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Editorial

When is PEA really ROSC?

In this issue of *Resuscitation*, Elola et al. present the results of a studyexploring the potential value of incorporating end-tidal carbon dioxide ($EtCO_2$) measurement into an automatic algorithm for pulse detection previously based upon electrocardiogram (ECG) and thoracic impedance (TI).[1] Despite recent advances, a sensitive technique for the automatic detection of return of spontaneous circulation (ROSC) for out-of-hospital cardiac arrest (OHCA) remains elusive. On the surface, the underlying message of this study seems to be that a three-factor classifier works better than a two-factor classifier — hardly a novel conclusion. But this team's use of $EtCO_2$ to enhance a detection algorithm also raises the question of whether current methods of detecting ROSC are, in fact, adequate.

In this retrospective study, the authors identified a total of 426 OHCA cases from the prehospital records of a single institution over a 5-year period, ultimately including 117 (27.5%) patients who achieved ROSC and 309 who did not. The first instant that a palpable pulse was announced by the on-scene rescuer was considered the "gold standard" for determining ROSC onset. The authors compared $EtCO_2$, ECG rhythms, and TI values for these patients, and found that $EtCO_2$ values increased significantly within 1 min of ROSC, and that $EtCO_2$ values for pulsed rhythms (PR) were significantly higher than those for subjects with pulseless electrical activity (PEA). The addition of $EtCO_2$ to the machine learning models for pulse detection increased the area under the curve (AUC) to 0.92, up from 0.90 with ECG and TI alone. In this analysis, the authors measured a 96.6% sensitivity and 94.5% specificity for the detection of ROSC and no-ROSC, respectively. The addition of $EtCO_2$ to the algorithm appears to improve the specificity of the detection method with little loss of sensitivity.

Of course, this study has the usual drawbacks of retrospective research. Almost half (409, or 49.0%) of the 835 subjects identified for inclusion were subsequently excluded due to incomplete documentation of ROSC, shocks delivered after presumed ROSC onset, periods >2 min without chest compressions, or lack of adequate capnography before and after ROSC. Additionally, the authors did not have access to the type of airway device (e.g., BVM, supraglottic airway, endotracheal intubation) utilized in these patients, which may affect the accuracy of $EtCO_2$ readings. Ventilatory rates and minute ventilation were not constant throughout the resuscitations, also potentially affecting the accuracy of $EtCO_2$ readings. Though the authors assert that ventilation rates remained within normal limits and should not cause wide variation in recorded $EtCO_2$ values, tidal volumes are historically highly variable. Patients with transient ROSC, an interesting subset, were also not included in this study, so it is unclear whether these findings can be anticipated with any patient experiencing ROSC, or only those with sustained ROSC. The authors found a mean $EtCO_2$ of 41 mmHg at 3 min before ROSC, which is somewhat higher than the 25–35 mmHg values seen in other studies.[2,3] The median change in $EtCO_2$ between pre- and post-ROSC was reported to be 16 mmHg, which is also somewhat higher than the 9–10 mmHg reported by other groups.[3–5] It seems possible that this variance may be related to their exclusion of patients with unsustained ROSC, delayed ROSC recognition or the inclusion of those in pseudo-PEA. However, the authors present a strong argument for combining $EtCO_2$ measurements and conventional algorithms for ROSC detection, as the ability of this combined diagnostic algorithm to confirm ROSC appears to be greater than with $EtCO_2$ alone.[1]

Once upon a time, the *Advanced Trauma Life Support (ATLS)* guidelines suggested that the detection of a radial, femoral, or carotid arterial pulse by providers was evidence of a systolic blood pressure above 80-mmHg, 70-mmHg, or 60-mmHg, respectively. But more recent evidence has shown that these estimates of systolic blood pressure are highly-variable in human hands.[6,7] Given this variability, what other proof of forward blood flow should be allowed to stimulate a change in management? More importantly, if the mountains of evidence that inform our decisions about post-ROSC management are predicated upon the presence of a detectable pulse, is it fair to extrapolate the appropriateness of this management to patients with forward flow but no palpable pulse?

Pulseless electrical activity (PEA), previously referred to as "electromechanical dissociation (EMD)," is broadly defined as the absence of a *palpable* pulse in the presence of organized cardiac electrical activity.[8,9] In conventional terms, the diagnosis of PEA is contingent upon the inability of a *human being* to perceive a pulse in the patient. What happens, then, when the "pulse" is perceived by a highly-sensitive mechanical device? Many patients labeled as "PEA" may have cardiac output that remains undetected by the rescuer's hand. In this setting, is the ability to palpate a pulse the right determinant of care? Or are we compelled to establish a more inclusive definition of ROSC, given the availability of alternative means for measuring forward flow and end-organ perfusion? Perhaps it is time to query our traditional definitions of PEA and ROSC in the face of new technologies, such as echocardiography, thoracic impedance, continuous $EtCO_2$ monitoring, and the emerging field of automatic pulse detection.

To be fair, these definitions have already begun to evolve. "Pseudo-PEA" has been defined as PEA in the presence of inadequate but organized mechanical cardiac activity, as confirmed by echocardiography or very low blood pressures (e.g., 20–40 mmHg) registered on invasive monitoring devices.[10–12] The distinction between PEA and pseudo-PEA hinges entirely upon observations made by mechanical devices (e.g., ultrasound) that can detect evidence of organized cardiac effort beyond that which is perceptible to the human touch. Pseudo-PEA seems to be associated with better outcomes than PEA, and is highly-responsive to vasopressors.[8–10,12] There is also evidence that synchronization of external chest compressions with residual cardiac systole in pseudo-PEA may lead to better outcomesthan synchronization with diastole.[9] In short, PEA appears to be an integrated categorization requiring further subdivision.

Taking it one step further, if we decide to universally-adopt more sensitive techniques to detect forward blood flow, how should this change traditional cardiac arrest management? Is the "pulseless" pre-hospital cardiac arrest patient with residual cardiac systole better served by inotropes, chronotropes, and vasopressors, by volume replacement, or by continued chest compressions? It seems likely that external chest compressions could be injurious (or, at least, counterproductive) for pseudo-PEA patients if the compressions are not synchronized properly with the patient's residual systolic function.[9,13] Perhaps the time is coming soon when point-of-care ultrasound will be widely employed by prehospital rescuers, aiding in the identification of pseudo-PEA, and allowing for earlier detection of reversible causes of cardiac arrest (e.g., pneumothorax, tamponade, pulmonary embolism; etc.). Until then, an optimal automatic algorithm for pulse detection should be able to reliably distinguish PEA from pseudo-PEA, allowing the prehospital rescuer to transition quickly from external chest compressions to solely pharmacological interventions.

Ultimately, the rescuers' ability to declare ROSC represents a crucial decision node in the resuscitation of OHCA patients, with ramifications for the cessation of chest compressions and the use of vasoactive medications that may have a profound effect upon a patient's outcome. As providers, it is no longer clear that we can afford to remain anchored to the traditional "human" determinants of ROSC that have informed previous studies. Regardless of our current ambiguity, it is clear that future studies will continue to stimulate discussion on the inevitable dilemma for cardiac arrest rescuers: when is PEA really ROSC?

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