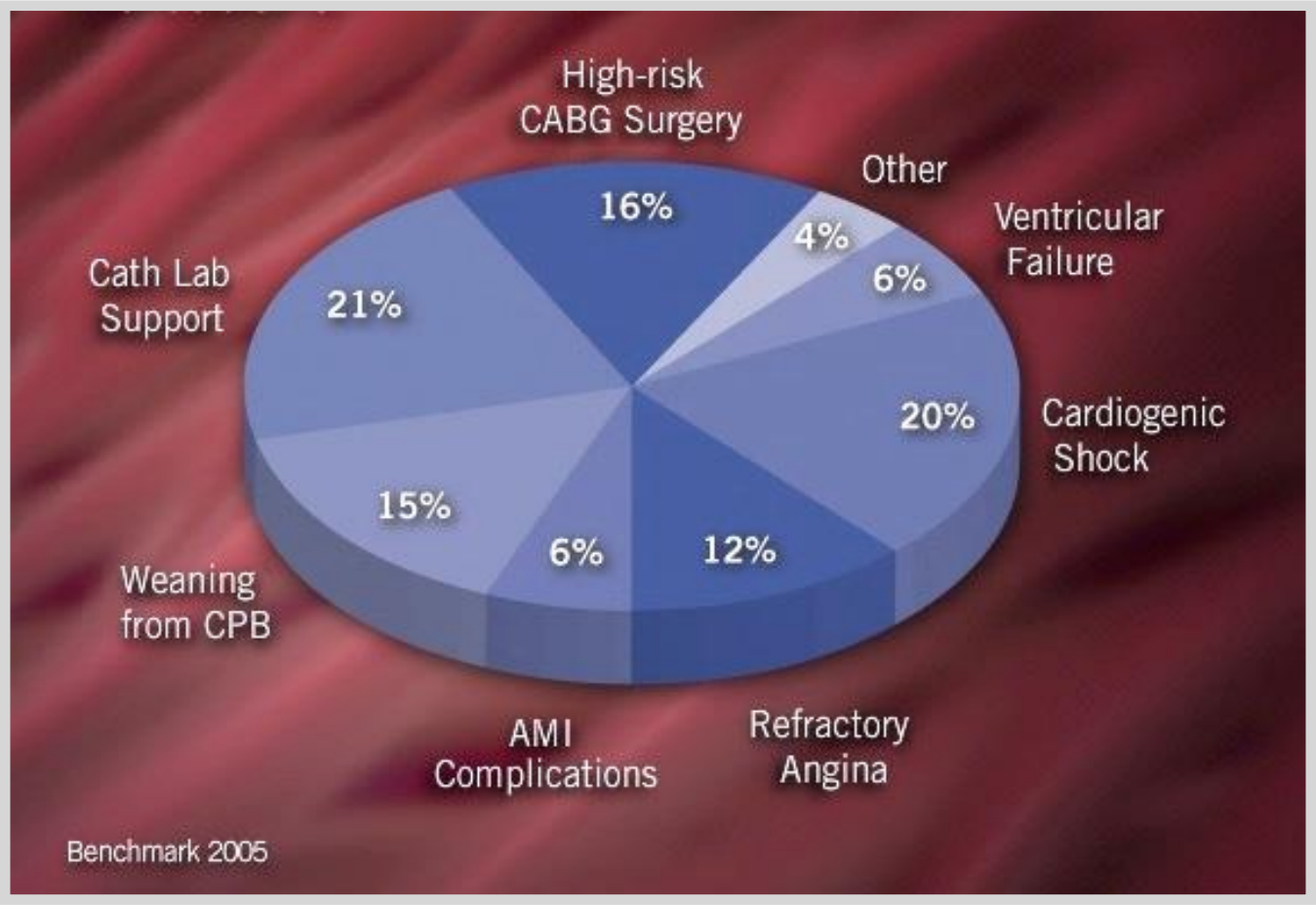
Indications



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Indications – Cardiogenic Shock

Definition

- State of end-organ hypoperfusion due to cardiac failure

Mortality Rate

- Approximately 50% in the modern era

Incidence

- 5-8% of STEMIs
- 2-5% of non-STEMIs
- 40,000 to 50,000 cases per year in U.S.

Reynolds H, Hochman J; Circulation 2008;117(5):686-697

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Indications – Cardiogenic Shock

Hemodynamic Parameters

- Systolic BP < 80 to 90mmHg or a MAP 30mmHg lower than baseline
- Cardiac Index < 1.8L/m/M^2 without support and adequate filling pressures
- Cardiac Index < 2.0-2.2L/m/M^2 with support and adequate filling pressures
- LVEDP > 18mmHg

Recommendation regarding IABP use

- Whether shock onset occurs early or late after MI, rapid IABP placement and angiography are recommended

Reynolds H, Hochman J; Circulation 2008;117(5):686-697

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Indications – Cardiogenic Shock

IABC in AMI Complicated by Cardiogenic Shock:

The Forest and Trees of the Door-to-Balloon Time Metric

- Use of an IABP in the presence of Cardiogenic Shock in AMI has a Class IIa therapeutic recommendation in the ACC/AHA clinical practice guidelines for managing AMI
- The need to stabilize patients with Cardiogenic Shock must be emphasized
- IABP insertion is considered an acceptable reason to delay PCI, and these patients therefore are not included in the D2B performance measure

Brindis R; J Inv Cardiol 2010; Vol 22: Suppl C
O'Gara et al ,Circulation 2013;127:e362-e425

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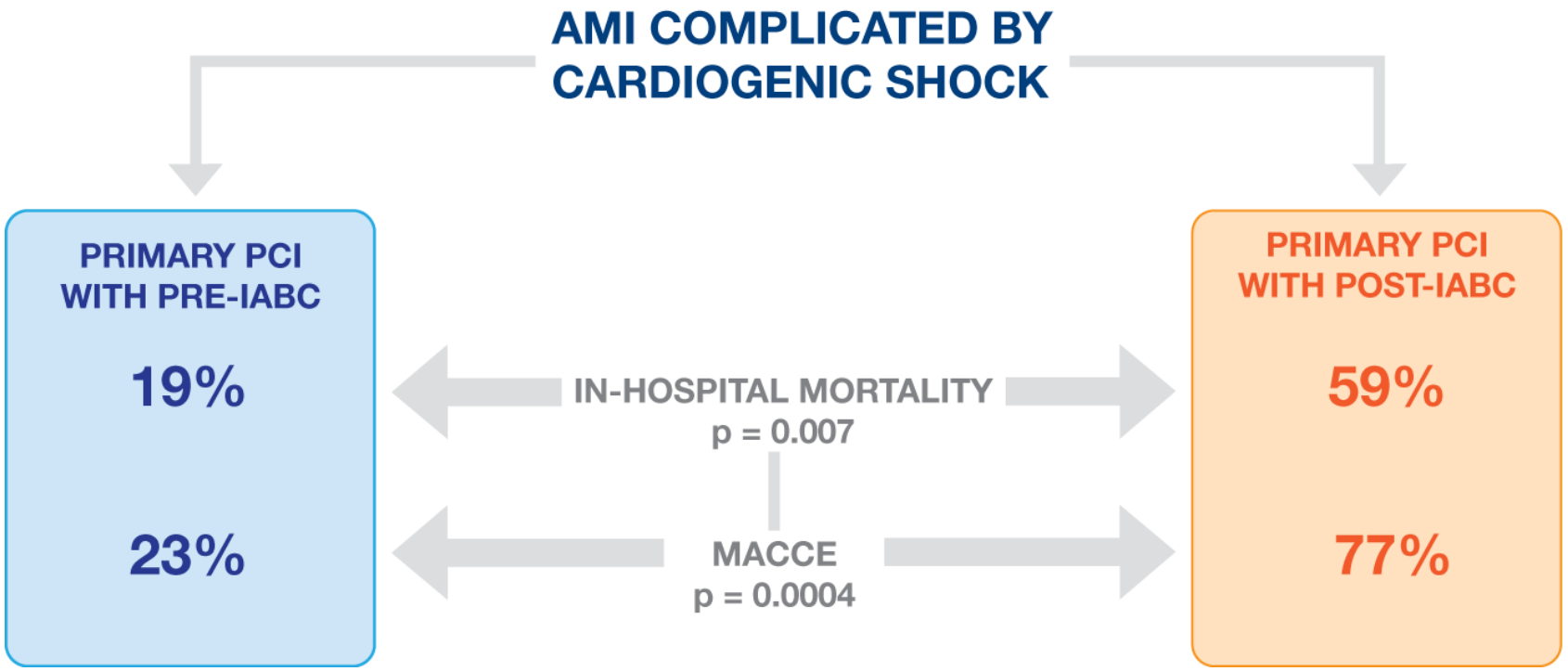
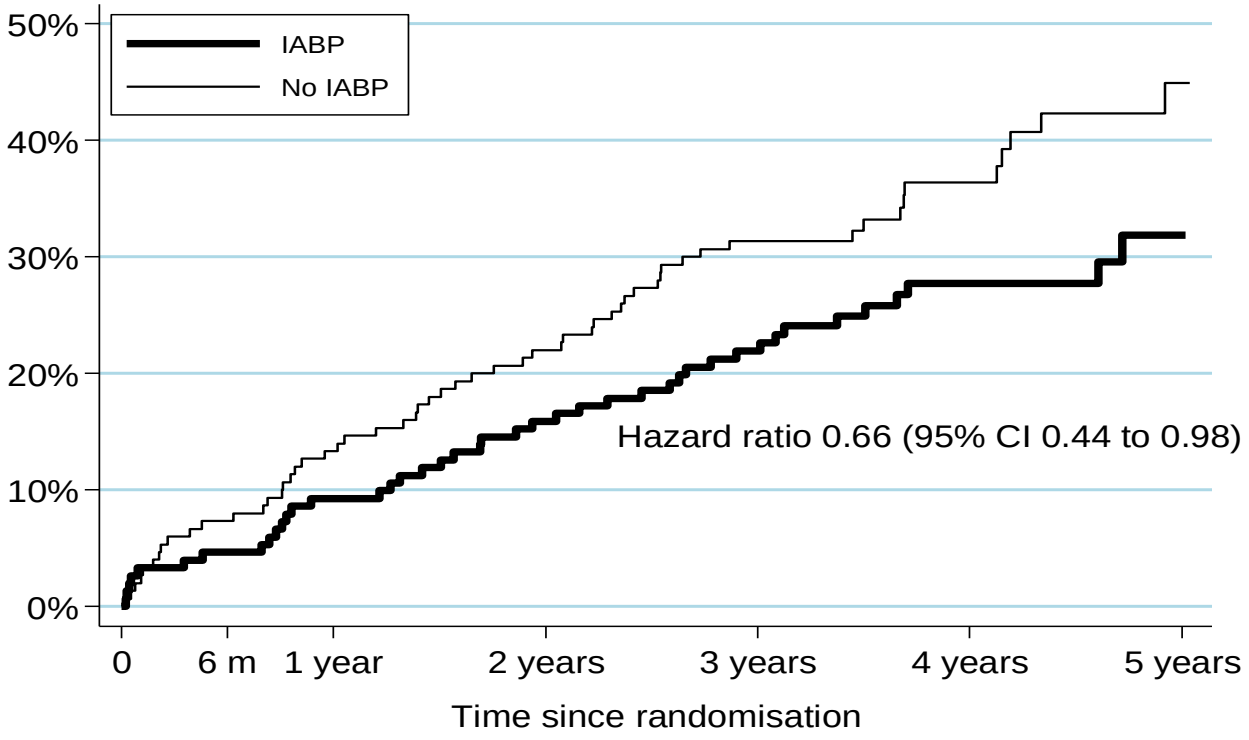
Indications – Cardiogenic Shock



Abdel-Wahab, et al; Am J Cardiol 2010;105:967-971

Indications – High Risk PCI

BCIS-1 all-cause mortality by treatment assignment



Perera, et al.,Circulation 2013 Jan 15, 127(2)207-12

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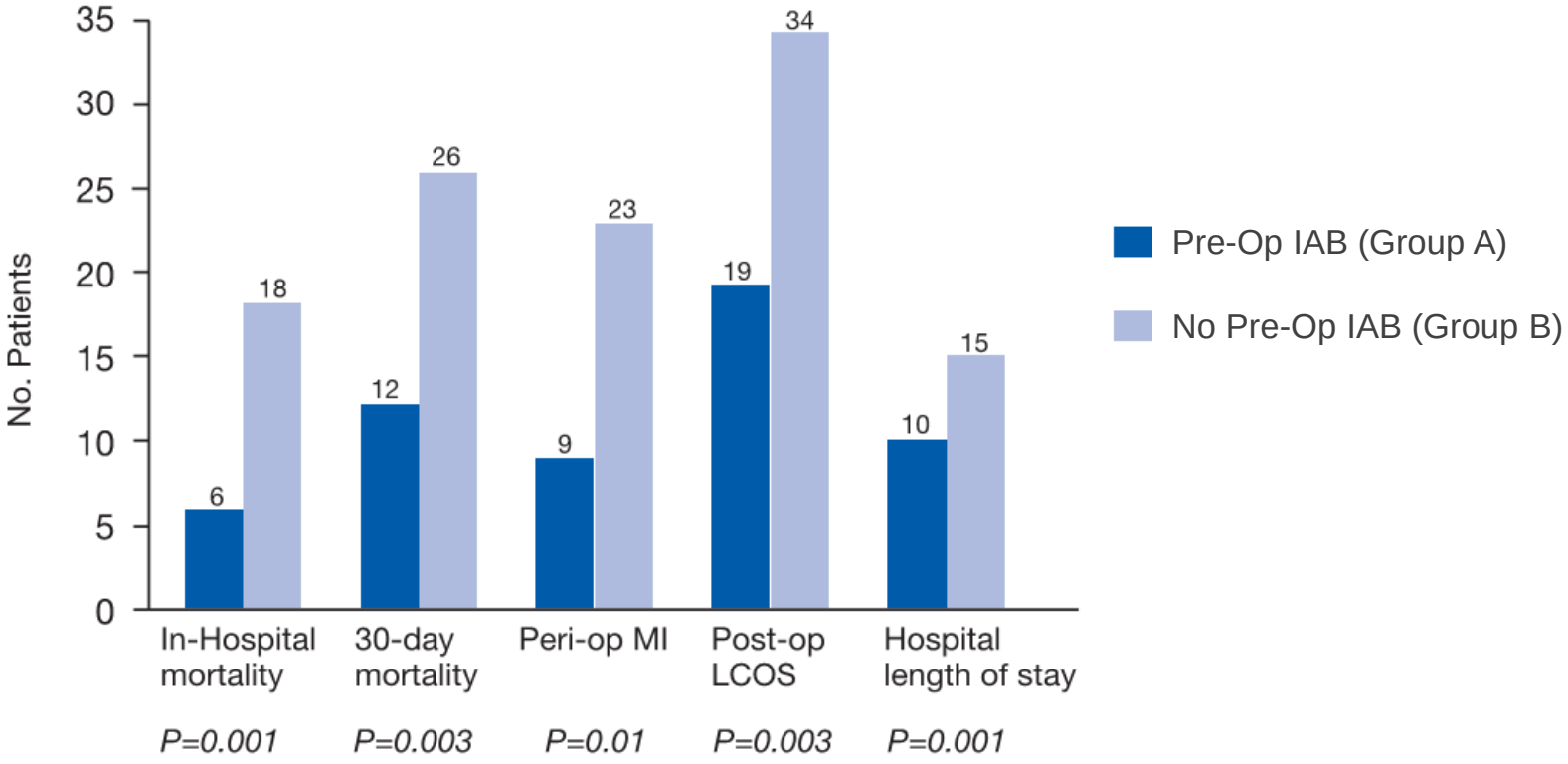
Indications – High Risk CABG

PRE-OP VS. NO PRE-OP IAB USE



Lorusso R, et al; Euro J of Cardio-Thoracic Surg 2010; 38:585-591

Contraindications

- Severe aortic insufficiency
- Abdominal or thoracic aortic aneurysm
- Severe calcific aorta-iliac disease or peripheral vascular disease
- Sheathless insertion with severe obesity, scarring of the groin

SIDE EFFECTS & COMPLICATIONS/PATIENT ASSESSMENT

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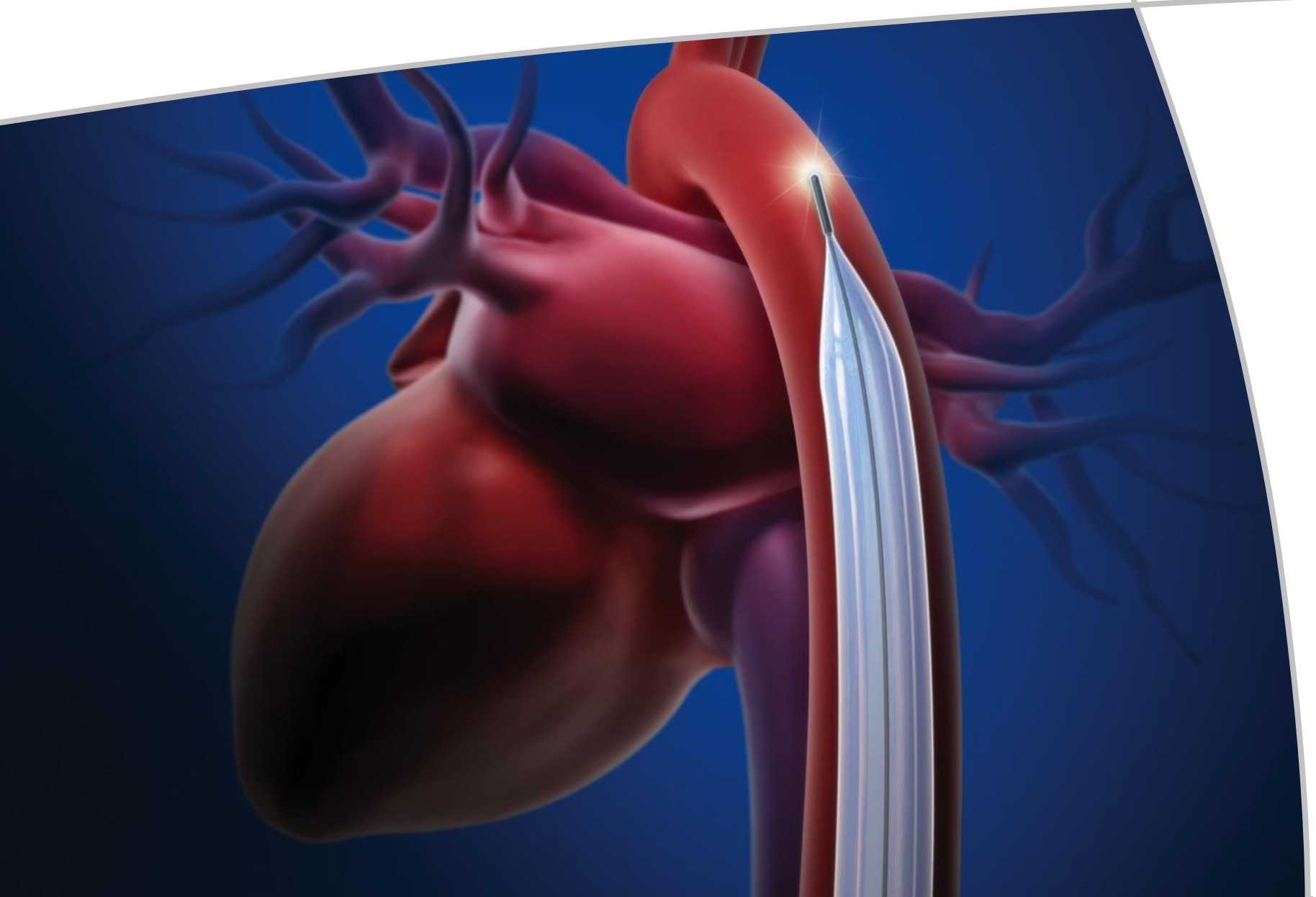

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Side Effects & Complications

- Limb Ischemia
- Bleeding at the insertion site
- Thrombocytopenia
- Immobility of the balloon catheter
- Infection
- Aortic dissection
- Compartment syndrome
- Balloon leak

Balloon Leak

What causes a balloon leak?

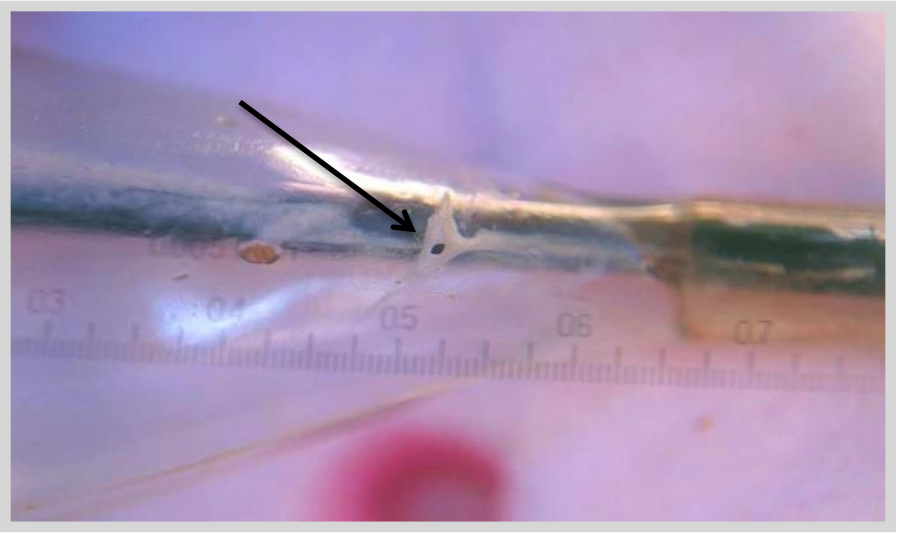
- Majority are caused by plaque abrasion

How are balloon leaks diagnosed?

- Blood appears in extracorporeal tubing or helium extender tubing
- Be suspicious with any “Gas Loss in IAB Circuit” alarm

What is the treatment?

- Stop pumping and notify physician
- Remove IAB catheter



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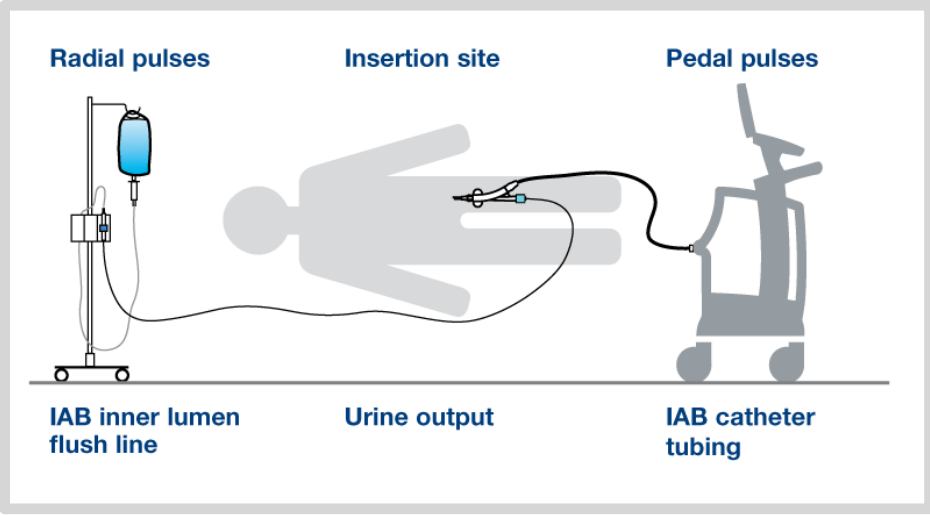
Patient Assessment

Assessment	Corrective Action
Radial pulses Left radial pulse weak or left arm ischemia	Check position of IAB
Insertion site Excessive bleeding from insertion site	Apply pressure, ensure distal flow
Pedal pulses Limb ischemia detected	Consider removing IAB, consider insertion via opposite limb
IAB inner lumen flush line Pressure waveform damped (if using a conventional IAB)	Aspirate inner lumen. If line patent, flush for 15 seconds (with IABP on Standby)
Urine output Urine output low	Check position of IAB
IAB catheter tubing Blood observed in catheter tubing	STOP pumping and prepare for IAB removal



TECHNICAL ASPECTS – IAB CATHETER

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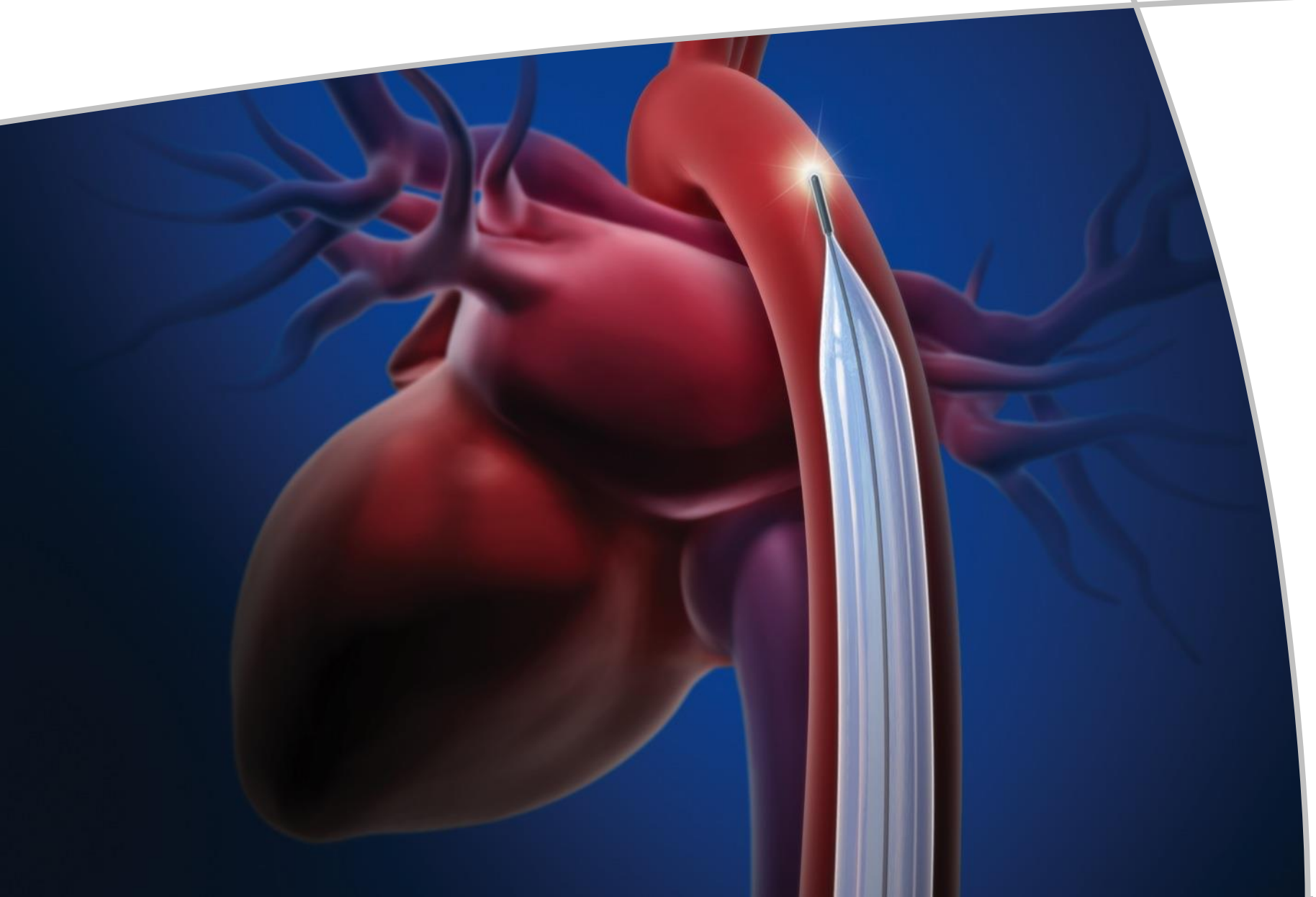

Conventional Catheter Components

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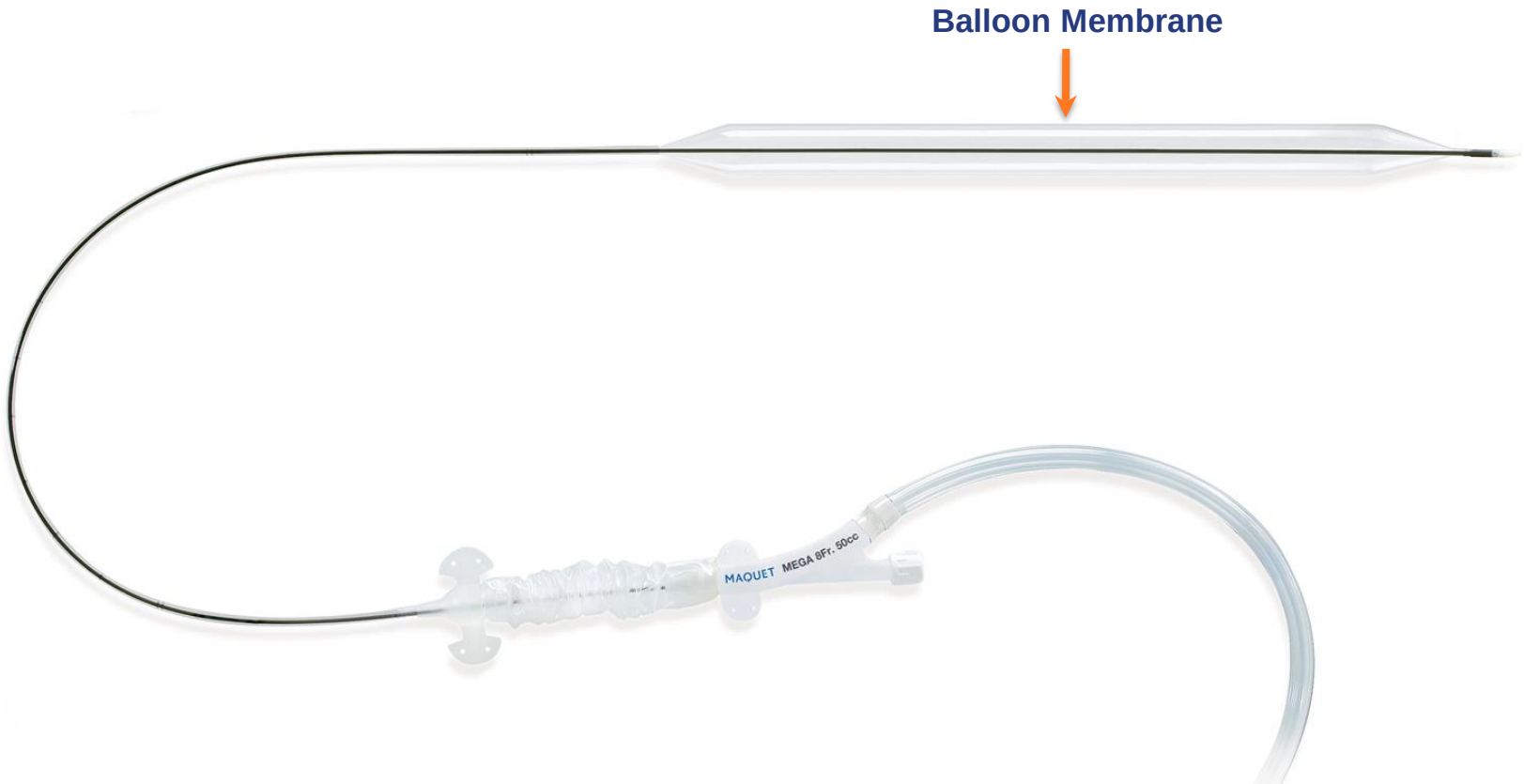
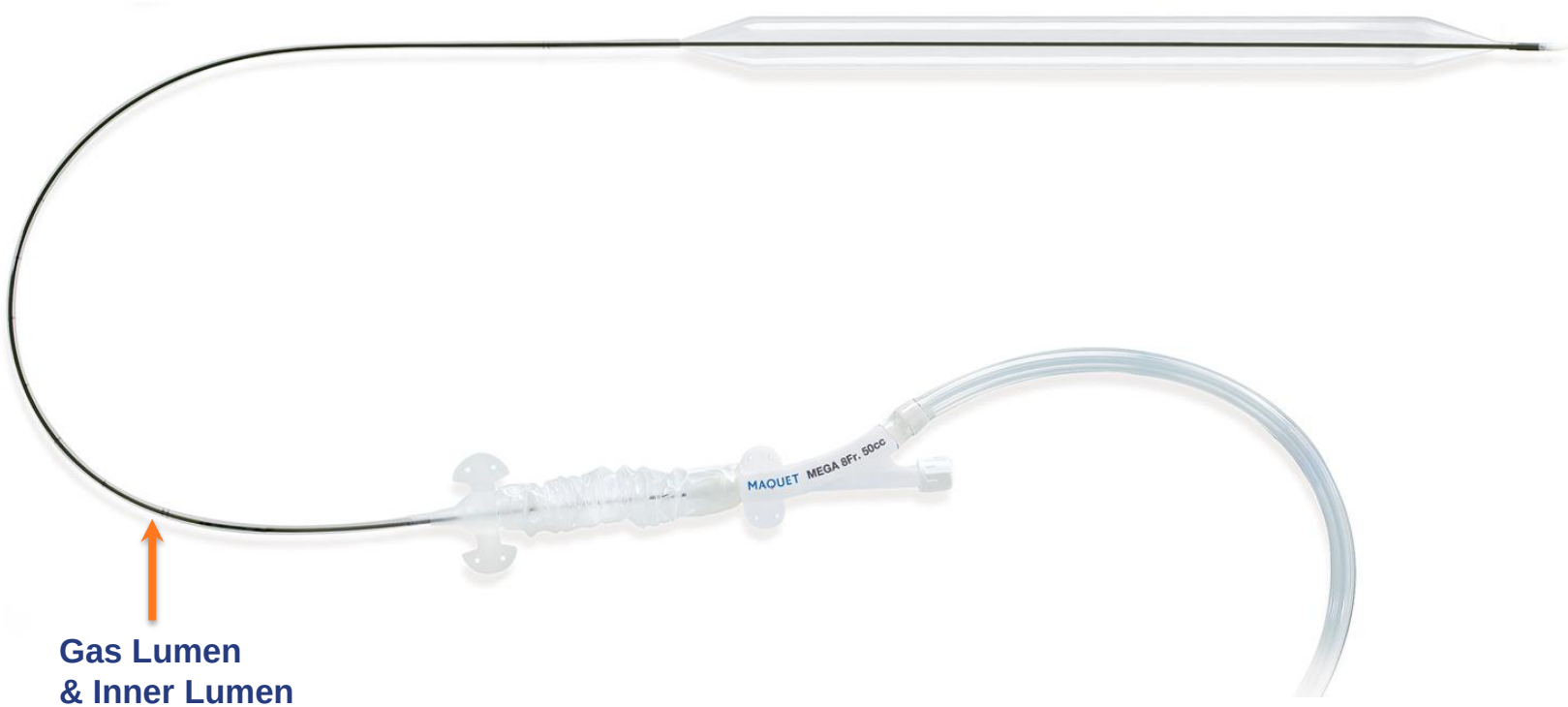
Conventional Catheter Components



Conventional Catheter Components



Gas Lumen
& Inner Lumen

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Conventional Catheter Components

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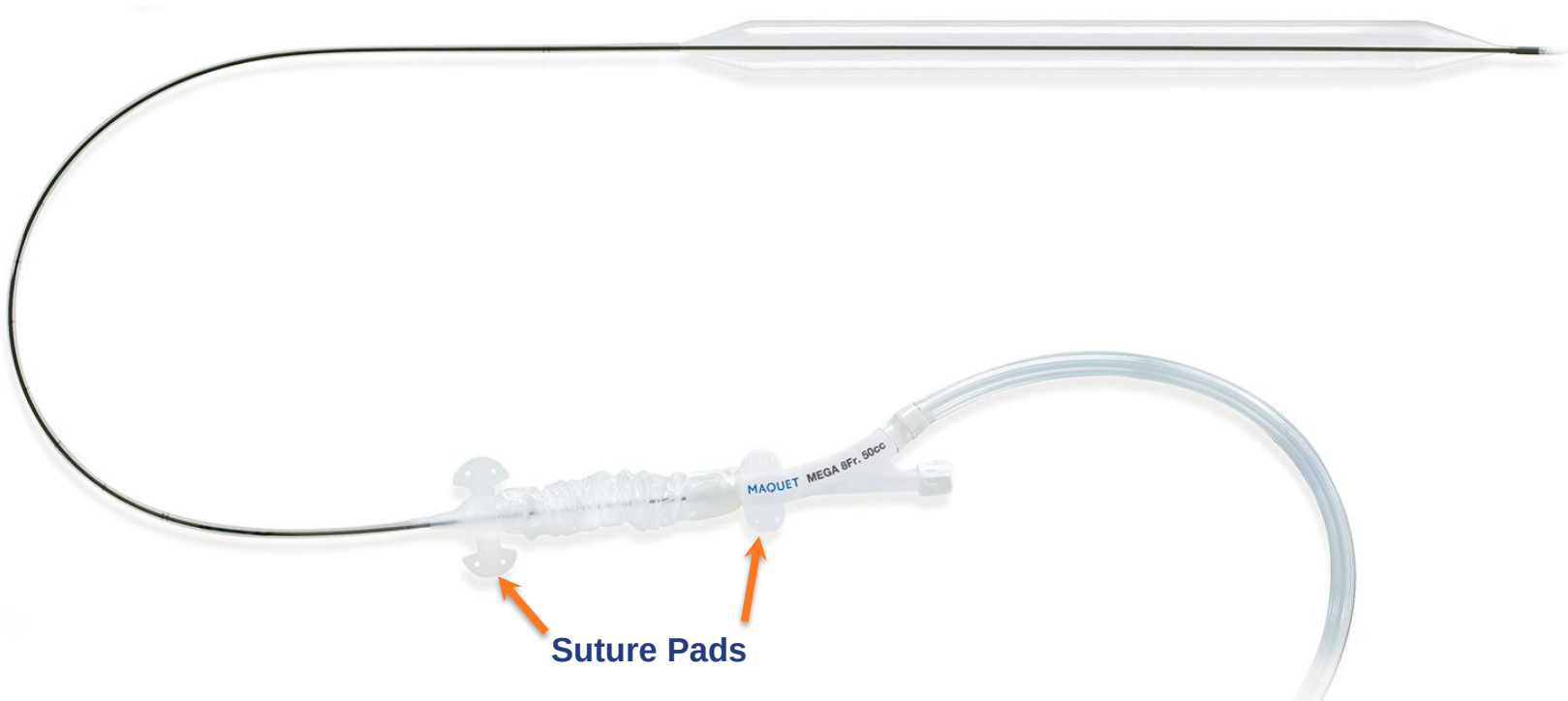
Conventional Catheter Components



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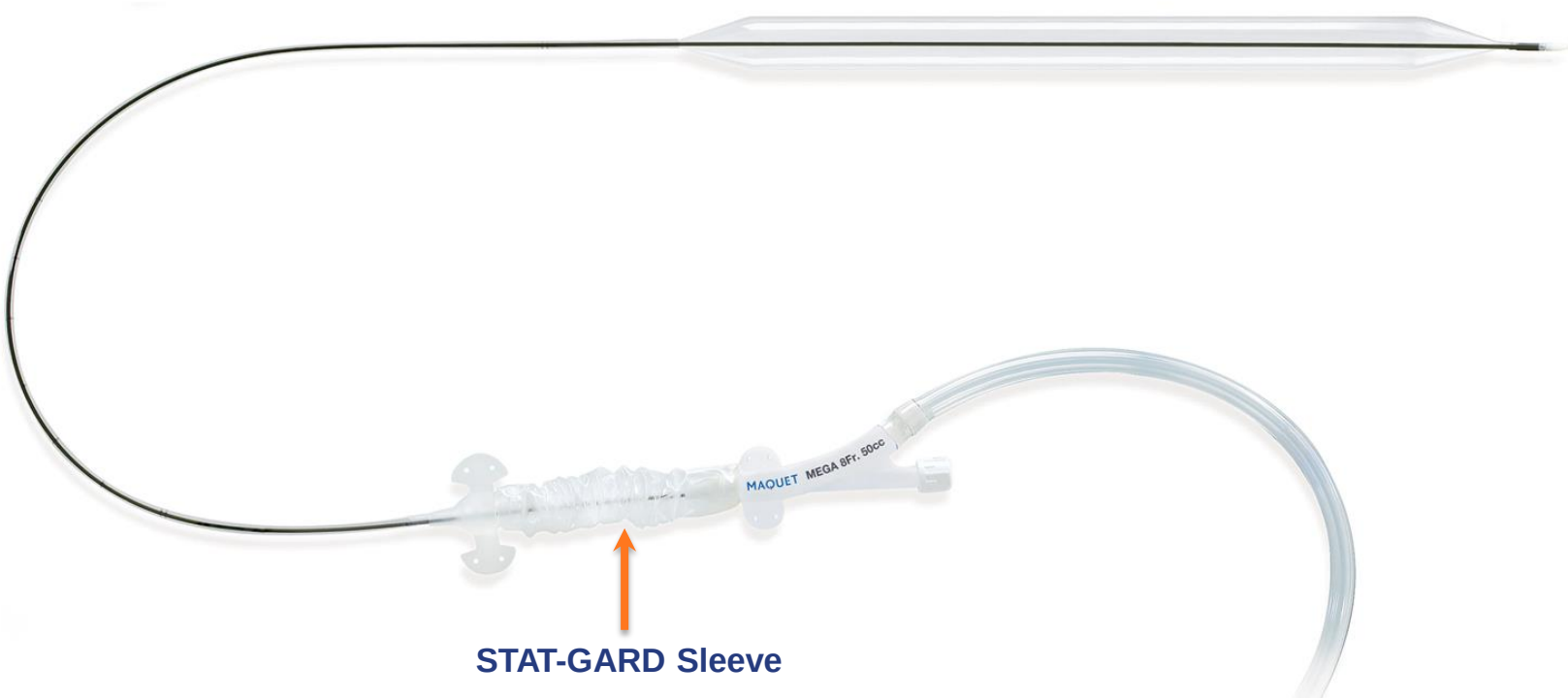
Conventional Catheter Components



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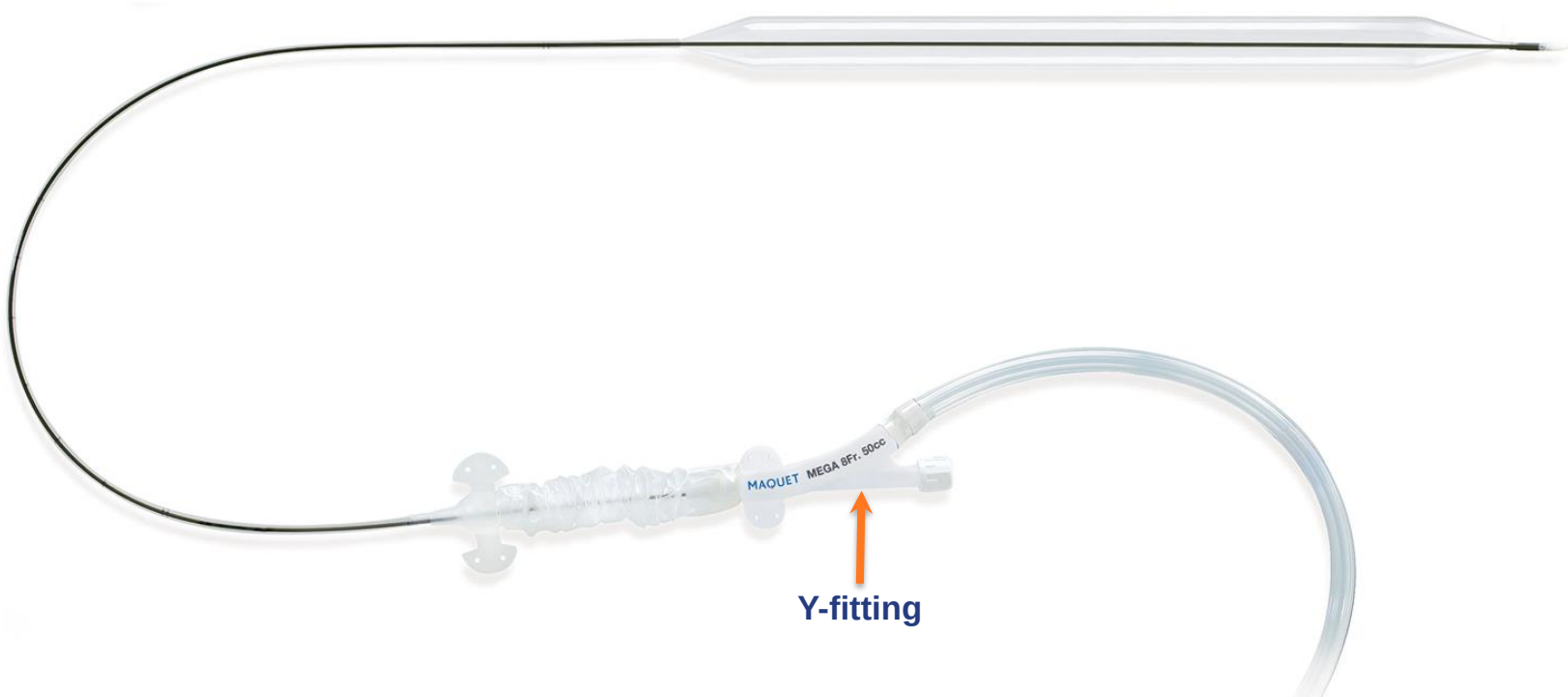
Conventional Catheter Components



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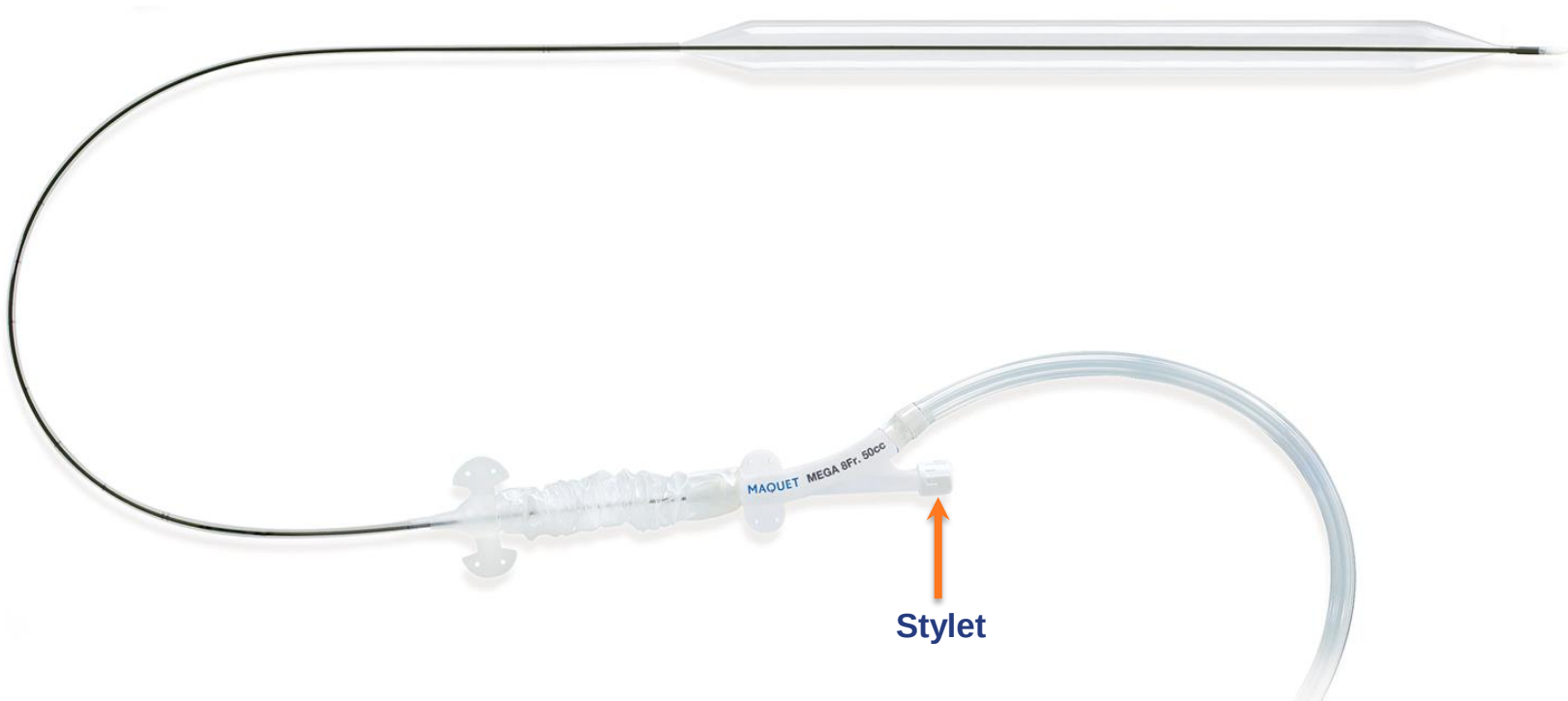
Conventional Catheter Components



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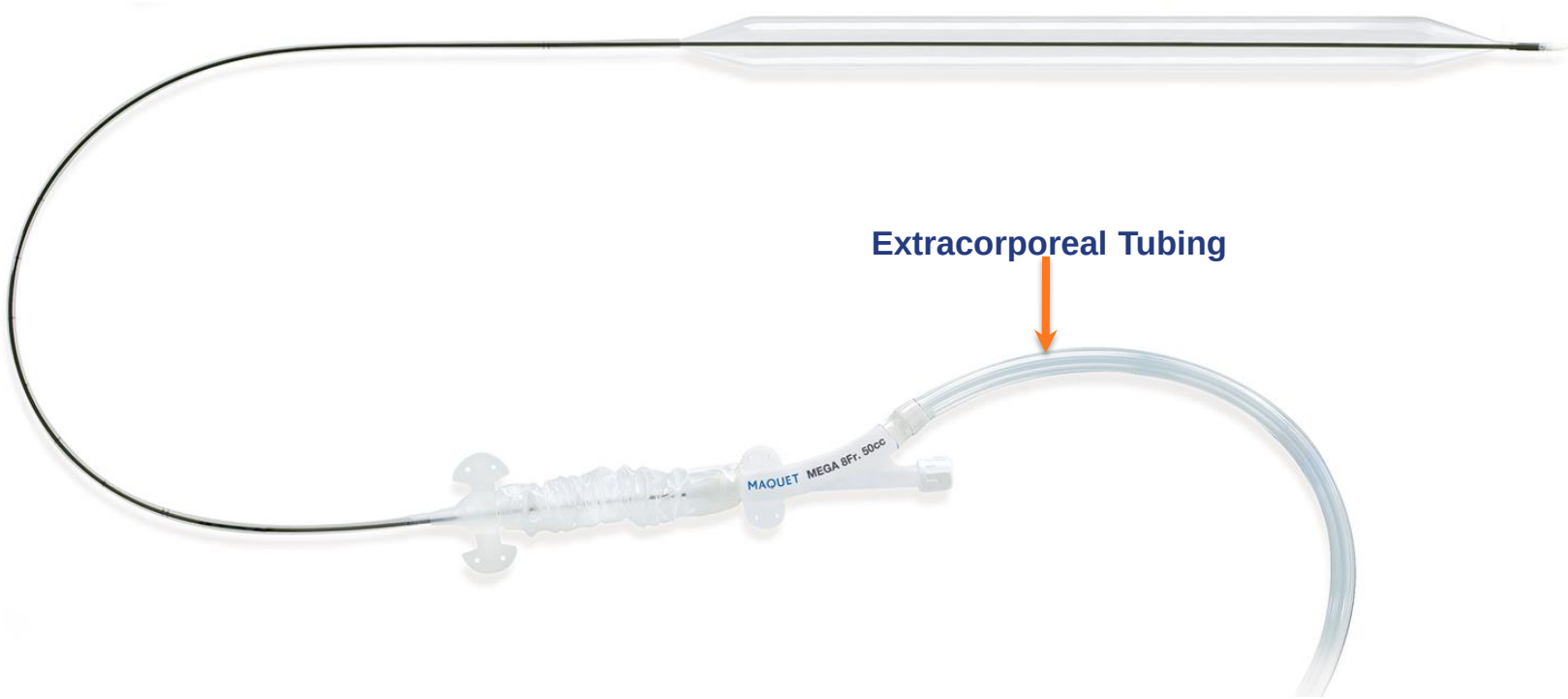
Conventional Catheter Components



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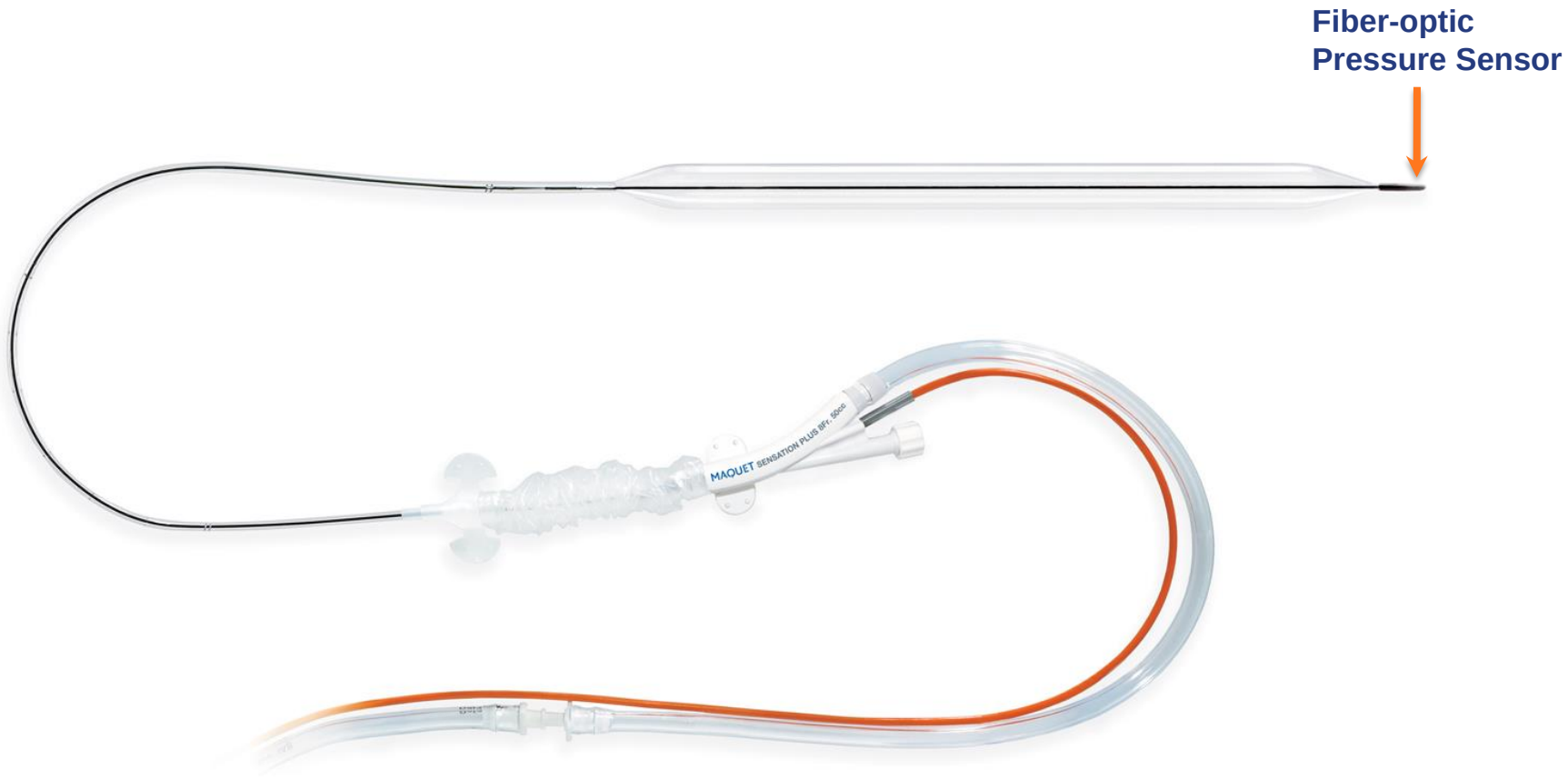
Fiber-optic Catheter Components



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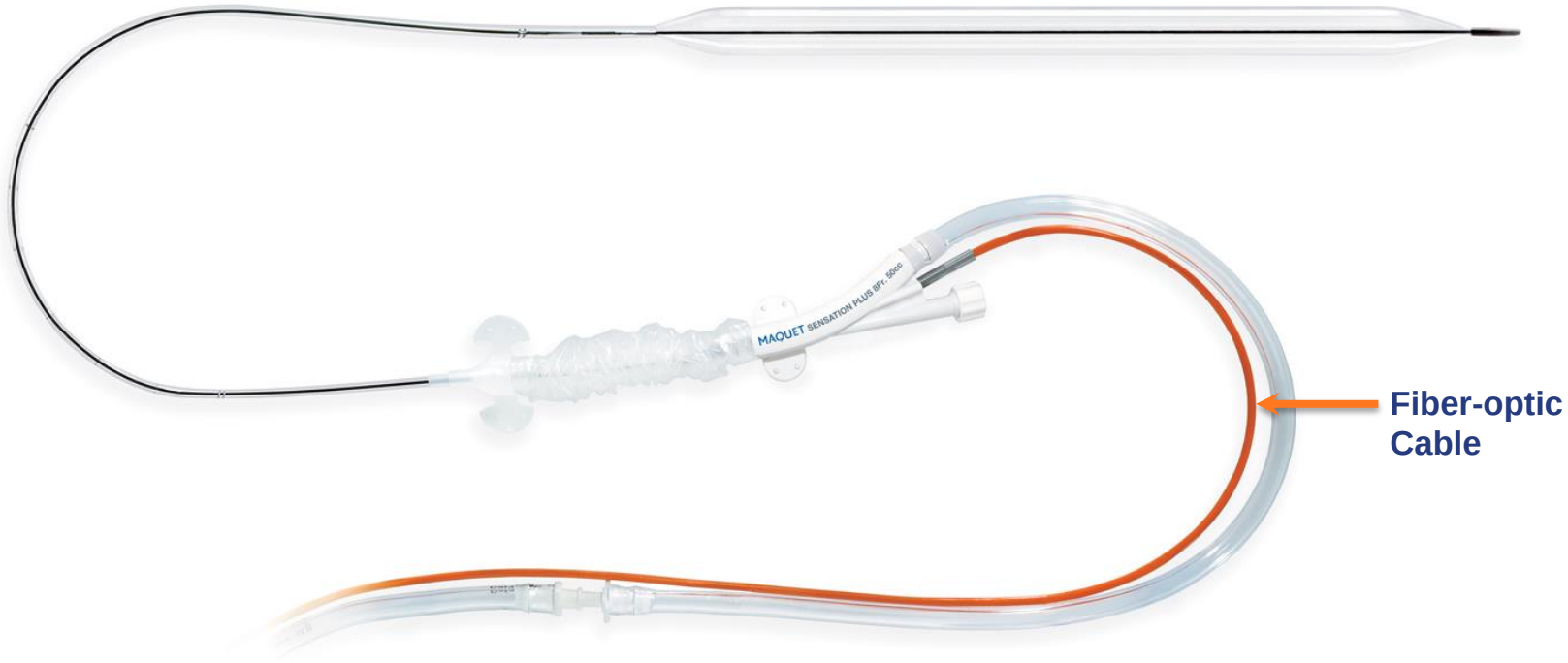
Fiber-optic Catheter Components



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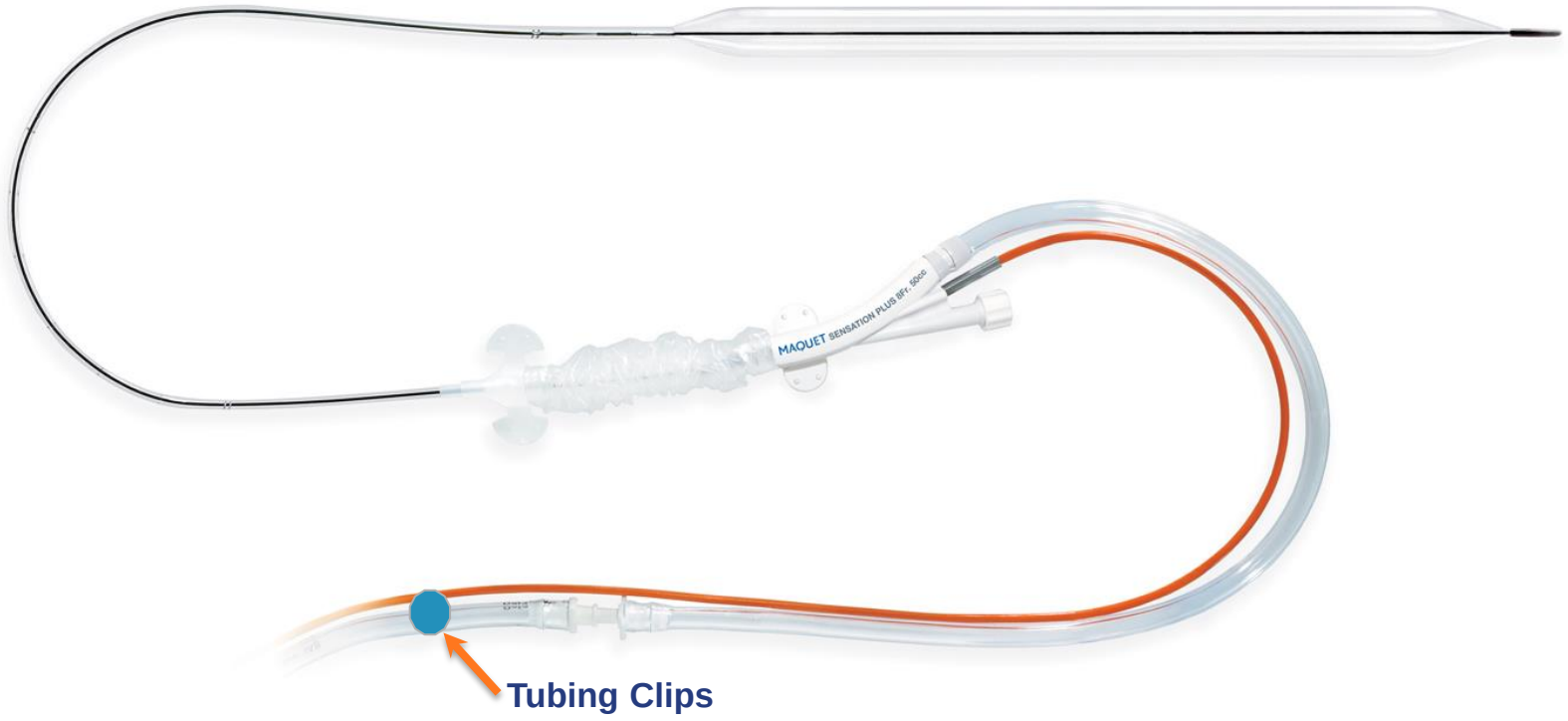
Fiber-optic Catheter Components



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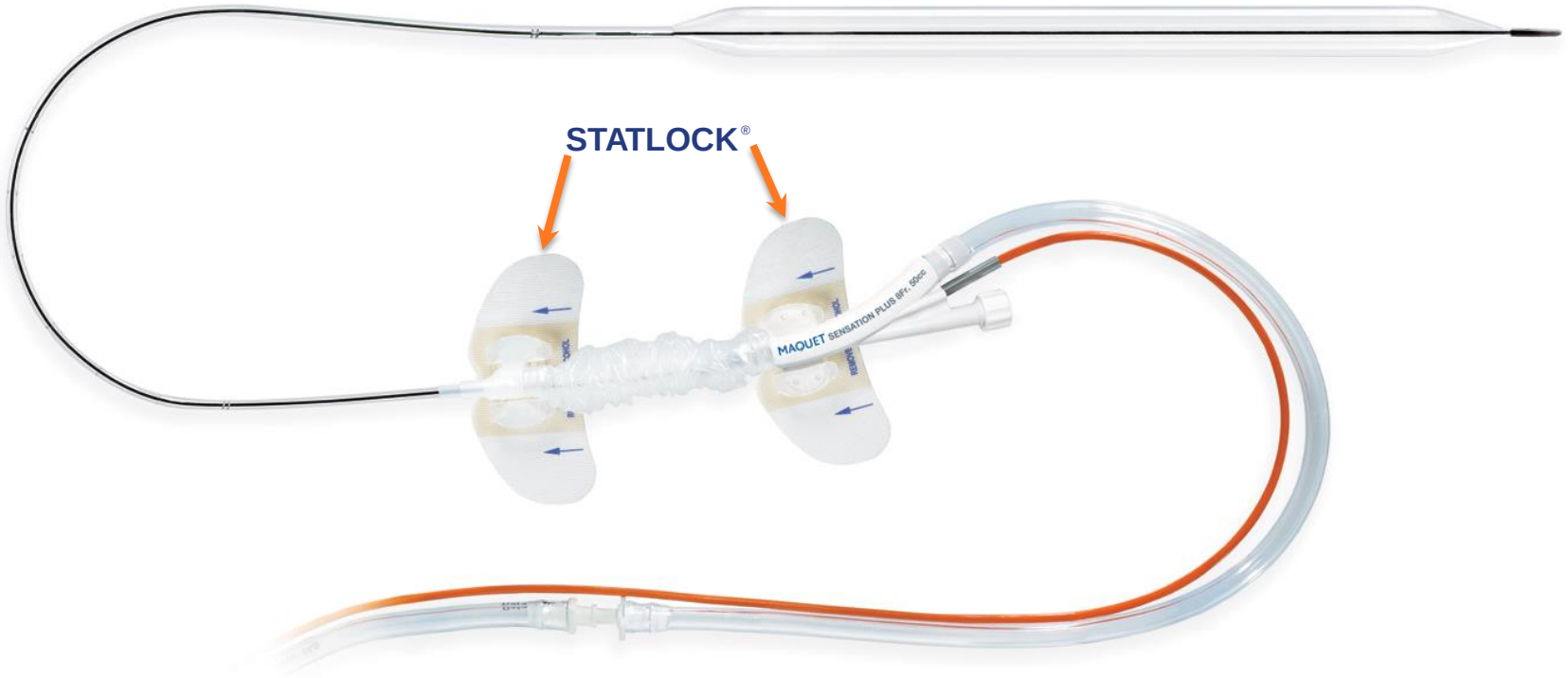
STATLOCK® Stabilization Device



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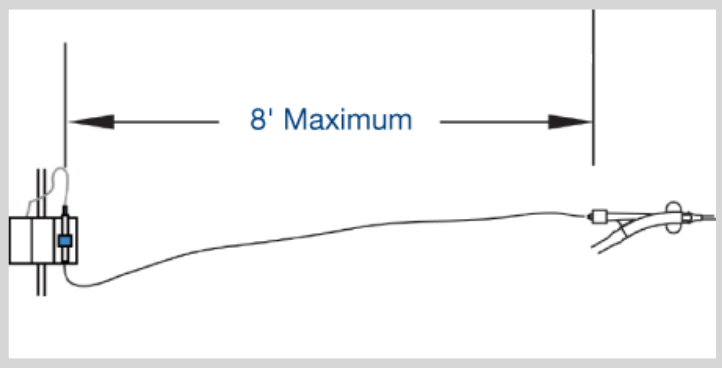
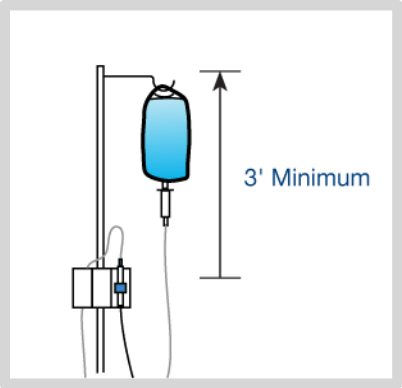
Proper Care of Inner Lumen

- Minimize length of pressure tubing
- Use **only** low compliance pressure tubing
- Elevate flush bag at least 3’ (91.44cm) above transducer
- A 3cc/hour continuous flow through inner lumen is recommended
- If inner lumen becomes damped:
  – Aspirate and discard 3cc of blood
  – If **unable** to aspirate blood, consider inner lumen clotted, cap lumen, provide alternate pressure source
  – If **able** to aspirate blood, fast flush to clear pressure tubing for at least 15 seconds (with IABP on Standby)
- **Do not** sample blood from inner lumen





TECHNICAL ASPECTS – CARDIOSAVE IABP

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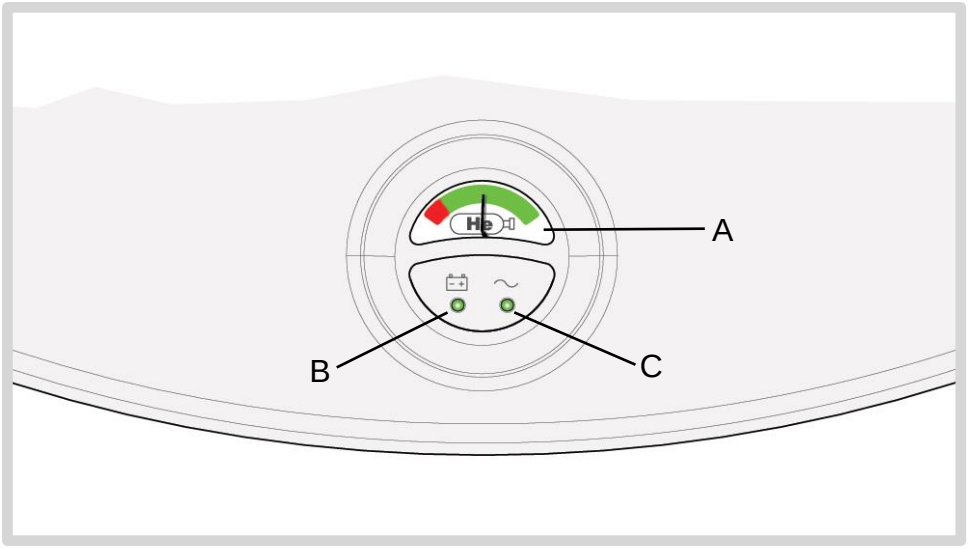
TECHNICAL ASPECTS – CARDIOSAVE IABP

Top Panel

A: Helium Pressure Gauge

B: Battery Charging LED

C: AC Connected LED



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Doppler

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Storage Compartment

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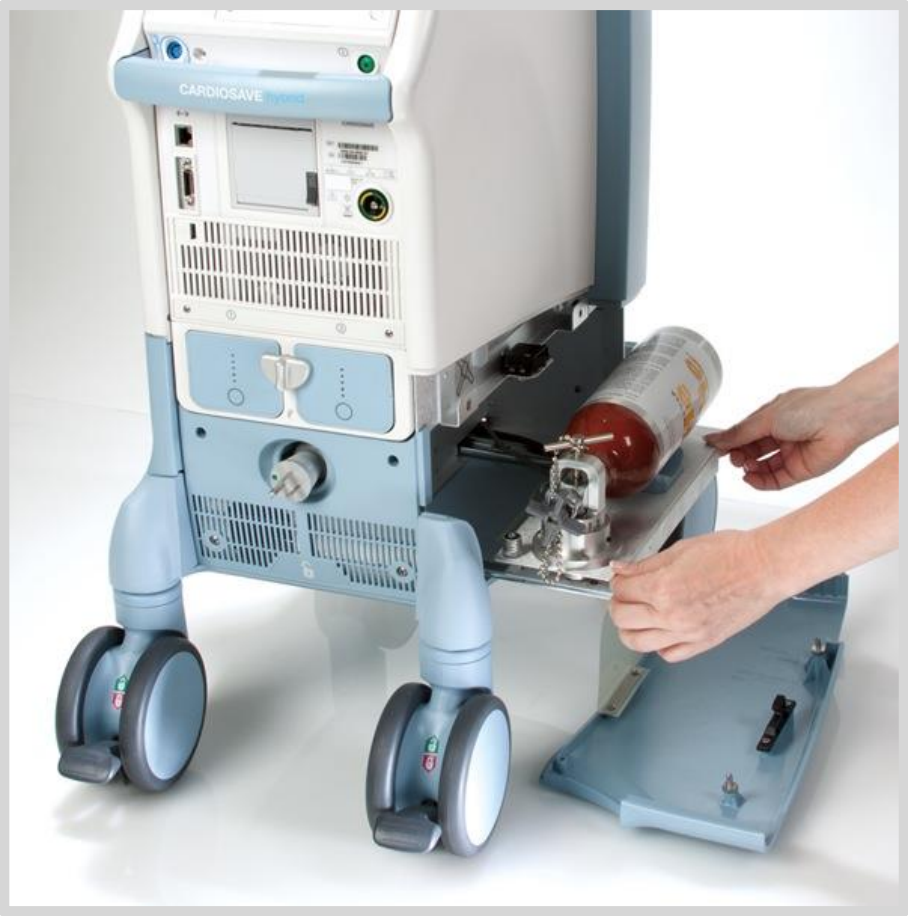
Helium Tank



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Back Panel

MAQUET
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Back Panel – With a Fiber-optic IAB

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Back Panel – With a Conventional IAB

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Back Panel – With ECG External Monitor Interfacing

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Back Panel – Hot Swappable Lithium Ion Batteries

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Back Panel – Retractable Power Cord

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Transport Configuration

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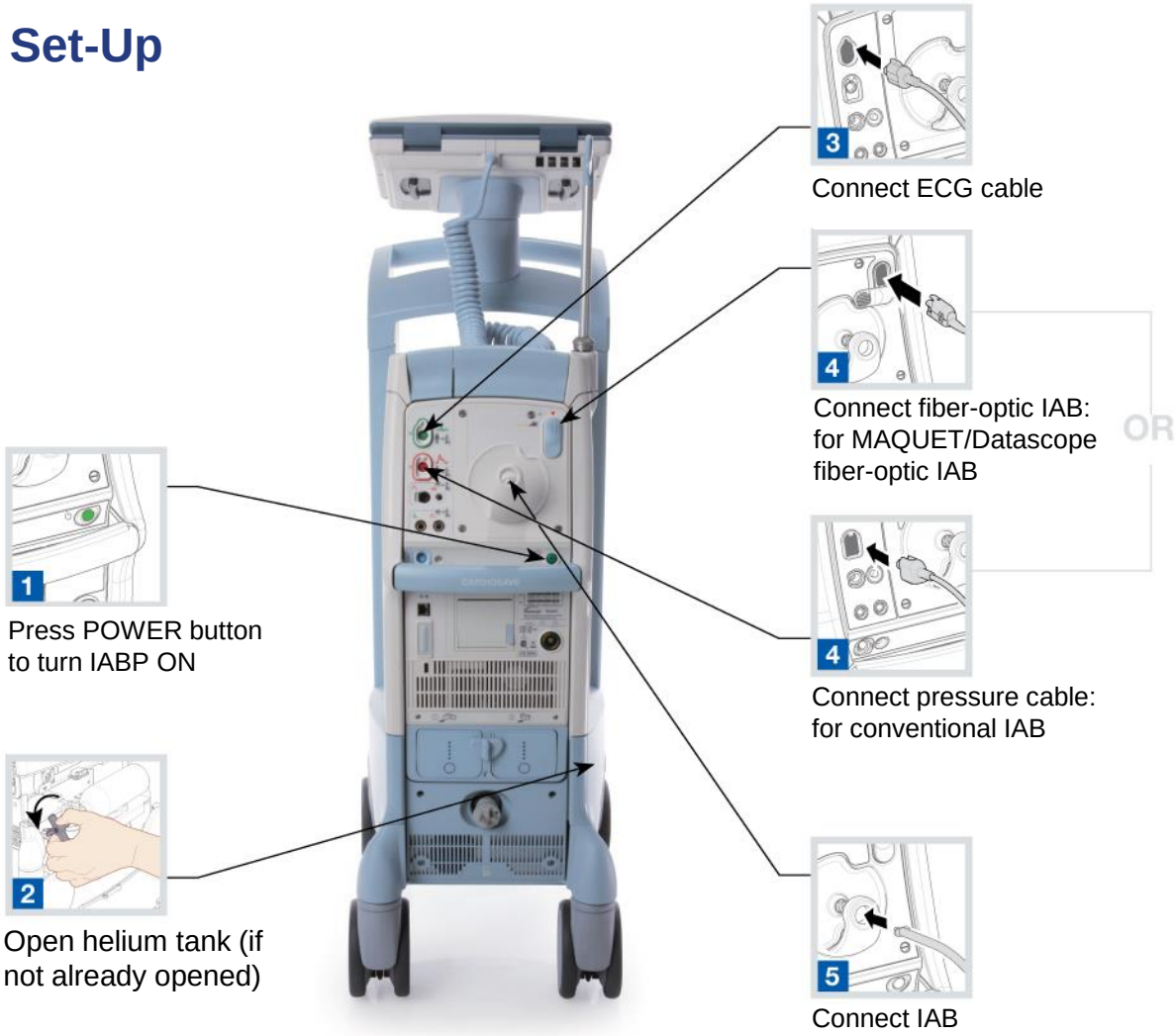
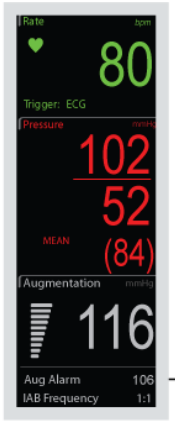
CARDIOSAVE Initial Set-Up



Initial set-up using a MAQUET/Datascope fiber-optic IAB (continued)



Verify Aug. Alarm is set 10mmHg below patient's augmented diastolic pressure (approx. 3 min. after initiation of assist)

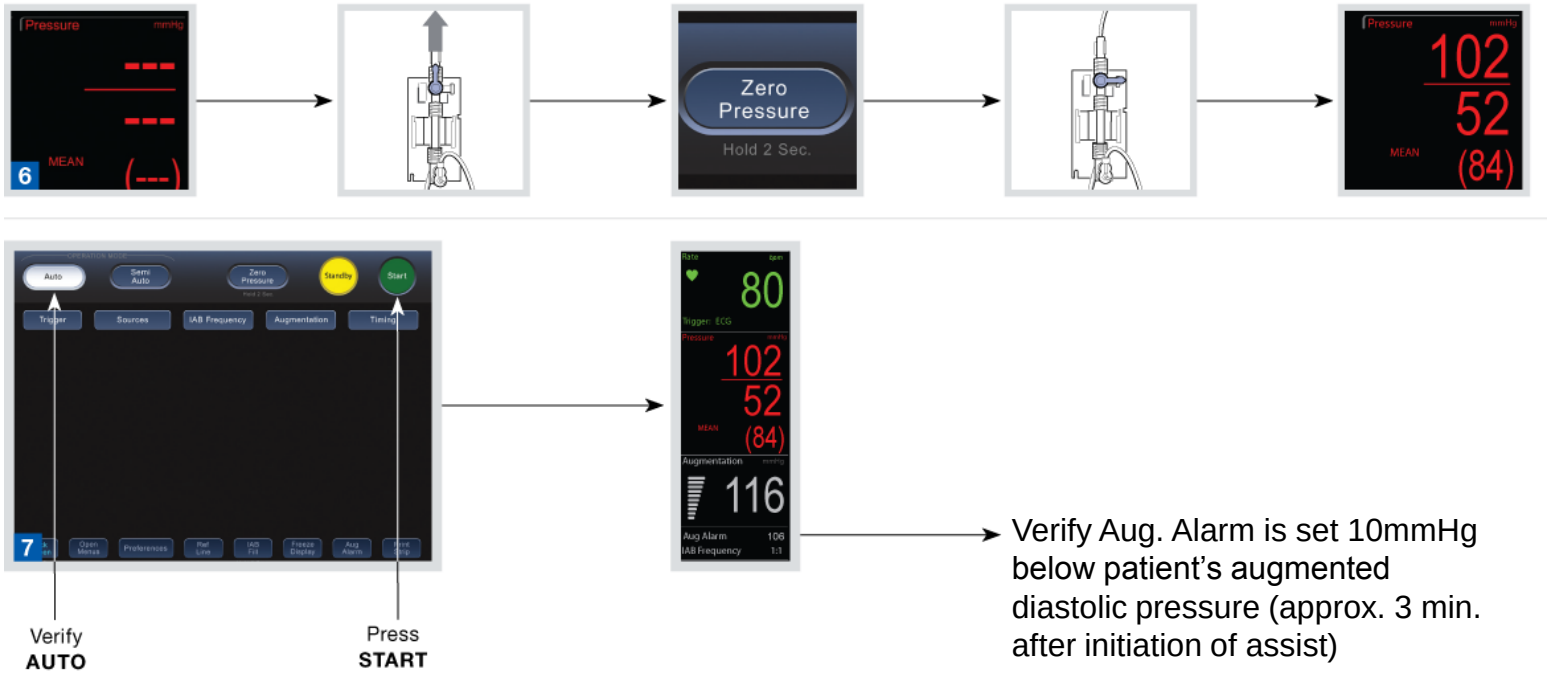
Verify **AUTO**

Press **START**

Pressing the START key

- Automatically purges and fills IAB
- Automatically performs an *in vivo* calibration
- Automatically selects most appropriate lead and trigger
- Automatically sets inflation and deflation timing

Initial set-up using a conventional IAB (continued)



Verify Aug. Alarm is set 10mmHg below patient's augmented diastolic pressure (approx. 3 min. after initiation of assist)

Pressing the START key

- Automatically purges and fills IAB
- Automatically selects most appropriate lead and trigger
- Automatically sets inflation and deflation timing

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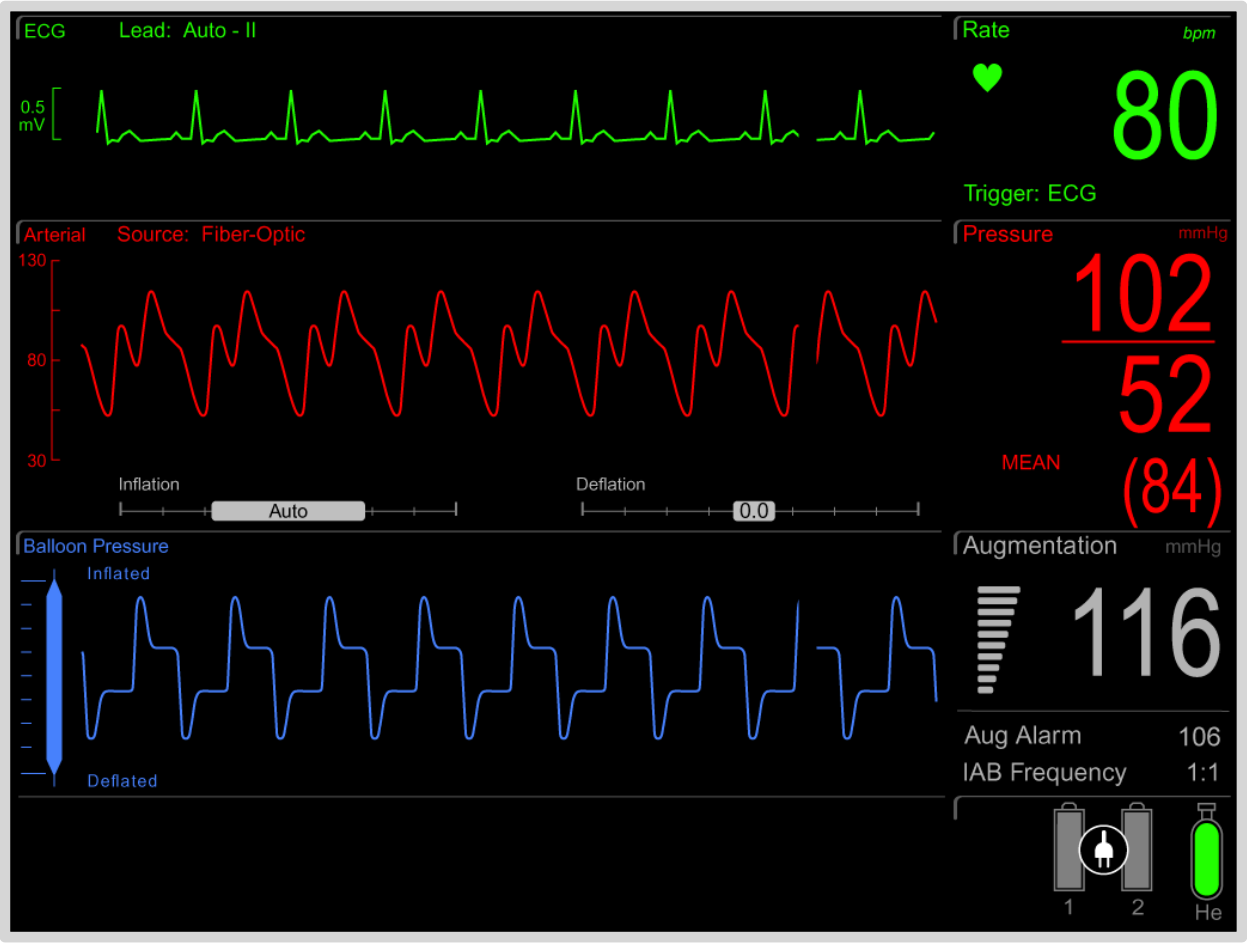
Monitor Display



MAQUET
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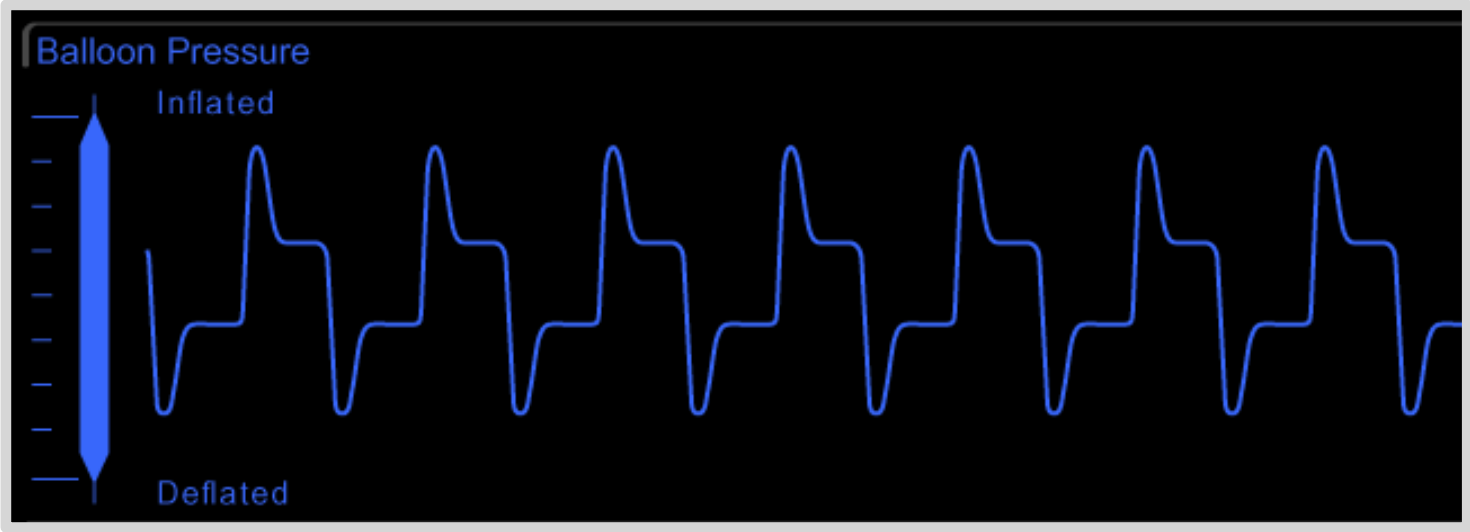
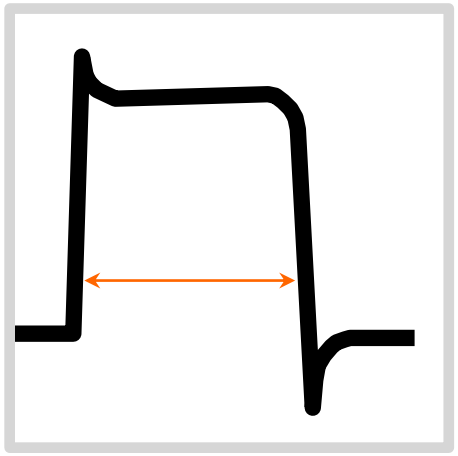
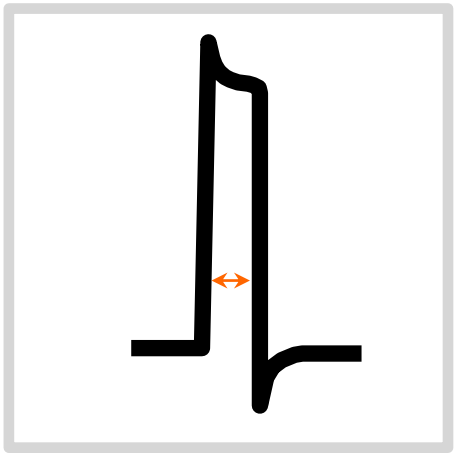
Normal Balloon Pressure Waveform



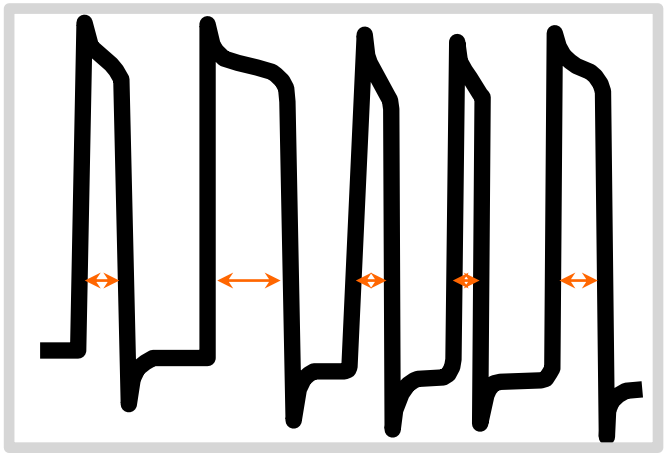
Variations in Balloon Pressure Waveform



Bradycardia

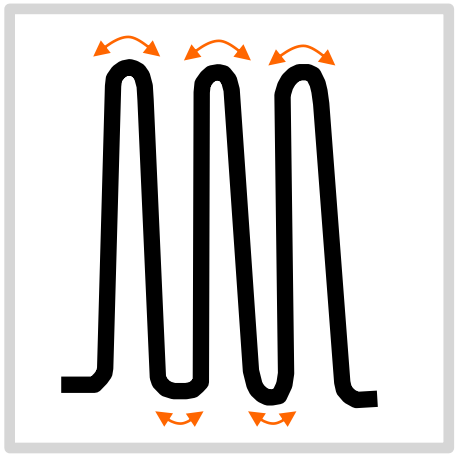


Tachycardia

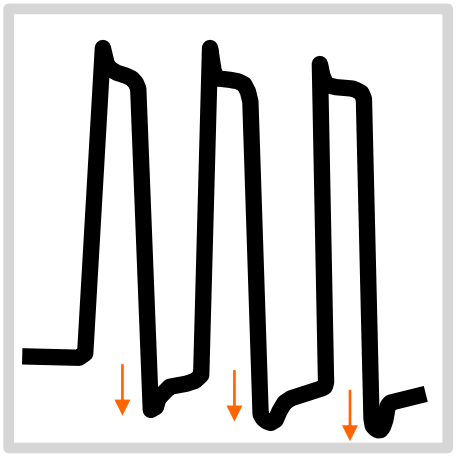


Irregular Rhythm

Variations in Balloon Pressure Waveform



Catheter Restriction



Gas Loss

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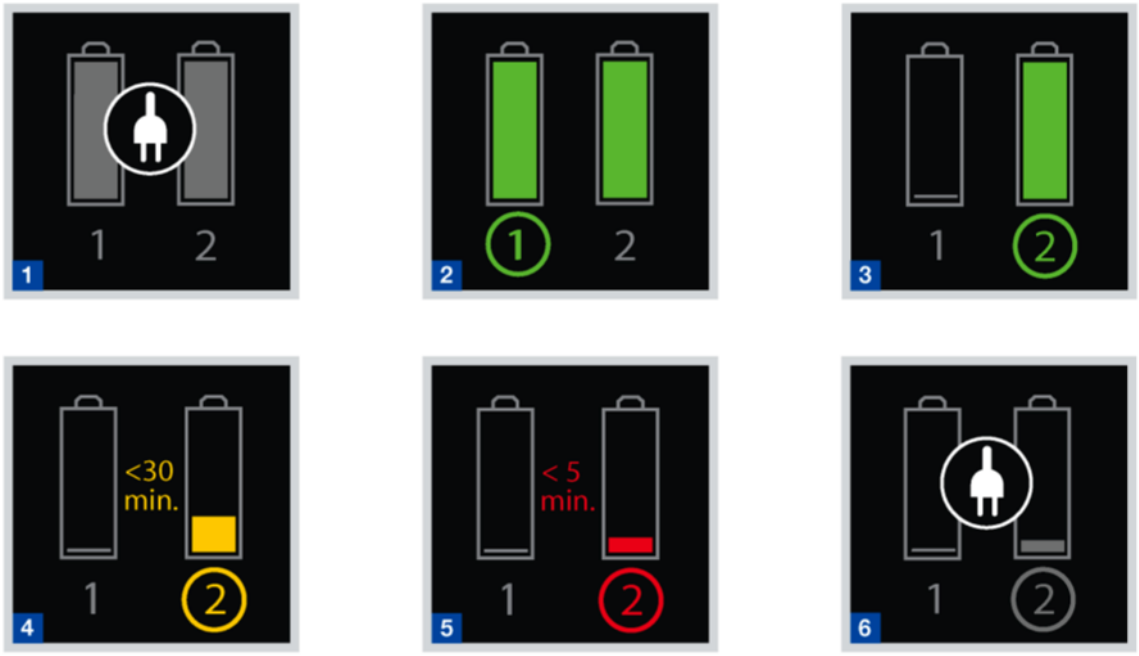
Battery Status (Examples)

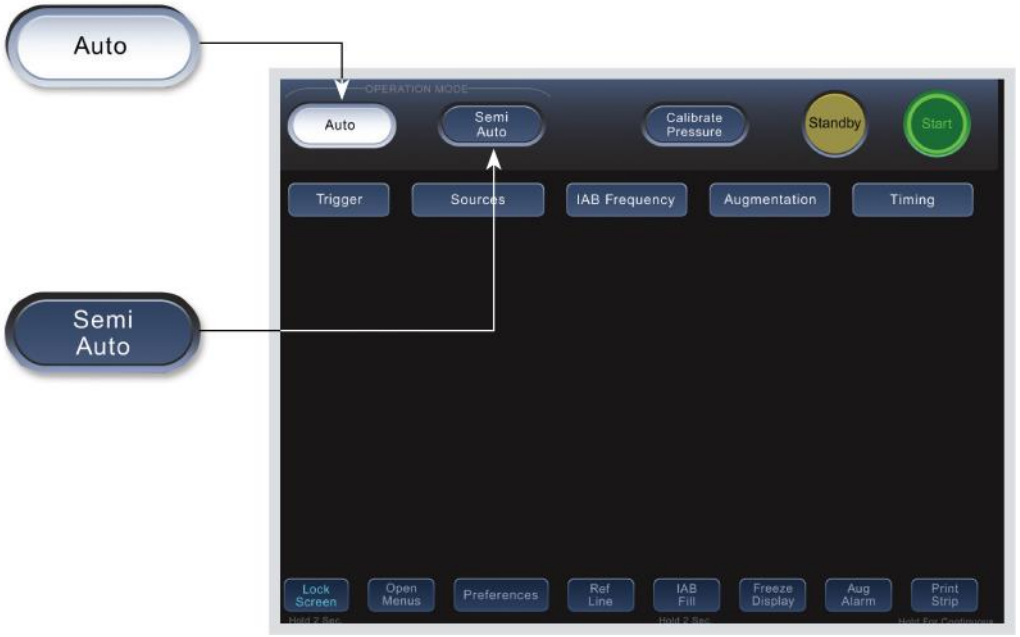


Auto Operation Mode

- Automatic lead and trigger selection
- Automatic and continuous inflation and deflation timing management
  - User has ability to fine-tune deflation timing
- Automatic management of irregular rhythms
- Automatic *in vivo* calibration (when using a MAQUET/Datascope fiber-optic IAB)

Semi-Auto Operation Mode

- Operator selects most appropriate lead and trigger source
- Operator establishes timing, then CARDIOSAVE automatically adjusts timing with heart rate and rhythm changes
- Automatic management of irregular rhythms
- Automatic *in vivo* calibration (when using a MAQUET/Datascope fiber-optic IAB)



Touchscreen

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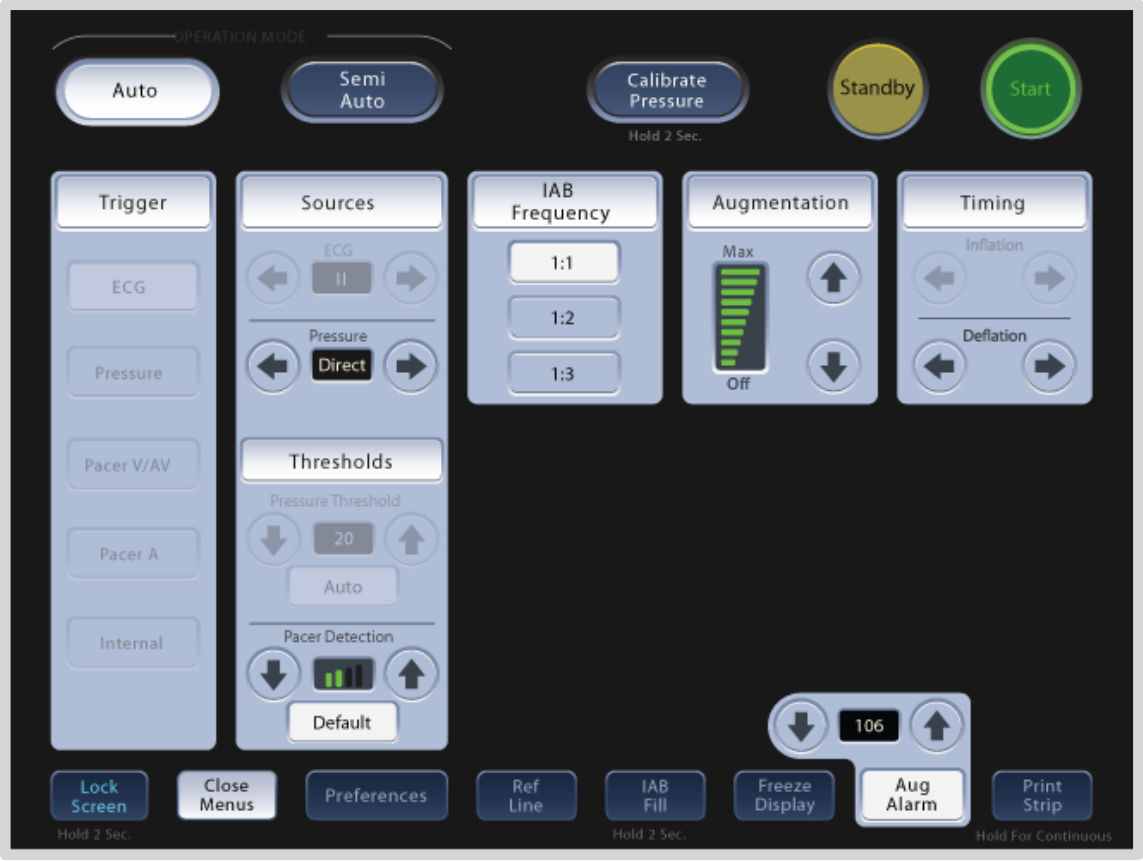
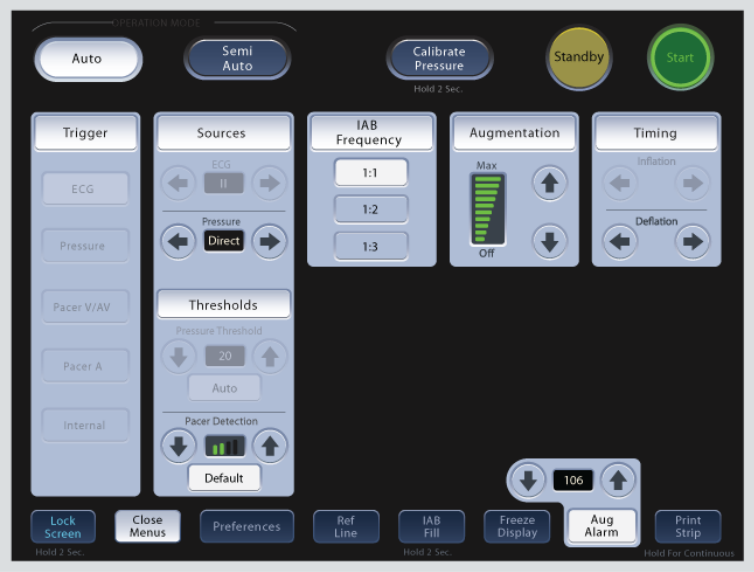
Touchscreen



Lock Screen Feature



Touchscreen Unlocked

Touchscreen Locked

Touchscreen will Lock:

- Automatically after 2 min. of inactivity
- When operator presses **LOCK SCREEN** key for 2 sec.

Touchscreen will Unlock:

- Automatically with any Technical, High, Medium, or Low Priority Alarm
- When operator presses **UNLOCK SCREEN** key

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Touchscreen with Preferences menu opened

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Touchscreen with Help Screen displayed

HANDS-ON/TROUBLESHOOTING

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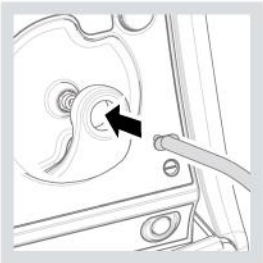
Alarms

Augmentation Below Limit Set

Probable Cause	Corrective Action
Hemodynamic status has changed	Attempt to optimize patient's hemody-namic status
Alarm limit set too high	Press AUG. ALARM key, decrease limit

Autofill Failure



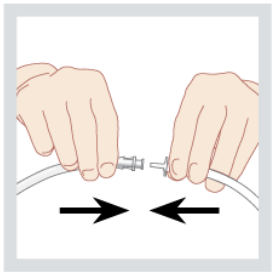
Probable Cause	Corrective Action
IAB disconnected	Attach IAB catheter
Helium tank is closed	Open helium tank
Helium tank is empty	Change helium tank
Incorrect IAB catheter extender tubing length	Ensure only one IAB catheter extender tubing is connected

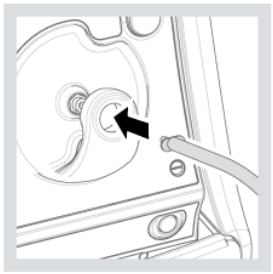
Alarms

IAB Catheter Restriction

Probable Cause	Corrective Action
Restriction in IAB catheter or tubing	Relieve restriction if possible, press START
Membrane has not completely unfolded	Manually inflate and deflate IAB
IAB remains in sheath	Check markings on IAB and if IAB has not exited sheath, refer to IFU to reposition sheath

IAB Disconnected





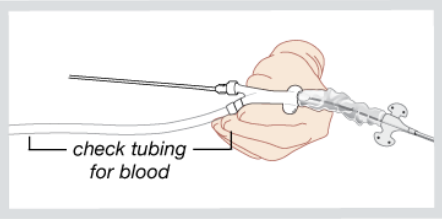
Probable Cause	Corrective Action
IAB catheter or extender tubing is disconnected	Reattach IAB, press START

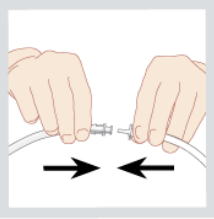
Alarms

Prolonged Time in Standby

Probable Cause	Corrective Action
IABP has been in Standby for at least 10 minutes	Verify whether it is appropriate to resume pumping

Gas Loss in IAB Circuit





Probable Cause	Corrective Action
A helium loss has been detected in IAB circuit	If blood observed - STOP pumping and prepare for removal If blood not observed - verify connections are tight If appropriate, perform an Autofill, then press START

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Alarms

Unable to Update Timing

Probable Cause	Corrective Action
Poor waveform quality	Check cable connections, verify transducer was not left vented, if in use If transducer is in use, aspirate and flush arterial pressure line If problem persists, switch operation mode to SEMI-AUTO, verify TRIGGER SOURCE, adjust timing, resume pumping
Sustained heart rate is less than 30 or greater than 150 BPM	Switch to SEMI-AUTO, verify TRIGGER SOURCE, adjust timing, resume pumping
Poor diastolic augmentation	If diastolic augmentation is poor, when AUG level is set to MAX, attempt to improve patient's hemodynamic status

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Alarms

Unable to Calibrate Fiber-Optic Sensor

Probable Cause	Corrective Action
Patient's pulse pressure is inadequate for calibration	When patient's pulse pressure improves, press CALIBRATE PRESSURE key for 2 seconds while IABP is assisting Provide alternate A.P. source (i.e.: radial)
Extender tubing or balloon catheter may be restricted	Relieve restriction Attempt calibration by pressing CALIBRATE PRESSURE key for 2 seconds while IABP is assisting

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Alarms

Fiber-Optic Sensor Calibration Postponed

Probable Cause	Corrective Action
A non-scheduled calibration update has been intentionally postponed because either patient's mean arterial pressure may be too low to pause assist or less than 15 minutes have elapsed since last calibration	Assess patient to determine if a brief pause in assist would be tolerated, and if so, press CALIBRATE PRESSURE key for 2 seconds while IABP is assisting Provide alternate A.P. source (i.e.: radial)
Pump is in STANDBY	Resume pumping, then press CALIBRATE PRESSURE key for 2 seconds to initiate a calibration

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Alarms

Fiber-Optic Sensor Module Failure

Probable Cause	Corrective Action
There has been a failure of the internal Fiber-Optic Sensor Module in the IABP	If a MAQUET/Datascope fiber-optic IAB is NOT in use, continue normal IAB use If a MAQUET/Datascope fiber-optic IAB is in use, replace IABP with another MAQUET/Datascope IABP that supports the fiber-optic IAB If a replacement IABP is not available, provide alternate A.P. source (i.e.: radial) Contact MAQUET Service for Fiber-Optic Sensor Module repair

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Alarms

Fiber-Optic Sensor Failure

Probable Cause	Corrective Action
There is a failure in communication of the fiber-optic sensor signal with the IABP	Unplug Fiber-Optic Sensor Connector and reconnect Relieve any visible kinks in orange Fiber-Optic Cable If problem persists, disconnect Fiber-Optic Sensor Connector and provide alternate A.P. source (i.e.: radial)

Q & A – WRAP UP