Recent trends on hemodynamic monitoring in cardiac surgery

The main aim of hemodynamic monitoring in cardiac surgery is to maintain the balance between tissue oxygen demand and supply. There are various instances during cardiac surgery where a significant hemodynamic instability occurs that warrants the use of effective monitoring tool. As we know that an ideal monitor should be easy to use, readily available, operator independent, has a rapid response time, should be cost-effective, and should provide information that is able to guide therapy. Moreover, it should provide the measurement of relevant variable, accurate and reproducible measurements, and interpretable data.[1]

There are various modalities for monitoring during cardiac surgery ranging from pulmonary artery catheter (PAC) since 1970s to newer minimally invasive devices like pulse contour analysis devices. Nowadays, even noninvasive devices are used for cardiac output (CO) monitoring in the perioperative period. The primary target to all these devices is to prevent tissue hypoxia and early goal-directed therapy (EGDT).

PAC has been considered as a "gold standard" monitor in cardiac surgery as we get useful hemodynamic data during surgery and postoperative period. However, some authors have shown mortality and morbidity risk with the use of PAC.[2,3] While some are not agreeing with their findings.[4] There are a lot of complications associated with the use of PAC such as arrhythmia, infection, pulmonary artery rupture, valve injury, knotting, and thrombosis leading to embolism and technical errors such as loss of injectate, variability of temperature, thermistor malfunction, clot over catheter tip, coiling of catheter, or timing of injectate >4 s may leading to inappropriate readings.[5] Misinterpretation of data is another risk of these techniques when used by junior colleagues.[6] In an editorial, it was suggested to have a complete moratorium on its use.[7]

Recently, a survey study was conducted among the Society of Cardiovascular Anesthesiologists to assess its use and found that PAC was used by 68.2% respondents for more than 75% of time. The use of PAC was also relates to their area of practice, as well as surgeon preference. Moreover, the survey also showed the use of transesophageal echocardiography as an adjuvant to PAC in 94% of patients.[8] From commercial angle also there is a negative annual growth of 2% in sales of PAC, while 15% positive growth in the sale of newer CO monitoring devices.[9] Therefore, newer modalities are finding space in routine hemodynamic monitoring during cardiac surgery primarily to monitor CO.

There is a continuous evolution in the modalities of hemodynamic monitoring. In the last decade, PAC was modified for continuous monitoring of CO and mixed venous oxygen saturation (SvO_2). However, the problems mentioned above remained there, and there is no mortality or morbidity benefit with its use. In the last 15 years, there was the development of pulse contour analysis devices along with a prediction of fluid responsiveness as well. The dynamic indices such as pulse pressure variation (PPV) and stroke volume variation (SVV) are used for fluid responsiveness along with CO measurement.[10]

Pulse contour CO techniques are primarily divided into three categories such as calibrated, uncalibrated, and noninvasive devices. Calibrated devices are transpulmonary thermodilution devices which include PiCCO monitor (Pulsion Medical Systems, Munich, Germany) and VolumeView monitor (Edwards Lifesciences, Irvine, USA). Main variables obtained from these are CO, global end-diastolic

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volume, global ejection fraction, intrathoracic blood volume extravascular lung water, and pulmonary vascular permeability index. Thus, we can assess preload, cardiac contractility, and permeability of the lung capillary membrane with these techniques. The accuracy may be affected by the vascular compliance, aortic impedance, air bubbles in the system, clotting of the catheter, valvular regurgitation, aortic aneurysm, significant arrhythmias, and rapidly changing temperature.[11] Validation studies have found a good correlation with PAC in cardiac surgery with the exception of off-pump coronary artery bypass surgery (OPCAB).[12] Lithium dilution CO (LiDCO Ltd., London, UK) system combines pulse contour analysis with lithium indicator dilution for continuous monitoring of SV and SVV. This technique has also been validated against PAC.[13] Its accuracy is also affected by aortic regurgitation, postaortic reconstruction, intraaortic balloon pump (IABP), damped arterial line, severe peripheral arterial vasoconstriction, arrhythmia, and intra- or extra-cardiac shunts. It requires regular calibrations as well.[11] Thus, it is not considered a favorable technique in cardiac surgery.

Another technique which is quite popular in cardiac surgery is the FloTrac/Vigileo technology (Edwards LifeSciences, Irvine, USA). The system does not need any external calibration and is operator independent and easy to use. Its software algorithm analyses characteristics of the arterial pressure waveform and uses this analysis along with patient-specific demographic information to calculate CO and SVV.[14] We have found a good agreement between FloTrac and PAC in patients undergoing OPCAB.[15] The accuracy is affected in patients with altered vascular tone and problems with the arterial waveform. The third-generation algorithm in FloTrac is considered to be useful in sepsis and other critical illnesses as well.[9] In this issue of journal, Kapoor *et al*[16] have used FloTrac with presep catheter for EGDT in on cardiopulmonary bypass coronary artery bypass grafting in a multicentric trial[16] and found it advantageous with shorter mechanical ventilation and intensive care unit and hospital length of stay as compared to the control group.

The ProAQT/PulsioFlex (Pulsion Medical Systems, Munich, Germany) is a newer pulse contour analysis device that also does not need external calibration. Its pressure waveform analysis software is different and the initial CO value from which the pulse contour analysis is started is not estimated by pulse contour analysis itself but by an innovative proprietary algorithm that performs an "auto-calibration."[9] It is found useful in OPCAB, but trending of CO is poor with this method.[17]

Others techniques such as LiDCOrapid system and pressure recording and analytic method MostCare (Vytech, Padova, Italy) also measures SVV and CO but still not validated in cardiac surgery, as well as Critical Care Units (CCU).[10,11] Moreover, dynamic preload assessment (volume responsiveness) parameters such as SVV or PPV may have limitations in cardiac surgery due to atrial fibrillation, open chest, or IABP.

Esophageal Doppler monitors CO by continuously measuring flow in the descending aorta. It is a relatively noninvasive technique that calculates aortic blood flow value from aortic blood velocity and diameter. There are various limitations with this method like measures flow in descending thoracic aorta which is 70% of total flow. A correction factor needs to be added to compensate aortic arch flow. Moreover, discrepancies in flow may be seen in aortic coarctation, aneurysm or cross clamp, IABP, and various metabolic states. The aortic cross-sectional area also changes with variation in pulse pressure, vascular tone, aortic compliance, volume status, or catecholamine use.[11] It is a good method in critical care patients but in OPCAB in comparison with PAC, it cannot be used as a sole method for CO monitoring.[18]

Noninvasive devices like Nexfin device (BMEYE B. V, Amsterdam, The Netherlands) based on photoelectric plethysmography, bioreactance device (NICOM; Cheetah Medical, USA), and partial gas rebreathing the NICO system (Novametrix Medical Systems, Wallingford, Conn, USA) are useful in CCU, outpatient or emergency room (ER), and noncardiac operating rooms (ORs). However, in cardiac surgery, they are still not validated against the standard techniques.[11,19]

Ultrasonic CO Monitors (USCOM, Sydney, Australia) is a portable noninvasive device and uses a probe placed suprasternally to measure the flow through the aorta or on the left chest to measure transpulmonary flow.[20] It can be used with ease in OR, ER, CCU, and even in wards and can be used by a trained nursing staff. It is an important screening tool for postoperative cardiac surgical patients as well.[11] We have used this device in postcardiac surgical patients for both left- and right-sided CO, cardiac index, and SV measurements and found a good agreement with PAC.[21,22]

ClearSight system (Edwards Lifesciences, Irvine, USA) is comprised the ClearSight finger cuff and EV1000 clinical platform. The system presents SV, SVV, CO, and systemic vascular resistance clearly and simply on the EV1000 monitor. It also sends an analog pressure to visualize noninvasive blood pressure on a bedside monitor. Moreover, there are color-based indicators, and a visual clinical support screen allows early recognition of the hemodynamic status.[23]

Finally, the role of central venous pressure (CVP) and central venous oxygen saturation ($ScvO_2$) is very important to assess the hemodynamic status.[24] It uses a central venous line which is simple monitoring tool with regard to cardiac surgery and CCU. CVP is an important marker of volume status and cardiac function as well. However, it may overestimate the true CVP in patients under mechanical ventilation. $ScvO_2$ is an important parameter to determine the adequacy of oxygen delivery and CO.[24] A low $ScvO_2$ may suggest tissue hypoxia due to a low or inadequate CO, anemia, hypoxemia, agitation, or a combination of all factors [Figure 1]. Moreover, it is an important surrogate of SvO_2.

To conclude, hemodynamic monitoring is an important aspect in cardiac surgery. The use of appropriate technique depends on the clinical scenario of the patient. PAC is a standard tool as it gives useful data that can be used for trending and therapy. However, there are question marks on its use. Other techniques such as pulse contour analysis or noninvasive devices may be validated against PAC but useful only at a particular stage. Even echocardiography is an important tool that cannot be used as a continuous monitor. Thus, PAC is still a gold standard, but the use of latest gadgets should be based on patient's clinical condition, institutional practice, and cost analysis.

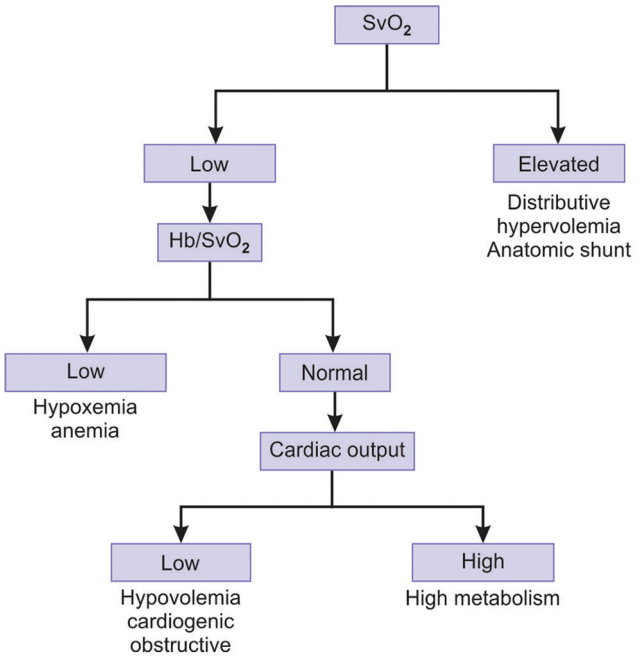

Figure 1: Interpretation of mixed venous oxygen saturation[24]

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