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Intra-Aortic Balloon Pump - A Review

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TITLE:

The Intra-Aortic Balloon Pump

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Intra-aortic balloon pump, mechanical circulatory support, balloon pump, cardiogenic shock

SUMMARY:

We describe the steps for the percutaneous implantation of the intra-aortic balloon pump (IABP), a mechanical circulatory support device. It acts by counterpulsation, inflating at the onset of diastole, augmenting diastolic aortic pressure and improving coronary blood flow and systemic perfusion, and deflating before systole, reducing left ventricular afterload.

ABSTRACT:

Cardiogenic shock remains one of the most challenging clinical syndromes in modern medicine. Mechanical support is being increasingly used in the management of cardiogenic shock. Intra-aortic balloon pump (IABP) is one of the earliest and most widely used types of mechanical circulatory support. The device acts by external counterpulsation and uses systolic unloading and diastolic augmentation of aortic pressure to improve hemodynamics. Although IABP provides less hemodynamic support when compared with newer mechanical circulatory support devices, it can still be the mechanical support device of choice in appropriate situations because of its relative simplicity of insertion and removal, need for smaller size vascular access and better safety profile. In this review, we discuss the equipment, procedural and technical aspects, hemodynamic effects, indications, evidence, current status and recent advances in the use of

IABP in cardiogenic shock.

INTRODUCTION:

Cardiogenic shock is a clinical condition characterized by decreased end organ perfusion due to severe cardiac dysfunction. The most widely accepted definition of cardiogenic shock is based on the Should We Emergently Revascularize Occluded Coronaries for Cardiogenic Shock trial (SHOCK)[1] and Intra-aortic Balloon Support for Myocardial Infarction with Cardiogenic Shock (IABP-SHOCK-II) trial[2] and includes the following parameters:

1. Systolic blood pressure <90 mm Hg for ≥30 min or vasopressor and/or mechanical support to maintain SBP ≥90 mm Hg
2. Evidence of end-organ hypoperfusion (urine output <30 mL/h or cool extremities)
3. Hemodynamic criteria: cardiac index ≤2.2 L/min/m^2 and pulmonary capillary wedge pressure ≥15 mm Hg

Acute myocardial infarction (AMI) is the most common cause of cardiogenic shock accounting for approximately 30% of cases[3]. Despite advances in the treatment of patients with AMI with early invasive revascularization, the mortality of cardiogenic shock remains high[4]. The mechanism of diastolic augmentation showing improvement in coronary perfusion and decreased left ventricular work was first demonstrated in 1958[5]. Subsequently, in 1962 the first experimental prototype of IABP was developed[6]. Six years later, Kantrowitz et al.[7] presented the first clinical experience of IABP use in four patients with AMI and cardiogenic shock unresponsive to medical therapy.

The IABP's mechanism of action involves inflation of the balloon during diastole and deflation during systole. This results in two important hemodynamic consequences: When the balloon inflates in diastole, the blood in the aorta is displaced proximally towards the aortic root thereby increasing coronary blood flow. When the balloon deflates in systole, it causes a vacuum or suction effect decreasing afterload and augmenting cardiac output[8]. The hemodynamic changes caused by IABP are listed below[9] (**Table 1**):

1. Increase in aortic diastolic pressure
2. Decrease in systolic blood pressure
3. Increase in mean arterial pressure
4. Decrease in pulmonary capillary wedge pressure
5. Increase in cardiac output by ~20%
6. Increase in coronary blood flow[10]

The major indications of IABP are cardiogenic shock (due to AMI and other causes like ischemic and non-ischemic cardiomyopathy, myocarditis), mechanical complications of AMI like ventricular septal defect or severe mitral regurgitation, mechanical support during high risk percutaneous coronary interventions[11], as a bridge to coronary artery bypass surgery in patients with critical CAD, inability to wean off cardiopulmonary bypass and as a bridge to decision or advanced therapies like left ventricular assist devices (LVAD) or cardiac transplantation in end

stage heart failure[12,13,14,15]. Contraindications to use of IABP include moderate or severe aortic regurgitation which can worsen with counterpulsation, severe peripheral vascular disease which would preclude optimal arterial access and placement of the device and aortic pathologies like dissection[12,15.]

The IABP device consists of a console to control the unit and a vascular catheter with the balloon. The console includes the following four components:
a) Monitor unit which helps to process and determine a trigger signal for the balloon. The signal can be either electrocardiographic (ECG) triggering or pressure signal triggering;
b) Control unit: Processes the trigger signal and activates the gas valve to help with inflation or deflation;
c) A gas cylinder that contains helium. Carbon dioxide is an alternative but is less preferred than helium. Helium has a lower density and provides better balloon inflation characteristics with more rapid inflation and deflation[16];
d) A valve unit which helps with gas delivery.

The IABP (balloon) catheter is a 7-8.5 F vascular catheter with distance markings. The catheter has a polyethylene balloon mounted at the tip. The balloon size can vary from 20-50 mL. The ideal balloon has a length to cover from the left subclavian artery to the celiac artery take off, the inflated diameter measuring 90 to 95% of that of the descending aorta. The most commonly used balloon size in adult patients (height 5'4"/162 cm to 6'/182 cm) is 40 mL. A 50 mL balloon is used for patients >6'/182 cm and 34 cm balloon for 5'/152 cm to 5'4"/162 cm tall patients[12,17] (**Table 2**).

PROTOCOL:

This protocol follows the guidelines of institutional human research ethics committee.

1. Pre-insertion preparation

NOTE: The IABP is preferably inserted in the cardiac catheterization lab under fluoroscopic guidance. Bedside placement can be considered in very critical clinical situations.

1.1 Begin by preparing the catheterization laboratory for the procedure. Prepare sterile drapes and chlorhexidine or povidone iodine, IABP control unit, IABP catheter, ultrasound for arterial access, 1% lidocaine for local anesthesia, micropuncture needle and wire, micropuncture sheath, 7-8.5 F arterial access sheath for the IABP depending on the balloon size or IABP manufacturer, sutures and sterile dressing.

1.2 Prepare and drape the patient in the usual sterile fashion with a plan to access the femoral artery.

NOTE: IABP can also be inserted through the axillary artery but this often requires a surgical cut down.

1.3 Have the patient lay down flat on his or her back. Administer moderate conscious sedation if the clinical scenario permits, by infiltrating the groin access site liberally with 1% Lidocaine.

1.4 Prepare the IABP catheter. Use a 50 mL syringe to apply a vacuum and completely deflate the balloon, using the one-way valve at the catheter hub.

1.5 Remove the stylet in the catheter and manually flush the inner lumen with 3-5 mL of saline.

2 Insertion of the IABP

2.1 Obtain arterial access using the Seldinger technique[18]. Use ultrasound guided vascular access to improve first pass success and minimize vascular complications.

2.2 Insert a micropuncture needle at a 45˚ angle and insert the introducer wire once blood return is obtained.

2.3 Insert the micropuncture sheath.

2.4 Exchange the micropuncture sheath for a larger IABP sheath. The sheath size varies by manufacturers and balloon size but is usually 7-8.5 F.

NOTE: There are two methods to introduce and advance the IABP catheter. The catheter can either be backloaded with a wire or can be advanced over a wire.

2.5 Advance the IABP catheter through the sheath using short strokes until correct placement is achieved. The optimal balloon position is where the tip is situated distal to the left subclavian artery take off. This is often not easy to identify, and hence, use the carina of the trachea as a landmark, ensuring that the proximal end is above the renal arteries.

2.6 Confirm position by fluoroscopy. Secure the catheter in place either by using sutures or manufacturer provided locking plates and apply sterile dressing.

CAUTION: Incorrect balloon position results in reduced diastolic augmentation or vascular complications due to direct endovascular injury.

3 Switching on and setting up the IABP

3.1 Remove the guidewire and aspirate 3 mL of blood from the inner lumen. Flush the inner lumen with 3-5 mL of saline.

3.2 Attach a standard arterial pressure monitoring tubing to the catheter hub. Remove the

one-way valve from the catheter and attach the catheter hub to the console using the provided extension catheter.

3.3 Turn IABP **On**, then open the gas tank. Connect the ECG cable to the console. Connect the fiber optic or pressure cable to the console (depending on the manufacturer).

3.4 Press the **Start** key on the console. This automatically purges and fills the balloon, calibrates, selects an appropriate ECG lead and trigger, and automatically sets the inflation and deflation timing.

3.4.1 Select an appropriate operation mode – Automatic, Semi-automatic or Manual depending on the clinical scenario.

3.4.2 Select a trigger source. The IABP uses a trigger to identify the beginning of the next cardiac cycle. It deflates the balloon when it recognizes a trigger event. Trigger can be either ECG (R wave) or pressure (systolic upstroke).

3.4.3 Observe the pressure changes on the IABP console by setting a 1:2 frequency. Confirm that the assisted systolic pressure is lower than unassisted one, there is decrease in assisted end-diastolic pressure and that diastolic augmentation is above the systolic pressure - all of which is associated with optimal IABP support (**Figure 1**).

3.4.4 Set appropriate IABP frequency which can be 1:1, 1:2 or 1:3. This represents the frequency of balloon inflation with each trigger.

3.4.5 Confirm that the IABP timing is appropriate.

NOTE: An ideal IABP timing consists of the following: a) Inflation occurring at the dicrotic notch which appears as a sharp “V”. Ideally, the diastolic augmentation rises above systole, and b) Deflation occurring just prior to the next systole (**Figure 1**).

3.5 Use a continuous flush through the inner lumen (usually 3 mL/h).

NOTE: The patient and the IABP console are now ready to be transported.

3.6 Use systemic anticoagulation to reduce the risk of arterial thromboembolism.

NOTE: This is institution dependent and some centers do not use systemic anticoagulation for an IABP frequency of 1:1[19].

4 Assessment of the patient after placement of IABP

4.1 Check distal pulses. If the left radial pulse is weak, verify the position of the balloon to make sure that it is not occluding the left subclavian artery. If no distal pulses are detected in the

lower limb, consider removing the IABP and possibly alternate access.

4.2 Check the insertion site for any bleeding or hematoma.

4.3 Monitor urine output. If there is a drop in urine output or if there is a concern for hematuria, recheck balloon position to confirm that the balloon lies above the level of the renal arteries.

4.4 If there is blood in the IABP tubing, suspect balloon rupture. Immediately stop the IABP (this is usually done automatically) and remove the catheter.

4.5 Obtain a chest X-ray daily to verify optimal device positioning. Also change the sterile dressing daily to reduce the chances of infection.

5 Removal of IABP

5.1 Stop systemic anticoagulation and set IABP to 1:1.

5.2 Palpate the femoral pulse and check the baseline distal perfusion by obtaining a Doppler of the pedal pulse.

5.3 Check the activated clotting time. It should ideally be less than 150-160 seconds.

5.4 Remove sutures.

5.5 Once ready to pull, press the **Stop** button on the IABP console screen.

5.6 Pull the IABP until resistance is met against the sheath.

5.7 Pull the sheath and IABP as a unit.

5.8 Hold manual pressure over the femoral artery for 20-30 minutes or until bleeding stops.

5.9 Reassess distal pulses with Doppler.

NOTE: Manual pressure has been mentioned here in the protocol because it is universal. However, there are numerous other methods apart from manual pressure to help achieve femoral arterial hemostasis. These are institution dependent and include but are not limited to: external compression devices like FemoStop, vascular closure devices like Angioseal and Perclose ProGlide Suture-Mediated Closure System. The above-mentioned protocol was partly developed by using official device information guides and manuals across various manufactures of IABP.

REPRESENTATIVE RESULTS:

Despite being used for many decades now, the evidence on IABP use has been controversial.

Routine use of IABP in patients with AMI and cardiogenic shock is not recommended. The previous guidelines of the American Heart Association/American College of Cardiology (AHA/ACC) and the European Society of Cardiology (ESC) strongly recommended the use of the IABP in patients with AMI-associated cardiogenic shock (Class I B and Class I C) on the basis of pathophysiological considerations, non-randomized trials and registry data. However, the AHA/ACC in 2013 downgraded the use of IABP to class II A, primarily based on the results of the IABP Shock II trial[13.] The ESC STEMI Guidelines 2017 recommended no routine IABP counterpulsation but the guidelines state that IABP may be considered for haemodynamic support in selected patients as those with severe mitral insufficiency or ventricular septal defect[14]. The ESC NSTE-ACS 2020 guidelines discourage form routine use of IABP in patients with CS (class IIIB) but recommend IABP in ACS-related mechanical complications (class IIA)[20].

The IABP Shock II trial[2,] randomized 600 patients with acute MI complicated by cardiogenic shock to either IABP or no IABP. At 30 days, there were no differences in outcomes, including length of stay in the intensive care unit, renal function, rates of major bleeding, peripheral ischemic complications, sepsis, or stroke. There was no difference in mortality at long-term follow-up of 12 months and 6.2 years[21].The major limitations of the trial were – the timing of insertion of IABP was not controlled (86.6% were inserted post PCI). A lower mortality rate compared to other studies precludes application of this study to severe cardiogenic shock. Subsequent meta-analyses have showed that there is no convincing randomized data to support the routine use of IABP in AMI related cardiogenic shock[22].

However, several recent studies have shown that there is still some utility for the use of IABP. A meta-analysis of 9212 patients investigated the utility of the IABP when implanted preoperatively in patients undergoing coronary bypass graft surgery. The results support the use of IABP in this clinical setting, with a 4% relative risk reduction of mortality. Also, the risk of MI, renal failure, intensive care, and hospital length of stay were reduced with IABP[23]. Interestingly, with the increasing use of advanced heart failure therapies, IABP is being increasingly used in combination with extracorporeal membrane oxygenation and was associated with better survival in a recent meta-analysis[24].

FIGURE AND TABLE LEGENDS:

Table 1: Hemodynamic effects of IABP

Table 2: Comparison of catheter and sheath sizes across different IABP manufacturers[33]

Table 3: Troubleshooting of potential device malfunction and major patient complications from IABP

Figure 1: Hemodynamic waveform with IABP and appropriate timing of IABP augmentation

DISCUSSION:

Mechanical circulatory support is a rapidly evolving field. Even with the arrival of newer support devices, IABP remains the most widely used and simplest to deploy mechanical circulatory

support device available currently[25]. In this article we describe in detail, the procedure for percutaneous insertion of IABP, the indications, evidence, troubleshooting and complications. Despite conflicting evidence regarding the use of IABP in AMI-related cardiogenic shock, it remains the most widely used form of mechanical support. In addition to use in AMI related cardiogenic shock IABP is also used in coronary artery bypass surgery and as a bridge to advanced heart failure therapies like LVAD or cardiac transplant.

Insertion of the IABP is straightforward and the technique can be rapidly deployed either at bedside or preferably in the cardiac catheterization laboratory where fluoroscopic guidance can be used to confirm positioning. We recommend using ultrasound guidance to obtain arterial access to improve first pass success and better safety profile[26]. The IABP wire can either be backloaded (advancing the balloon and wire together as a unit) or over the wire as mentioned above. However, in patients with known peripheral vascular disease, we recommend the "over the wire" method. This helps confirm whether it is possible to navigate the IABP catheter through a narrow or tortuous vasculature. In patients with risk factors for limb ischemia, sheathless insertion technique can be considered which reduces the risk of ischemic complications secondary to the vascular sheath[27].

IABP is now being increasingly used in patients with end stage heart failure as a bridge to decision or advanced heart failure therapies like LVAD or cardiac transplant. A large study looking at the use of IABP in 1342 patients showed that IABP utilization increased over three fold since the 2018 cardiac transplant allocation change [28]. Since these patients often require mechanical support for a prolonged period of time, IABP insertion through the axillary artery can be considered. The axillary approach is well tolerated and permits ambulation and reduces the risk of infection in those requiring prolonged mechanical support. This overcomes the major limitation of the femoral approach which restricts ambulation and thereby promoting deconditioning in this tenuous patient population[29]. Newer devices which operate on the same principles as an IABP like the intravascular ventricular assist system (iVAS) are currently being studied which allow the patient to be discharged home with a temporary mechanical support device[30].

Complications from IABP most commonly result from difficult arterial access, malposition and patient risk factors like peripheral vascular disease. Due to the endovascular nature of the device, the most common complications are primarily related to vascular injury. Other complications include cerebrovascular accident, thrombocytopenia, insertion site bleeding, aortic dissection, spinal cord ischemia, blood stream infections, balloon rupture and gas embolism[11,27,31,32]. Troubleshooting of the device and the common complications are summarized in **Table 3**.

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Figure 1

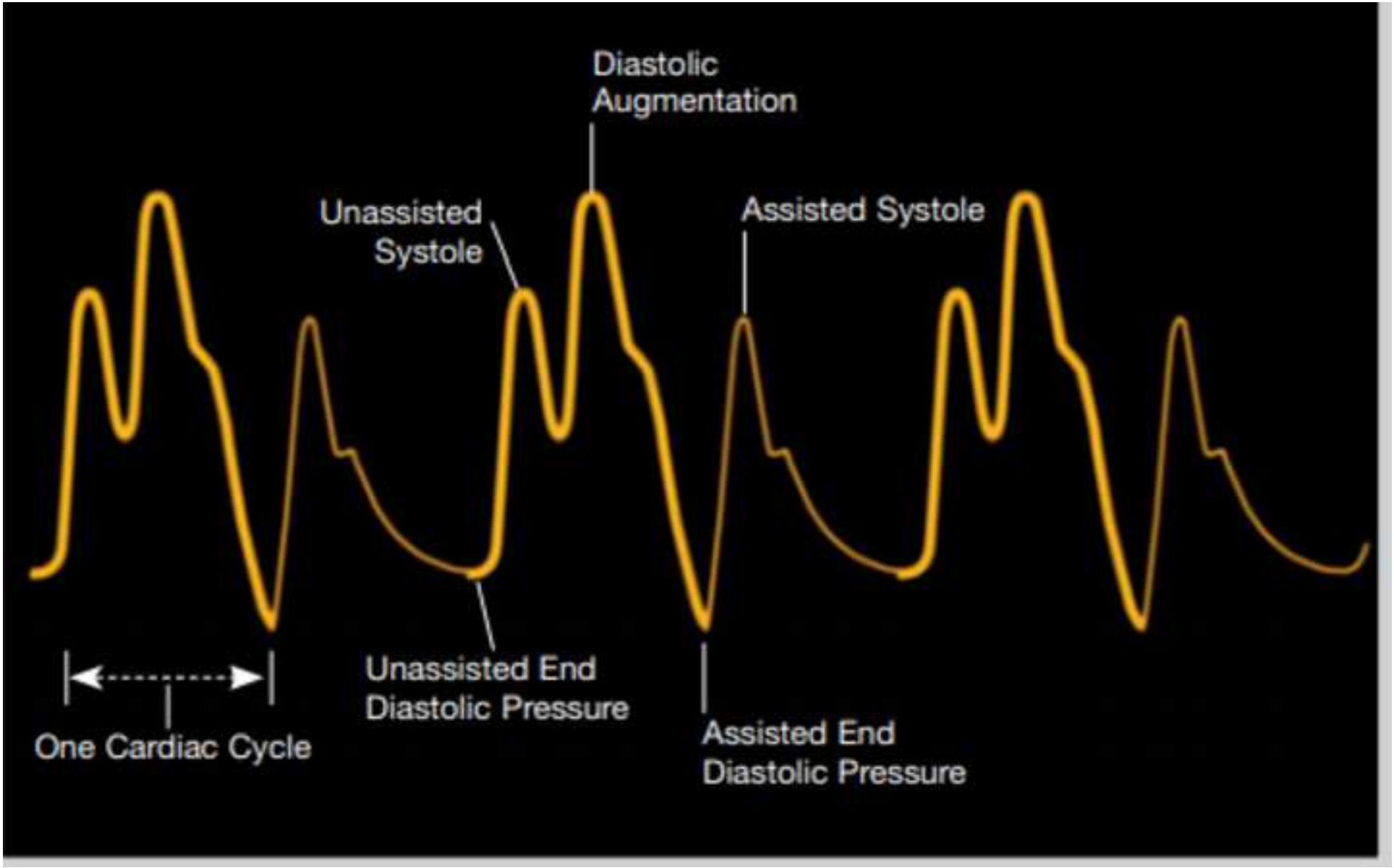

Table 1

Structure	Hemodynamic effect
Aorta	↓systolic pressure, ↑diastolic pressure
Left ventricle	↓systolic pressure, ↓end-diastolic pressure, ↓volume, ↓wall tension
Heart	↓afterload, ↓preload, ↑cardiac output
Coronaries	↑/unchanged coronary blood flow

Table 2

Company	Product	Catheter size (F)	Sheath size (F)	Balloon size (ml)
Balton	IABC Balloon	7.5, 8	7.5, 8	20, 25, 30, 34, 40, 50
Getinge	Cardiosave IABP	7, 7.5, 8	7.5,8	25, 30, 34, 40, 50
Getinge	CS300 IABP	7, 7.5, 8	7.5,8	25, 30, 34, 40, 50
Getinge	Linear	7.5	7.5	25, 34, 40
Getinge	Mega	7.5, 8	7.5, 8	30, 40, 50
Getinge	Sensation	7	7	34,40
Getinge	Sensation Plus	7.5, 8	7.5,8	40,50
Teleflex	Arrow AC3 Optimus Intra-Aortic Balloon Pump	7, 7.5, 8	8,8.5	30,40,50
Teleflex	Arrow RediGuard IAB Catheters	7,8	8,8.5	30,40,50
Teleflex	Arrow Ultra 8 Fiber-Optic IAB Catheters	8,8.5	8,8.5	30,40,50
Teleflex	Arrow Ultra 8 Fluid-Filled IAB Catheters	8	8	30,40
Teleflex	Arrow UltraFlex 7.5 IAB Catheters	7.5, 8	8,8.5	30,40,50

Table 3 Click here to access/download;Table;Table 3.xlsx

Problem	Probable cause	Solution
Console alarm - "check IABP Catheter"	Kink in tubing	Relieve kink
	Incomplete unfolding of balloon membrane	Manually inflate and deflate balloon
	A part of the balloon is in the sheath	Check balloon position
Rapid Gas Loss or Leak in IABP Circuit	Possible rupture	Check tubing for blood
		If there is no blood in the tubing, double check the connections
Weak left radial pulse or left arm ischemia.	Left subclavian artery occlusion	Check position of IABP
Low urine output or hematuria	Renal artery occlusion	Check position of IABP
Excessive bleeding from insertion site	Difficult arterial access, multiple sticks	Apply firm pressure while ensuring distal flow
Limb ischemia	Arterial access site issues, peripheral vascular disease	Consider removing the IABP. Consider alternate access
Blood noted in catheter tubing	Balloon rupture	Stop the IABP and remove the catheter immediately
Arterial dissection	Improper advancement of the guidewire with subsequent insertion of the IABP into a false lumen	Remove IABP

Table of Materials

Name of Material/ Equipment	Company	Catalog Number	Comments/Description
IABP catheter and console	Getinge	Sensation Plus	
Micropuncture Introducer Set	Cook Medical	G48006	
Sterile drapes	Haylard		
Ultrasound	GE		
Lidocaine	Pfizer		

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2. Please provide an email address for each author.

Contact info has been added to the manuscript

3. Please revise the following lines to avoid overlap with previously published work: 232-235, 248 (timing of…)-251 (…IABP), 255-258 (…reduction)

Edited a few lines. The others are either referenced or it is our original work

4. Please do not cite references in the abstract.

The references have been deleted

5. Please include an ethics statement before the numbered protocol steps, indicating that the protocol follows the guidelines of your institution’s human research ethics committee.

Done

6. Please revise the text, especially in the protocol, to avoid the use of any personal pronouns (e.g., "we", "you", "our" etc.).

Sentences using personal pronouns have been edited

7. Please ensure that all text in the protocol section is written in the imperative tense as if telling someone how to do the technique (e.g., “Do this,” “Ensure that,” etc.). The actions should be described in the imperative tense in complete sentences wherever possible. Avoid usage of phrases such as “could be,” “should be,” and “would be” throughout the Protocol. Any text that cannot be written in the imperative tense may be added as a “Note.” However, notes should be concise and used sparingly. Please include all safety procedures and use of hoods, etc.

The protocol has been edited to address this concern

8. Please note that your protocol will be used to generate the script for the video and must contain everything that you would like shown in the video. Please add more details to your protocol steps. Please ensure you answer the "how" question, i.e., how is the step performed? Alternatively, add references to published material specifying how to perform the protocol action. Please add more specific details (e.g., button clicks for software actions, numerical values for settings, etc) to your protocol steps. There should be enough detail in each step to supplement the actions seen in the video so that viewers can easily replicate the protocol.

We believe the protocol is succinct but detailed enough to help guide anyone to insert an IABP. Please let us know if you would absolutely like more details.

9. Please move all information about equipment, reagents, software etc to the Table of Materials.

Additional items have now been mentioned in the table of materials

10. 3.1 (Seldinger technique), 3.8 (fluoroscopy): Please provide more details or cite references that do.

Seldinger technique is a standard technique but we have now included a reference. Fluoroscopy is a standard term for X-ray

11. 5.3: what is "low urine output"?

The sentence has been edited. There is no definition for low urine output in this setting as it is a relative measure

12. Please format the manuscript as: paragraph Indentation: 0 for both left and right and special: none, Line spacings: single. Please include a single line space between each step, substep and note in the protocol section. Please use Calibri 12 points and one-inch margins on all the side. Please include a one line space between each protocol step and then highlight up to 3 pages of protocol text for inclusion in the protocol section of the video.

The manuscript was appropriately edited

13. Please discuss all figures and tables in the Representative Results. However, for figures showing the experimental setup, please reference them in the Protocol.

We have referenced the figure and tables in the protocol section. Table 3 is discussed in the discussion section.

14. Please include an Acknowledgements section, containing any acknowledgments and all funding sources for this work.

The filed has been now filled to mention "none"

15. Please ensure that the references appear as the following: [Lastname, F.I., LastName, F.I., LastName, F.I. Article Title. Source. Volume (Issue), FirstPage–LastPage (YEAR).] For more than 6 authors, list only the first author then et al. Please include volume and issue numbers for all references, and do not abbreviate journal names.

References are edited in the JOVE endnote format.

Reviewers' comments:

Reviewer #1:

Manuscript Summary:
In this article, the authors briefly review the pathophysiology of cardiogenic shock and mechanism of action for intra-aortic balloon counter pulsation. They provide a very nice overview of the device, indications and controversies around its use in addition to a very nice step by step guide reviewing best practices for device insertion.

Major Concerns:
None

Minor Concerns:
The authors should consider including mention of a 'sheathless' insertion technique, which may reduce the risk of ischemic limb complications in some settings.

Thank you for bringing this up. The sheathless technique is now mentioned in the discussion section

Also 50cc (or mega50) IABPs are frequently used in patients under 6'0 tall with data suggesting safety. Pros and cons may be worth mentioning despite it being off label indication.

The authors have decided not to mention this off label use because of lack of large randomized data and also since this will be published as a standard protocol video.

Additionally, a number of centers no longer routinely anticoagulate patients particularly when the devices are placed on 1:1 settings.

Thank you for this feedback. We have now touched upon this in the protocol section.

Including therapeutic goals for anticoagulation (eg target ACT or PTT may be beneficial to readers as well as a brief discussion about the risks/benefits for use of IABP without anticoagulation and best practices for holding it prior to device removal. Although it may be a bit beyond the spectrum of the intended review, there is a lot of variance in practices for device removal and arteriotomy closure, whether that be by manual pressure, pre-closure with a Perclose device, post closure with a Perclose, or deployment of collagen based plug. Lastly, protocols for monitoring position during prolonged implantation (serial xrays etc) and site management (daily site assessment, cleaning, use of antimicrobial bandaging etc) may be worth mentioning to help make this serve as a complete reference. There were a few minor grammatical errors noted.

Another excellent point. There is now a separate section in the protocol called "Removal of IABP". The point on dressing changes is now mentioned in protocol 5.6.

Reviewer #2:
Manuscript Summary:
The protocol is well and clearly described. The authors detail all essential steps for correct and save IABP catheter placement. They rightly stayed that US guidance could decrease or prevent arterial site complication. There is nice hint on how to discover inappropriately high position of IABP (above left subclavian artery) by checking left radial pulsations or too low (below the level of renal arteries) by observing decreased urine output or hematuria.

Major Concerns:
I would add that after pump activation it is important to observe the pressure changes on IABP console by setting initially 1:2 mode to be sure that assisted systolic pressure is lower than unassisted one, there is decrease in assisted end-diastolic pressure and that diastolic augmentation is above the systolic pressure - all of which is associated with optimal IABP support.

Thank you for this feedback. We have now mentioned this and also have referenced Figure 1

I would recommend to complete the protocol adding information how to safely remove IABP catheter

There is now a separate section in the protocol called "Removal of IABP".

Minor Concerns:
[line 42] 1st reference is missing in text, references start from 2nd

This has been fixed

[line 42-43] can't agree with the statement that „The role of IABP in cardiogenic shock and high risk percutaneous coronary intervention is a subject of debate given the paucity of randomized controlled trials" - esp. in the field of CS there is strong randomized evidence against routine use of IABP (IABP Shock II trail) and, according to that, the ESC guidelines give class III indication in that setting

This statement has been deleted

[line 49-50] Cardiogenic shock is not only „...a clinical condition characterized by decreased end organ perfusion due to severe cardiac dysfunction" but a condition when blood supply does not match the tissue needs leading to ischaemia, organ disfunction and, if not promptly corrected, to irreversible organ damage (MOF) and death.

This statement has been left unchanged since we have defined cardiogenic shock per the major trials below this statement.

[line71-73] ambiguous statement: „When the balloon inflates in diastole, the blood in the aorta is displaced proximally towards the aortic root thereby increasing coronary blood flow and displaces blood distally in systole thereby increasing systemic perfusion„ - this is a description of the hemodynamic effect in systole - erroneously the second part of statement is not true -blood is not displaced distally in systole due to balloon inflation - this happens in diastole.

This statement is now edited so that it is more clear

[line 83] - increase in coronary blood flow occurs only in conditions of exhausted coronary autoregulation as in slow-flow/now flow in AMI. In contrary, in more stable situations (e.g. in

high risk PCI) increase in diastolic aortic pressure (coronary drive pressure) is counterbalanced by an increase in coronary arteriole resistance and there is no change in blood flow.

This statement has been left unchanged and we have included a reference to support it

[line 88] reference not appearing in right order

This has been corrected

[line 104] english shortcut of „electrocardiografic" is ECG instead of EKG [also line 188, 192, 199]

"EKG" has been corrected to "ECG"

[line 105] hemodynamic trigger - means probably -pressure signal triggering (worth to note that nowadays there are two ways of pressure triggering - the older/cheper traditional pressure fluid-filled line recording with analogue transducer and novel one using light-transmission (fiber optic) with shorter time-to reaction and automatic zeroing and triggering optimisation); moreover I would mention to add pace rhythm trigger and AFiB trigger modes

Line 105 has been edited to reflect your statement. We have not mentioned Afib / pace trigger modes since it is included in the EKG trigger button on our console (which will be used for the video)

[line 115] IABP catheter size is from 7 to 8,5 F [see also in line 139]

This has been corrected

[line 121] for EU readers please add height in centimetres.

Height in cm is now mentioned

Moreover, standard balloon of 40 cc is used for patient >162 cm and 50 cc >182 cm, but on the market there is an increased volume balloon (MEGA - Getinge) designed in the way that 50 cc is used >162 cm and offers greater diastolic augmentation and systolic unloading compared to 40 cc balloon [Postepy w Kardiologii Interwencyjnej (2020) 16(1) 30-40], [Journal of Invasive Cardiology (2015) 27(4) 182-188]

Since this is a standard methods video, we have decided not to mention this given absence of large-scale randomized data

[line 228] It is worth to mention that IABP could be of value in the treatment of decompensated heart failure with low output and that there is recent evidence that compared to inotropes IABP leads to higher SvO2 and CPO change, greater reduction of NT-pro-BNP, more negative fluids balance and greater reduction of dyspnoea [EuroIntervention (2019) 15(7) 586-593]

We have decided not to include this given absence of large scale data