Question: How can end-tidal carbon dioxide (ETCO2) monitoring guide our management of cardiac arrest?

In 2010, the American Heart Association (AHA) revised the Advanced Cardiac Life Support (ACLS) guidelines to include the recommendation of using capnography to monitor end-tidal carbon dioxide (ETCO2) during cardiopulmonary resuscitation (CPR), and has continued this recommendation to date. Measured ETCO2 during cardiac arrest is a measure of the cardiac output generated by chest compressions but is affected by various other factors including endotracheal tube complications, ventilation, and medications administered. These issues notwithstanding, studies supporting ETCO2 as a surrogate marker of cardiac output outside of cardiac arrest indicate that ETCO2 could be a non-invasive, more readily available means of providing feedback in real time during resuscitation efforts. Previous studies have shown that low (<10 mmHg) ETCO2 values during resuscitation are predictive of mortality and that initial, average, and final ETCO2 are higher in successfully resuscitated patients, and there is an emerging possibility that ETCO2 could possibly even predict survival to discharge. Here we review some of the more recent literature regarding the use of ETCO2 during CPR and evidence on how it can guide resuscitation efforts.


Based on previous studies that suggested ETCO2 as an indicator of cardiac output, Sheak et al. hypothesized that it may also reflect the quality of chest compressions (CC) during CPR, thus giving feedback on resuscitation efforts in real time. They specifically sought to investigate the relationship between ETCO2 and CC depth, CC rate, and ventilation rate in both in-hospital cardiac arrests (IHCA) and out-of-hospital cardiac arrests (OHCA).

They conducted a prospective, multicenter study at hospital sites in the United States in which they were able to capture CPR-recording defibrillator and continuous side-stream CO2 data in patients with an advanced airway (endotracheal tube or laryngeal mask airway), regardless of the etiology of the cardiac arrest or initial rhythm, with at least two minutes of synchronized chest compressions and ETCO2 data. The data metrics were averaged over 15-second epochs. In total, their study included 583 cases, 227 (39%) IHCA and 356 (61%) OHCA.

While chest compression rate did not significantly affect ETCO2, the depth of compressions was a significant predictor of ETCO2 values independent of CC or ventilation rate. For every 10 mm increase in depth there was an associated increase in ETCO2 by an average of 1.4 mmHg (p < 0.001), independent of CC rate (slow, medium, fast). Perhaps unsurprisingly, ventilation rate was inversely related to ETCO2 values. Every additional 10 breath per minute increase in rate lowered ETCO2 by an average of 3.0 mmHg (p < 0.001). The overall case-averaged mean ETCO2 values in those with ROSC were higher compared to those who did not achieve ROSC (34.5 ± 4.5 vs 23.1 ± 12.9 mmHg, p < 0.001). They also observed a similar relationship seen in regard to survival to hospital discharge (38.2 ± 12.9 vs 26.1 ± 15.2 mmHg, p < 0.001).

The authors found a significant relationship between CC depth and ETCO2 and performed a fairly robust assessment, albeit not without limitations. The inability to assess for the effect ventilatory volume, which minute ventilation cannot be calculated, leaves a possible confounder of the relationship between CC depth with ETCO2. They list other confounders they were unable to measure, such as the administration of epinephrine, the cause of cardiac arrest, underlying metabolic rate, and any metabolic derangements during the arrest. Also, because they did not know the relationship between the onset of resuscitation and initiation of active recording, they were unable to see if the CC relationship ETCO2 after the moment of return of spontaneous circulation. J Emerg Med. 2010;38(5):614-621.

While an increase in partial pressure ETCO2 has been observed after ROSC in both experimental and clinical studies, Pokornao et al. set out to determine whether an increase in ETCO2 could be used as a reliable indicator of ROSC in their retrospective case-control study. They looked at two extremes of patients experiencing OHCA: those who had single uncomplicated ROSC followed by stable spontaneous circulation and those with no signs of ROSC who died at the scene.

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In total a group of 140 patients were included. ROSC was defined by the researchers as a palpable central pulse with an organized spontaneous ECG rhythm and measurable blood pressure. All patients were intubated in the field by either emergency medicine physicians or anesthesiologists who were part of the EMS personnel, and consistent lung ventilation was maintained for each patient by an automatic device. Patients were reviewed regardless of age, cardiac arrest etiology, first ECG rhythm pattern, or bystander BLS. Exclusion criteria included patients with either capno-sensor moisturization or contamination with blood as well as patients who received sodium bicarbonate. Thirty-two records were excluded from patients in whom ROSC was achieved but the ensuring spontaneous circulation was unstable and failed again or repeatedly, leaving 108 patients for analysis. ETCO₂ values were continuously recorded from the time ACLS was administered to when either ACLS was discontinued or when ROSC was achieved. All ETCO₂ records were analyzed in two minute intervals and compared with each other against an arbitrarily set of threshold values ranging from two to 20 mmHg. True positive was noted when an increase equaled or exceeded a particular threshold value and ROSC was achieved. Mean values and standard deviations were compared by a two-tailed paired t-test.

Analysis of the ETCO₂ recording showed a mean difference of ETCO₂ before and after ROSC was 9.95 mmHg (95% CI 6.46 - 13.50 mmHg). Individual comparisons of ETCO₂ readings before and after ROSC showed a significant value of p <0.0001. Notably, patients who were not successfully resuscitated had lower mean ETCO₂ values for all time points compared to patients who achieved ROSC. For patients in whom ROSC was achieved, mean ETCO₂ values were always higher after ROSC than before.

The authors acknowledge their study examined two extreme situations: uncomplicated ROSC and no signs of ROSC at all. The study did not cover cases when circulation restarted immediately after defibrillation because these patients were not intubated. It is worth mentioning that the majority of the patients who achieved ROSC ultimately were in vegetative states. The authors concluded that ventilated patients undergoing ACLS in out of hospital cardiac arrest have an increase in ETCO₂ of about 10 mmHg after ROSC is achieved. They also suggested the increase of ETCO₂ could be a suitable moment for checking pulse versus the pre-arrest values for all time points compared to patients who achieved ROSC. For patients in whom ROSC was achieved, mean ETCO₂ values were always higher after ROSC than before.


Lui et al. sought to evaluate the diagnostic accuracy of an “abrupt and sustained increase” in ETCO₂ to indicate ROSC in their cross-sectional prospective study. They looked at a relatively narrow population of adult patients in Hong Kong with non-traumatic OHCA who only received basic life support in the field prior to transport to one of two regional hospitals. All of the data used in the study was prospectively recorded and then later retrieved by researchers from a cardiac arrest registry as well as the electronic health record, except for presumed etiology of arrest, which was determined based on clinical history from the scene, subsequent diagnostic testing, and autopsy data.

They documented any rise of ≥10 mmHg sustained for at least three minutes, specifically noting rises of ≥10 or 20 mmHg, or to the level of ≥40 mmHg. They performed subgroup analysis based on cardiac vs. non-cardiac arrest etiology as well as occurrence of re-arrest. Of the 548 patients fulfilling their inclusion criteria, 370 were excluded due to inadequate documentation of ETCO₂ values; comparison analyses between the included and excluded groups demonstrated no difference in baseline characteristics or outcome measures. The only baseline characteristics significantly different within the included cohort were witnessed arrest and ETCO₂ change during resuscitation. Within the included cohort, 34% of patients had ROSC achieved, which is relatively in line with the heterogeneous published data. For the four different parameters (rise of 10, rise of 20, rise of 10 to 40, rise of 20 to 40), they found poor sensitivities from 33% to 15%, worsening as the parameters became more restrictive, and excellent specificities from 97% to 99%. They also performed detailed statistical analysis to conclude there was a significant difference between the readings immediately pre-ROSC and post-ROSC. When performing their subgroup analysis based on arrest etiology, they concluded the rise in ETCO₂ was higher in the non-cardiac group (17.5 mmHg in non-cardiac vs. 5 mmHg in cardiac) with improved sensitivity (45% in non-cardiac vs. 18% in cardiac).

The authors do identify some major limitations to their study that serve as future areas for investigation. They did not control for other factors that can affect ETCO₂ such as tidal volume, medications administered, or quality of compressions. Commonly used ACLS medications such as sodium bicarbonate and epinephrine are documented to alter ETCO₂ levels and the interaction of these effects with these data is unknown. In addition, these conclusions may not be generalizable to IHCA patients, patients on ventilatory support or intubated at the time of arrest, and patients who receive ACLS care in the field prior to arrival at the hospital. This was a good first prospective study into the accuracy of changes in ETCO₂ to indicate ROSC and supported existing data indicating an increase of 10 mmHg or greater is indicative of successful resuscitation.


As part of the 2015 international Liaison Committee on Resuscitation (ILCOR) Consensus on Science and Treatment Recommendation (CoSTR) process, this systematic review was performed with the intention to identify whether any level of ETCO₂ measured during CPR correlates with return of spontaneous circulation (ROSC) or survival or...
survival to discharge, irrespective of cardiac arrest setting. This systematic review included existing studies up to December 13, 2016, and found only five studies that reported enough data allowing them to be used in a quantitative synthesis. Of those five studies, only one single study was able to be included in the relationship between ETCO2 and achievement of ROSC. Only one additional study was designed to study survival at discharge, despite two others being included in the analysis. All studies included were purely observational, with high risks of bias (high rates of convenience sampling, some with >14% having already achieved ROSC, or extremely small numbers of patients).

For the outcome of return of spontaneous circulation, only one study by Ahrens et al. was included, thus no meta-analysis was actually performed. This showed correlation between initial ETCO2 ≥10 mmHg and ≥20 mmHg and increased rates of ROSC (OR 11.41, 95% CI 1.44 - 90.17 and OR 13.82, 95% CI 3.5 - 53.37, respectively). Increased odds ratios of ROSC were also noted with ETCO2 ≥20 mmHg for 20 minutes (OR 20, 95% CI 1.97 - 203.32). This study, however, noted that 14% of patients had already achieved ROSC at first measurement of ETCO2.

For the outcome of survival to discharge, a few other studies were included in the meta-analysis, but the primary study that affected the outcomes was the same Ahrens study with weights of >90% in all analysis except one, the correlation between initial ETCO2 ≥10 mmHg in which that study still had a weight of 66%. The pooled odds ratio for survival to discharge for initial ETCO2 ≥10 mmHg was reported as 10.71 (95% CI 5.65 - 20.30). For initial ETCO2 ≥20 mmHg, increased odds of survival was noted with OR 12.24 (95% CI 5.13 to 29.22). Increased odds of survival was also reported with ETCO2 ≥10 mmHg and ≥20 mmHg with OR 181.57 (95% CI of 40.08 to 822.61) and OR 234 (95% CI of 19.48 to 2811.42), respectively.

Although reported as a systematic review and meta-analysis, nearly all the results came from a single study by Ahrens et al., which reported rates of >14% ROSC having been achieved prior to measurements and that samples were taken conveniently. As such, the authors conclude that initial ETCO2 should not be used to reliably predict outcomes and should not be used for determination of continuation of resuscitation. They do suggest that late in resuscitation, higher levels of ETCO2 are correlated with increased rates of ROSC and survivability to discharge but based on the poor quality and number of studies available, this is not supported in the literature. Physiologically, it makes sense that higher ETCO2 levels would indicate improved likelihood of ROSC or survival, but there are large variables that could affect this measurement that are not taken into account in the current available literature (rates and quality of ventilation, timing of intubation, presence of ROSC initially, etc.). As such, it is more reasonable to conclude from this study that insufficient data and research exists to make a claim on the utility of ETCO2 on the guidance of further resuscitative efforts and cardiac arrest outcomes.

Conclusion

The American Heart Association's ACLS guidelines include monitoring ETCO2 as a surrogate marker of cardiac output to help guide resuscitation during cardiac arrest. This concept is appealing given the non-invasive nature and wide availability of ETCO2: real-time feedback during resuscitation, limiting chest compression interruptions, and the ability to decide when to terminate resuscitation efforts. Existing data indicates that, in ventilated patients with a definitive airway, persistent ETCO2 values <10 mmHg despite maximum efforts are predictive of unsuccessful resuscitation, and that higher ETCO2 values are associated with ROSC. It is difficult to create an absolute numeric guide, however, due to the wide variability and inconsistent evidence regarding thresholds, due to many existing variables that may affect ETCO2, especially in causes related to pulmonary function. We need further evidence to understand what cutoffs and thresholds to use and how certain variables might affect them.

Answer

In the management of patients with cardiac arrest and a definitive airway, a persistent ETCO2 of <10 mmHg, despite maximal resuscitative efforts, is associated with lack of ROSC, while an abrupt increase in ETCO2 of 10 mmHg or greater may be reliably indicative of ROSC. It remains that existing studies do not clearly account for confounding variables to clearly define a threshold to be the single deciding factor as to whether to stop or continue ACLS. Similarly, depth of chest compressions is associated with ETCO2 levels, but there remains no set number or guide by which to adjust chest compressions during cardiac arrest.

References


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