

REVIEW ARTICLE / ПРЕГЛЕД ЛИТЕРАТУРЕ

Cardiac arrest and cardiopulmonary resuscitation in the operating room

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The occurrence of cardiac arrest during anesthesia and surgery is nowadays associated with many challenges imposed by 21st century medicine. On the one hand, good education of healthcare practitioners, sophisticated anesthetic techniques and equipment, along with safer anesthetics and improved surgical techniques have significantly reduced the risk of cardiac arrest during the perioperative period. Still, the introduction of new, invasive diagnostic and therapeutic procedures in the aging patients and those with comorbidities carries along new risk and challenges.

Epidemiological data indicate that intraoperative cardiac arrest is an extremely rare event.

Due to variety of moral and ethical prejudices, intraoperative cardiac arrest is frequently presented as if it has happened in the immediate postoperative period, following surgery and anesthesia. The preventive measures, the etiology and diagnosis of cardiac arrest, as well as the specificities regarding organization and performance of cardiopulmonary resuscitation in the operating room, result in a better prognosis compared to other hospital departments.

The article also describes the specifics of cardiopulmonary resuscitation in the catheterization laboratory, while a separate section is dedicated to cardiopulmonary resuscitation following systemic toxicity of local anesthetics.

Since intraoperative cardiac arrest and death represent very rare complications, European Resuscitation Council has only recently published Guidelines for Resuscitation for performing cardiopulmonary resuscitation in the operating room – in 2015.

Keywords: heart arrest, etiology, therapy; cardiopulmonary resuscitation; operating room; anesthesia, adverse effects; anesthesiology, methods, standards; medical errors, prevention, control

INTRODUCTION

The perioperative cardiac arrest (CA) is much less likely to happen nowadays due to contemporary education in anesthesiology, good preoperative preparation of patients, the use of modern anesthesiologic techniques, equipment and safe anesthetics, and improved surgical techniques. On the other hand, the introduction of new, invasive diagnostic and therapeutic procedures in the aging patients and those with comorbidities carries along new risks and challenges. CA is the most dramatic and most urgent situation for a physician in the operating room (OR). A trained team of OR personnel and specific work organization, mandatory monitoring, the availability of equipment and medications for cardiopulmonary resuscitation (CPR), secured airway and placed intravenous cannulas facilitate perioperative CPR and increase survival rates [1].

Since intraoperative cardiac arrest and death represent very rare complications, European Resuscitation Council (ERC) has only recently published Guidelines for Resuscitation for performing cardiopulmonary resuscitation in the operating room – in 2015 [2, 3, 4].

Due to a variety of moral and ethical prejudices, intraoperative cardiac arrest is frequently presented as if it has happened in the immediate postoperative period, following surgery and anesthesia. When CA happens in the OR, many doctors feel unjustified guilt that some intervention during anesthesia or surgery may have contributed to CA occurrence, so they feel responsible and obligated to perform CPR, even in situations when it is completely clear that it should not be performed (i.e. terminal illnesses, signed “Do not resuscitate” protocol). That is why the operating team starts CPR in order to achieve return of spontaneous circulation (ROSC), finish the surgery, and transport the patient from the OR, although they are fully aware that in the immediate postoperative period ROSC will briefly result in a death outcome. Therefore, the majority of epidemiological data regarding the frequency of CA in the OR should be carefully considered.

The low incidence of CA caused by anesthesia and surgery prevents conduction of controlled studies in this area [5, 6].

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PROGNOSIS AND OUTCOMES OF CARDIAC ARREST DURING ANESTHESIA AND SURGERY

In developed countries, the incidence of CA during anesthesia is 0.2–1.1 cases per 10,000 procedures in adults, and 1.4–2.9 cases per 10,000 procedures in children (with a considerably higher incidence in newborns), which is much more rare than 30 or more years ago (20 in 10,000) [1, 7, 8, 9]. Certainly, there are higher-risk groups of patients among whom perioperative CA is seen much more often (Table 1) [2, 10, 11]. Data from the Mayo Clinic indicate that the incidence of CA perioperatively during general anesthesia is three times higher than during regional anesthesia [2, 9].

Table 1. Risk factors for operating room cardiac arrest

Risk factors	
1.	Urgent surgery 163/10,000 patients
2.	Elderly patient 54/10,000 patients
3.	Children < 2 years
4.	Male sex
5.	COPD
6.	Hypotension (shock) AP < 90 mmHg
7.	AKI, CKD
8.	Malignant disease
9.	Major surgery

COPD – chronic obstructive pulmonary disease; AP – arterial pressure; AKI – acute kidney injury; CKD – chronic kidney disease

The differences related to the organization and execution of CPR in the OR compared to other hospital departments reflect different survival rates for CA patients. Documented reports show that patients' survival following intraoperative CA is 34.5–43.9% [8]. In situations when CA was associated exclusively with anesthesia, survival rates were as high as 70–80%, which is much higher than survival rates in other hospital wards: only 15–20% [1, 12].

ETIOLOGY OF CARDIAC ARREST IN THE OPERATING ROOM

Numerous factors are associated with perioperative CA: the preoperative factors (comorbidities), poor risk assessment, inadequate monitoring, mistakes during anesthesia and surgical procedures [9, 13].

The universal mnemonic “4H and 4T”, which causes of CA defined by the ERC, Moitra et al. [14] have described as many as 16 (8H and 8T) potentially reversible causes of CA in the OR (Table 2) [2].

According to the literature data, the most frequent causes of intraoperative CA are as follows:

- hemorrhage (with the highest fatal outcome rate of 10.3%);
- heart complications, myocardial infarction;
- medications (anesthetics, muscle relaxants), complications of central venous catheterization;
- hypoxia caused by compromised airway or complications associated with mechanical ventilation [8, 9, 15].

Table 2. Potentially reversible causes of cardiac arrest in the operating room

8H	8T
Hypoxia	Toxins (anaphylaxis/anesthesia)
Hypovolemia	Tension pneumothorax
Hyper-/hypokalemia	Thrombosis/embolus, pulmonary
Hydrogen ion (acidemia)	Thrombosis, coronary
Hypothermia	Tamponade
Hypoglycemia	Trauma/hemorrhagic shock, CV injury
Malignant hyperthermia	QT prolongation
Hypervagal reaction	Pulmonary hypertension

CV – cardiovascular

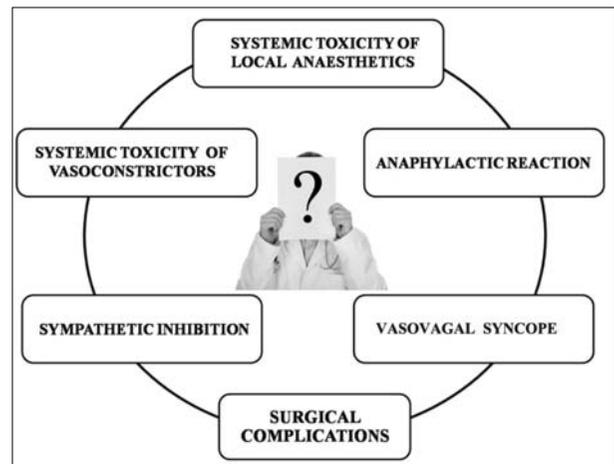


Figure 1. The most frequent causes of a patient's deterioration during regional anesthesia

The most frequent causes of CA in the OR in children are the airway obstruction caused by laryngospasm and bronchospasm, hypovolemia (blood loss) and hyperkalemia (from transfusion of stored blood) [2, 16].

Unlike seen in out-of-hospital CA and in other hospital departments, the most frequent CA rhythm seen in the OR during general anesthesia is asystole (Figure 1). Fortunately, the prognosis of CPR following asystole in the OR is much better than in other hospital departments [2, 7, 9].

PREVENTION OF INTRAOPERATIVE CARDIAC ARREST

The prevention of intraoperative CA begins with good pre-operative preparation of patients, assessment of comorbidities and current physical status (according to the American Society of Anesthesiologists – ASA score), and stabilizing any concomitant chronic conditions. The prevention of operating room CA is affected by the choice of anesthesia technique (general or regional), which depends on the type of surgery, the condition of the patient and comorbidities, but also on the patient's personal desires and the anesthesiologist's experience. Furthermore, the choice of the optimal operative technique depends on the surgeon's experience. Teamwork in the OR has contributed to more rapid recognition and timely reversal of any deterioration of the patient, whereby the occurrence of CA is prevented [2, 17].

The physician's failure to notice the deterioration of the patient's condition in time is the most frequent cause of CA in the OR [2, 17]. The patient's state can sometimes worsen within minutes, but also over hours during the intraoperative period, so appropriate monitoring and timely correction of pathophysiological changes are crucial.

THE DIAGNOSIS OF CARDIAC ARREST IN THE OPERATING ROOM AND MANDATORY MONITORING – CONTROL OF CPR QUALITY

If the minimum mandatory monitoring standard is ensured in the OR, there should be no delay in making a diagnosis of CA. Insertion of an arterial line for invasive blood pressure monitoring in high-risk patients is invaluable for prompt diagnosis of CA. It is recommended that these patients should be equipped with self-adhesive defibrillation pads prior to anesthesia induction [2, 8].

Asystole and ventricular fibrillation (VF) must be identified immediately in the OR. However, in the case of pulseless electrical activity, the diagnosis of CA should be verified by capnography (EtCO₂) and pulse oximetry, and definitely confirmed by the pulse or the arterial line curve (Table 3).

Table 3. Incidence and pattern of cardiac arrest rhythms in the operating room (Mayo Clinic data) [2]

Pattern of cardiac arrest rhythms	Incidence (%)
Asystole	41.7
Ventricular fibrillation	35.4
Pulseless electrical activity	14.4
Unknown	8.5

Performing proper and uninterrupted chest compressions is essential for the success of CPR. There are multiple ways to assess the quality of chest compressions and check the success of CPR in the OR. Palpation of the carotid or femoral artery pulse during CPR is not a proper indicator of chest compressions' quality. Some newer generation defibrillators can provide feedback regarding the quality of compressions. Non-invasive blood pressure monitoring has no relevance in the CA diagnosis, in the quality of CPR, nor in the prediction of CPR success, and can only be used following ROSC. When hypotension and hypoxia are present, pulse oximetry is not an appropriate monitoring touchstone for a prompt CA diagnosis or for assessing chest compressions' quality. Capnography, a part of minimum mandatory monitoring, is very important in assessing CPR quality. When EtCO₂ > 20 mmHg, ROSC is much more likely to occur than in cases when EtCO₂ < 10 mmHg is achieved with chest compressions. If there is an arterial line in place, diastolic pressure (DP) over 40 mmHg is also associated with higher ROSC incidence. Monitoring central venous pressure (CVP) and diastolic pressure in the OR during CPR permits the calculation of coronary perfusion pressure (CPP) based on the following formula: $CPP = DP - CVP$. CPP values of over

15 mmHg during CPR are associated with higher survival rates [8, 18, 19, 20].

However, activation of various alarms due to monitoring failure while the state of the patient is satisfactory is a very frequent occurrence in the OR. This may happen due to detachment of an ECG electrode from the patient's chest, the pulse oximeter slipping off the patient's finger, or technical problems in CO₂ sampling. Such occurrences may sometimes lead the anesthesiologist to ignore the monitoring alarms and to miss a serious deterioration of the patient's condition. Regardless of the mandatory monitoring, "the physician is the most important monitor in the operating room" [8].

RESPONSIBILITIES OF THE OPERATING TEAM MEMBERS IN PERFORMING CPR – THE TEAMWORK

Good communication among members of the resuscitation team in the OR is the key to the success of resuscitation. Confusion or miscommunication must not be permitted during CPR, and no time must be wasted while resuscitation procedures are being performed. This is why teamwork, good organization, following the team leader's instructions and the availability of equipment in good working order are crucial in the performance of CPR measures. In order to advance the teams' professionalization, simulation sessions are held periodically to practice handling of this type of crisis situation. The responsibilities of the surgical team members in performing CPR measures are shown in Figure 2 [21, 22, 23].

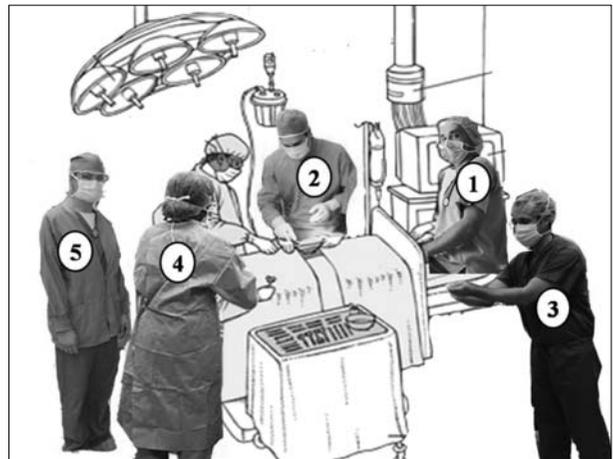


Figure 2. Operating room (OR) team members' tasks during cardiopulmonary resuscitation (CPR): 1) the anesthesiologist makes the diagnosis of cardiac arrest, acts as the CPR team leader, executes advanced life support and removes any reversible causes; 2) the surgeon halts the surgical procedure, controls bleeding, protects vital organs, executes the anesthesiologist's orders and performs chest compressions; 3) the anesthesiologist executes the anesthesiologist's orders, prepares the defibrillator and takes part in the defibrillation, prepares and applies treatment ordered by the anesthesiologist; 4) the scrub nurse monitors and secures the sterility of the wound and the operating field, and of the surgical equipment; 5) the circulating nurse calls for additional assistance, adjusts the height of the table, oversees OR comings and goings, retrieves and delivers disposable materials and equipment [23]

PERFORMING CPR IN THE OPERATING ROOM

It is interesting to note some authors' comparison of general anesthesia and CPR. While it is completely inaccurate to declare that general anesthesia is an "ongoing resuscitation," there are certain similarities between the two medical procedures. Under general anesthesia, as in CPR, the patient is unconscious. Both procedures require maintaining and monitoring of the airway and mechanical ventilation. Administering vasopressors and antiarrhythmic drugs, which are mandatory during CPR, is not unusual during general anesthesia. As in advanced life support (ALS) measures of CPR, continuous monitoring is present during general anesthesia too. Based on this, one may raise the question regarding differentiation of the routine procedures done during general anesthesia in the OR and the urgent skills required in CPR. According to some authors, the only difference that draws the medical line between these two procedures is the need for defibrillation and the execution of chest compressions [5].

The advantages and disadvantages of CPR in the OR are shown in Table 4.

Table 4. Advantages and disadvantages of cardiopulmonary resuscitation in the operating room

Advantages	Disadvantages
1. CA is always observed by witnesses;	1. False alarms, interruption of ECG, pulse oximetry connection;
2. CA cause is usually known and reversible;	2. Hypotension and bradycardia that may be discounted or overlooked;
3. Airway is secured and mechanical ventilation is ongoing;	3. Impossibility of adequate monitoring (obesity, the patient's position on the operating table);
4. Multiple vein lines, CVC in place;	4. Contamination through non-sterile contact;
5. Continuous monitoring, arterial line is often in place;	5. Medically and ethically unjustified reasons
6. Entire CPR team is present;	
7. CPR equipment and medications are available	

CA – cardiac arrest; CPR – cardiopulmonary resuscitation; CVC – central venous catheter; ECG – electrocardiography

In the OR, the time of CA occurrence is always observed by witnesses and the direct cause of the CA is usually known. That is why, along with the progress of CPR, reversible causes should be removed (bleeding, hypoxia, etc.) [3].

When non-shockable rhythms are found and accompanied by the inability to palpate the pulse for more than 10 seconds along with a drop in the capnographic and arterial curve, chest compressions should be started immediately, following ALS protocols for non-shockable rhythms [2, 24]. In view of the surgeon's position relative to the patient, he or she should begin chest compressions, or direct heart compression, depending on whether the thorax is surgically open [8]. The height of the operating table should be adjusted in order to permit the performance of high-quality chest compressions [2]. CPR is optimally performed on a patient in a supine position, but in certain situations it is possible to perform CPR on patients in prone position if it is not feasible to place the patient in a supine position

quickly [3, 4]. Chest compressions in prone patients may be performed manually or using a mechanical chest compression device in continued compression (10 compressions/minute) if an endotracheal tube is in place [2, 3]. If a supraglottic airway device has been inserted and there is an air leak, the CPR should be performed at a ratio of 30:2 [18, 25]. Depending on the ECG rhythm (shockable or non-shockable), CPR should be performed immediately based on new ERC guidelines for CPR [2, 24].

- The decision when to terminate CPR is complex and often, in addition to the medical aspect, includes a series of moral, ethical, and legal elements. Adhering to medical positions, CPR should be terminated when the following criteria are met: fatal injuries or signs of certain death are present;
- an objective suggestion has been made by a senior – the team leader;
- an assessment has been made that all further CPR would be futile and useless;
- asystole has been present for over 20 minutes despite ALS measures and there are no reversible causes [18, 19, 20].

CARDIAC ARREST AND CPR IN THE CATHETERIZATION LABORATORY

CA may occur during percutaneous coronary intervention in patients with myocardial infarction, but it can also arise as a complication of angiography. Most complications will lead to VF, which requires urgent defibrillation. This is why a patient in the catheterization laboratory must be continuously monitored, with a defibrillator standing by. In high-risk patients, self-adhesive radiolucent defibrillation pads should be placed prior to starting the procedure. If the defibrillation is not successful or VF re-occurs, defibrillation should be repeated urgently two times [2]. If VF persists after the third defibrillation, begin chest compressions and ventilation without delay, and continue the angiography in order to find the cause of the CA. It is extremely important not to interrupt chest compressions during the angiography. On an angiography table, where the image intensifier is located above the patient, it is almost impossible to perform high-quality chest compressions, and there is the risk of exposing the practitioner to dangerous radiation. This is why it is strictly advised to use a mechanical chest compression device. In patients with non-shockable rhythm, immediate transthoracic echocardiography should be performed in order to diagnose the cause (pericardial tamponade or another issue) [26, 27].

CARDIAC ARREST CAUSED BY SYSTEMIC TOXICITY OF LOCAL ANESTHETICS

CA as a consequence of systemic toxicity of a local anesthetic (LA) occurs in 1.8 cases per 10,000 regional anesthesia procedures [28]. Significant clinical experience is needed to find the cause of a patient's deterioration during regional

anesthesia (Figure 1), since this determines the type of the treatment. If systemic toxicity of LA is not recognized and not treated promptly, it may lead to CA.

The typical development of the clinical features is the result of a progressive biphasic effect on the central nervous system (CNS) and subsequently on the cardiovascular system (CVS), which are highly sensitive to changes of tissue electrophysiology. Since the CNS alterations are the first ones to occur, this compartment is considered the “mirror” of LA concentration in the blood. Initially, patients become agitated and logorrheic, feel a metallic taste in their mouths, and may experience nystagmus, tinnitus, dysphagia, and confusion. Further progression of the intoxication produces muscle tremors and the development of convulsions. Nausea and vomiting may also be present, along with breathing disturbances, respiratory vasomotor depression, and loss of consciousness [28].

The CVS is considered more resistant to LA effects than the CNS, and cardiotoxicity occurs as a consequence of the direct negative inotropic effects of the anesthetic on the heart and the direct relaxant action on the smooth muscle tissue of the blood vessels. Cardiotoxicity associated with systemic LA toxicity is characterized by hypotension, AV block, idioventricular rhythm, bradycardia, and cardiovascular collapse. The cardiotoxic effect of the LA is exacerbated by hypoxia, hypoventilation, acidosis, and hyperkalemia [28].

In the case of CA, perform ALS according to the ERC guidelines for CPR [2, 3, 24].

Patients with cardiovascular collapse and CA caused by systemic LA toxicity can benefit from a 20% lipid emulsion applied intravenously during ALS [2, 28]. The widely accepted hypothesis of the mechanism of action of the 20% intravenous lipid emulsion in the treatment of cardiotoxicity is based on the absorption and removal of the circulating lipophilic toxin – the LA – from the blood,

which reduces the amount of free LA able to bind to the myocardium. This non-specific removal of LA from the plasma or heart tissue is called “lipid sink” in Anglo-Saxon literature [29]. Another possible mechanism is that the intravenous lipid emulsion acts directly on the heart muscle by neutralizing the inhibitory effect of LA on fatty acid oxidation in mitochondria, whose ultimate purpose is creating energy – adenosine triphosphate, thus preventing the depressive effect of LA on the functioning of the heart muscle [29, 30]. Some authors suggest that successful resuscitation could be due to spontaneous clearance of the instigating LA within of routine ALS without administering intravenous lipid emulsion. [31, 32].

Clinical recommendations for the dosage of 20% intravenous lipid emulsion during CPR were published in ERC guidelines for CPR in special circumstances in 2015 [2, 3, 4]. However, many questions remain open: should the lipid dose be titrated by patient weight, local anesthetic dose, or the symptoms, severity of toxicity; what is the best rate and total dose and what are the possible complications or adverse effects of lipid infusion? Furthermore, pediatric doses of IV lipid emulsion to treat systemic LA toxicity have not been defined. [30, 31, 32].

CONCLUSION

Cardiac arrest in the OR is associated with pre-existing medical or surgical diseases, the quality of preoperative evaluation and preparation for anesthesia and surgery, but also with the anesthetic and surgical technique.

Good organization and well-trained operating room team members, along with appropriate monitoring and readily available equipment and medication, result in a better prognosis when CPR is performed in the OR compared to other hospital departments.

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Акутни застој срца и кardiопулмонална реанимација у операционој сали

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САЖЕТАК

Акутни застој срца током анестезије и операције је у данашње време повезан са многим изазовима које доноси медицина XXI века. С једне стране, добра едукација здравствених радника, савремене технике анестезије и опрема, безбедни анестетици и усавршене оперативне технике значајно су смањили ризик за настанак акутног застоја срца у периоперативном периоду. Међутим, увођење нових, инвазивних дијагностичких и терапијских процедура код све старијих болесника са коморбидитетом доноси нове ризике и изазове.

Епидемиолошки подаци указују да се ради о изузетно ретком догађају. У медицинској пракси, због моралних и етичких предрасуда, интраоперативни акутни застој срца се често приказује у непосредном постоперативном току, после операције и анестезије. Мере превенције, етиологија

и дијагноза акутног застоја срца, као и специфичности у организацији и извођењу кardiопулмоналне реанимације у операционој сали дају бољу прогнозу у поређењу са другим одељењима болнице.

У овом раду описане су и специфичности кardiопулмоналне реанимације у сали за катетеризацију срца и посебно после системске токсичности локалних анестетика.

С обзиром на то да акутни застој срца и смртни исход током интраоперативног периода представљају веома ретке компликације, Европски савет за реанимацију је први пут објавио препоруке за извођење кardiопулмоналне реанимације у операционој сали тек 2015. године.

Кључне речи: акутни застој срца, етиологија, лечење; кardiопулмонална реанимација; операциона сала; анестезија, нежељени ефекти; анестезиологија, методе, стандарди; медицинске грешке, превенција, контрола