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Possibilities of using open chest cardiac massage in sudden, non-traumatic cardiac arrest

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Abstract: Cardiopulmonary resuscitation is one of the most studied procedures in medicine. Over the years, despite numerous scientific studies, changes in guidelines, refining algorithms, expanding the availability of resuscitation equipment and educating the public, it has not been possible to improve the results of treatment of patients after cardiac arrest. Only 10% of them survive until hospital discharge. There is a well-tested medical procedure, wide application of which could improve results of resuscitation. This procedure is open chest cardiac massage (OCCM).
OCCM is not a new technique, its use dates back to the nineteenth century, now it is reserved for patients sustaining trauma and those after surgical procedures. A number of experimental and clinical studies have proven its advantage over the currently preferred indirect massage (CCCM) also in the group of non-traumatic patients. Of course, OCCM is an invasive method with a number of possible complications accompanying surgical procedures, and its wide implementation would require a long-term training program, but it seems that it could be an impulse that would significantly improve survival in this group of patients.

Keywords: Sudden Cardiac Arrest (SCA), Cardiopulmonary Ressuscitation (CPR), Oppen Chest Cardiac Massage (OCCM), European Resuscitation Council (ERC).

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Introduction

Cardiopulmonary resuscitation is the best researched and algorithmic procedure in medicine. However, decades of scientific research, subsequent editions of guidelines, and work of thousands of people around the world have not led to a significant change in results of treatment of patients with cardiac arrest. Only one in ten of them survive until discharge from the hospital [1]. For this reason, we should continue to look for new methods of resuscitation or try to extend the use of already tested methods, for which we are sure of their therapeutic effectiveness in selected patient groups. Such a procedure is open chest cardiac massage (OCCM), which, according to the guidelines of the European Resuscitation Council (ERC) 2021, is recommended in treatment-resistant cardiac arrest in patients during surgical procedures, in the postoperative course and in the group of traumatic patients with penetrating wounds [2].

Body of the article

OCCM is a procedure well-described in the literature. Until the 1960s it was the only resuscitation technique. The first experimental reports on the animal model date back to 1878, and the first clinical use of OCCM with ROSC in 1902 [3].

In 1953, Stephenson analyzed 1,200 cases of perioperative cardiac arrest treated with open chest cardiac massage, with over 50% ROSC and 26% survival. A good clinical result depends on obtaining access (thoracotomy in the left 4 intercostal space or transdiaphragmatic) to the heart within 4 minutes [4]. In the analysis of cardiac arrest cases from 1925–1954, Brigss reported survival of up to 50% of patients, without neurological defects [5].

The 1960s brought a change in resuscitation procedures, a much simpler method of resuscitation with closed chest cardiac massage (CCCM) was introduced [6].

Effectiveness of both resuscitation methods was found comparable in a number of experimental studies on animal models. The first studies come from the early 1960s and showed significantly higher blood flow in the carotid arteries during OCCM [6, 7].

In an experimental study performed in 1962, Weale *et al.* compared effectiveness of both resuscitation methods. The experiment was carried out on a sample of 19 dogs with cardiac arrest induced by ventricular fibrillation after induction of general anesthesia. During the study, venous and arterial pressure was monitored by cannulation of femoral vessels and electrocardiogram recording from electrodes placed on the chest wall of the animals.

At the time of induction of ventricular fibrillation (electric current), an increase in venous pressure and a drop in arterial blood pressure were observed.

In the next part of the study, blood pressure was compared in two animals during close and open chest massage, which resulted in an increase in systolic blood pressure from 40 to 90 mmHg in animal A and from 80 to 120 mmHg in animal B, and in diastolic blood pressure by 30 mmHg in animal A and 15 mmHg in animal B after conversion from CCCM to OCCM. At the same time, a decrease in mean venous pressure by 4 to 15 mmHg was observed during massage after changing the massage method to OCCM. In conclusion, the authors questioned effectiveness of closed chest massage because it generated significantly lower mean arterial pressure and higher mean venous pressure, and thus worse organ perfusion. They suggested using CCCM as a bridging method until the chest is opened and direct cardiac massage begins [8]. Another study in 1962 assessed cardiac output by tracer dilution method and systolic, diastolic and mean arterial pressure in a group of 22 dogs with cardiac arrest induced by ventricular fibrillation during general anesthesia. Additionally, a myocardial infarction was induced in 10 dogs in this group. In both groups, an indirect massage was started 15 seconds after the diagnosis of cardiac arrest. In the fifth minute, hemodynamic measurements were made. Then, after getting access to the heart by thoracotomy in the 4th or 5th intercostal space, direct massage was started and after subsequent five minutes, hemodynamic measurements were made once again. In both groups of animals, both cardiac output (61% vs. 20% of control values), systolic, diastolic and mean blood pressure (48% vs. 21% of control values) were higher during open chest massage. During the closed chest massage, despite relatively good systolic pressure values, the cardiac output and mean arterial blood pressure remained significantly lower than in the open chest method, and these parameters are the most important determinants of systemic and coronary blood flow. Attention was paid to the better efficiency of close chest massage in the group of "smaller" dogs weighing up to 10 kg, in which higher cardiac output values (39% vs. 13% of control values) could be achieved [9].

Another experimental study was performed in 1981 on a group of 10 intubated, mechanically ventilated and generally anesthetized dogs in which the carotid artery, aortic arch, right atrium, external jugular vein, sagittal sinus, subdural space and pleura were cannulated. During the examination, the following were monitored: arterial blood pressure, venous blood pressure, flow through the carotid artery, intracranial pressure, pleural pressure and EEG. During the study, cardiac arrest was induced and then, after 2 minutes, a closed chest massage was started for a period of 2 hours. Next, after access to the heart was obtained, direct heart massage was started. After 10 minutes, a clamp was placed on the descending aorta, direct massage was continued and obtained parameters were compared. During indirect massage, despite obtaining comparable systolic and average blood pressure, values of blood flow through the carotid artery were significantly lower (16% of control values) compared to those generated during open chest massage (25%) and during OCCM with abdominal aorta clamping (38%). During the indirect massage, the pressure in the chest, in the sagittal sinus and the intracranial pressure also increased, and thus the perfusion pressure of the brain decreased and the cerebral flow and oxygenation of the brain decreased. ICP during OCCM was significantly lower than that generated during CCCM, which translated into higher oxygen saturation of venous blood in the sagittal sinus as well as more frequent return of EEG activity and pupillary reflex [10].

In an experiment performed in 1981, William Barsan *et al.* compared the effectiveness of external manual heart massage with external massage performed by an automatic pneumatic device and with the effectiveness of open chest massage on a group of 13 dogs. Values of cardiac output, blood pressure and ECG were compared. For both external methods, cardiac output did not exceed 17% of control values. The open chest method resulted in 35% of the control cardiac output values with a systolic blood pressure of 50 to 100 mmHg [11].

Another comparative study performed in 1984, in which Robert Bartlet compiled three types of cardiac massage: CCCM, OCCM and DMVA (direct mechanical ventricular assistance), i.e. a bell-shaped device that is fixed by sucking it to the apex of the heart and which alternately contracts and stretches ventricles of the heart. In fifteen anesthetized dogs, aortic pressure, pulmonary artery pressure, cardiac function and ECG were monitored. After induction of cardiac arrest, CCCM was started for 10 min. After this time, manual OCCM was started in group I, and DMVA in group II (with a frequency of 60 and 90/min in both groups). CCCM was continued in group III.

During CCCM, an average CI of about 780 ml/min/m^2 was generated, which was 19% of the control value, and the MAP value was 26 mmHg, which was 23% of the control value. In group I, OCCM was started at a frequency of 60/min, generating a CI of 2078 ml/min/m^2 (52% of the control value) and MAP of 50 mm Hg (36% of the control value). In group II, where DMVA was applied with the frequency of 60/min, a CI of 2780 ml/min/m^2 (70% of the control value) and MAP 72 mmHg (65% of the control value) were generated. Then, the frequency of compressions was increased to 90/min, which resulted in an increase in MAP and CI by 26% and 23% in the DMVA group and by 15% and 14% in the OCCM group [12].

In 1984, Artur Sanders *et al.* compared coronary perfusion pressure (CPP) during CCCM and OCCM in a group of 10 dogs. After induction of anesthesia, the aorta was cannulated through the carotid artery and the right atrium of the heart through the internal jugular vein, and blood pressure was continuously measured at both sites. During CCCM, none of the dogs managed to exceed a CPP of 30 mmHg, which was associated with a worse prognosis. Then five dogs underwent thoracotomy and started OCCM, the remaining dogs continued with CCCM. In the group in which direct massage was used, statistically higher values of PCC were obtained than in the second group, moreover, in the OCCM group, ROSC was achieved in four out of five dogs, as opposed to the CCCM group, where no return of spontaneous circulation was achieved in any of animals [13].

A completely different approach was presented by Blaine White and the research team in their study performed in 1985 on a group of 24 dogs. Animals were anesthetized and had a parietal craniotomy followed by cardiac arrest and were divided into six groups. 1) non-ischemic control group; 2) group after 15-minute cardiac arrest without resuscitation; 3) group after 45-minute cardiac arrest without resuscitation;

4) group after 15 minutes of cardiac arrest and 30 minutes of CCCM; 5) group of 15 min in cardiac arrest and 30 min of CCCM resuscitation and combined with interposed abdominal compression (IAC); 6) 15 min cardiac arrest and 30 min OCCM group. Then, about 5 g of brain tissue were collected in each group, which was tested for the content of superoxide dismutase corresponding to metabolic activity of mitochondria in the brain tissue. The study showed a decrease in superoxide dismutase activity during initial 15 minutes of cardiac arrest. During the next 30 minutes of cardiac arrest, cerebral mitochondrial oxygen consumption was only slightly disturbed. Both CCCM and IAC-CPR lead to a further large inhibition of oxygen consumption in the mitochondria, and thus to their further damage. OCCM performed after 15 min cardiac arrest was not associated with additional inhibition of tissue oxygen consumption and was not associated with additional mitochondrial damage [14].

A similar study was conducted in 1986 by W. Badylak's team on a group of 29 dogs in which cardiac arrest was induced. Animals were divided into two groups: OCCM and CCCM. The dogs' brains were then submitted to a histopathological examination which showed more intense microscopic damage in animals in the CCCM group [15].

Another study was performed in 1984 by M. Barnet on a group of 12 anesthetized dogs in which both systolic and diastolic blood pressure, intracranial pressure and carotid blood flow were monitored. After induction of anesthesia and stabilization of vital signs, control measures were taken, then cardiac arrest was induced and CCCM was started. After accessing the heart by thoracotomy in the fifth intercostal space, OCCM was started, but the dogs were divided into 3 groups depending on the direct massage technique used: group A — one-handed technique with the thumb on the left ventricle, fingers on the right ventricle, and the tip of the heart resting on the palm; group B — two-handed technique with the right ventricle pressed with the left hand and the fingers of the right hand pressing the left ventricle; group C — one-handed technique in which fingers of the right hand are placed around the left ventricle and press the heart to the sternum. All OCCM techniques generated higher diastolic arterial pressure, carotid flow, and lower intracranial pressure than CCCM. Techniques B and C generated similar systolic diastolic blood pressure, carotid flow, and cerebral flow. These parameters were statistically significantly higher than those generated during OCCM using the A technique [16].

An extension of the previous research, which included, in addition to OCCM and CCCM, also extracorporeal gas exchange techniques, ECMO (ECPR), is a study of 1991 in which Daniel J. DeBehnke *et al.* caused cardiac ischemia leading to cardiac arrest in a group of 26 dogs. Dogs were divided into three groups depending on the resuscitation technique used. During the examination, an ECG, pressure in the descending aorta and in the right atrium were recorded. At the end of the observation period, each dog's heart was subjected to histopathological examination to determine the extent of the ischemia. ROSC was obtained in 9 out of 9 dogs in the ECPR group, 6 out of 9 dogs in the OCCM group and 3 out of 8 dogs in the CCCM group. Four hours after the end of resuscitation, 3/9 dogs in the ECPR and OCCM groups and 2/8 dogs in the CCCM group survived. It was shown that the coronary perfusion pressure was significantly higher in the OCCM and ECPR group of dogs than in the CCCM group. It was also proved that the amount of myocardial ischemia in the OCCM and ECPR groups was significantly lower than in the CCCM group [17].

Another experimental study on open chest cardiac massage dates back to 2005 and compared the survival and neurological status 72 hours after cardiac arrest, in a group of 12 anesthetized dogs. The group of 7 dogs were resuscitated by CCCM method, the other group of 5 dogs were resuscitated with open chest cardiac massage. Dogs that obtained ROSC were subjected to neurological examination (according to the Safer canine neurodeficit score) after 72 hours, and then the dog's brain tissue was subjected to histopathological examination. In the OCCM group, ROSC was achieved in all dogs and no neurological deficits were found in any of the dogs. In the CCCM group, ROSC was obtained in only six of the seven dogs, of which only three survived past 72 h. Two of these dogs had profound neurological deficits, the last one suffering from ataxia. In the histopathological examination, brain tissue of dogs from the OCCM group showed no changes or only slight damage. Moderate and high degree changes were found in the brain tissue of dogs from the CCCM group [18].

Unfortunately, the clinical material comparing the effectiveness of open and closed chest cardiac massage is limited to a few series of clinical cases, small observational studies and one systematic review. In the analysis of 11 cases of patients with SCA from 1965. Louis R.M. Del Guerico *et al.* demonstrated that the cardiac index was significantly higher and that the time to massage the heart to achieve ROSC was significantly shorter during OCCM [19]. The study of 1993. in which Takino and Okada compared effectiveness of both resuscitation techniques on a group of 95 non-traumatic patients with out-of-hospital SCA, trying to answer not only which one was more effective, but also what was the optimal time for thoracotomy so that it would not be performed unnecessarily but at the same time it would be effective. In 26 patients from this group, open chest cardiac massage was performed in a hospital setting, and in this group the ROSC frequency was the highest. In addition, the rate of ROSC was higher the sooner thoracotomy was performed and OCCM was started. The optimal time for the procedure was up to 5 minutes from arrival at the hospital [20]. In another observational study in a group of 10 patients with non-traumatic community-acquired SCA refractory to standard management according to ACLS guidelines, a clinically significant difference in coronary perfusion in favor of OCCM was demonstrated [21]. 2019 systematic review demonstrated a significantly higher frequency of ROSC after OCCM in patients with non-traumatic SCA as long as the heart was accessed early and CCCM was performed by then [22].

Guidelines for resuscitation set clear priorities in the management of SCA known as the chain of survival. These are: early diagnosis of a life-threatening condition and calling for help, undertaking high-quality chest compressions, early defibrillation, and post-resuscitation care. Of course, the intention to perform an open chest massage does not affect the general assumptions of the guidelines. Until the chest is opened, the patient with SCA should undergo external massage, receive appropriate medications, and should receive electrotherapy in the event of defibrillation rhythms. In the light of the research presented above, we already know that access to the heart must be obtained within a few minutes. The emergency access of choice is left anterior thoracotomy LAT [23], although comparative studies suggest that bilateral clamshell incision provides more convenient access [24]. LAT is performed under sterile conditions by incision and preparation of tissues in the fifth intercostal space from the edge of the sternum to the midaxillary line. During preparation, special care should be taken not to damage the lungs. We perform the massage with both hands, wrists joined, embracing the heart and performing rhythmic compressions. Compression rate and the rest of the CPR algorithm remain unchanged. Additional modifications relate to the possibility of direct defibrillation and the possibility for the operator to sense heart movements. It is also possible to modify the above-described procedure to a minimally invasive method with the performance of a 7.5 cm parasternal minithoracotomy and the use of an automatic device that compresses the heart directly [25]. The post-resuscitation procedure also does not require major modifications and changes to the algorithm. Open chest massage is a highly invasive method with a high percentage of complications typical for thoracotomy surgery. During tissue preparation, damage to the intercostal vessels and nerves, as well as damage to the lung, pericardium or heart muscles may occur. There is a risk of damage to the internal thoracic vein, pulmonary veins or coronary vessels with subsequent hemorrhage. The risk of postoperative wound infection was estimated at 0–9.1%, and of mechanical heart damage 0–1.4% [26]. 123 OCCM cases were analyzed in 2011, of which 63 (51%) were performed despite the lack of chance of the patient's survival. ROSC was obtained in 4 patients who died in intensive care units. Attention was drawn to incorrect qualification for OCCM, which entailed additional procedures (among others, 335 units of concentrated red blood cells were used). There were three occupational exposures to the patient's blood during thoracotomy [27].

Discussion

Standard management of non-traumatic cardiac arrest, including closed chest cardiac massage, pharmacotherapy and electrotherapy, despite many years of modifying the guidelines, does not bring significant improvement in survival of patients. The advantage of open chest massage over the closed method has been proven in numerous experimental studies, unfortunately the clinical material, the analysis of which could ultimately answer the question of the higher effectiveness of any of these methods, is limited.

Of course, OCCM is not a flawless method. One of them is the need for highly specialized personnel trained to perform surgical access. Currently, this procedure is not performed outside the operating room, hospital emergency department or intensive care unit. Wider application of this method would require the introduction of a multi-year training program for early response teams, ambulance or air ambulance crews. The invasiveness of the method also causes complications such as organ damage or hemorrhage.

It seems, however, that OCCM should be considered as an alternative method of resuscitation in refractory cardiac arrest which, despite its disadvantages related to invasiveness, seems to be easier to implement than wide access to ECMO.

Conflict of interest

None declared.

References

1. *Sasson C., Rogers M.A.M., Dahl J., Kellermann Arthur L.*: Predictors of survival from out-of-hospital cardiac arrest a systematic review and meta-analysis. Circ Cardiovasc Qual Outcomes. 2010; 3: 63–81.
2. *Lott C., et al.*: European Resuscitation Council Guidelines 2021: Cardiac arrest in special circumstances. Resuscitation. 2021; 161: 152–219. https://doi.org/10.1016/j.resuscitation.2021.02.011
3. *Lee W.E., Downs M.*: Resuscitation by direct massage of the heart in cardiac. Ann Surg. 1924; 80 (4): 555–561.
4. *Stephenson H.E. Jr., Reid L.C., Hinton J.W.*: Some common denominators in 1200 cases of cardiac arrest. Ann Surg; 1953; 137 (5): 731–774.
5. *Briggs B.D., et al.*: Cardiac arrest; study of a thirty-year period of operating room deaths at Massachusetts General Hospital, 1925–1954. J Am Med Assoc. 1956; 160 (17): 1439–1444.
6. *Jude J.R., et al.*: Cardiac arrest. Report of application of external cardiac massage on 118 patients. Jama. 1961; 178: 1063–1070.
7. *Pappelbaum S., Lang T.W., Bazika V., Bernstein H., Herrold G., Corday E.*: Comparative Hemodynamics during open versus closed cardiac resuscitation. Jama. 1965; 193: 659–662.
8. *Weale F.E., Rothwell-Jackson R.L.*: The efficiency of cardiac massage. Lancet. 1962; 1 (7237): 990–992.
9. *Weiser F.M., Adler L.N., Kuhn L.A.*: Hemodynamic effects of closed and open chest cardiac resuscitation in normal dogs and those with acute myocardial infarction. Am J Cardiol. 1962; 10: 555–561.
10. *Bircher N., Safar P.*: Comparison of standard and "new" closed-chest CPR and open-chest CPR in dogs. Crit Care Med.. 1981; 9 (5): 384–385.
11. *Barsan W.G., Levy R.C.*: Experimental design for study of cardiopulmonary resuscitation in dogs. Ann Emerg Med. 1981; 10 (3): 135–137.
12. *Bartlett R.L., Stewart N.J. Jr., Raymond J., Anstadt G.L., Martin S.D.*: Comparative study of three methods of resuscitation: closed-chest, open-chest manual, and direct mechanical ventricular assistance. Ann Emerg Med. 1984; 13 (9 Pt 2): 773–777.
13. *Sanders A.B., Kern K.B., Ewy G.A., Atlas M., Bailey L.*: Improved resuscitation from cardiac arrest with open-chest massage. Ann Emerg Med. 1984; 13 (9 Pt 1): 672–675.

14. *White B.C., Hildebrandt J.F., Evans A.T., Aronson L., Indrieri R.J., Hoehner T., Fox L., Huang R., Johns D.*: Prolonged cardiac arrest and resuscitation in dogs: brain mitochondrial function with different artificial perfusion methods. Ann Emerg. 1985; May; 14 (5): 383–388.
15. *Badylak S.F., Kern K.B., Tacker W.A., Ewy G.A., Janas W., Carter A.*: The comparative pathology of open chest vs. mechanical closed chest cardiopulmonary resuscitation in dogs. Resuscitation. 1986; 13 (4): 249–264.
16. *Barnett W.M., Alifimoff J.K., Paris P.M., Stewart R.D., Safar P.*: Comparison of open-chest cardiac massage techniques in dogs. Ann Emerg Med. 1986; 15 (4): 408–411.
17. *DeBehnke D.J., Angelos M.G, Leasure J.E.*: Comparison of standard external CPR, open-chest CPR, and cardiopulmonary bypass in a canine myocardial infarct model. Ann Emerg Med. 1991 Jul; 20 (7): 754–760.
18. *Benson D.M., O'Neil B., Kakish E., Erpelding J., Alousi S., Mason R., Piper D., Rafols J.*: Open-chest CPR improves survival and neurologic outcome following cardiac arrest. Resuscitation. 2005; 64: 209–217.
19. *Delguercio L.R., Feins N.R., Cohn J.D., Coomaraswamy R.P., Wollman S.B., State D.*: Comparison of blood flow during external and internal cardiac massage in man. Circulation. 1965; 31 (Suppl 1): 171–180.
20. *Takino M., Okada Y.*: The optimum timing of resuscitative thoracotomy for non-traumatic out-of-hospital cardiac arrest. Resuscitation. 1993; 26 (1): 69–74.
21. *Boczar M.E., Howard M.A., Rivers E.P., Martin G.B., Horst H.M., Lewandowski C., Tomlanovich M.C., Nowak R.M.*: A technique revisited: hemodynamic comparison of closed- and open-chest cardiac massage during human cardiopulmonary resuscitation. Crit Care Med. 1995 Mar; 23 (3): 498–503. doi: 10.1097/00003246-199503000-00014. PMID: 7874901.
22. *Wang M., et al.*: Open-chest cardiopulmonary resuscitation versus closed-chest cardiopulmonary resuscitation in patients with cardiac arrest: a systematic review and meta-analysis. Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine. 2019; 27: 116. https://doi.org/10.1186/s13049-019-0690-7
23. *Morgan B.S., Garner J.P.*: Emergency thoracotomy — the indications, contraindications and evidence. J R Army Med Corps. 2009 Jun; 155: 87–93. doi: 10.1136/jramc-155-02-02
24. *Seamon M.J., Chovanes J., Fox N., Green R., Manis G., Tsiotsias G., Warta M., Ross S.E.*: The use of emergency department thoracotomy for traumatic cardiopulmonary arrest. Injury. 2012; 43: 1355–1361. doi: 10.1016/j.injury.2012.04.011
25. *Buckman R.F., Jr., Badellino M.M., Mauro L.H., Aldridge S.C., Milner R.E., Malaspina P.J., Merchant N.B., Buckman R.F.*: Direct cardiac massage without major thoracotomy: Feasibility and systemic blood flow. Resuscitation. 1995; 29: 237–248.
26. *Bircher N., Safar P.*: Manual open-chest cardiopulmonary resuscitation. Ann Emerg Med. 1984 Sep; 13 (9 Pt 2): 770–773. doi: 10.1016/s0196-0644(84)80432-1
27. *Passos E.M., et al.*: Social costs of inappropriate emergency department thoracotomy. J Am Coll Surg. 2012; 214: 18–25.