Comparison of ETCO$_2$-directed chest compressions to optimized chest compressions in a pediatric model of basic life support

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**INTRODUCTION**
- Successful cardiopulmonary resuscitation (CPR) requires the rapid and effective implementation of infrequently used skills.
- High-quality CPR is essential to generate blood flow to vital organs and to achieve return of spontaneous circulation (ROSC).
- Despite 20 years of research, survival to discharge from out-of-hospital cardiac arrest remains low.
- The most critically important CPR skill is the delivery of appropriate chest compressions; inadequate chest compressions can result in failed resuscitative efforts and/or permanent neurologic injury.
- Current American Heart Association guidelines recommend 100 chest compressions/minute at a depth of one-third to one-half the anteroposterior (AP) diameter.
- The recommended depth is empirically derived and difficult to accurately estimate and consistently perform.
- The recommended rate is inconsistently achieved without the aid of a timing device or invasive monitoring.
- The ideal model of CPR would take into account patient-specific geometry and hemodynamic realities, and would allow the rescuer to adapt as these variables change.
- A technically simple, widely available, noninvasive, real-time method of physiologic feedback that helps rescuers optimize the delivery of CPR could improve both rates of ROSC and neurologically intact survival.
- End tidal CO$_2$ (ETCO$_2$) monitoring is readily available, easily used, and a standard of care in the operating suite and critical care setting.
- ETCO$_2$ is a quantitative surrogate for pulmonary blood flow and therefore systemic blood flow, and has been shown to correlate well with cardiac output.
- ETCO$_2$ produced during CPR has been shown to have prognostic value for ROSC.
- ETCO$_2$ has been used to evaluate different modalities of chest compressions.
- ETCO$_2$ has not been evaluated as a physiologically responsive guide for the delivery of chest compressions.

**OBJECTIVES**
- To evaluate ETCO$_2$ as a physiologically responsive guide for the delivery of chest compressions.
  - When ventilation is held constant, ETCO$_2$ is dependent on pulmonary blood flow, which increases as CPR generates greater systemic blood flow.
  - Therefore, ETCO$_2$-targeted chest compressions should provide an objective measure of the adequacy of CPR.
  - ETCO$_2$-directed chest compressions should result in superior rates of resuscitation when compared to the standard guidelines.
- We compared outcomes of ETCO$_2$-directed chest compressions to those of optimal chest compressions.
- Outcomes included the level of ETCO$_2$, myocardial perfusion pressure (MPP), and the rates of ROSC.

**MATERIALS AND METHODS**
- 40 male piglets 3-6 days of age and weighing 2.1 ± 0.38 kg were randomly assigned to either the ETCO$_2$-directed or the optimized CPR group.
- All piglets underwent induction of general anesthesia, tracheostomy, placement of femoral central and arterial lines, and placement of a femoral venous perfusion wire.
- Ventricular fibrillation was induced.
- After a no-flow interval of 90 seconds, PBLS was started via either the optimized or ETCO$_2$-directed protocol.
- In the optimized CPR group, chest compressions were performed at the AHA-recommended depth and rate. Resuscitators were blinded to ETCO$_2$.

**METHODS**
- Comparison of ETCO$_2$ between groups was not statistically significant (p = 0.16), but after 6 minutes of CPR the ETCO$_2$-directed group had significantly higher levels. We were able to maintain ETCO$_2$ in the ETCO$_2$-directed group.
- The overall difference in ETCO$_2$ between groups was not statistically significant (p = 0.04), but after 6 minutes of CPR the ETCO$_2$-directed group had significantly higher levels. We were able to maintain ETCO$_2$ in the ETCO$_2$-directed group.
- The survival rate was not significantly different among groups, and there was no interaction between group and survival. The 10 minute ETCO$_2$ levels were significantly greater for survivors than non-survivors in the optimized group (p = 0.02). We were able to maintain ETCO$_2$ in both survivors and non-survivors in the ETCO$_2$-directed group.

**RESULTS**
- MAPs were significantly higher in the ETCO$_2$-directed group as compared to the optimized group (p = 0.04) and in survivors versus non-survivors of both groups (p = 0.001). MAP was significantly higher in the ETCO$_2$-directed survivors than in the optimized survivors at 10 minutes (p = 0.02).
- CVP was better maintained in the ETCO$_2$-directed group than in the optimized group (p = 0.04), was equivalent among survivors, and was highest in the non-survivors of the ETCO$_2$-directed group. The difference in CVP between survivors and non-survivors was not significant (p = 0.41).
- Overall MPP (MAP-CVP) was not different between the two groups.

**RESULTS CONTINUED**
- Survivors in both groups maintained MPPs >10 mmHg throughout PBLS resuscitation, whereas non-survivors consistently had MPPs <10 mmHg after 5-6 minutes of CPR, and this difference in MPP was related to survival (p = 0.02).
- The maintenance of ETCO$_2$ in the ETCO$_2$-directed group did not correlate with MPP, where there was correlation in the decline of MPP and ETCO$_2$ in the optimized group.

**CONCLUSIONS**
- Consistently achieving AHA guidelines for depth and rate of chest compressions is difficult in clinical practice.
- Additional equipment to ensure optimal CPR is being performed is impractical and/or unavailable.
- ETCO$_2$ levels were easily monitored and provided an objective measure of the adequacy of chest compressions.
- Using only ETCO$_2$ monitoring, we were able to gauge the effectiveness of chest compressions and provide resuscitation that was as effective as AHA-optimized CPR.
- The ETCO$_2$-directed method of CPR can help rescuers bring typical CPR up to the level of optimized CPR, and may improve the rates of ROSC and neurologically intact survival.