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Can Passive Blood Redistribution to the Thorax Improve the Effectiveness of Cardiopulmonary Resuscitation? A Physiological Hypothesis Based on Frank-Starling's Law

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Abstract

During cardiopulmonary resuscitation (CPR), external chest compressions generate an artificial blood flow with limited efficacy. This work proposes that the passive redistribution of the blood volume from the lower extremities to the central axis - by the elevation of legs or devices such as the antishock (mast) trusses - would improve the ventricular filling in diastole and, therefore, would increase the systolic volume generated by each rib custody. This hypothesis relies on Frank-Starling's law and basic hemodynamic principles. Although these maneuvers are not part of the current CPR protocols, their implementation would be simple and potentially beneficial. It is proposed that clinical or experimental studies evaluate this strategy as an adjuvant in resuscitation.

Keywords: Cardiopulmonary resuscitation, Antishock trusses, Frank-Starling's law

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Introduction

When a patient suffers respiratory arrest, progressive anoxia begins in all organs, including the heart. However, the myocardium has a high oxygen consumption and therefore suffers the consequences of hypoxia particularly rapidly. Among the earliest effects of this energy deprivation is dysfunction of the sodium-potassium pump (adenosine triphosphatases), which leads to a massive leakage of potassium from the cell into the extracellular space.

The accumulation of extracellular potassium generates a sustained depolarization of the membrane potential of myocardial cells. This depolarization reduces the number of sodium channels available for activation, decreases the amplitude of the action potential, and ultimately leads to cellular inexcitability. In this context, cardiac arrest does not necessarily represent myocardial cell death, but rather a functional state of reversible inexcitability.

It has been shown that during acute ischemia, extracellular potassium can reach concentrations of up to 14.7 mmol/L, as experimentally documented by Kléber et al. [1] in isolated guinea pig hearts.

This concept opens up a relevant therapeutic possibility: if myocardial perfusion could be minimally restored-even partially or transiently and this facilitated the removal of accumulated potassium and lactic acid, the myocardium could recover its action potential, automaticity, and contractility.

Conventional CPR achieves only a fraction of normal cardiac output-between 20 and 30% in the best-case scenario [2].

One of the main limiting factors of CPR is the almost nonexistent venous return, which reduces the end-diastolic volume and, consequently, the stroke volume generated by each chest compression. Given that the hemodynamic efficacy of CPR is a crucial determinant of cerebral and coronary perfusion, even small improvements could translate into a significant clinical benefit.

Furthermore, when a person experiences syncope, it is common for those assisting them to elevate their legs in an attempt to increase venous return. Lensini et al. [3] have demonstrated an increase in cerebral blood flow in 10 patients using this technique during CPR. While the immediate cause of syncope is cerebral ischemia, a vagal reflex triggered by the contraction of a virtually empty left ventricle, resulting from the sequestration of blood volume in the lower limbs during prolonged standing, also plays a role. This mechanism has been linked to the Bezold-Jarisch reflex [4].

The development of the anti-gravity suit for aviators in the 1940s later inspired the creation of anti-shock garments designed to counteract hemorrhagic hypotension in wounded soldiers during the Vietnam War [5].

Hypothesis

The central hypothesis of this study is that passive redistribution of blood to the thorax, through elevation of the lower limbs or pneumatic compression of the legs (as in anti-shock garments), can increase ventricular end-diastolic volume during CPR and, therefore, improve the stroke volume produced by external chest compressions.

Physiological Basis

The Frank-Starling law states that the stroke volume of the heart increases with increasing diastolic filling volume, up to a point of maximum elongation [6]. During CPR, where there is no active myocardial contraction, chest compressions act on a passively filled ventricle. A ventricle with greater preload could respond to compression with a larger stroke volume, within the mechanical limits imposed by the technique.

Similarly, the CPR chest pump model [7] suggests that flow depends on pressure changes generated in the thorax; therefore, a higher intrathoracic blood content should increase the volume mobilized per cycle.

Application and Management

Generally, antishock trousers consist of three separate, air-tight, pneumatic compartments: one for each leg and one for the abdomen. The patient is lifted or turned onto the open trousers and then covered with flaps that fold over the legs and abdomen, securing them with Velcro fasteners. Using a rubber foot pump, the leg compartments are inflated first, and the abdominal compartment is inflated last. Once each section has been inflated, a valve on the corresponding tubing is closed. The trousers are designed to maintain a pressure of 104 millimeters mercury (mm Hg); if the pressure exceeds this level, a safety valve releases the air, and the Velcro fasteners begin to open. Inflating the entire device takes approximately 1 min.

The antishock pants should not be deflated until adequate fluid resuscitation has been performed. The air should be released slowly, starting with the abdominal compartment. Throughout the process, the patient's blood pressure should be monitored to ensure it does not drop abruptly.

Mode of action: The pants are designed to inflate to a maximum pressure of 104 mm Hg, which, in a human, would produce an autotransfusion of 1.5 liters of blood [8], increasing preload and generating an increase in systolic pressure of approximately 50 mmHg [9]. It would also increase peripheral resistance in the lower body, redistributing flow to areas of lower resistance (primarily the brain). Because they can be inflated or deflated rapidly or in sections, the autotransfusion balance can be controlled on demand [9].

Proposal

- Passive leg elevation (approximately 30° - 45°) at the start of CPR, as an immediate volume redistribution maneuver.
- Use of anti-shock garments (medical anti-shock trousers) or intermittent pneumatic compression of the lower extremities to shift blood toward the thorax.
- Evaluation in simulated models, animals, or humans, with measurement of parameters such as coronary perfusion pressure, cardiac output during CPR, and clinical outcomes, if possible.

These interventions are simple, potentially safe, and reversible. They could be part of an expanded CPR protocol in out-of-hospital settings or in environments where advanced life support measures are unavailable.

Discussion

- Lack of direct evidence: While leg elevation has been studied in the context of orthostatic hypotension or shock, its use during CPR has not been formally evaluated [10].
- Contraindications: It would not be applicable to patients with abdominal trauma or fractures of the pelvis or lower extremities.

Conclusion

It is proposed that redistributing blood from the lower extremities to the thorax could improve the effectiveness of CPR by increasing ventricular end-diastolic volume and, therefore, the stroke volume produced by chest compressions. This strategy is physiologically plausible, low-cost, and easy to implement. This hypothesis is encouraged to be evaluated in controlled studies and considered for inclusion in advanced resuscitation protocols if the results are favorable.

Acknowledgments

None.

Conflict of Interest

None.

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