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A NEW CONCEPT FOR  
CARDIO-CIRCULATORY RESUSCITATION:  
PILOT EXPERIMENTAL STUDY

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NOVI KONCEPT ZA  
KARDIO-CIRKULATORNO OŽIVLJAVANJE:  
PILOT EKSPERIMENTALNA STUDIJA

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*Abstract:*

*Aim:* To assess the value of the new concept for providing a sufficient blood flow during cardiac arrest. *Methods:* Four anaesthetized pigs had pressure and angiography catheters introduced percutaneously into right atrium and aortic root. A large bore single access cannula was placed transapically into the left ventricular cavity. The access cannula was connected to the large syringe equipped with mechanism for facilitated mechanical driving. Echo probe was placed epicardially. Ischaemic cardiac fibrillation and arrest was produced by temporary ligation or occlusion of coronary arteries. Mechanical circulation was initiated with the new system and hemodynamic, angiographic and echocardiographic parameters were recorded. *Results:* During cardiac arrest, the new concept of mechanical circulation provided significant changes of LV diameters (LV short axis fractional shortening 50- 68%), significant dynamics of mitral and aortic valves corresponding to intracavitary pressure changes, significant coronary perfusion pressure of 60- 80 mmHg with pulsatile aortic pressure of up to 140/80 mmHg, and angiographically visible coronary and carotid flow. *Conclusion:* The pilot study proved the efficacy of the new concept for providing an effective perfusion of vital structures during cardio- circulatory arrest and thus warrants the ongoing experimental and potential clinical activities.

*Ključne reči:*

Zastoj srca; Kardiopulmonalna reanimacija; Mehanička cirkulacija; Asistirana cirkulacija

*Key words:*

Cardiac Arrest; Cardiopulmonary Resuscitation; Mechanical Circulation; Assisted Circulation

*INTRODUCTION*

Treatment of cardio circulatory arrest has not substantially changed since Kouwenhoven ( an engineer ) reported successful resuscitation by external chest compressions 50 years ago (1). With tracheal intubation, respiratory function is completely replaced by mechanical ventilation while chest compressions are aimed at maintaining vital organ perfusion. Electrical instability is effectively corrected with defibrillators. Today's advanced life support results in return of spontaneous circulation in about 10% in "out of hospital" victims and in 20-30% in "in-hospital" victims. Only a small number of these primary successfully resuscitated victims survive and even smaller is the number of victims who survive without significant neurological sequels. The dismal low resuscitation success rate is mainly attributed to the failure of chest compressions in achieving effective blood flow. The aortic/right atrial (AO/RA) pressure difference as the principal determinant of systemic circulation is negligible during chest compression (2). Emergency widespread utilization of surgical mechanical circulatory assist devices or

cardiopulmonary bypass is not practicable. Percutaneous circulatory assistance like percutaneous LA-AO or LV-AO bypass (3,4), or miniaturized percutaneous cardiopulmonary bypass like ECMO (5) is complex, expensive and time consuming. Obviously, there is need for a device system that could provide sufficient supply of oxygenated blood to vital organs during cardio-circulatory arrest, which device could be applied in hospital as well as out of hospital environment, the device manually driven independent of any energy power sources, the device that could be brought into function rapidly by a professional aid trained for this procedure.

*THE NEW CONCEPT*

Placement of a single large bore cannula into the left ventricular cavity and connection of the access cannula to a large volume syringe equipped with mechanism for facilitated manual driving; repetitive aspiration of blood volume out of the left heart into the large syringe and injection of the large amount of aspirated blood volume back into the non-contracting left ventricle. The concept is based up-on utiliza-

tion of the naturally existing two unidirectional check valves within the arrested left heart: inflow check valve (mitral valve), and outflow check valve (aortic valve). Application of aspiration pressure within the arrested left ventricle opens the inflow mitral valve and closes the outflow aortic valve allowing drainage of the whole left heart and even drainage of the lung. During rapid injection of the aspirated large blood - and /or fluid volume back into the left ventricle through the same cannula the pressure inside the left ventricle rises and closes the inflow mitral valve. Since the injecting volume exceeds the volume capacity of the arrested left ventricle the blood surplus is injected across the outflow valve into aorta.

Maximal aspiration volume = left ventricular volume + left atrial volume.

Injecting stroke volume = total injecting volume - volume capacity of the left ventricle.

Assuming a left atrial volume of 80 ml, a left ventricular volume of 100 ml the maximal aspirating volume would be 180 ml. Assuming an injecting volume of 180 ml by known left ventricular volume capacity of 100 ml the injecting stroke volume would be 80 ml.

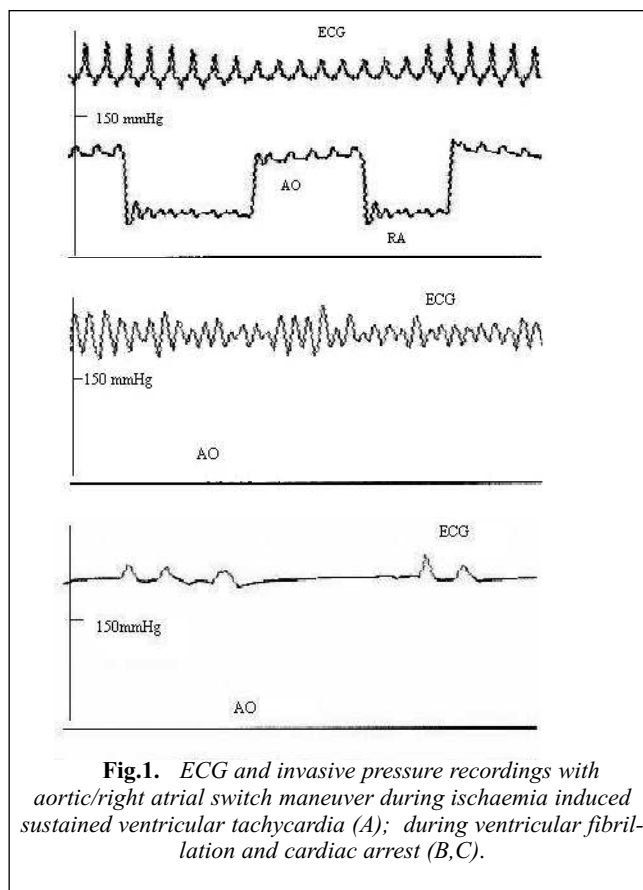
### METHODS

This pilot study was performed in 4 domestic pigs (40-50 kg body weight-BW). Experiments were conducted in compliance with "Law About Animal Experiments" and EU-directive 86/609EOF, article 7,2. After premedication with 0.5mg/kg BW midazolam and 20mg/kg BW ketamine intramuscularly the animals were intubated and mechanically ventilated with respirator (Draeger-UV2). Anesthesia was maintained with fentanyl and propofol intravenously. The 5 F pigtail catheters were placed from the groin vein and artery into the right atrium and aortic root respectively. The pressures in the right atrium and aorta and the ECG were monitored (Hellige -Servomed). After median sternotomy (3 pigs) both coronary arteries were temporarily ligated to produce ischemic ventricular fibrillation and cardiac arrest. After achieving of cardiac arrest the left ventricular apex was punctured with a 17 gauge vascular needle and Heparin 100 IU/kg BW was injected into the left ventricle; next the 18F access cannula was placed by Seldinger technique into the left ventricular cavity with the distal cannula tip placed near the apex. The apical access entry site was tightened with a tourniquet -type purse string suture. The cannula was connected via a T connecting tube (3/8 ") to the large volume (200 ml) syringe equipped with mechanism for facilitated manual driving (Fig. 2A, 3A, ). An infusor was connected over the T connecting tube to the system for additional fluid infusion (Fig.4A). After induction of cardiac arrest the mechanical ventilation was stopped. The large volume syringe was partially primed with 100 ml heparinized fluid (5000 IU/ L) from the infusor; Air was removed through the T connector and the blood was repeatedly aspirated out of the left heart (left ventricle and left atrium) and injected back into the left ventricle. The mechanical ventilation was restarted, the ligation of coronary arteries removed. The ECG and right atrial and aortic pressure tracing were recorded; the flow dynamics were recorded angiographically after infusing contrast medium into the left ventricle. Echocardiography was performed with the 3,5 MHz Echo probe (Vignemed) placed epicardially. No attempts were undertaken to restore spontaneous circulation, no defibrillation was performed. In one pig, the access cannula was

inserted by percutaneous transthoracic route. The coronary arteries in this pig were temporary occluded with selective percutaneous transluminal coronary angioplasty balloon technique.

### RESULTS

After temporary ligation or occlusion of coronary arteries morphological ECG changes, ventricular tachycardia, ventricular fibrillation and arrest were recorded. During sustained ventricular tachycardia the aortic- and right atrial

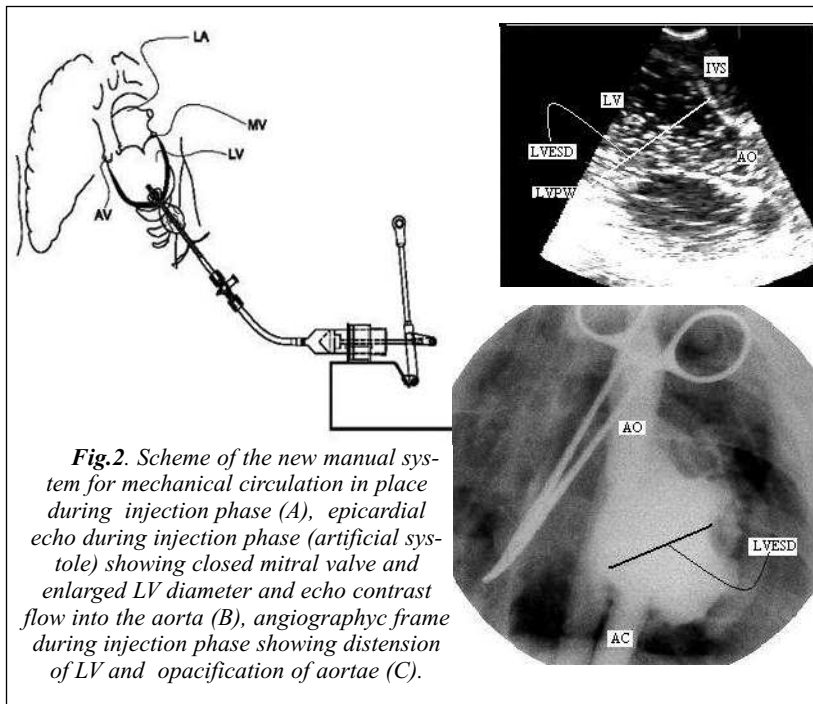


**Fig.1.** ECG and invasive pressure recordings with aortic/right atrial switch maneuver during ischaemia induced sustained ventricular tachycardia (A); during ventricular fibrillation and cardiac arrest (B,C).

pressures were still recordable (Fig.1A). During the following ventricular fibrillation and cardiac arrest the aortic pressure showed no fluctuations indicating absence of any flow. (Fig.1B and 1C). Mechanical circulation was initiated with the new system and angiographic, echocardiographic, and haemodynamic parameters were recorded after removal of coronary arteries ligation (or deflation of coronary occlusive balloons) and after restoring of mechanical ventilation. The percutaneous insertion of the large bore cannula needed less than 1 minute time. Another 2 minutes were needed to set up the system (connecting the tubes to cannula and to prime the syringe).

### ANGIOGRAPHY

Two hundred ml of contrast medium was aspirated into the large volume syringe and injected into the arrested left ventricle as a bolus. The short left to right diameter (in anteroposterior projection) of the non-contracting left ventricle increased to 29-37 mm during the vigorous injection. Instantaneous opacification of aortic root and carotid arteries was seen (Fig. 2C). During the vigorous aspiration of the left ventricular fluid back into the large syringe, the short diameter of the non contracting left ventricle reduced to 4- 8 mm. The calculated shortening fraction was between 50-68

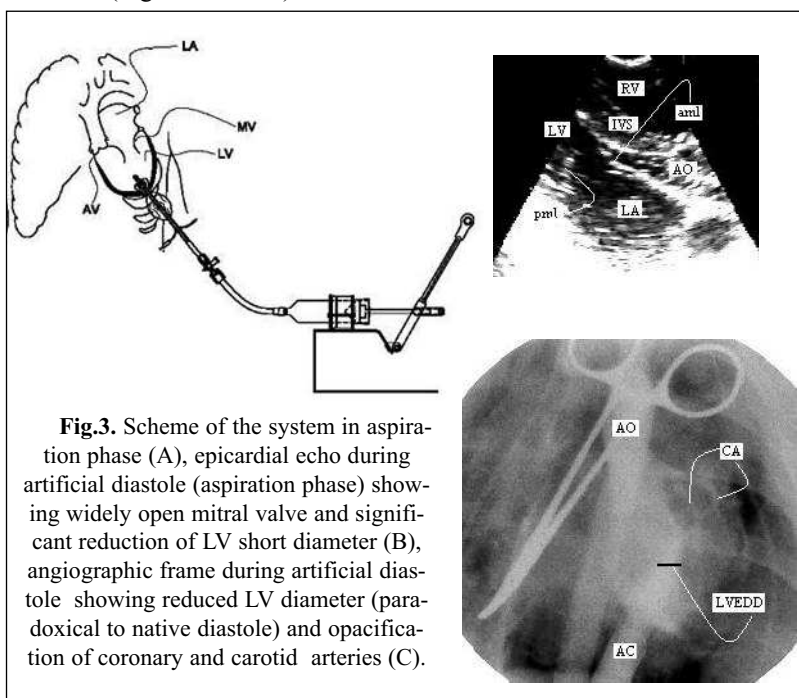


**Fig.2.** Scheme of the new manual system for mechanical circulation in place during injection phase (A), epicardial echo during injection phase (artificial systole) showing closed mitral valve and enlarged LV diameter and echo contrast flow into the aorta (B), angiographic frame during injection phase showing distension of LV and opacification of aortae (C).

%, significantly higher than during a native cardiac pump action. During the aspiration phase significant opacification of coronary and carotid arteries was visible (Fig. 3C).

**ECHOCARDIOGRAPHY**

Epicardial echocardiography was performed in 3 pigs with sternotomy. The large volume syringe was filled with agitated echo contrasted (air bubbles mixture) fluid. During rapid repeated injections of 200 ml of agitated fluid into the left ventricle the Echo recording showed increase of the left ventricular short diameter from 3-11 mm to 32-41 mm-corresponding well to angiography. During aspiration phase the left ventricular diameter reduced to 3 - 11 mm resulting in calculated fractional shortening of >60%. The striking finding was an excessive mobility of the interventricular septum of 15-19 mm left and right (total > 30 mm). During consecutive repetitive aspiration and injection maneuvers the pressure appropriate mitral and aortic valves mobility was recorded (Fig. 2B and 3B).



**Fig.3.** Scheme of the system in aspiration phase (A), epicardial echo during artificial diastole (aspiration phase) showing widely open mitral valve and significant reduction of LV short diameter (B), angiographic frame during artificial diastole showing reduced LV diameter (paradoxical to native diastole) and opacification of coronary and carotid arteries (C).

**HAEMODYNAMICS**

The aortic pressure tracing showed a pulsatile curve during repeated injection and aspiration. The peak aortic pressure was between 120-140 mmHg and the diastolic pressure 60-85 mmHg (Fig.4B and 4C). The simultaneous aortic and right atrial pressures recording with switch maneuvers showed the diastolic AO/RA pressure difference of 60-75 mmHg indicating a good coronary perfusion pressure of > 60 mmHg (Fig/4D). The aspiration and injection maneuvers were repeated during a period of 10 minutes. The cycles rate of this maneuver had to be adjusted to the blood volume within the left heart. In average 35-40 cycles/minute were possible without having any cavitation within the tubing. An attempt to increase the cycles rate over 50/minute resulted in tubing cavitation and air aspiration around the connecting sites (access cannula to syringe, or left ventricular entry site). No attempts were undertaken to restore of spontaneous circulation, no defibrillation was done.

**COMMENTS**

During the past 50 years external chest compressions have been a part of standard cardiopulmonary resuscitation for victims of sudden cardiac death. The mechanism of forward flow during external chest compressions is still speculative. The intrathoracic pressure pump theory postulates that chest compression rises the intrathoracic pressure which is transmitted to the great vessels. However the recorded small pressure changes do not prove existence of forward flow. The cardiac compression pump theory postulates that blood is squeezed from the heart into great vessels during chest compressions. However, no motion of the mitral valve and no significant changes of left ventricular diameters could be recorded by echocardiography during external chest compressions (6,7,8). Experimental and clinical studies have shown that restoration of cardiac function after cardiac arrest is related to the level of coronary perfusion generated during resuscitation. However, it is known that AO/RA pressure difference during chest compressions remains negligible (2) i.e. there is no significant coronary perfusion pressure. Today's strategies propose a rapid providing of an effective blood flow with mechanical circulation implemented surgically or percutaneously (9-12). The crucial determinant of this recommended strategy is time in which such a procedure can be implemented in an "in hospital" and in an "out of hospital" environment. To implement a percutaneous extracorporeal circulation (ECMO) there is need to insert the venous and arterial cannula and to prime and set up the system – which takes in average about 20-30 minutes (13). During cardiopulmonary bypass the left heart cannot be decompressed.

The coronary perfusion pressure of >30 mmHg is found to be associated with significantly higher rate of resuscitation success (2, 14.). During cardiac arrest the shortest way to

the heart is the transthoracic left ventricular puncture which has been utilized for diagnostic and interventional procedures for many years (15-16). A method of rapid transthoracic percutaneous insertion of a large bore cannula into the left ventricle have been proved earlier in our experimental studies (17). To puncture the left ventricular apex during cardiac arrest there is no need for any guidance (e.g., echocardiography or fluoroscopy). Red colored blood aspirated from the puncturing needle indicates that the left ventricle is punctured (LV oxygen saturation during resuscitation >90%, right heart saturation <30% (2) ). The left ventricle can be reached percutaneously within one minute, and the herein described manual mechanical circulatory support system can be implemented within 3 minutes. With the new concept presented in this report the left ventricle is hydraulically forced to perform mechanical systole and mechanical diastole without any intrinsic or external electrical activation. During artificial systole ( injection phase) mitral valve is closed, aortic valve is open but the left ventricular cavity distends (reversed to a native systole). During the artificial diastole (aspiration phase) the mitral valve is widely open, aortic valve closed but the left ventricular cavity reduces (reversed to native diastole) due to decreased intraventricular pressure which promotes additionally coronary and myocardial epicardial to endocardial blood flow. The right heart functions like a passive conduit, as in Fontan's circulation facilitated by dynamics of mechanical ventilation. The recorded excessive left to right motion of the interventricular septum might contribute additionally to increased flow through the right heart. Nevertheless the blood amount coming through the lung into the left heart might not be enough to allow rapid blood aspiration and injection for long period. For this reason additional fluid volume can be added over side-arm. Also hypothermic fluid or medication can be added by this route. There is no need to keep the pulsatile rate too high.

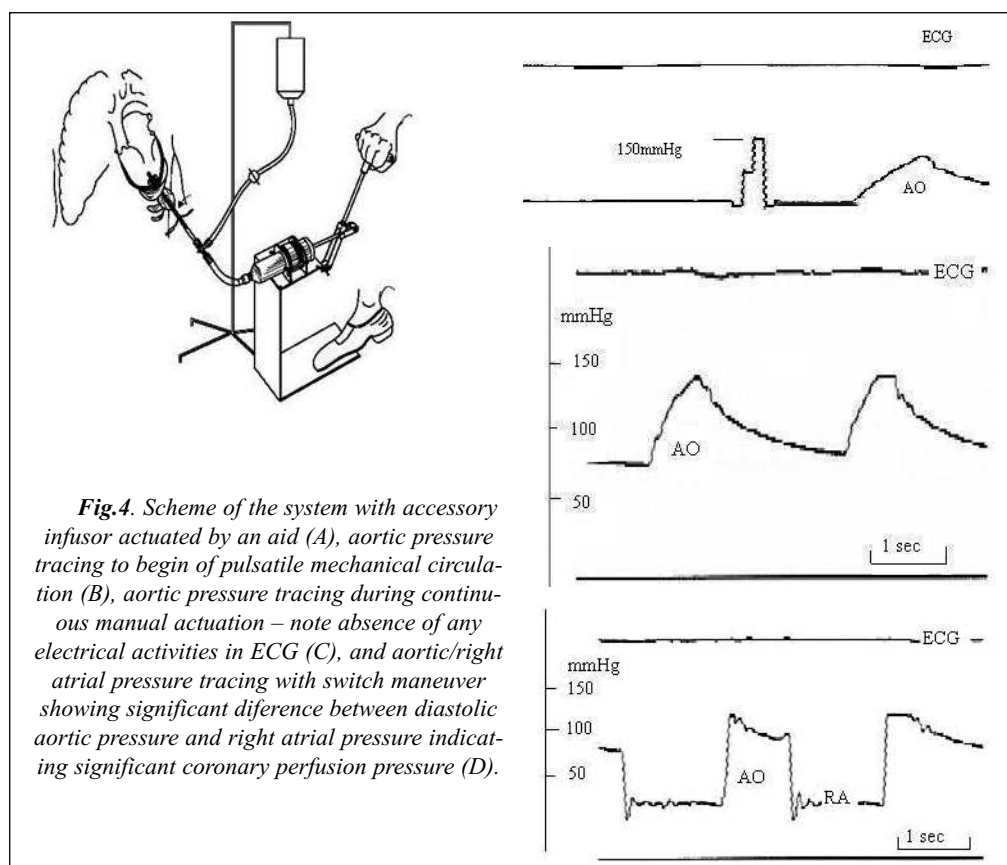
The manual adjustment of the pulsatile rate to the available aspirated blood volume is important. The low pulsatile rate may be compensated by larger injection volume keeping the aortic mean pressure at a desired level. After possible successful resuscitation with this concept applied percutaneously the left ventricular entry site could be closed with catheter based insertion of a myocardial free wall occluder without surgery (17).

**CONCLUSION**

This pilot study confirms that the new concept of invasive cardio-circulatory resuscitation provides: a rapid implementation of the manually driven simplified invasive mechanical circulatory support; effective coronary and carotid perfusion pressures; hydraulically regulated LV mechanical systole and diastole with paradoxical myocardial wall motion compared to native function and corresponding mobility of mitral and aortic valves. Thus, the results of this pilot study warrant the ongoing further experimental and clinical activities.

*Abbreviations :*

- AC= access cannula ;
- CA= coronary arteries
- aml= anterior mitral leaflet
- pml= posterior mitral leaflet
- IVS= interventricular septum
- LA= left atrium
- LV=left ventricle
- LVEDD= left ventricular end diastolic diameter
- LVESD= left ventricular end systolic diameter
- LVPW= left ventricular posterior wall
- RV= right ventricle



**Fig.4.** Scheme of the system with accessory infusor actuated by an aid (A), aortic pressure tracing to begin of pulsatile mechanical circulation (B), aortic pressure tracing during continuous manual actuation – note absence of any electrical activities in ECG (C), and aortic/right atrial pressure tracing with switch maneuver showing significant difference between diastolic aortic pressure and right atrial pressure indicating significant coronary perfusion pressure (D).

## Apstrakt

**Cilj studije:** Provera vrednosti primene novog koncepta za uspostavljanje dovoljnog protoka krvi za vreme srčanog zastoja. Metod: Kod četiri anestezirane svinje plasirani su kateteri za angiografsko i hemodinamsko praćenje u desnu pretkomoru i aortni bulbus. Pristupna jednokanalna kanula većeg lumena plasirana je kroz levo ventrikularni apeks u levu komoru. Kanula je povezana sa špricom velikog volumena opremljenom sa mehanizmom za olakšani manuelni pogon. Eho sonda je plasirana epikardijalno. Ishemična ventrikularna fibrilacija i kardijalni arrest su produkovani temporenom ligaturom ili okluzijom koronarnih arterija. Mehanička cirkulacija je uspostavljena sa novim sistemom i hemodinamski, ehokardiografski i angiografski parametri su snimljeni. Rezultati: Za vreme srčanog aresta, novi koncept mehaničke cirkulacije obezbeđuje značajne promene levo ventrikularnih diametara (LV frakcionalno skraćanje poprečnog diametra 50-68%), značajan mobilitet mitralne i aortne valvule korespondirajući sa promenama intrakavitarnog pritiska, značajne koronarne perfuzione pritiska (60-80 mmHg) pri pulsativnim aortalnim pritiscima od 140/80 mmHg, i angiografski vidljiv protok kroz koronarne i karotidne arterije. Zaključak: Ova pilot studija pokazuje efikasnost novog koncepta u obezbeđivanju efektivne perfuzije vitalnih struktura za vreme kardijalnog aresta i time opravdava već postojeće eksperimentalne i potencijalno kliničke aktivnosti.

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