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Monitoring in cardiologic intensive care units

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Summary

The article examines main modern methods of physiological parameters monitoring in patients of cardiologic intensive care units: pulse oximetry, ECG, invasive blood pressure monitoring, cardiac output monitoring. Clinical monitoring is continuous monitoring of patient's condition, based on the registration of biological signals and evaluation of organism's diagnostic characteristics in order to detect deviations from normal values, to prevent risks and complications arising during treatment. Methods of physiological processes investigation that are used in clinical monitoring equipment should provide continuous registration of biological signals in real time together with high diagnostic value of parameters derived from processed signals.

Keywords

A*cute coronary syndrome, sudden cardiac death, arrhythmias, monitoring.*

The first in the world intensity care units (ICU) for patients with acute coronary syndrome (ACS) have been organized in the beginning of the sixties in the USA (Kansas, Miami, Philadelphia, New-York). American cardiologist Bernard Lown had made a significant description of the difference in patients' management before and after ICU introduction [1].

Before this time all intensive care units in the Peter Bent's hospital had been mostly oriented to resuscitation after sudden cardiac arrest. Monitoring had been performed before the start of ventricular fibrillations. Electronic monitor was the main device that controlled constantly the heart rate and gave the signal in case of any deviations. Well-educated nurses had been constantly alert in order to start resuscitation if it was necessary. All this reminded of fire-fighting units where everyone is waiting for warning alarm.

But when there was an alarm, superior medical staff started to take care of the situation. If patient had cardiac arrest, a lot of interns, trainees, residents, students, laboratory assistants and duty doctors started to make a fuss over him. Excited voices were ringing, the atmo-

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sphere was getting unbearable. Unlike nurses, doctors did not have distinct plan of actions, but they felt obliged to have overall charge. All procedure was accompanied with endless shouts, fuss and nervousness.

There was a popular joke at that time. Patient with the heart attack is admitted to the intensive care unit. He is frightened, agitated and wants to know what will happen to him. All medical staff is busy saving the life of another patient and does not answer to his questions. Patient is connected with different devices and he, entangled in wire, can hear his loud heartbeat and see the paling lines on the screen of oscillograph.

The evening is coming. Patient starts to think about future disability or death. Charwoman enters the room and starts to wash the floor. Patient turns his face on her and asks: "What will happen with me after?" – "I don't know but I can say this. Can you hear "Beep-beep-beep"? The most important thing is not to let it fell silent. If it happens, a dozen of people with white scrubs will rush into the room and they will wring this "beep" from you by all means".

When the intensive care department was opened in Peter Bent's hospital in 1965, I stopped immediately this disgrace. The main goal remained the same – the rescue of patients with acute myocardial infarction who had cardiac arrest. We used new oscillographs to identify the moment of ventricular fibrillations' start, that were connected with screens on nurses' area. Now they were allowed not to stay nearby patients waiting for arrhythmia to start, but to take care about patients under their charge from their duty stations.

Our department was organized in the way allowing to put as few psychological pressure on patients as possible. The light was dim, patients were able to listen to the radio using headphones, to keep silence was an unalterable rule. Since the surgeons always speak too much loud, we put the plate with the words "Surgeons should knock before entering!" on the door of our department. We tried to achieve the maximal privacy of all patients, but at the same time they could constantly see nurses, and they in their turn could always look after them. I always highlighted the necessity to protect patients from everything that can bring him anxiety in my endless instructions for medical staff. One can hear a faint moan or a heavy thigh only in silence.

Thus, active cardiac rhythm monitoring with the possibility of defibrillation became one of the main reasons of dramatic decrease of mortality in patients with ACS together with the prevention of fatal arrhythmias with lidocaine and the development of reperfusion techniques (thrombolysis and endovascular interventions).

As a half a century ago, nowadays prevention, early detection (another common name of these units – intensive observation units – is derived from here) and treatment of ACS complications including ventricular arrhythmias as the most frequent one, remain the main functions of ICU.

Modern ICU should have not less than six beds. The optimal way is to place a patient in a separate ward, the dimensions of which are enough to put all the necessary equipment like electrocardiograph, electric defibrillators, ventilator, ultrasound machine, counterpulsation device, portable X-ray machine etc, and to leave enough space for 3-4 persons working simultaneously. Wards should be equipped with water supply, oxygen delivery systems and vacuum system. According with international standards, the square of a ward should be not less than 25 m^2.

ICU are equipped with monitors, using which it is possible to control not only electrocardiogram (ECG) but also central hemodynamics parameters. Monitoring system usually has automatic alarm that turns on when controlled characteristics go beyond the normal values. Apart of bedside monitor, there is a central monitor in the area where medical staff stays that collects the information about all patients. The bedside console has a panel with an alarm button, which patient can easily push in case of slightest discomfort. Apart of this, in ICU there are the rooms for staff, equipment storage, making laboratory assays etc.

A team of qualified doctors and nurses is in 24-hour attendance at the ICU: for each 6 patients there is one doctor, 2-3 nurses and one junior nurse [2].

Since monitoring has a great importance in survival statistics of patients with ACS, further we will observe main techniques like ECG monitoring, peripheral oxygen saturation (SpO_2), CO_2 concentration, invasive blood pressure monitoring and cardiac output monitoring.

Pulse oximetry, ECG

Physiological parameters' monitoring is an important part of intensive care complex and it can promptly indicate the aggravation of ICU patient's condition and also evaluate the efficacy of treatment. Despite their high efficacy and importance of instrumental techniques of monitoring, it is necessary to remember that they are addition and not substitution of clinical estimation of heart rate, blood pressure, capillary filling time, respiratory rate, neurological status and diuresis rate.

ECG, SpO_2 estimation require the presence of power supply and, in general, some active storage like pulse oximetry sensors or electrodes. More than that, it is necessary to provide maintenance service and monitor repair if necessary. All these aspects make it difficult to use these techniques under conditions of less-developed healthcare system.

There are several advantages of monitor system use:

• **Additional clinical information.** ECG, SpO_2, CO_2 monitoring provide important clinical information about the condition of cardiac and respiratory function. This information constantly enters the system in real-time mode that gives it particular importance in critical conditions.

• **Non-invasiveness.** These monitoring approaches are not invasive and well-tolerated by patients.

• **Early alarm system.** Alarm limits of each monitor can be regulated in the way allowing determining deviations of the most important parameters from the permissible level thus providing well-timed notification about changes of physiological characteristics. Careful analysis of the character of these deviations allows warning the doctor about early signs of deterioration.

Pulse oximetry (SpO_2)

If anesthesiologists were able to choose the only monitoring technique, the majority would choose pulse oximetry. It demonstrates how much important and useful can be the information obtained with this technique. The majority of pulse oximeters are separate units requiring battery. Pulse oximeter can also be a part of complex multipurpose systems. It consists of sensing element that is put on patient's finger and visual display reproducing obtained information.

Which information gives pulse oximeter?

The most important information that can be obtained with this technique is the value of peripheral oxygen saturation (SpO_2) reflected in percentage terms. Healthy patient breathing atmospheric air has SpO_2 value around 96-100%. SpO_2 of smokers and patients with chronic pulmonary diseases is reduced to 92-95. Patients in critical condition with primary (for example pneumonia) or secondary (for example acute respiratory distress-syndrome) pulmonary lesion are characterized with impaired gas exchange and lowered saturation. Target saturation levels that are reached by oxygen administration and ALV should be established on the basis of initial respiratory system condition [3]. For example, for the patient with concomitant chronic pulmonary disease complicated with infection it is reasonable to set up the lower limit of alarm for SpO_2 as 88%.

The majority of SpO_2 monitors quantify the heart rate (HR) that is accompanied with the sound. The pitch of tone varies according with the change of SpO_2, although it is enough difficult to estimate SpO_2 using just this signal. The change of volume is the sign for a doctor indicating that it is necessary to pay attention on monitor's reading.

Displays of several types of monitors demonstrate pulse wave that gives information about the quality of a signal and indicates how low is the real SpO_2 value. SpO_2. Good quality of the signal means that perfusion in the measuring area is not impaired. This sign has additional meaning in the conditions when limb perfusion can be impaired, for example, after injury or vascular operation. Weak or absent signal should urge the doctor to estimate patient's perfusion and blood pressure (BP). Signal can temporally disappear during cuff inflation on the limb for BP measurement.

Which information pulse oximeter does not provide?

SpO_2 reflects just partially the delivery of oxygen (DO_2) to tissues, because this characteristic depends also on hemoglobin(Hb) concentration and cardiac output (CO) value. Patient with Hb levels 35 g/L can have SpO_2 100%, but low oxygen arterial blood concentration (CaO_2), and therefore low DO_2 [3].

SpO_2 value is determined by ventilation efficacy, so by pulmonary pumping function, and by gas exchange through alveolar-capillary membrane. But ineffective ventilation (for example due to upper airways obstruction, opioid overdose, weakness after muscle relaxant use) can lead to the development of the second type of respiratory insufficiency that is characterized with CO_2 accumulation. Pulse oximetry does not provide information about CO_2 levels in arterial blood. Weakened patient can have promisingly normal SpO_2 levels especially during oxygen therapy, but it will be accompanied with evident respiratory acidosis with arterial blood CO_2 levels > 75 mm Hg and high risk of vascular collapse development [4].

Several specifics of pulse oximeter use

Bright artificial light source and bright sunlight can interfere with signal detection. Bright light effects can be minimized closing the limb and the sensor with dark tissue. Patient movements can lead to noises and instability of measurements. This problem is quite important for agitated and aggressive patients. It is possible to fix the sensor on patient's finger using plaster and allowing them to move together.

Nowadays several types of sensors are available. All sensors are based on the same working principle; the difference is just in the size of patient and sensor's position on patient's body. Ear clip and pediatric sensors are smaller. If special pediatric sensor is absent, it is possible to put sensor for adult patients on the limb of a child. Quite often pediatric sensor is made as a sticker that can be attached on child's arm or leg. If it has been used for a short time, it is possible to reuse it after cleaning its adhesive surface. After all, these self-adhesive sensors can be effectively used during transportation of adult patient providing reliable fixation of sensor to finger [4].

It is reasonable to use central censor in patient with hypothermia or shock. It is possible to place finger sensor in the mouth of patients, making the measurements through cheek, nose or auricle. Small ear clip sensor can be also put on cheek, lip or nostril.

Electrocardiographic monitoring

ECG monitoring in ICU usually includes observation of a single, usually II lead and measurement of heart electric activity in longitudinal left axis. It is necessary to put three electrodes: the first one (usually red) on the right shoulder, the second one (yellow) on the left shoulder and the third one (usually green) on the left part of the chest. Using II lead it is possible to register the majority of arrhythmias, and it is the most important role of ECG-monitoring in ICU.

Which information gives ECG?

Monitor quantifies HR averaging the number of complexes during fixed period of time. If patient has arrhythmias like atrial fibrillation it is necessary to use the period of time as much long as it is possible for this monitor in order to estimate HR correctly.

Arrhythmias are diagnosed more often with the adjustment of upper and lower alarm signals in order to detect tachi- and bradyarrhythmias. Default alarm settings can be appropriate for healthy patient during manipulations under anesthesia, but they are not correct to be used in patients in critical condition. Patient with sepsis can have HR 120 beats per minute that will be higher than upper alarm signal. All alarm signal levels can be set up manually, making them significantly different from actual patient's parameters.

Several monitors allow to set up upper and lower alarm limits making them 10% different from actual value of parameter measured in patient. Several more advanced monitors can detect arrhythmia's character, although in general medical doctor should be responsible for detection of arrhythmia's cause (artefacts of movement, trembling that are often taken as ventricular fibrillation). It is very useful to use ECG and pulse oximetry together. The development of tachycardia with wide QRS complex together with the extinction of signal from pulse oximeter indicates ventricular tachycardia without pulse that is an urgent situation [5].

Often it can be useful to print registered ECG to study precisely cardiac rhythm (for example, to detect P wave). It is also possible to "freeze" the screen pushing the pause in order to perform more detailed ECG analysis. Frequently several ECG-monitor signals can be interpreted in a false way. For example, high T waves can be evaluated as separate QRS complexes that doubles measured HR. It is possible to use pulse oximetry to solve this problem, comparing HR and pulse oximeter readout. Multiple channel monitors including ECG, pulse oximetry (and the possibility of invasive BP measurement) demonstrate HR according with ECG analysis as the default, but these settings can be changed and HR value can be taken from another channel.

Bad quality of ECG-monitor signal can be the consequence of unsatisfactory contact between electrodes and patient's skin (sweat, dirt). If patient is shivering or moving, some background noise resembling arrhythmia can appear on the screen.

What ECG-monitor cannot estimate?

In case of myocardial ischemia development ECG can demonstrate the presence of morphological changes only if the ischemia has appeared in the area of corresponding lead. Otherwise ischemic changes would be impossible to see. In case of suspected myocardial ischemia doctor should make detailed ECG in 12 leads in order to check all parts of myocardium. Normal ECG does not always indicate normal patient's condition, in case of pulseless electrical activity (PEA), previously called electromechanical dissociation, and cardiac arrest there will be no CO, but ECG will demonstrate normal sinus rhythm. It is always necessary to compare monitor's readout and real clinical manifestations [5].

Conclusions

Pulse oximetry and ECG-monitoring use can be an useful addition to the management of patients in ICU increasing safety and optimizing therapeutic schemes. It is necessary to remember that all monitors are as much good as the people who use them, so it is necessary to think what is measured, set up alarm levels correctly and always use monitoring together with clinical estimation of patient's condition.

BP invasive monitoring

Invasive (intra-arterial) BP monitoring is widely used in ICU and in operating rooms. This technique considers catheter insertion in the lumen of appropriate bacteria with consequent displaying of arterial wave on the screen of monitor. The most frequent indication for invasive BP monitoring is the necessity to obtain information about hemodynamics condition for "each heartbeat".

Advantages of invasive BP monitoring:

- continuous BP measurement "with every heartbeat" is reasonable in case of patients who have sudden and unpredictable BP changes (like in case of cardiac and vascular operations) and when invasive BP control is prescribed. BP should be measured invasively in patients who receive inotropic and/or vasopressive agents (like adrenalin);
- this technique allows to measure BP precisely and accurately even for its low values for example in shock condition;
- prevents accidents due to constant cuff inflation who need long-term BP monitoring;
- intravascular volume status can be estimated according with the shape of BP curve or by visual estimation or by mathematical analysis of pulse wave shape (circuit);
- BP invasive monitoring can be used in patients in whom non-invasive BP measurement is not prescribed, for example, in case of evident peripheral edema or morbid obesity;
- fixed arterial catheter can be used for blood sampling and consequent analysis, for example, for gas composition estimation [6];
- Thus, there are several reasons for arterial catheter insertion.

Disadvantages of invasive BP monitoring:

- Arterial catheter is a potential infection source, although it is less prone to be infected comparing with venous catheters.
- Catheter staying in the lumen of artery can cause local thrombosis that in its turn can cause the formation of emboli migrating in vascular lumen or arterial occlusion. This complication occurs rarely if catheter is cleaned regularly and puncture position has been chosen correctly. Radial, femoral and axillary artery or foot arteries like posterior tibial artery and dorsal artery of foot can be used for catheter insertion. If it is possible it is better to avoid brachial artery catheterization. It is a terminal vessel and has no collateral connection, it means that brachial artery occlusion will lead to termination of forearm blood supply.
- All agents inserted in arteries can be crystallized and cause critical limb ischemia. Thiopental sodium and antibiotic can be the examples of the drugs that act in the same way. All arterial tubing should be signed accurately, and all tubing should have a red mark in order to prevent mistakes. You should not put the drugs inside the arterial catheter insertion!
- Arterial catheter insertion can be complicated in patients in shock condition, that can distract doctor from solving of more important problems that appear during the treatment of this patient.
- Equipment for monitoring, catheter and tubing are enough expensive, especially comparing with standard non-invasive monitoring technique.
- Invasive BP monitor requires external power supply, this can restrict its use in some cases [6, 7].

Invasive monitoring components and principles

Invasive monitoring components can be subdivided into three parts: detection system, transducer (signal transducer) and monitor.

Invasive BP monitoring precision

The following characteristics of measuring instruments will convince doctor that BP measurement precision is maximal.

- arterial catheter should be short and ad much wide as possible;
- normal saline solution column, so the length of the tubing, should be as much short as possible;
- catheter and tubing should be as much hard as possible;
- transducer diaphragm should be as much rigid as possible;

Settings and possible problems during work

Radial artery is a typical localization for catheter insertion. Radial artery advantage is that it is situated superficially, easy to palpate, it is also important that hand has collateral blood supply from ulnar artery. It is recommended to perform Allen's test to estimate the adequacy of hand's collateral blood supply with ulnar artery, although this test has some mistakes and it can be performed only in unconscious patients [8].

Alllen's test:

Patient is asked to clench his fist, doctor should push on patient's radial and ulnar arteries with his thumbs.

Patient is asked to unclasp his hand, the palm remains pale.

As soon as doctor removes his finger from patient's arm, patient's palm turns red, if the blood supply is functioning adequately.

It is not recommended to insert arterial catheter in brachial artery, because there is no collateral blood supply. If necessary, femoral artery, ulnar artery, foot and ankles arteries and even axillar artery can be used. Whatever artery has been used for catheter insertion, distal part of the limb should be checked regularly to exclude embolism or ischemia signs.

Arterial catheter insertion

This procedure should be performed in aseptic conditions. Wrist should be disinfected with chlorhexidine alcoholic solution before cannulation. It is necessary to infiltrate the skin of conscious patients with 1% lidocaine solution. The limb should be abducted in anatomical position and the hand should be overstraightened in order to facilitate cannulation (radial artery lays superficially and subcutaneously and limb movement lead to its shift during catheterization). More often assistant provides limb's correct position. If there is no assistant, it is possible to use plaster that allows to fix fingers on some surface (like container with infusion solution). Nowadays there are many rigid and short arterial catheters. Some of them are designed in the shape of "catheter on needle", reminding normal intravenous cannula, others should be inserted using catheter guide with Seldinger's technique. Artery is catheterized with a needle, catheter guide should be inserted though this needle and it should be used for catheter introduction. It is better to use the catheters with which doctor is well-acquainted. Ideally cannula should be connected with injection port in order to prevent unintended intraarterial drug administration. If arterial cannula has injection port, it should be closed and the catheter by itself should be marked clearly as an arterial one [8].

It is important to fix arterial catheter firmly in necessary position, and do not allow bending the catheter. Sometimes it is useful to fix catheter to skin with several stitches.

Arterial catheter should be connected with tubing, and transducer should be fixed on heart level and previously "zeroized", that means it should be closed in the direction of patients and open "for air" to obtain information about atmospheric pressure (taken as 0). Often it is convenient to fix the transducer on patient's shoulder using plaster to make it stay on the heart level.

Practical advices and solution of appearing problems

- Reach-through puncture occurs frequently when it is impossible to find artery (sometimes doctors consciously use this technique): *needle is extracted, and cannula is pulled slowly, in parallel aspiration with a syringe should be performed. As soon as catheter tip enters again arterial lumen, blood starts to enter syringe under pressure. Cannula should be moved slowly from this position, possibly, with a bit of rotation in the direction of vascular axis. This insertion technique leads to positive result and successful artery catheterization more frequently than the others.*
- In case of successful insertion of a needle in the artery but unsuccessful catheterization it is useful to change the hand, arterial spasm develops very often after unsuccessful catheterization and it makes it very difficult to proceed with the catheterization.
- Catheter insertion into artery in patients in shock condition is complicated. Medical stuff should not lose time for retries, it is much more important to perform urgent interventions.
- After connection of catheter and tubing filled with normal saline solution it is necessary to make sure that air bubbles in the system are absent before the start of washing.
- Sudden elevation of BP values can signify that transducer fell on the floor.
- If wave on monitor's screen disappeared or became too much smooth it can mean that catheter is bent or blocked with blood clot, otherwise it can be the sign of air bubbles presence in the system.

Pulse wave form analysis

Useful information can be obtained during observation of arterial wave on the monitor.

• High amplitude or peak amplitude variation of systolic BP going along with the respiratory cycle can demonstrate the presence of hypovolemia in patient.

• Conscious patients due to evident changes of intrathoracic pressure can have significant fluctuations of arterial pulse wave.

• Narrow, high amplitude peaks combined with tachycardia can indicate hypovolemia.

• Arterial wave slope angle can give information about myocardial contractility; steep slope indicates more evident pressure change during unit of time and higher contractility. In practice this characteristic can roughly and approximately estimate myocardial contractility [9].

Conclusions

Invasive BP monitoring is very useful since it allows to examine BP dynamics in ICU patients. More than that, presence of arterial catheter facilitates arterial blood sampling for further estimation of its gas compositions and other characteristics. It is important to understand the main measuring principles to optimize the efficiency of monitoring systems and solve successfully appearing problems.

Cardiac output (CO) monitoring

Studies that have been performed since 1980 have proved that oxygen delivery optimization (that is the product of CO and oxygen concentration in blood) prevents the development of polyorgan insufficiency and improves survivability in high risk patients. Although neither one of the studies did not provide obvious evidences, their total impact demonstrates that therapy directed to improve oxygen delivery (task-oriented therapy) should be the priority. It has been proved that patients with hypovolemia should undergo infusion therapy to optimize oxygen delivery, whereas excessive infusion therapy can be harmful [9].

The only limiting factor in this area was the search of reliable and precise monitoring technique that could have helped to control volume and velocity of infusion therapy. Measurement of heart "filling" is not an easy task. We are trying to use a Frank-Starling law in that part when heart efficiency grows with the stretching of ventricular muscle fiber up to certain point, after which further stretching impairs heart productivity. To use this principle it is necessary to know end-diastolic volume of the left ventricle (LV) and observe its changes during ongoing infusion therapy. Its best characteristic measured in case of presence of Swan-Ganz catheter is pulmonary wedge pressure (PWP) that gives an idea about BP inside the left atrium, which, in its turn, defines LV end-diastolic volume, that is a "surrogate" of LV end-diastolic volume (in case of normal LV extensibility. These characteristics do not reflect correctly enough heart chambers filling during ALV and when catheter's tip passes through pulmonary artery small branches. Thermodilution with Swan-Ganz catheter use allows obtaining precise CO values, that can be changed constantly when all necessary equipment is available.

Nowadays the attention of researchers and technologies has moved into the direction of less invasive monitoring, risk of complications is reduced in case of its use. In wide understanding, these techniques using Doppler-based analysis of aorta blood flow velocity (in case of sensor's position inside the esophagus). or methods analyzing pulse wave curve [10,11]. In some monitors that analyze pulse wave shape to measure CO, it is possible to perform simultaneously the dilution of cold indicator or dye used to obtain reliable CO values that, in their turn, can be used after for machine calibration and following continuous measurement of this characteristic using pulse wave shape transmitted with arterial catheter. To facilitate this process, several monitors calibrate pulse wave using population data obtained from healthy volunteers and that have not been validated for patients with changed vascular resistance that, undoubtedly, affects the precision of quantifiable characteristics like CO. Thransesophageal Doppler ultrasound also uses population data to estimate the size of aorta cross-section.

Even if one is skeptical about absolute values obtained with these monitors, they still can be useful to estimate CO changes and efficacy of infusion therapy. The key question is the answer to the question: "Will patient respond to infusion load?" Otherwise, will the introduction of liquid bolus increase the productivity of cardiovascular system (like CO) and, consequently, oxygen delivery? The possibility to "respond" to infusion load indicates the movement "above" along Starling's curve.

Areas of present and future development include the use of systolic volume variability and pulse pressure variability measured using arterial wave. Observations demonstrated that hypovolemia can lead to evident fluctuations of systolic BP during respiratory cycle. These characteristics are expressed in percentage and not in absolute values and are used for prediction of sensitivity to infusion load.

Below we observe three methods of CO evaluation the most frequently used in Russian Federation: echocardiography (EchoCG), transesophageal EchoCG, right heart chambers catheterization with PWP estimation and thermodilution technique.

Echocardiography

Transthoracic EchoCG

EchoCG is an ultrasonic heart examination that can be used for CO estimation using direct heart visualization in real-time mode. EchoCG has become widespread being one of the most safe and available ways to perform CO monitoring in patients in critical condition.

EchoCG can be performed within minutes and can be helpful to determine the cause of unstable hemodynamics. 4 observation positions(sensor position) are available for transthorachic EchoCG: parasternal long axis, parasternal short axis, apical and subcostal positions, it is possible to evaluate ventricular function and heart chambers size [7].

Transesophageal EchoCG

Theoretical premises

Specific sensor is inserted into esophagus allowing to obtain ultrasound image of high resolution in real-time mode. 2-D square measurement of cross-section, Doppler-based flow velocity measurement and HR estimation allow to estimate CO qualitatively and quantitatively.

Practical use

Multiaxial transducer can be inserted into esophagus or stomach allowing to obtain images in different planes.

Advantages

A lot of information is available apart from CO measurement (Table 1).

Disadvantages

Sensors are quite expensive and equipment is heavy. Working experience is necessary, and it takes time and money to obtain it. Complete observation can require up to 20 minutes. Patient should be sedated; otherwise local pharynx anesthesia should be performed to provide successful sensor insertion. There is a risk of injury with the sensor, but it is lower in patients without esophageal pathology. Sensors can lead to the heating of tissues that makes their long-term use impossible. Further development of technologies and reduction of its price can lead to even more frequent use of transesophageal EchoCG in ICU and operation rooms.

Swan-Ganz catheter

Swan-Ganz catheter use is widely discussed during last years, and the frequency of its use in the majority of countries is not high. The PAC-Man study did not demonstrate improved survivability of patients comparing with the control group where catheter has not been used [12].

Theoretical premises

Flexible catheter with the balloon on its tip, directed with the blood blow (flotation catheter) is introduced through central venous catheter with big lumen (introducer). Catheter "floats" through right atrium and ventricle and enters pulmonary trunk. In this position if the balloon is inflated catheter can occlude one of pulmonary artery branches.

Using this catheter it is possible to measure several characteristics, and additional variables can be calculated.

Measured characteristics are: pulmonary artery pressure, PWP, CO and mixed venous blood saturation. CO is traditionally measured using termodilution and introducing 10 ml of cooled solution through proximal (central venous) catheter's port. Change of blood temperature decrease after introduction of indicator and its passing through the distal catheter's tip allows to estimate right ventricle CO and, consequently, LV CO. Semi-continuous CO measurement is available in case of use of catheter with heating spiral

Table 1. **Transesophageal EchoCG technical characteristics**

Characteristic	Desciption	Interpretation
Peak height	Peak velocity	The highest, recognizable flow velocity in aorta can be used for afterload, vascular resistance and contractility.
Angle of slope	Average acceleration	Contractility measure
Basement width (Ejection time)	Duration of flow	LV contraction time (duration of blood flow in aorta). Being corrected for HR it can be used for preload index quantification (if the basement is narrow it is possible to suspect hypovolemia).
Area under wave curve	Systolic distance	Length of blood column that is moved through aorta during each heart beat
Systolic distance	Systolic volume	Aortic cross-section
Afterload	Systemic vascular resistance	Is estimated using peak height and basement width reduction

that is built-in into the part of catheter staying in the right ventricle. Consequent heating of spiral together with analysis of obtained blood temperature changes allows to estimate average CO value after a short period of time.

Practical use

Catheter is inserted under the control of pressure curve shape change appropriate for each heart chamber and pulmonary artery and also controlling wedge position. Sometimes it is necessary to make several attempts to insert the catheter correctly, and this procedure is more difficult to perform in patients with low CO.

Advantages

The most frequent parameter obtained with flotation catheter is CO that allows estimating the efficacy of medical treatment. During PWP interpretation as the characteristic of preload it is necessary to take into account a big number of assumptions that lowers its reliability. Sometimes mixed venous blood saturation can be used as an universal tissue perfusion characteristic and it is obtained by slow aspiration of blood from pulmonary artery.

Limitations

Pulmonary artery catheterization is a highly invasive monitoring technique linked with several potential complications. The PAC-Man study has identified non-lethal complications in 10% of Swan-Ganz catheter insertion. Apart of typical complications that can occur during central venous catheter insertion, pulmonary artery catheterization can lead to the development of arrhythmias, blockade and rupture of right parts of heart or pulmonary artery, thromboembolism, pulmonary infarction, heart valves damage and endocarditis [12, 13].

Conclusion

Currently there is no ideal system, but each one of the monitors mentioned above can help a medical practitioner in case of doubts related to the management of patients in critical condition. Obtained information should be interpreted taking into account possible limitations of the used technique and particular patient's situation. Only in this case it can be safely used for control and modification of intensive care.

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