Monitoring for Cardiac Surgery

Ricard Navarro-Ripoll and Albert Carramiñana Domínguez

Abbreviations

CPB	Cardiopulmonary bypass
CO	Cardiac output
ECG	Electrocardiography
IBP	Invasive blood pressure
DHCA	Deep hypothermic circulatory arrest
BIS	Bispectral index
CPP	Cerebral perfusion pressure
MAP	Mean arterial pressure
CVP	Central venous pressure
ICP	Intracranial pressure
NIRS	Near-infrared spectroscopy
PAC	Pulmonary artery catheter
ECMO	Extra-corporeal membrane oxygenation
VAD	Ventricular assist device
PEEP	Positive End Expiratory Pressure
$ScvO_2$	Central venous saturation
TCD	Transcranial Doppler

R. Navarro-Ripoll (✉) · A. C. Domínguez
Anaesthesia and Intensive Care Department, Hospital Clinic Barcelona, Barcelona, Spain
e-mail: rnavarr1@clinic.cat

A. C. Domínguez
e-mail: carraminana@clinic.cat

M. Vives and A. Hernandez (eds.), *Cardiac Anesthesia and Postoperative Care in the 21st Century*, https://doi.org/10.1007/978-3-030-79721-8_5

Hemodynamic Monitoring

Hemodynamic parameters are essential during cardiac surgery because of sudden changes in cardiovascular stability may happen during and after general anaesthesia in patients with important comorbidities, primary advanced cardiac disease and before, during and after cardiopulmonary bypass (CPB). The main purpose is to maintain the balance between oxygen demand and supply. There are some standard parameters and some other more controversial and that are in constant evolution with new monitors. According to the authors, these are the most important hemodynamic parameters in cardiac surgery..

A. *Electrocardiography (ECG)*

Main objectives in monitoring ECG during general anaesthesia are detection of ischemia and dysrhythmias, as well as electrolyte disorders.

It is crucial to monitor for all cardiac patients a 5 electrode surface ECG that displays 6 frontal limbs plus one precordial limb, registering two leads at the same time. Evidence suggests that II and V_5 leads are the most accurate to diagnose around 90% episodes of myocardial ischemia. The electrodes should be protected with waterproof tape to avoid loss of signal, and placed in the back of the patient when possible.

B. *Invasive Blood Pressure (IBP)*

Invasive arterial pressure monitoring is mandatory in patients undergoing cardiac procedures because of the likelihood of hemodynamic instability, use of vasopressors/inotropic support and abrupt blood volume or arterial tone changes. For radial artery cannulation, Seldinger technique has better success rate than direct insertion of peripheral intravenous cannula.

More frequent sites for cannulation:

- Radial artery: easier, cleaner and good correlation with aortic pressure. Special attention should be paid in coronary artery bypass surgery as radial artery may be used as free graft.
- Femoral artery: especially useful in patients undergoing deep hypothermic circulatory arrest (DHCA), such as aortic dissection or pulmonary endarterectomy. Be aware of patients with previous vascular groin surgery or with groin skin infections.
- Humeral artery: used as an alternative to femoral artery when both radial arteries are unavailable. Has a good correlation with aortic pressure but there is a potential risk of limb ischemia.
- Aortic root: punctually used through the aortic root surgical cannula, to compare measurements between radial or femoral artery when concerns regarding reliability arise. Extreme attention to avoid air emboli is crucial.

C. *Central Venous Pressure (CVP)*

Defined as the right atrium pressure, its normal values range between 0 and 7 mmHg. Very useful to assess systemic drainage and right ventricle function, but poorly correlated with fluid responsiveness. Central venous catheter tip should be located between the junction of the superior vena cava and the right atrium.

Main accesses for central venous catheterisation:

- Internal jugular vein (IJV): Most common access route.
- Subclavian vein: is an acceptable alternative.
- Femoral vein: more often in pediatric cardiac surgery.
- Arm veins: not recommended for cardiac surgery.

Depending on the insertion site, placement of central catheters may present significant complications: accidental artery puncture, nerve damage, air embolism, pneumothorax, infection, thrombosis, etc. The use of ultrasound decreases the rate of complications and should always be considered.

D. *Cardiac Output (CO)*

One of the most interesting and controversial monitoring parameters. There are various modalities for CO monitoring during the perioperative period. In the following lines some of the most important will be exposed.

- Pulmonary Artery Catheter (PAC, Swan-Ganz): considered the gold standard since the 70s. CO is measured after a cold saline bolus is injected into the proximal port and a thermodilution curve is generated. The use of PAC is controversial because of the morbidity and mortality reported, nevertheless some authors do not agree with those findings. Probably not a routine but a proper patient selection is the key to advocate for this monitor (see Table 1).
- Minimally invasive methods: Based on the pulse power analysis and pulse contour analysis, there are multiple monitors and each have is main advantages and disadvantages (see Table 2).

E. *Central venous saturation ($ScvO_2$)*

Indicator of the balance between oxygen consumption and delivery and the adequacy of CO (normal $ScvO_2$ is >70%). A low value may indicate tissue hypoxia due to low blood concentration of haemoglobin, hypoxemia or to insufficient cardiac output. On the other side, a high value may suggest hypervolemia, anatomic shunt or inability to extract oxygen in the peripheral tissue, the latter with an extremely poor prognosis.

Table 1 Main PAC indications

Main indications for PAC colocation
Impaired left ventricular systolic function (EF <30%)
Impaired right ventricular systolic function
Severe left ventricular diastolic dysfunction
Acute ventricular septal defect
Left ventricular assist device
Complex valve surgery
Heart transplantation
Emergency aortic surgery

Table 2 Main semi-invasive CO monitors

Device	Advantage	Disadvantage
PiCCO	– Continuous CO measurement – Quantifies pulmonary oedema and fluid responsiveness	– Requires calibration – Low accuracy during hemodynamic instability/ OPCAB
Transesophageal echocardiography	– Useful for GDT – Judge adequacy of valve or congenital disease repair	– Operator dependency – No continuous monitoring
LiDCO	– Continuous measures CO and SVV	– Requires regular calibration – Poor reliability in cardiac surgery
FloTrac/Vigileo	– Only arterial line – No external calibration – Operator independent	– Low liability in severe vasoconstriction (arterial waveform) – Low accuracy in arrhythmias, IABP, morbid obesity
PRAM	– No external calibration	– Still not validated

Respiratory Monitoring

General anaesthesia induces many changes in respiratory system, as well as formation of atelectasis and decrease in functional residual capacity, etc. Respiratory monitoring is basic to detect and treat appropriately any event and to adjust properly protective ventilation parameters.

A. *Pulse oximetry* (SpO_2)
   Simple and non-invasive method useful to monitor oxygen saturation (SpO_2), peripheral perfusion and cardiac rate based on the amount of oxyhaemoglobin and deoxygenated haemoglobin in arterial blood (Fig. 1). Finger probe is normally used as first option, being the earlobe probe a good alternative when distal perfusion is compromised.
B. *Capnography* ($EtCO_2$)
   Non-invasive monitor that assesses end-expiratory CO_2, an indirect measurement of $PaCO_2$ (Fig. 2). It reflects alterations in alveolar ventilation, cardiac output, pulmonary perfusion or accidental ventilator disconnection.

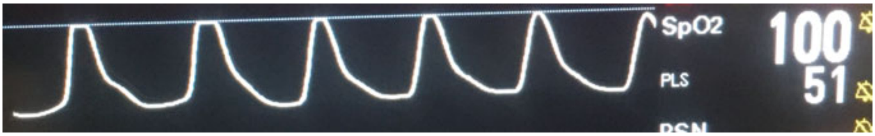

Fig. 1 Pulse oximetry curve

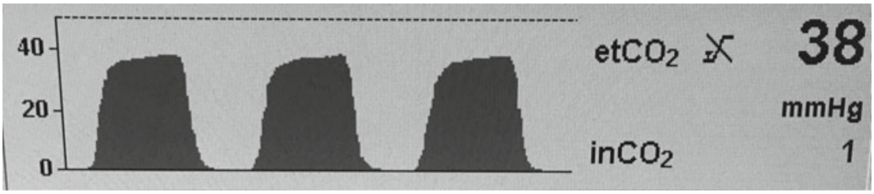

Fig. 2 Capnography curve with end-expiratory CO_2

C. *Respiratory Mechanics*
Measurement of airway pressure (Peak, Plateau, and Driving Pressure) and compliance is helpful to optimize ventilator parameters as well as to adjust individualized PEEP and perform recruitment manoeuvres if needed (Fig. 3). General anaesthesia and CPB facilitate the formation of atelectasis as well as hypoxemia and ARDS.

Temperature Monitoring

Temperature is a paramount parameter during cardiac surgery where wide changes may happen during CPB. Choosing an appropriate site of monitoring has relevant consequences as hypothermia may be needed in order to properly protect organs during CPB or DHCA. Cooling and rewarming at a certain temperature and temperature rate change imply deep physiologic changes and reliable monitoring is mandatory to ensure optimal management. It is well known that hyperthermia during CPB may cause neurologic injury and that excessive fast rewarming after cooling may result in rebound hypothermia after resuming spontaneous circulation. Although temperature management and monitoring site is not uniform between centres, monitoring should include at least two locations. Main advantages and disadvantages of different monitoring sites are showed in Table 3.

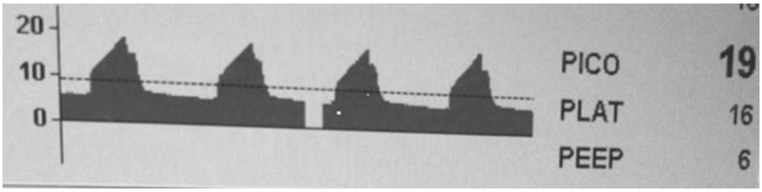

Fig. 3 Respiratory mechanics and airway pressure values (Peak and plateau, PEEP)

Table 3 Main sites of temperature monitoring during cardiac surgery

Temperature monitoring site	Advantage	Disadvantage
Intravascular	Gold standard	Not useful when the heart is not ejecting
Nasopharyngeal	Reliability and availability	Risk of epistaxis
Urinary bladder	Easy to place, availability, no added risk	Delay in rapid core temperature changes, reliability depends on urinary output
Oesophageal	Ease of placement, minimal risk	Incorrect positioning can alter its reading, transoesophageal echocardiography
Tympanic membrane	Estimation of brain temperature	Risk of tympanic damage
Rectal	Ease of placement, minimal risk	Artefacts, lower reliability

Monitoring sites:

- *Intravascular*: devices that monitor intravascular temperature are the gold standard of core temperature measurement. They directly monitor the blood temperature through a thermistor located at the tip of the catheter and are normally used to measure cardiac out through thermodilution. The pulmonary catheter is the most frequently used in the cardiac surgery environment, but it has strong limitation as it can only be used when there is pulmonary flow but not during CPB.
- *Nasopharyngeal*: probably one of the most commonly used sites thanks to its reliability. When correctly positioned in the upper pharynx, it is surrounded by highly irrigated mucosa and it reflects the brain and core temperature. Its main drawback is the risk of epistaxis that may be significant in patients who receive systemic heparinisation.
- *Bladder*: after nasopharyngeal, the most common site used. The temperature is measured through a thermistor attached to a Foley catheter. It is may have a delay of up to 3 °C compared to nasopharyngeal temperature in rapid cooling or rewarming. Its accuracy decreases when there is low urinary output.
- *Oesophageal*: it correctly reflects the heart and core temperature. The temperature probe should be placed in the distal oesophagus; about 45 cm form the nose. Positioning is important because false measurements may be obtained if placed proximal to the trachea. Its main limitations consist in false measurements due to pericardial cold solutions applied during myocardial protection, pericardial saline irrigation and probe displacement during transoesophageal echocardiography assessment during the surgery.

- *Tympanic membrane*: mostly used as a surrogate of brain temperature, very useful during DHCA. The tympanic membrane lies next to the hypothalamus and is irrigated by the carotid artery. There is a risk of tympanic membrane damage.
- *Rectal*: it can be used to estimate the core temperature but some artefacts such as splanchnic vasoconstriction, the presence of stool and heat generated by bacteria limit its reliability. Rectal temperature usually exceeds core temperature. Frequently used for general cases but less commonly for active cooling and rewarming due to its drawbacks.

Neurologic Monitoring

Neurologic monitoring has a potential to facilitate anaesthetic titration, improve cerebral perfusion and decrease postoperative neurologic dysfunction. Different devices are available to estimate neuronal transmission and brain perfusion. However, there is still no non-invasive monitor that can reliably assess global cerebral perfusion. The integration of different data including clinical parameters and specific monitoring such as the bispectral index, near-infrared spectrometry or transcranial doppler is probably the best available information when trying to optimize neurologic outcomes.

Clinical parameters:

Basic clinical neurologic monitoring includes hemodynamic parameters and temperature. Although there is a lack of consistent evidence, ensuring appropriate cerebral perfusion during cardiac surgery seems a promising strategy to decrease neurological injury. The cerebral blood flow (CBF) will depend on the cerebral perfusion pressure (CPP), calculated as:

$$\boxed{\mathrm{CPP} = \mathrm{MAP} - (\mathrm{CVP} + \mathrm{ICP})}$$

where MAP = mean arterial pressure, CVP = central venous pressure, ICP = intracranial pressure.

Maintaining an optimal CPP during all the procedure will depend on maintaining an adequate MAP and avoiding significant increase in CVP and ICP. Cerebral hypo-perfusion and hypotension should be avoided as they may be related to an increase in postoperative neurological dysfunction, in particular in those with previous neurologic conditions and in the elderly. The main problem arises when trying to define an "adequate" MAP for every patient. Cerebral auto-regulation curve may be shifted rightwards in hypertensive and in the elderly and higher values of MAP may be necessary. Moreover, there are some specific situations in cardiac surgery that may impair cerebral venous drainage, due to inadequate positioning of drainage cannula, superior vena constriction or surgical manoeuvres.

Temperature affects cerebral metabolic rate and hypothermia has been used to minimize cerebral metabolism during DHCA. There is little evidence regarding the effect of mild to moderate hypothermia but there is consistent evidence regarding the deleterious effect of hyperthermia. In fact, cerebral hyperthermia associated to actively rewarming during CPB is related to worse neurologic outcome. Monitoring the temperature to avoid hyperthermia (>37 °C) and limiting the arterial line temperature to 37 °C might be useful to avoid cerebral hyperthermia.

Bispectral index:

The bispectral index (BIS) is one of the most common neurophysiologic monitors used in cardiac surgery. One of the most important reasons why it gained such popularity is that cardiac surgery has been deemed at high risk for intraoperative awareness, especially when low dose of hypnotics and high dose of opioids to avoid hemodynamic instability were used. Modern anaesthetics techniques and drugs suppose a different scenario but the bispectral index has continued to gain more acceptation. Different reasons may explain why. Anaesthetic dose titration may be facilitated using BIS and therefore it can help to limit hemodynamic side effects of anaesthetic drugs. Moreover, excessive anaesthetic depth and over-suppression (prolonged BIS of <40) has been related to worse neurologic outcomes and increased mortality. BIS can also help when aiming for isoelectrical cerebral activity during DHCA and avoiding excessive neuronal activity in the periods of rewarming. Despite these potential benefits, the main limitation is that there is a lack of evidence that BIS may contribute to better outcomes in cardiac surgery. Another limitation is artefacts due to signal contamination and sensor mobilization.

Other neurophysiologic monitoring:

Some other methods have been assessed but they are rarely used. Electroencephalogram and somatosensory evoked potentials could be helpful but to the moment there is scarce evidence in general cardiac population. They are more complex and difficult to interpret and are sensitive to many artefacts that make them less attractive for clinical practice.

Cerebral oximetry:

Near-infrared spectroscopy (NIRS) technology is used to assess haemoglobin oxygen saturation in the brain. In a different manner than pulse-oximetry does, NIRS measures the haemoglobin oxygen saturation of not only of the pulsatile blood but also venous blood and tissue. When placed in the forehead, it theoretically measures regional saturation of the frontal lobe, a zone irrigated by both mean and anterior cerebral arteries with transitional zones susceptible to ischemia. Cerebral oximetry has the potential to assess the mismatch of oxygen supply and demand in the brain and it can help to assess cerebral auto-regulation during cardiac surgery.

One of the main limitations of NIRS is the lack of normal values. 75% of saturation has been used as a desired target and desaturation below 50% or more than 20% below the baseline (obtained in the non-sedated awake patient breathing

Table 4 Main benefits and pitfalls of NIRS

Benefits	Pitfalls
Non-invasive	Not well-defined baseline value
Easy to interpret	Only anterior perfusion is assessed
Continuous monitoring	Extra-cranial signal contamination
Bilateral assessment	Cost-efficiency
Interventional algorithms created	Lack of evidence

room air) seem to be related to worse outcomes. Recent studies suggest that desaturation episodes can successfully be treated in 95–97% of the patients and that may have an impact in a reduction of postoperative complications. Main advantages and disadvantages of NIRS are showed in Table 4.

Despite its limitations, NIRS is a useful tool when used combined to clinical parameters in many situations. As said before, cerebral auto-regulation curve is different between patients and NIRS can help to elucidate the desired MAP during CPB and to assess tolerance to hypotension. It can also help to assess correct cannulation and perfusion during arch surgery and antegrade cerebral perfusion, tolerance to circulatory arrest during DHCA (Fig. 4) and can help in the decision making on when to transfuse. Use of cerebral oximetry differs widely between

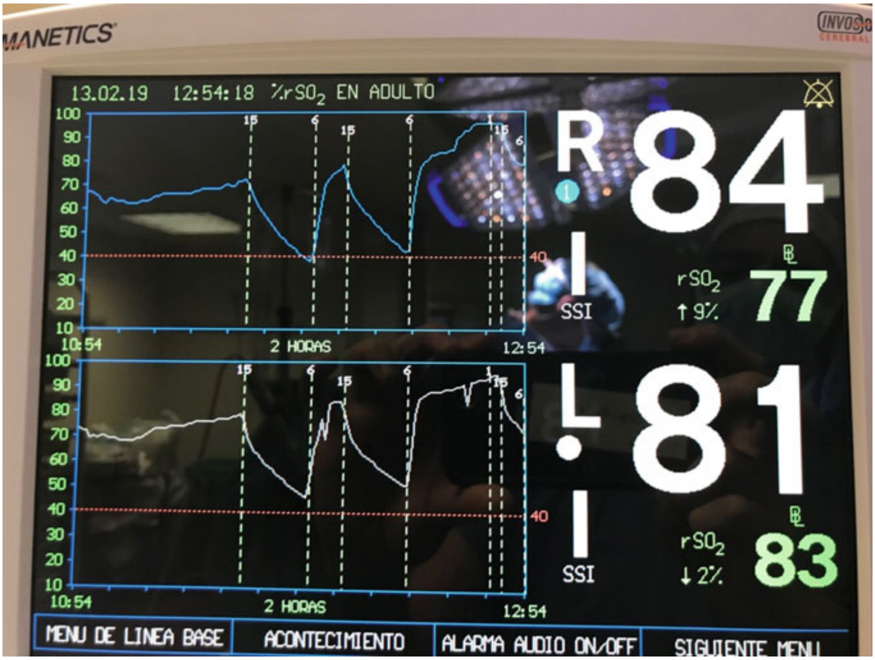

Fig. 4 Desaturation observed in the NIRS monitor during DHCA in a pulmonary endarterectomy

Table 5 Suggested indications of NIRS in cardiac surgery

Suggested indications of NIRS
Aortic arch surgery/aortic dissection
Increased risk of postoperative neurological dysfunction (frailty, age, anaemia, previous cerebrovascular disease)
Risk of cerebral blood flow impairment (significant carotid stenosis)
DHCA
Advanced heart failure and mechanical support (ECMO/VAD)

institutions and no clear indications have been established, being part of the standard monitoring in some centres whereas in some others it is only used in selected patients (see Table 5).

Transcranial Doppler:

Transcranial doppler (TCD) has been used in cardiac surgery to assess cerebral blood flow during both pulsatile spontaneous flow and during CPB. The doppler beam interrogates the mean cerebral artery and reduction of systolic velocity or absence of diastolic velocity suggests cerebral hypo-perfusion. TCD can also be helpful to detect embolic phenomena and to assess correct flow during selective cerebral perfusion. However, some drawbacks limit its use due to the time consuming learning curve, presence of artefacts, difficult probe positioning and position maintenance during all the surgery. These limitations have made other perfusion monitoring such as cerebral oximetry much more popular.

Recommended Readings

1. Saad H, Aladawy M. Temperature management in cardiac surgery. Glob Cardiol Sci Pract. 2013;2013(1):44–62. https://doi.org/10.5339/gcsp.2013.7.
2. Kowalczyk AK, Bachar BJ, Liu H. Neuromonitoring during adult cardiac surgery. J Biomed Res. 2016;30(3):171–3. https://doi.org/10.7555/JBR.30.20150159.
3. Green DW, Kunst G. Cerebral oximetry and its role in adult cardiac, non-cardiac surgery and resuscitation from cardiac arrest. Anaesthesia. 2017;72(Suppl 1):48–57. https://doi.org/10.1111/anae.13740.
4. Kobe J, et al. Cardiac output monitoring: technology and choice. Ann Card Anaesth. 2019;22(1):6–17. https://doi.org/10.4103/aca.ACA_41_18.
5. Arora D, Mehta Y. Recent trends on hemodynamic monitoring in cardiac surgery. Ann Card Anaesth. 2016;19(4):580–3. https://doi.org/10.4103/0971-9784.191557.