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Review Article

Intraoperative Cardiac Arrest: Literature Review and New Tool to Patient's and Team's Safety

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- Advanced cardiac life support
- Open chest cardiopulmonary resuscitation
- Crew resource management
- Check list

Abstract

The international guidelines describe the management of cardiopulmonary arrest (CPA) in out-of-hospital and in-hospital settings, stipulating algorithm to management a CPA; the intraoperative environment is a setting with unique characteristics respect other hospital place for example the presence of ALS team and advanced monitoring.

Intraoperative cardiac arrest (ICA) is complex in relation to the anesthetic procedure (i.e. consciousness and breathing are altered by anesthetic drugs), in relation to surgical procedures (i.e. thoracic, general nonvascular and robotic surgery), in relation to election, urgency or emergency. The presence of these elements makes CPA in OR unique, also its recognition and treatment must be specific to the operating theatre: the international mnemonic acronym "4H-4T" represents only the 50% of total causes of ICA, in fact the causes discoveries by literature are sixteen16. Some authors identified roles and competences of health care provider in OR, others elaborated treatment algorithms, but many subject continue to be remain controversial (i.e. the application of open chest cardiopulmonary resuscitation and the absence of a team leader).

ABBREVIATIONS

CPR: Cardiopulmonary Resuscitation; ACLS: Advanced Cardiac Life Support; TCA: Traumatic Cardiac Arrest; CCCPR: Closed Chest Cardiopulmonary Resuscitation; OCCPR: Open Chest Cardiopulmonary Resuscitation; ICA: Intraoperative Cardiac Arrest; ATLS: Advanced Trauma Life Support

INTRODUCTION

This research started after a professional experience of several episodes of intraoperative cardiac arrest in a road trauma victim. The personal gap of knowledge about intraoperative phenomenon and the absence of specific guidelines about Perioperative context, a literature review was performed to study the ICA, with the development of a tool that can help the health care providers with a check list, as used in aviation, in a context of crew resource management to approach the OR rare crisis.

In the guidelines for Resuscitation 2015, the cardiac arrest is defined as a sudden event, a "the cessation of cardiac mechanical activity... confirmed by the absence of a detectable pulse, unresponsiveness and apnoea (or agonal respirations)" [1]; the analysis on initial heart-rhythm demonstrates 25-50% of ventricular fibrillation (VF) [2]. In the 2013, 200 000 in-hospital cardiac arrests occur in USA, with a survival rates of 18-20% [3], in which the neurologic outcome is near to normal [4,5]; when it happens to in-patient, the primary intervention is represented by cardiopulmonary resuscitation (CPR) following the advanced life support (ALS) guidelines to achieve a return of spontaneous circulation (ROSC) [6]. In the operating theatre, the cardiac arrest is rare phenomenon and the most catastrophic event that compromises the postoperative recovery [7,8]. In particular, intraoperative cardiac arrest (ICA) differs from other setting in- and out-of-hospital events because during anesthesia it's usually witnessed and anticipated [9]. ICA is caused frequently by hypovolemia due to difficulty of airway management or by bleeding [8], two of the eight reversible causes of cardiac arrest, called "4H-4T" (Figure 1): if those are treated, the ROSC can be achieved.

Trauma deserves to be an independent etiology: firstly because several reversible causes (i.e. hypovolemia, hypoxia) can be occurred at once; secondly, in trauma, many serious injuries can be expanded to multiple part of human body. Traumatic cardiac arrest (TCA) is responsible of over 9 millions of death around the world [10] and the victims are people under 45 years old [11], thus in represents the third cause of death in the world, while the first is cancer and the second is cardiovascular disease[5].

Sebbag evaluated the frequency and outcome of ICA: in his study reported an incidence between 5-13 events each 10,000

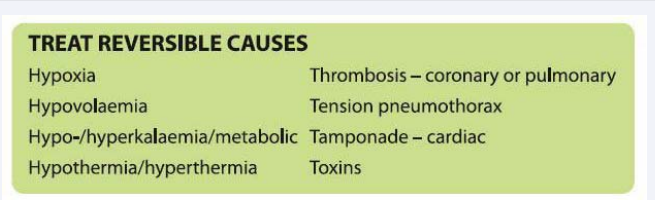

Figure 1 The "4H-4T" (ERC, 2015).

anesthetic procedures, but in case of emergency and trauma the rate gets on 15:10,000, with a low survival in hemorrhagic events as ICA's cause. These data confirm the event's rarity respect to in-hospital cardiac arrest that the incidence is 1-5 arrests in 1000 patient admissions [1].

In case of CPA, the primary action is the cardiopulmonary resuscitation according to guidelines; there are further manoeuvres to resuscitation as the emergency thoracotomy in OR, with references to Guidelines for Resuscitation ERC 2015, in Section 3 "Adult advanced life support", in which it suggests the use of direct heart massage when chest or abdomen (transdiaphragmatic approach) is already open, in particular in trauma [12].

The Perioperative cardiac arrest remains attributable primary to anesthesia, with an incidence of ICA higher in general anesthesia than regional anesthesia [13].

Moitra studied ICA and they discovered another causes to formulate advanced cardiac life support algorithms in anesthesia, called anesthesia advanced circulatory life support (AACLS).

MATERIALS AND METHODS

Between August 2014 and December 2015 a literature review was conducted to research articles about intraoperative cardiac arrest, in particular the presence of protocols and/or guidelines to manage the crisis. The principal databases used to this aim were PubMed of NCBI and CINAHL of EBSCO; in addition, the sites of European Resuscitation Council and American Heart Association were consulted. The review analyzes different aspects, for example the incidence and outcome of cardiac arrest in out-of-hospital, in-hospital and intraoperative setting, the definitions of perioperative and perianesthesiology periods, the problem of trauma, its mortality and morbidity with reference to advanced trauma life support of American College of Surgeon – Committee on Trauma; concepts were reported about direct heart massage with many animal and human studies and about the program of crew resource management.

Finally, the author proposes, from a literature's synergy, a new tool to manage the intraoperative cardiac arrest with a check list to the safety of the patient and of the surgical equipe. It can be part of a future guideline to manage the distinctive features of intraoperative cardiac arrest

RESULTS

Cardiac arrest is not common [14] in perioperative and perianesthesiology period: the differentiation of these two terms is originated from the characteristic of these two parallel periods that integrate themselves in many different elements [15]. Cardiac arrest is considered rare because of improved patient monitoring system and advanced anaesthesiologist techniques [16,17]. ICA has a low survival rate [18], it represents the most catastrophic event that can occur in OR and it's caused by a lot more factors [19]. The incidence of ICA in literature is more variable with incidence between 0.5:10,000 [17] and 25.5:10,000 and 1/3 of patients not survive from ICA [14].

From the analysis of the literature, the 52% of ICA happens because of the pre-existing pathology (i.e. high blood pressure, diabetes mellitus, hepatic or renal failure, previous heart attack) is not properly administered, 40% is related to anesthesia (i.e. drugs administration's overdose, failure in monitoring) and the last 8% related to surgery (i.e. massive uncontrolled bleeding); in the relation to anesthesia, the general anesthesia, in maintenance, is the period in which more happens ICA's events, while related to surgery, thoracic and abdominal nonvascular have its high incidence [8].

In the major of cases, the first rhythm is represented by non-shockable rhythm, in particular pulse less electrical activity (PEA) and systole while the principal causes are hypovolemia (i.e. abdominal hemorrhage), respiratory cause (i.e. inadequate ventilation or oxygenation), myocardial ischemia and metabolic/electrolyte disturbances[29] [8]. Robotic surgery induces ICA in patients with severe comorbidities and few risks are presents related to surgical position due to the Trendelemburg position, related to CO_2 insufflating (i.e. pneumo-peritoneum) in the abdomen with high risk of pulmonary thrombo-embolism and difficult venous blood return [20] . Malignant Hyperthermia has a poor incidence, but it's fatal if dantrolene is not administered and the trigger agent is not stopped (i.e. halogenated gases, succinylcholine administration) [9].

First step to manage an ICA is its recognition, in particular less of consciousness; however in a patient undergoing to general anesthesia the conscious is already altered due to anaesthetic drugs. Various proposals are reported to recognize the cardiac arrest in OR, for example, the view of electrocardiogram heart rhythm, the presence of saturation curve and the palpation of carotid pulse [21]; another article proposes the evaluation of ECG, oximeter, end-tidal of CO_2, central venous pressure, invasive blood pressure [9].

The international organisms about resuscitation indentify eight reversible causes, the "4H-4T" but in the perioperative and perianesthesiology period, Moitra identified sixteen causes of ICA (Figure 2).

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	Pulmonary hyperTension

CV = cardiovascular

Figure 2 The 16s reversible causes.

Table 1: Check list for the safety of patient and perioperative and perianesthesiology team.

Check list for the safety of patient and perioperative and perianesthesiology team During Cardiopulmonary Arrest

1) CPA is confirmed by vital signs
Consciousness
Breathing (RR, End-Tidal CO_2, SpO_2)
Circulation (ECG, HR, NBP, ART, Carotid Pulse)

2) CPA is declared by
Anesthetist
Surgeon
Nurse anesthesia
Scrub nurse
OR nurse

3) Patient is on supine position
Yes No

4) External Thoracic Compression (ETC) are applied
Yes No

5) OR nurse has activated the timer
Yes No

6) Crash cart is in the OR
Yes No

7) Shock delivery
Yes No

1) Emergency coordinator is anesthetist
Yes No

2) First rhythm presentation
VF VT PEA Asystole

3) Airway patency is guaranteed by
ET Tube LMA Tracheostomy

4) Nurse anesthesia do the ACLS algorithm
Yes No

5) Scrub nurse and surgeon do the ETC
Yes No

6) OR nurse avoids the excessive influx of helper health care providers
Yes No

7) CPR is effective (control vital sign on monitor and the carotid pulse perception)
Yes No

8) Indications to Open Chest CPR (Intrathoracic or transdiaphrammatic approach)
Yes No

1) Type of Anesthesia
LA LRA Sedation GA

2) Reversible causes is identified
Yes No
Hypoxia Hypothermia
Hypovolemia Acidemia
Hypo-Hyper K^+ Hypoglycemia
Malignant Hyperthermia Vagal Stimulation
Toxins Tension Pneumothorax
Pulmonary Thromboembolism
Acute Myocardial Infarction
Cardiac Tamponade Hemorrhagic Shock
Pulmonary Hypertension Extension QT

3)Appropriate pharmacologic algorithm is administered
Yes No

4) Return of Spontaneous Circulation (ROSC) is obtained
Yes No

5) ICU admission in planned
Yes No

The patient data
Name and Surname _____

Date of birth ___/___/___

Signature and serial Check List Coordinator: _____

Abbreviations: ETC: External Thoracic Compression; CPR: Cardiopulmonary Resuscitation ; LA: Local Anesthesia; LRA: Locoregional Anesthesia; GA: General Anesthesia; Hypo – Hyper K^+: Hypo – Hyper Kaliemia ; ICU: Intensive Care Unit

Table 2: Event's Registry

Event's Registry :

Time (hh:mm)	Event (CPA, Drug administration, external thoracic compression, delivery shock, instrumental examinations and values)
__:__	ICA STARTS
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Notes/Critic:

Abbreviation: ICA: Intraoperative Cardiac Arrest

1. In particular, trauma is not pathology, but it's a cause that can evolve in cardiac arrest due to bleeding or severe injuries at the expense of different vital organs as in head, in thoracic or abdomen district. Trauma management is oriented by recommendation of ATLS program, in particular about the assessment and the treatment of traumatic patient by physicians: a life-treatment proposed in the ATLS recommendation is represented by resuscitation thoracotomy in emergency department, performed following four clinical indications:Cardiac tamponade
2. Management of severe intra-thoracic bleeding
3. Direct heart massage
4. Descending aorta clamping.

In addition to these indications, the resuscitation thoracotomy in not indicated in emergency room in:

1. asystole in penetrating trauma
2. PEA in bleeding trauma

However a problem comes to light: the closed chest cardiopulmonary resuscitation (CCCPR) is ineffective in patient undergoing to cardiopulmonary arrest, with PEA rhythm presentation, due to hypovolemia [10]. In the review, the open chest cardiopulmonary resuscitation (OCCPR), with direct heart massage, comes to light to be better than CCCPR in hemodynamic parameters and neurological outcome. In a randomized study 29 large mongrel dogs were separated in two group: one was a group of control, where CCCPR was performed, and one an experimental group, where OCCPR was realized; the results demonstrated better survival in the OCCPR group than CCCPR in terms of hemodynamic values (aortic systolic, diastolic and coronary perfusion pressure), short-term and long-term survival, with a better neurologic outcome in OCCPR group [22]. Some years later, a study was conducted to analyze hemodynamic pressure and, with biopsy, three cerebral vulnerable areas (cerebral cortex, hippocampus, cerebellum) to compare cerebral deficit OCCPR versus CCCPR: the results reported an absence of minimally alteration of neurons of these three areas. The study demonstrated the increase of hemodynamic values with OCCPR as reported in Kern's article, adding the increase of carotid and cerebral perfusion [23]. In the human clinical studies, Fialka reported a 10.5% (4/38) of survival patients with no neurological deficit and a long-term survival in thoracic and abdominal trauma. The literature analysis demonstrated that some authors recommended the application of direct heart massage in failure after 10 minutes of advanced cardiac life support, cardiac arrest with CPR < 20 minutes, penetrating and bleeding trauma, hypovolemic shock [24, 25].

Loco - regional anesthesia can be a ICA's cause, in particular when there is an overdose of local drugs, as lidocaine, that causes atrioventricular block, or bupivacaine, the most toxic local drug that cause PEA and asystole; the treatment of systemic toxicity is the administration of lipid emulsion to rescue patient [9].

In the review, many articles invoked the crew resource management (CRM), an aeronautic concept about the crew training to evolve non-technical skills (NTS) and to management the crisis events (i.e. emergency landing of Airbus A320 on the Hudson river); it was established in the 1979 by National Aeronautics and Space Administration (NASA), in responding to aeronautic accident caused by failure in communication (i.e. Tenerife's accident in 1977) [26]. The American Institute of Medicine, in 1999, recommended the use of crew resource management program in health care to improve the group work and to reduce the communication errors, in particular in the OR [27,28]. This program was used in the traumatic resuscitation in a trauma center with a questionnaire to fill before and after CRM program, that studied many NTS as the communication, the figure of team leader, team efficacy, decision making; it demonstrated an increase of all variable observed, in particular about the communication. Improvement of communication is one aim of this complex program, because of the communication error's incidence is around 60%, with a mortality of 74%[14] [29]. However many physician resist to CRM program they believe to be enough the evidence-based medicine, but CRM adopts a program based on non-technical skills to manage the risk using all available resources and to work together[24] [28]. In Health Care System, a program similar to CRM was adopted in anesthesia, it's called "Anesthesia Crisis Resource Management" (ACRM), a course based to more videos that show air disaster, errors in anaesthesiology with a part of simulation to manage many difficult situations [30].

Crew Roles in Intraoperative Cardiac Arrest

In literature there aren't some articles that studied the roles of the health care providers during an intraoperative cardiac arrest. From the literature analysis, the figures involved are:

1. **Anesthesist**. He represents who calls the emergency code [17,21,31] and he prescribes the drug administration leading by rhythm presentation and by possible reversible causes.
2. **Nurse anesthesia**. He collaborates with anesthetist in the administration of drugs [17], he must control the correct CPR and application of defibrillator.
3. **Surgeon**. He is the alternative leader in the emergency code [21,31], he interrupts the surgical procedure and he does the external thoracic compressions [17].
4. **Scrub nurse**. The sterile nurse must control the sterility of surgical wound, with an application of temporally medication [21] and the uncontaminated sterility of the surgical instrument cart.
5. **Non sterile nurse**. This figure calls help, recovery the emergency cart and control the comings and goings in the OR [31] and he helps the scrub nurse with opening the necessary materials and the nurse anesthesia to manage the ICA.

Check list for the safety of patient and perioperative and perianesthesiology team

In reference to aviation, a check list is compiled in every circumstance (i.e. takeoff, landing, emergency landing), and a new tool for safe control of ICA is proposed at the end of the literature review.

During CPA in OR, chaos can be present and it can produce

communication errors, losing time to reanimation maneuvers, time delayed for defibrillation: the check list has the aim to control the health care providers in critical steps focused on CPR, on defibrillation. As demonstrated, the ICA occurs in a peculiar place, where an ALS team is present on the scene, monitoring of patient's vital signs is continuing, where some elements (i.e. Patient Positioning, surgical procedure performed) can make the CPR laborious. For these reasons, additional techniques of resuscitation must be considered (for example the open chest CPR following ATLS's guidelines, extracorporeal membrane oxygenation - ECMO) but the first steps of CPR is, obviously, the external thoracic compressions to maintain circulation to "noble" organs.

The check list for the safety of patient and perioperative and perianesthesiology team is composed by two parts: on the front, the first part checks the steps of resuscitation efforts. In particular the check list is composed by three columns:

- The left column focuses on the recognition of CPA by the monitoring observation of vital signs, the health care provider who declares the emergency, the supine positioning of the patient, the application of CCCPR with starting of a timer for time management, the application of defibrillator and any delivering of shock.

- The central column analyzed the anesthetist's presence in OR, the first rhythm monitored (VF, VT, PEA, a systole), the application of instrument to airway patency, the nurse anesthesia role in the application of ALS while scrub nurse and surgeon do CCCPR (if they don't have to control bleeding), if the external thoracic compressions are effective and if there are indications to OCCPR (indication due to ATLS guidelines and/or clinical status) by intrathoracic or transdiaphragmatic approach. Last but not least, it's the personnel flow in OR during the emergency crisis to help OR health care providers.

- The right column is represented by the type of anesthesia and if the reversible causes are identified, in particular refers to the sixteen causes identified by Moitra. Another step is the application of corrected pharmacologic algorithms and if they led to ROSC and in case of "yes" if it's planned an ICU admission.

Under the check list there is an appositive space where the health care provider must sign as check list coordinator.

In the back of check list there is a registry where the coordinator must annotates the time (hour and minutes) of the event (i.e. CPA starts) and all actions done during the emergency (i.e. pharmacologic administration, CCCPR convert to OCCPR, arrive of second anesthetist/nurse anesthesia, execution of diagnostic test as arterial blood gases exam, how many shock delivery). At the end of the page, the coordinator can annotates eventual notes or critical situation found during the emergency situation.

DISCUSSION & CONCLUSION

Considering the complex argument treated, the cardiac arrest is the worst experience that a person can experience. An health care provider must do everything to guarantee body's perfusion, in particular to "noble organs", with application of a basic and advanced life support. The cardiac arrest in OR is peculiar than another in-hospital and out-of-hospital setting, because of the patient is undergoing to continuing monitoring and there is a ALS team that can prevent and can treat the ICA.

In operating theatre, there are one anaesthetist, one anesthesia nurse, one scrub nurse and one/two surgeons; furthermore in the italian reality there is a presence of an another person, the non-sterile nurse who collaborates with scrub nurse and anesthesia nurse or, in an alternative non equal, a auxiliary non-professional figure. Various authors have analyzed competence and roles in OR during a cardiac arrest, but the anaesthetist results to be the leader of the emergency code in collaboration with anesthesia nurse, who does the ALS algorithm, while the surgeon and the scrub nurse do the CCCPR, preserving the sterility of the surgical field and wound, if they don't have to control an hemorrhage. In local procedures in which there aren't the anaesthetist's presence, the team leader can be the nurse anesthesia, the only health care provider who supervises the consciousness, the airways, breathing and circulation with application of defibrillator and delivery shock in case of defibrillable rhythm. suggest the training of perianesthesia nurse into ALS program, because of the ICA's is an event with reversible causes more than other settings: in fact the "4H-4T" acronym is resizing than the "8H-8T" acronym [9] . The "8H-8T" describes purposely and explicitly all reversible causes that can occur in operating theatre.

The first step to manage this event is call "help", but it's recommended the call and the admission of just one anesthesist and just one nurse anesthesia to avoid chaos and confusion [32].

To help the OR personnel, a check list for the safety of patient and perioperative and perianesthesiology team can be used to control every steps, from ICA's recognition to return of spontaneous circulation, as used by aviation team during all activities. The concept is working in election as in emergency and working in emergency as in election, without agitation, improvisation but with algorithm, trough a program that prepares to manage safely an emergency crisis, where everyone knows what to do.

In this "Check list for the safety of patient and Perioperative, perianesthesiology team during cardiopulmonary arrest" there are the three steps to discover and to treat the ICA, finally to take care of the patient in the post resuscitation phase. The left column there is the points to recognize the CPA, with the initial life-treatment; in the central column there is the part of advanced anesthesia cardio circulatory life. Finally in the right column there is the outcome of the patient, the detection of the reversible cause (refer to the Moitra's study) and death or transfer in the ICU. In the back of this check list there is a registry of what happening in the operating room, marking the time and what kind of event.

In conclusion the check list's aim to help the OR personnel to manage and to control the first steps to resuscitate a patient undergoing to ICA: the check list don't want to replace the ALS preparation, because all OR personal should do an ALS course, but it can help to identify the precise roles of actors in the OR, with an institution of a leadership in the health care team, who does the CCCPR, the scrub nurse with the help of the surgeons.

It's more important that two more health care provider arrive on the scene, an anaesthetist and a nurse, because of they can

be collaborate with the OR personal in application of blood tests, obtaining another venous access, request for blood components.

Finally the intraoperative cardiac arrest's phenomenon must be studied to create the better condition to manage an ICA and to have a better outcome of our patient, stipulating a specific course, the aim of the author, specific in "Operating Room Advanced Life Support".

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