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Commentary: Restorative resuscitation after cardiac arrest with Controlled Automated Reperfusion of the whoLe body (CARL)—the Freiburg approach with guiding principles from cardiac surgery

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CENTRAL MESSAGE

Cardiac arrest results in generalized ischemia. Extracorporeal cardiopulmonary resuscitation can be tailored to restore perfusion and to enhance organ protection from reperfusion injury.

The outcomes after cardiac arrest remain disappointing.[1,2] This practice domain has been invigorated with clinical guidelines, targeted temperature management, extracorporeal cardiopulmonary resuscitation, and a research agenda for pragmatic multicenter trials.[1-4] Furthermore, specialized cardiac arrest centers are evolving to concentrate multidisciplinary expertise and to champion better patient outcomes.[1-5]

The systematic observations by Beyersdorf and colleagues[3] in Freiburg have resulted in a refined approach to extracorporeal cardiopulmonary resuscitation with tailored reperfusion to limit the extent of reperfusion injury. In their approach, known as Controlled Automated Reperfusion of the whoLe body (CARL), the reperfusion milieu has been designed with respect to flow parameters (flow, temperature, pressure, pulsatility) and reperfusate composition (oxygen and carbon dioxide levels, acid–base balance, viscosity, free radical scavengers, electrolytes).[3,6] This design has been based on perfusion principles from cardiac surgery with further adaptions to address the pathophysiology of reperfusion injury.[3,6] Furthermore, the pilot data are promising, suggesting clinical efficacy of this curated approach to extracorporeal life support.[3,6,7]

Although CARL may be a silver lining in extracorporeal cardiopulmonary resuscitation, an appraisal remains important to discern how it differs from existing techniques and what it adds to clinical management. Beyersdorf and colleagues[3] have highlighted how the functionality in CARL extends the therapeutic potential of extracorporeal resuscitation. This extended functionality includes online blood–gas monitoring, titratable oxygen delivery, pulsatile blood flow, and cooling capability for induction of hypothermia.[3,6] These additional features facilitate the targeted perfusion management in CARL as a platform for standardization of protocols for extracorporeal cardiopulmonary resuscitation.[8] The tailored reperfusion strategy in CARL could encourage more precision to follow the trend in postcardiotomy extracorporeal life support.[9-11] Although knowledge gaps remain, the development CARL by Beyersdorf and colleagues[3] will likely inform future research and development in this setting.[1-5] Their platform could also direct further optimization of the metabolic milieu for additional organ protection during reperfusion.[3,6,7]

So where do we go from here? What are the next steps to extract yet more life from the machine—vita ex machina?[11] A multicenter trial has been launched in Europe to test CARL in clinical practice.[3] As experience with CARL matures, it is

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possible that the indications and management pathways for this platform will be refined.[12,13] Future data will influence their evolution to address the "metabolic shock" and the reperfusion injury that accompany resuscitation after cardiac arrest.[3,11] The current clinical pathways may be adapted to include this tailored perfusion management, if it proves effective in clinical trials.[1-5] The introduction of CARL may also dovetail with the evolution of specialized cardiac arrest centers for standardized high-quality delivery of evidence-based resuscitation that includes protocolized reperfusion and bundled critical care.[1,2,5] The implementation of resuscitation goals from CARL may limit reperfusion injury and may foster more precise care in resuscitation after cardiac arrest.[8-13]

In conclusion, Beyersdorf and colleagues[3] from Freiburg are to be congratulated for highlighting the importance of integrated perfusion in the resuscitation. Their formulation of CARL has focused attention on perfusion quality to guide future advances in extracorporeal cardiopulmonary resuscitation.

References

1. Sinning C, Ahrens I, Cariou A, Beygui F, Lamhaut L, Halvorsen S, et al. The cardiac arrest center for the treatment of sudden cardiac arrest due to presumed cardiac cause—aims, function and structure: position paper of the Association for Acute CardioVascular Care of the European Society of Cardiology, European Association of Percutaneous Coronary Interventions, European Heart Rhythm Association, European Resuscitation Council, European Society for Emergency Medicine and European Society of Intensive Care Medicine. *Eur Heart J Acute Cardiovasc Care*. 2020;9:S193-202.
2. Nolan JP, Berg RA, Bernard S, Bobrow B, Callaway CW, Cronberg T, et al. Intensive care medicine research agenda on cardiac arrest. *Intensive Care Med*. 2017;43:1282-93.
3. Beyersdorf F, Trummer G, Benk C, Pooth JS. Application of cardiac surgery techniques to improve the results of cardiopulmonary resuscitation after cardiac arrest: controlled automated reperfusion of the whole body. *J Thorac Cardiovasc Surg Open*. 2021;8:47-52.
4. Saeed O, Silvestry S. Extracorporeal membrane oxygenation support during COVID-19: outcomes and technical considerations. *J Thorac Cardiovasc Surg Open*. September 21, 2021 [Epub ahead of print].
5. Nolan JP, Sandoni C, Bottiger BW, Cariou A, Cronberg T, Friberg H, et al. European Resuscitation Council and European Society of Intensive Care Medicine guidelines 2021: post-resuscitation care. *Intensive Care Med*. 2021;47:369-421.
6. Trummer G, Benk C, Beyersdorf F. Controlled automated reperfusion of the whole body after cardiac arrest. *J Thorac Dis*. 2019;11:S1464-70.
7. Pennel T, Beyersdorf F, Gates E, Zilla P. Neurologic recovery after ten minutes of absent cerebral blood flow at normothermia. *Perfusion*. 2021;36:432-4.
8. Koen J, Nathaniel T, Philippe D. A systematic review of current eCPR protocols: a step towards standardisation. *Reusc Plus*. 2020;3:10018.
9. Lorusso R, Whitman G, Milojevic M, Raffa G, McMullan DM, Boeken U, et al. 2020 EACTS/ELSO/STS/AATS expert consensus on post-cardiotomy extracorporeal life support in adult patients. *J Thorac Cardiovasc Surg*. 2021;161:1287-331.
10. Altshuler PJ, Atluri P. Commentary: towards achieving precision in the management of postcardiotomy failure. *J Thorac Cardiovasc Surg*. 2021;161:1332.
11. Moran HRM, Yamashita MH, Arora RC. Commentary: vita ex machina—life from the machine. *J Thorac Cardiovasc Surg*. 2021;161:1333-4.
12. Rao V, Billia F. When not to use short-term mechanical circulatory support? *J Thorac Cardiovasc Surg Open*. 2020;3:106-10.
13. Qui SS, Shaffer AW, Cogswell R, John R. Short-term mechanical circulatory support: transitioning the patient to the next stage. *J Thorac Cardiovasc Surg Open*. 2020;2:29-34.