WORKSHEET for Evidence-Based Review of Science for Veterinary CPCR

1. Basic Demographics

Worksheet author(s)

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2. Clinical question:

In dogs and cats in cardiac arrest (P), does the use of EtCO2 monitoring during CPCR (I), compared with no EtCO2 monitoring (C), improve chances for ROSC (O)?

3. Conflict of interest specific to this question:

Do any of the authors listed above have conflict of interest disclosures relevant to this worksheet?
No.

4. Search strategy (including electronic databases searched):

4a. Databases

-MEDLINE via PUBMED (PubMed origin (date?) through August 9, 2011; performed on August 9, 2011)

Search 1
"Cardiopulmonary resuscitation "[MeSH]
AND
end[All fields] AND tidal[All fields] AND CO2[All fields]

Search 2
"Cardiopulmonary resuscitation"[MeSH] AND "heart arrest"[MeSH]
AND
end[All fields] AND tidal[All fields] AND CO2[All fields]

Search 3
"Cardiopulmonary resuscitation "[MeSH]
AND
"Capnog*"[All fields]

Search 4
"Cardiopulmonary resuscitation"[MeSH] AND "heart arrest"[MeSH]
AND
"Capnog*"[All fields]

-CAB (1910 through 2011 Week 32; performed on August 23, 2011)
All search terms searched in "All Fields"

Search 1
"cardiopulmonary resuscitation" and end and tidal and CO2

Search 2
"cardiopulmonary resuscitation" and "capno*"

Search 3
cardiopulmonary resuscitation capno*

Search 4
cardiopulmonary and resuscitation and capno*

Search 5
cardiopulmonary and resuscitation and Capnography

Search 6
CPR and Capnography

Search 7
CPR and end and tidal

4b. Other sources

Reference lists of relevant search results, including the reference lists of some articles that met exclusion criteria.

4c. State inclusion and exclusion criteria for choosing studies and list number of studies excluded per criterion

Inclusion criteria

Use of end-tidal CO_2 measurements (including quantitative capnometry or colorimetric estimates of $ETCO_2$) or capnography during performance of cardiopulmonary cerebral resuscitation to monitor efficacy of CPCR efforts and/or to predict ROSC.

Exclusion criteria
Abstracts only. Editorials, comments, and reviews.
Non-English language articles.
Evaluations of capnography or $ETCO_2$ in non-cardiopulmonary arrest scenarios (i.e. shock or other non-CPA altered perfusion states).
Articles that described only the increase in $ETCO_2$ noted at time of ROSC (i.e. when $ETCO_2$ was used as a *marker* of ROSC rather than as a predictor for its return).

4d. Number of articles/sources meeting criteria for further review: 28

-LOE1: There were no LOE1 studies identified.

-LOE2: There were no LOE2 studies identified.

-LOE3: There were 3 LOE3 studies identified:
Kern, Sanders, Voorhees, et al. 1989
Sanders, Atlas, Ewy, et al. 1985
Sanders, Ewy, Bragg, et al. 1985

-LOE4: There were no LOE4 studies identified.

-LOE5: There were no LOE5 studies identified.

-LOE6: There were 25 LOE6 studies identified:
Ahrens, et al. 2001
Callaham, et al. 1990
Cantineau, et al. 1996
Falk, et al. 1988
Garnett, et al. 1987
Grmec, et al. 2007
Grmec, et al. 2001
Grmec, Lah, Tusek-Bunc. 2003
Grmec, Kupnik. 2003
Gudipati, et al. 1988
Kalenda, et al. 1978
Kolar, et al. 2008
Levine, et al. 1997
Mauer, et al. 1998
Nakatani, et al. 1999
Ornato, et al. 1992

Salen, et al. 2001
Sanders, et al. 1989
Sato, et al. 1993
Steedman, et al. 1990
Trevino, et al. 1985
Varon, et al. 1991
von Planta, et al. 1989 – note: I do not have a copy of this article, only have a copy of the abstract, so evaluation limited.
Wayne, et al. 1995
Weil, et al. 1985

5. Summary of evidence

Evidence Supporting Clinical Question

***Note: *All* clinical human investigations reported here were observational in nature; therefore, none have control groups and many report various endpoints (i.e., ROSC, 24 hour survival, AND survival to discharge, for example).

There were NO STUDIES identified that compared the use of capnometry to the lack of use of capnometry and the resultant effect on ROSC. Rather, all studies used some form of capnometry and then observed an outcome associated with ETCO2.

Most studies have hypotheses / research questions such as: "Can PetCO2 values be used to predict survival from all causes of cardiac arrest?" Thus, if the answer is "yes" to such questions, that's fair evidence in my mind that the monitoring tool is helpful in CPCR and may improve likelihood of ROSC. I used the method below for article insertion into the tables.

Good = PetCO2 monitoring is shown to be superior to no PetCO2 monitoring to improve outcome of CPCR.
Fair = PetCO2 can be used to predict outcome in CPCR (and thus may be used to guide it, being the next logical leap).
Poor = PetCO2 can be used to predict a *surrogate* to CPCR outcome (i.e., when PetCO2 is shown to increase once compressions instituted, but may not have been associated with CPCR outcome specifically), or support is stated regarding CPCR outcome specifically but no statistics are given.

It was unclear that "survival to hospital admission" meant the same thing in each study. In some studies, this probably meant survival from the field to the point of hospital arrival, whereas in other studies this probably meant survival of the CPA event to the point of being admitted to the ICU. Thus, I listed all "survival to hospital admission" endpoints as E rather than as B and tried to use the authors' wording in the table.

Good						
Fair			*Kern 1989: A, E=coron perf pres* *Sanders 1985a: E=10 min surv post-ROSC; coronary perf pres*			*Ahrens 2001; A, C, E=24 hour surv* *Callaham 1990: A* *Cantineau 1996: A* *Grmec 2007: A, C, E=ROSC at hospital admission* *Grmec 2001; A, C* *Grmec 2003a: A* *Grmec 2003b: A, C* *Gudipati 1988: A, E=card index* *Kolar 2008: A, C* *Levine 1997: E=surv*

						to hosp admit *Mauer 1998: E=surv to hosp admit* *Nakatani 1999: A, E=surv to hosp admit* *Ornato 1992: E=surv to hosp admit* *Salen 2001: E=surv to hosp admit* *Sanders 1989: A, C* *Sato 1993: A* *Steedman 1990: E=dc from ED* *Varon 1991: B* *von Planta 1989: A, E=cor perf pres, mean aortic pres* *Wayne 1995: A, C*
Poor			*Sanders 1985b: E=coronary perf pres*			*Falk 1988: A* *Kalenda 1978: E=pulm perfusion / efficacy cardiac massage* *Trevino 1985: A* *Weil 1985: E=cardiac index*
	1	**2**	**3**	**4**	**5**	**6**
Level of evidence (P)						

A = Return of spontaneous circulation
B = Survival of event
C = Survival to hospital discharge
D = Intact neurological survival
E = Other endpoint
Italics = Non-target species studies

Evidence Neutral to Clinical question

Good						
Fair						*Garnett 1987: A*
Poor						
	1	**2**	**3**	**4**	**5**	**6**
Level of evidence (P)						

A = Return of spontaneous circulation
B = Survival of event
C = Survival to hospital discharge
D = Intact neurological survival
E = Other endpoint
Italics = Non-target species studies

Evidence Opposing Clinical Question

None identified – Table intentionally left empty

Good						
Fair						
Poor						
	1	**2**	**3**	**4**	**5**	**6**
Level of evidence (P)						

A = Return of spontaneous circulation
B = Survival of event
C = Survival to hospital discharge
D = Intact neurological survival
E = Other endpoint
Italics = Non-target species studies

6. REVIEWER'S FINAL COMMENTS AND ASSESSMENT OF BENEFIT / RISK:

There has been interest in monitoring end-tidal carbon dioxide (ETCO2) during cardiopulmonary cerebral resuscitation (CPCR) since Kalenda, et al. described its use as a noninvasive monitor of pulmonary perfusion (and thus cardiac output) during cardiac massage in 1978. Since that time, other authors have demonstrated strong correlation between ETCO2 values and cardiac output/index (Weil 1985; Gudipati 1988), coronary perfusion pressure (Sanders 1985a; Sanders 1985b; Kern 1989; von Planta 1989), and mean aortic pressure (von Planta 1989) during CPCR in various species; both Sanders investigations and the Kern study were performed in dogs.

While early research focused on experimental canine, porcine, and rodent models, clinical observational studies in humans followed shortly thereafter. As pertains to the question at hand, the next wave of studies, published largely from the early-1990s to the mid-2000s, focused primarily on the usefulness of ETCO2 monitoring in predicting various outcomes following CPCR. These investigations focused mostly on adult human beings with nontraumatic, primary cardiac arrest; different cardiac rhythms were represented in different investigations (i.e., pulseless electrical activity, CPA from any primary cardiac cause, etc). These studies uniformly found that patients with higher ETCO2 over the course of CPCR were more likely to achieve return of spontaneous circulation (ROSC), survival to hospital discharge, or both (Ahrens 2001; Callaham 1990; Cantineau 1996; Grmec 2007; Grmec 2001; Grmec 2003a; Grmec 2003b; Gudipati 1988; Kolar 2008; Nakatani 1999; Sanders 1989; Sato 1993; von Planta 1989; Wayne 1995). ETCO2 measurements well into the CPCR effort, for instance at the 20 minute mark, tended to predict survival, while initial ETCO2 values did so less reliably. Some investigations determined cutoff values of ETCO2 with maximal sensitivity, specificity, positive predictive values, and negative predictive values for different CPCR outcomes, which will be discussed in a different section (MON22). Only a single study identified (Garnett 1987) was neutral on the subject of ETCO2 monitoring as pertains to its usefulness in predicting CPCR outcome. Garnett found no difference between ETCO2% in CPA patients that could not be resuscitated (1.8%, +/-0.9) and ETCO2% in CPA patients that achieved ROSC (1.7%, +/- 0.6). The other 27 studies identified support the routine use of capnometry during CPCR to guide circulatory efforts.

There is sufficient evidence to support the routine use of capnometry during CPCR. Higher ETCO2 values are associated with higher cardiac output and coronary perfusion pressures in experimental models, and are strongly associated with survival from CPA in people. Thus, targeting a specific ETCO2 value by optimizing cardiac compressions or massage is likely to benefit patients undergoing CPCR and improve the likelihood of ROSC.

7. Conclusion

DISCLAIMER: Potential possible wording for a Consensus on Science Statement. Final wording will differ due to other input and discussion.
CONSENSUS ON SCIENCE: Twenty-seven experimental and clinical human observational studies support the use of capnometry during CPCR to improve outcome; one identified study neither supported nor refuted its utility for prediction of CPCR outcome. ETCO2 measurement can serve as a noninvasive surrogate measurement of cardiac output (Weil 1985; Gudipati 1988) and coronary perfusion pressure (Sanders 1985a; Sanders 1985b; Kern 1989; von Planta 1989) during CPCR efforts; therefore, rescuers can and likely should alter circulatory support methods to optimize ETCO2 values. No study has been performed comparing the use of a capnometer during CPCR to no use of a capnometer during CPCR. Such study will likely never be performed clinically because the indirect evidence supporting capnometer use during CPCR is so strong. ETCO2 monitoring during CPCR is beneficial because it provides information that can help guide

compressions and hemodynamic support during CPCR, and that can help provide support to continue CPCR efforts in patients with higher ETCO2 when, without knowing the ETCO2, we may discontinue efforts. Specific target values for ETCO2 will be discussed in a separate section (MON 22).

8. Acknowledgement

9. Citation list

1) Ahrens T, Schallom L, Bettorf K, et al. End-tidal carbon dioxide measurements as a prognostic indicator of outcome in cardiac arrest. Am J Crit Care 2001;10:391-398.
PURPOSE: To evaluate the use of end-tidal carbon dioxide values in predicting survival in cardiopulmonary arrest. BACKGROUND: The decision about when to terminate resuscitative efforts for patients with cardiopulmonary arrest is often subjective. End-tidal carbon dioxide values have been suggested as potential objective criteria for making this decision. METHODS: This study was a cooperative effort of the St Louis chapter of the American Association of Critical-Care Nurses and its members and involved 6 hospitals and an air evacuation service. All adult patients who had a cardiopulmonary arrest were eligible for the study. Once a patient with cardiac arrest was intubated, end-tidal carbon dioxide and cardiac rhythms were measured and recorded every 5 minutes for 20 minutes or until resuscitation efforts were terminated. Patients' survival at the time of the arrest, survival 24 hours after the arrest, and discharge status were followed up. RESULTS: A total of 127 patients were enrolled in the study. All but 1 patient with end-tidal carbon dioxide values less than 10 mm Hg died before discharge. End-tidal carbon dioxide values greater than 10 mm Hg were associated with various degrees of survival. Overall survival to discharge was less than 14%, regardless of the end-tidal carbon dioxide value. CONCLUSION: Measurements of end-tidal carbon dioxide can be used to accurately predict nonsurvival of patients with cardiopulmonary arrest. End-tidal carbon dioxide levels should be monitored during cardiopulmonary arrest and should be considered a useful prognostic value for determining the outcome of resuscitative efforts.
LOE 6
Supportive
Funding: American Assoc. of Critical Care Nurses, St. Louis Chapter; Sherwood Medical (St. Louis, MO); Mallinckrodt Medical (St. Louis, MO); Spacelabs (Redmond, WA).
Key points: 127 humans; prospective, multi-institution, convenience-sampled, pre- and in-hospital arrest, observational study. Specific research question: "Can PetCO2 values be used to predict survival from all causes of cardiac arrest?" Authors specifically state that the PetCO2 *was not* used to guide CPCR efforts. PetCO2 values were significantly higher in successful ROSC than in patients who died. PetCO2 > 20mmHg associated with improved chances of surviving cardiopulmonary arrest. Concluded that PetCO2 can be used to predict survival in adult humans with CPA, that PetCO2 < 10mmHg at any point during CPCR predicts mortality, and they suggest that PetCO2 values may be used to decide when to terminate CPCR efforts.

2) **Callaham M, Barton C. Prediction of outcome of cardiopulmonary resuscitation from end-tidal carbon dioxide concentration. Crit Care Med 1990;18:358-362.**
Capnography is a valuable tool in the management of cardiac arrest, since end-tidal CO2 (PetCO2) correlates well with cardiac output and there are no other suitable noninvasive ways to measure this important variable during resuscitation. Animal studies also suggest that PetCO2 correlates well with the likelihood of resuscitation, but this has never been confirmed in humans. We prospectively studied 55 adult, nontraumatic prehospital cardiac arrest patients. PetCO2 was monitored with an in-line sensor on arrival in the ED and throughout the arrest, which was managed by the usual advanced cardiac life-support treatment guidelines.

Chest compression was carried out mechanically. Patients were assessed for return of spontaneous pulse as evidence of initial resuscitation; hospital discharge and long-term survival were not examined. Fourteen patients developed spontaneous pulses and were resuscitated, and 41 were not. The length and aggressiveness of treatment and CPR were not different between the two groups, nor were there differences in down time, resuscitation time, or other factors known to affect outcome. Patients who developed a pulse had a mean PetCO2 of 19 +/- 14 (SD) torr at the start of resuscitation, and those who did not had a mean PetCO2 of 5 +/- 4 torr (p less than .0001). This difference was significant both in nonperfusing rhythms (asystole and ventricular fibrillation) and in potentially perfusing rhythms (electromechanical dissociation). An initial PetCO2 of 15 torr correctly predicted eventual return of pulse with a sensitivity of 71%, a specificity of 98%, a positive predictive value of 91%, and a negative predictive value of 91%. A receiver operating curve was generated for sensitivity and specificity of the test at varying PetCO2 thresholds.

LOE 6

Supportive

Funding: Hewlett-Packard Corporation

Key points: 55 human adults with nontraumatic CPA; prospective, single center, in-hospital, observational study. Research question: to investigate the usefulness of *initial* PetCO2 [PetCO2(i)] as a predictor of ROSC. PetCO2(i) was significantly less (5.2 +/- 4 (SD) mmHg) in those who never achieved a spontaneous pulse than the PetCO2(i) (19 +/- 14 (sd) mmHg) in those that developed a spontaneous pulse at some point during CPCR; $p < 0.0001$. Significant differences in ROSC between patients with higher and lower PetCO2(i) persisted in asystole and EMD (PEA) subsets; there were too few patients in ventricular fibrillation to determine whether a difference existed in that population. 4/55 patients that achieved ROSC had PetCO2(i) < 10mmHg. Concluded that PetCO2(i) can be used to predict survival in adult humans with nontraumatic CPA, but that low PetCO2(i) alone is not a sufficient criterion for terminating resuscitation.

3) **Cantineau JP, Lambert Y, Merckx P, et al. End-tidal carbon dioxide during cardiopulmonary resuscitation in humans presenting mostly with asystole: a predictor of outcome. Crit Care Med 1996;24:791-796.**

OBJECTIVE: To determine whether continuous semiquantitative assessment of end-tidal CO2 could provide a highly sensitive predictor of return of spontaneous circulation during cardiopulmonary resuscitation (CPR). DESIGN: Prospective, clinical study. SETTING: Prehospital CPR. PATIENTS: One hundred twenty patients, during nontraumatic cardiac arrest. INTERVENTIONS: End-tidal CO2 values were measured continuously after tracheal intubation, and were categorized as the initial value, and as minimal and maximal values during the first 20 mins. MEASUREMENTS AND MAIN RESULTS: Presenting rhythm was asystole in 22 of the first 24 patients. Return of spontaneous circulation occurred in eight patients. Initial, minimal, and maximal end-tidal CO2 values were significantly ($p < .01$) higher in these patients than in the patients without return of spontaneous circulation. Cutoff values providing a 100% sensitivity and the highest specificity in predicting return of spontaneous circulation were found to be 10 torr for initial and maximal end-tidal CO2 values, and 2 torr for the minimal end-tidal CO2 value. The number of patients required to reject (with a risk error of <.05) the hypothesis of an actual sensitivity of < or = 90% for an observed sensitivity of 100% was found to be 95. In the second part of the study, this hypothesis was prospectively tested for initial and maximal end-tidal CO2 values in the subsequent 96 patients. Presenting cardiac rhythm was asystole in 87 patients. Return of spontaneous circulation was obtained in 30 patients. The cutoff value of 10 torr for maximal end-tidal CO2 during the first 20 mins after tracheal intubation provided an observed sensitivity of 100% in predicting return of spontaneous circulation with a specificity of 67%. This result allows rejection of the hypothesis of an actual sensitivity of < or = 90% ($p = .042$). By contrast, the observed sensitivity of initial end-tidal CO2 was only 87%. CONCLUSIONS: End-tidal CO2 represents a valuable tool for monitoring patients presenting with asystole during prehospital CPR. Fluctuations in end-tidal CO2 during CPR and the utility of end-tidal CO2 in detecting return of spontaneous circulation justify its continuous measurement. In addition, a high sensitivity

(>90%) in predicting return of spontaneous circulation is prospectively demonstrated using the maximal end-tidal CO2 during the first 20 mins after tracheal intubation, with a cutoff value of 10 torr. Such a prognostic indicator could be used for a more rational approach to prolonged CPR.
LOE 6
Supportive
Funding: None stated
Key points: 120 humans with nontraumatic CPA; prospective, single center, prehospital, observational study. Objective: to determine whether continuous semiquantitative assessment of PetCO2 could provide a highly sensitive predictor of ROSC during CPR. Two-part study. First part: 24 consecutive patients (22/24 in asystole) – PetCO2 observed continuously throughout first 20 minutes of CPCR; the initial, minimal, and maximal PetCO2 were all significantly higher in ROSC patients than in those that never achieved ROSC. 10mmHg determined as most sensitive (100%) and specific (~62.5%) cutoff value to predict success of ROSC. Second part: 96 patients – PetCO2 cutoff of 10mmHg tested during first 20 minutes of CPCR as a predictor for ROSC. A PetCO2(initial) cutoff of 10mmHg predicted ROSC with 87% sensitivity (95% CI: 70-95%) and 74% specificity. A maximal PetCO2 cutoff of 10mmHg during the first 20 minutes of CPCR: 100% sensitive and 66% specific for ROSC. Concluded that fluctuations in PetCO2 during CPCR and usefulness of PetCO2 (esp maximal) in predicting ROSC justify continuous PetCO2 monitoring during CPCR. Suggest that PetCO2 may be used as a prognostic indicator for a "more rational approach in the prolonged resuscitation of cardiac arrest patients."

4) **Falk JL, Rackow EC, Weil MH. End-tidal carbon dioxide concentration during cardiopulmonary resuscitation. N Engl J Med 1988;318:607-611.**
We prospectively measured the end-tidal carbon dioxide concentration during 13 episodes of cardiac arrest in 10 critically ill patients receiving mechanical ventilation, to evaluate its usefulness as an indicator of circulatory status during cardiac arrest and resuscitation. The end-tidal carbon dioxide concentration decreased from a mean (+/- SD) of 1.4 +/- 0.9 to 0.4 +/- 0.4 percent after the onset of cardiac arrest. During precordial compression, it increased to 1.0 +/- 0.5 percent. The decreases in the end-tidal carbon dioxide concentration were associated with increases in systemic oxygen extraction (r = 0.79). Spontaneous circulation was restored on seven occasions. This was heralded by a rapid increase in the end-tidal carbon dioxide concentration, from 1.3 +/- 0.5 percent to an overshoot value of 3.7 +/- 2.1 percent, within approximately 30 seconds. The concentration then declined to a stable value of 2.4 +/- 1.8 percent four minutes after resuscitation. However, it remained 0.7 +/- 0.4 percent in six patients in whom resuscitative efforts failed to restore spontaneous circulation. These observations are consistent with experimental studies of cardiopulmonary resuscitation in pigs, in which the end-tidal carbon dioxide concentration varied directly with the cardiac output produced by precordial compression. We therefore propose that measurement of the end-tidal carbon dioxide concentration may be a practical, non-invasive method for monitoring blood flow generated by precordial compression during cardiopulmonary resuscitation and an almost immediate indicator of successful resuscitation.
LOE 6
Supportive
Funding: None stated
Key points: 10 critically ill humans with 13 events of CPA; prospective, single center, in-hospital, observational study. Objective: to evaluate the usefulness of ETCO2 as an indicator of circulatory status during CPA and resuscitation. Prior to CPA, ETCO2 was 1.4% +/-0.9; within 1 minute onset CPA, ETCO2 was 0.4% +/- 0.4. Precordial compressions increased mean ETCO2 compared to the ETCO2 at onset of CPA, particularly in patients that achieved ROSC (no statistical analysis). Concluded that ETCO2 could be used as an indicator of volume of blood flow produced by precordial compression, and that it is a reliable and noninvasive way to monitor CPCR efficacy.

5) **Garnett AR, Ornato JP, Gonzalez ER, et al. End-tidal carbon dioxide monitoring during cardiopulmonary resuscitation. JAMA 1987;257:512-515.**
The end-tidal carbon dioxide (CO2) concentration has been found to correlate with cardiac output during and after cardiopulmonary resuscitation (CPR) in animal models. We monitored end-tidal CO2 values continuously during cardiac resuscitation in 23 humans while ventilation was held constant with a computer-controlled CPR Thumper. This report focuses on ten of the 23 patients who experienced return of spontaneous circulation (ROSC) during monitoring. There was no significant difference in the end-tidal CO2 value of patients without ROSC (1.8% +/- 0.9%) and the end-tidal CO2 value of patients before ROSC in patients who had ROSC (1.7% +/- 0.6%). The end-tidal CO2 concentration increased immediately in all patients who had ROSC, from 1.7% +/- 0.6% to 4.6% +/- 1.4%, then gradually returned to a new baseline (3.1% +/- 0.9%). Change in the end-tidal CO2 value was often the first clinical indicator that ROSC had occurred. Our findings suggest that end-tidal CO2 monitoring may provide clinically useful information that can be used to guide therapy during CPR.
LOE 6
Neutral
Funding/Material support: Puritan-Bennett Corporation (Los Angeles, CA); Michigan Instruments (Grand Rapids, MI)
Key points: 23 adult humans with nontraumatic CPA; prospective, single center, in-hospital, observational study. Objective: to evaluate the usefulness of ETCO2 as an indicator of hemodynamic status during CPCR. There was no difference between ETCO2% in CPA patients that could not be resuscitated (1.8%, +/-0.9) and ETCO2% in CPA patients that achieved ROSC (1.7%, +/- 0.6). The study reported other positive uses for monitoring ETCO2 during CPR / after ROSC. Concluded that further investigation is needed to determine the relationship between ETCO2 and perfusion during CPR.

6) **Grmec S, Krizmaric M, Mally S, et al. Utstein style analysis of out-of-hospital cardiac arrest--bystander CPR and end expired carbon dioxide. Resuscitation 2007;72:404-414.**
INTRODUCTION: The aim of this prospective cohort study was to describe the outcome for patients with out-of-hospital cardiac arrest in Maribor (Slovenia) over a 4 year period using a modified Utstein style, and to investigate elementary knowledge of basic life support among potential bystanders in our community. PATIENTS AND METHODS: Through the prehospital and the hospital database system we followed up a consecutive group of patients with out-of-hospital cardiac arrest (OHCA) between January 2001 and December 2004. We investigated the effects of various factors on outcome in OHCA, especially partial end-tidal CO2 pressure (petCO2), efficacy of bystander CPR and their elementary knowledge of basic life support (BLS). We also examined motivation among potential bystanders and possible implementation for BLS education in our community. RESULTS: OHCA was confirmed in 592 patients. Advanced cardiac life support was initiated in 389 patients, of which 277 were of cardiac etiology. In 287 patients the event was bystanders witnessed and lay-bystander basic life support was performed only in 83 (23%). After treating OHCA by a physician-based prehospital medical team ROSC was obtained in 61%, the ROSC on admission was 50% and the overall survival to discharge was 21%. Initial petCO2 (OR: 22.04; 95%CI: 11.41-42.55), ventricular fibrillation or pulseless ventricular tachycardia as initial rhythm (OR: 2.13; 95%CI: 1.17-4.22), bystander CPR (OR: 2.55; 95%CI: 1.13-5.73), female sex (OR: 3.08; 95%CI: 1.49-6.38) and arrival time (OR: 1.29; 95%CI: 1.11-1.82) were associated with improved ROSC when using multivariate analysis. Using the same method we found that bystander CPR (OR: 5.05; 95%CI: 2.24-11.39), witnessed arrest (OR: 9.98; 95%CI: 2.89-34.44), final petCO2 (OR: 2.37; 95%CI: 1.67-3.37), initial petCO2 (OR: 1.61; 95%CI: 1.28-2.64) and arrival time (OR: 1.39; 95%CI: 1.33-1.60) were associated with improved survival. A questionnaire to potential bystanders has revealed disappointing knowledge about BLS fundamentals. On the other side, there is a welcomed willingness of potential bystanders to take BLS training and to follow dispatchers' instructions by telephone on how to perform CPR. CONCLUSION: After OHCA in a physician-based prehospital setting in our region, the overall survival to discharge was 21%. The potential bystander in our community is generally poorly educated in

performing CPR, but willing to gain knowledge and skills in BLS and to follow dispatchers' instructions. Arrival time, witnessed arrest, bystander CPR, initial petCO2 and final petCO2 were significantly positively related with ROSC on admission and with survival. Prehospital data from this and previous studies provide strong support for a petCO2 of 1.33 kPa to be a resuscitation threshold in the field. In our opinion the initial value of petCO2 should be included in every Utstein style analysis.

LOE 6

Supportive

Funding: Not stated

Key points: 389 adult humans with CPA; prospective, observational study. Objective: to investigate the effects of a physician-based prehospital emergency unit, initial value of PetCO2 and bystander CPR on outcome in out-of-hospital cardiac arrest. Initial (2.418 +/- 0.7413kPa vs. 0.944 +/- 0.6555kPa) and final (3.629 +/- 0.9711kPa vs. 1.000 +/- 0.3486kPa) PetCO2 were both significantly greater in patients that achieved ROSC than in those that did not. Initial (2.6 +/- 0.9kPa vs. 1.4 +/- 0.9kPa) and final (3.9 +/- 1.2kPa vs. 1.9 +/- 1.3kPa) PetCO2 were both significantly greater in patients that survived to discharge than in those that did not. Initial PetCO2 was significantly higher in those with ROSC at hospital admission than in those who died (2.4±0.8 kPa versus 0.9±0.7 kPa). Also, higher initial PetCO2 was significantly and strongly associated with: ROSC achievement prior to presentation to the hospital (OR 22.04 with 95% CI of 11.41-42.55). Higher initial PetCO2 was significantly associated with survival to discharge (OR 1.61; 95% CI 1.28-2.64), and higher final PetCO2 was significantly associated with survival to discharge (OR 2.37; 95% CI 1.67-3.37). There were significant differences in other comparison groups (initial and/or final PetCO2 higher in: survived to discharge than died; ROSC by hospital admit vs. not; ROSC by hospital admit vs. died; etc). All patients with ROSC had initial PetCO2 > 1.33kPa. Concluded there is strong support for performing CPCR in the field with PetCO2 initial >1.33kPa, and recommended that initial PetCO2 be ranked in future Utstein style reports to provide insight into initial condition of CPA patients.

7) Grmec S, Klemen P. Does the end-tidal carbon dioxide (EtCO2) concentration have prognostic value during out-of-hospital cardiac arrest? Eur J Emerg Med 2001;8:263-269.

We aimed to investigate the utility of end-tidal carbon dioxide concentration as a prognostic indicator of initial outcome of resuscitation, we conducted a prospective study of EtCO2 in adult victims of out-of-hospital non-traumatic cardiac arrest. We prospectively studied 139 adult patients. The initial, final, average, minimal and maximal EtCO2 was significantly higher in resuscitated patients than in non-resuscitated patients. Using an initial, average and final EtCO2 value of 10 mmHg correctly identified 100% of the patients who were subsequently resuscitated with an acceptable specificity (74.1%; 90%; 81.4%). Important observation from this study is that none of the patients with an average, initial and final EtCO2 level of less than 10 mmHg were resuscitated. Data from this prospective clinical trial indicate that initial, average and final EtCO2 monitoring during CPR is correlated with resuscitation. End-tidal CO2 monitoring has potential as a noninvasive indicator of cardiac output during resuscitation and a prognostic indicator for resuscitation.

LOE 6

Supportive

Funding: Not stated

Key points: 139 adult humans with nontraumatic CPA; prospective, observational study. Objective: to investigate the utility of end-tidal carbon dioxide concentration as a prognostic indicator of initial outcome of resuscitation. The initial, final, minimal, maximal, and average PetCO2 were greater in patients that achieved ROSC than in those that did not ($P < 0.01$ for all); the initial, final, minimal, maximal, and average PetCO2 were greater in those that survived to hospital discharge than in those that did not ($P < 0.01$ for all). All patients with ROSC had an initial PetCO2 of 10mmHg or greater. Sensitivities, specificities, and positive and negative predictive values for cutoff of 10-15mmHg PetCO2s (initial, final, minimal, maximal, average) to predict ROSC were presented, and an ROC generated to help select an appropriate cutoff for likelihood of

ROSC. Concluded that their findings suggest that EtCO2 levels can be used as a valuable and noninvasive prognostic guide during CPR, and that PetCO2 monitoring is correlated with ROSC and survival of cardiac arrest.

8) Grmec S, Lah K, Tusek-Bunc K. Difference in end-tidal CO2 between asphyxia cardiac arrest and ventricular fibrillation/pulseless ventricular tachycardia cardiac arrest in the prehospital setting. Crit Care 2003;7:R139-144. ("Grmec 2003a")

INTRODUCTION: There has been increased interest in the use of capnometry in recent years. During cardiopulmonary resuscitation (CPR), the partial pressure of end-tidal carbon dioxide (PetCO2) correlates with cardiac output and, consequently, it has a prognostic value in CPR. This study was undertaken to compare the initial PetCO2 and the PetCO2 after 1 min during CPR in asphyxial cardiac arrest versus primary cardiac arrest. METHODS: The prospective observational study included two groups of patients: cardiac arrest due to asphyxia with initial rhythm asystole or pulseless electrical activity, and cardiac arrest due to acute myocardial infarction or malignant arrhythmias with initial rhythm ventricular fibrillation (VF) or pulseless ventricular tachycardia (VT). The PetCO2 was measured for both groups immediately after intubation and then repeatedly every minute, both for patients with and without return of spontaneous circulation (ROSC). RESULTS: We analyzed 44 patients with asphyxial cardiac arrest and 141 patients with primary cardiac arrest. The first group showed no significant difference in the initial value of the PetCO2, even when we compared those with and without ROSC. There was a significant difference in the PetCO2 after 1 min of CPR between those patients with ROSC and those without ROSC. The mean value for all patients was significantly higher in the group with asphyxial arrest. In the group with VF/VT arrest there was a significant difference in the initial PetCO2 between patients without and with ROSC. In all patients with ROSC the initial PetCO2 was higher than 10 mmHg. CONCLUSIONS: The initial PetCO2 is significantly higher in asphyxial arrest than in VT/VF cardiac arrest. Regarding asphyxial arrest there is also no difference in values of initial PetCO2 between patients with and without ROSC. On the contrary, there is a significant difference in values of the initial PetCO2 in the VF/VT cardiac arrest between patients with and without ROSC. This difference could prove to be useful as one of the methods in prehospital diagnostic procedures and attendance of cardiac arrest. For this reason we should always include other clinical and laboratory tests.

LOE 6

Supportive (see bolded statements in key points, which are supportive even though study conclusions are not)

Funding: None stated ("no conflicts of interest" statement included).

Key points: 185 adult humans with nontraumatic CPA – 44 asphyxial, 141 primary cardiac; prospective, observational study. Objective: to compare the initial PetCO2 and the PetCO2 after 1 min during CPR in asphyxial cardiac arrest versus primary cardiac arrest. Findings: No significant difference in asphyxial patients' initial PetCO2 in those with and without ROSC (70.1±15.3mmHg versus 62.8±16.2mmHg, P=0.64). For primary cardiac arrest patients there was a significant difference in initial PetCO2 between patients without and with ROSC (8.2±4.3mmHg versus 20.3±6.2mmHg, P=0.04). **In all patients with ROSC the initial PetCO2 was higher than 10 mmHg. Significantly higher PetCO2 values achieved in patients with ROSC than in those without ROSC** (asphyxial arrest group, 35.8±8.6 mmHg versus 19.4±8.7mmHg, P<0.05; VF/VT arrest group, 30.2±8.3mmHg versus 14.2±5.2 mmHg, P<0.05). **The values of the final PetCO2 in both groups were significantly higher in patients with ROSC than in the patients without ROSC** (asphyxial arrest group, 31.2±8.4 mmHg versus 7.2±3.3mmHg, P<0.05; VF/VT arrest group, 28.1±4.8 mmHg versus 6.2±2.8 mmHg, P<0.05). Concluded that in asphyxial arrest there is no significant difference in initial PetCO2 in patients with and without ROSC. In asphyxial arrest the initial values of the PetCO2 therefore cannot be used as a prognostic factor of outcome of CPR.

9) Grmec S, Kupnik D. Does the Mainz Emergency Evaluation Scoring (MEES) in combination with capnometry (MEESc) help in the prognosis of outcome from cardiopulmonary resuscitation in a prehospital setting? Resuscitation 2003;58:89-96. ("Grmec 2003b")

We present an improved Mainz Emergency Evaluation Scoring (MEES) combined with capnometry. MEES combined with capnometry in a new scoring system MEESc compared with MEES is significantly better and has greater value in predicting survival after cardiopulmonary resuscitation (CPR) in patients with normothermic nontraumatic cardiac arrest. We show that higher pre-CPR and final post-CPR values of partial end-tidal CO(2) pressure (p(et) CO(2)) at the time of the return of spontaneous circulation (ROSC) are connected with improved rate of survival. In our prospective clinical study we observed 246 patients 18 years of age and over who were found in nontraumatic normothermic cardiac arrest from February 1998 to February 2001. 128 (52%) were men. Initial and final (post-CPR) values of PetCO2 were significantly higher in the group of patients with ROSC and in those who survived than in the group of patients without ROSC and those who died. All the patients with ROSC and those who survived had initial values of PetCO2 higher than 1.33 kPa (10 mmHg). The mean of all the initial values of PetCO2 in patients without ROSC was 2.12 kPa+/-0.68 and the mean of all the final values in patients with ROSC was 3.11 kPa+/-0.55 kPa. Our study shows that the initial and final values of PetCO2 of less than 2.13 kPa are connected with higher mortality rate and the values of less than 1.33 kPa incompatible with survival in normothermic nontraumatic cardiac arrest. We also must not forget the fact that prehospital use of the improved MEESc system enabled more efficient communication between the prehospital and hospital setting.

LOE 6

Supportive

Funding: Not stated

Key points: 246 adult humans with normothermic, nontraumatic CPA; prospective, observational study. Objective: to evaluate whether adding capnometry to the Mainz Emergency Evaluation Scoring (MEES) system improves outcome prediction value of this scoring system in patients with normothermic nontraumatic cardiac arrest in a prehospital setting. Findings: Initial PetCO2 was significantly higher in patients with ROSC compared with those without ROSC (2.12 +/- 0.68 vs. 1.09 +/- 0.84 kPa, P=0.035). Initial PetCO2 was significantly higher in those who survived to discharge compared with those who died (2.63 +/- 0.68 vs. 1.21 +/- 0.81 kPa, P < 0.01). Final PetCO2 was significantly higher in patients with ROSC compared with those without ROSC (3.11 +/- 0.55 vs. 0.87 +/- 0.41 kPa, P < 0.01) and final PetCO2 was significantly higher in those who survived compared with those who died (3.30 +/- 1.05 vs. 0.94 +/- 0.56 kPa, P < 0.01). All patients with ROSC and those who survived to discharge had initial PetCO2 > 1.33 kPa (10 mmHg). The mean value of all initial PetCO2 in patients with ROSC was 2.12 +/- 0.68kPa. With a cutoff point at 1.33 kPa the sensitivity of initial values in predicting ROSC is 1.0 and specificity 0.74. At the same cutoff point the sensitivity in predicting survival is 1.0 and specificity 0.8. With a cutoff point at 1.33 kPa the sensitivity of final PetCO2 in predicting ROSC is 1.0 and specificity 0.9. Likewise in predicting survival the sensitivity is 1.0 in specificity 0.92. With a cutoff point of initial PetCO2 at 2.13 kPa the sensitivity is 1.0 and specificity 0.94 in predicting survival to discharge. The final PetCO2 at the same cutoff point show a sensitivity 1.0 and specificity 0.95 in predicting survival to discharge. Concluded that addition of PetCO2 information into the MEES system added prognostic insight into chances of survival to discharge after ROSC.

10) Gudipati CV, Weil MH, Bisera J, et al. Expired carbon dioxide: a noninvasive monitor of cardiopulmonary resuscitation. Circulation 1988;77:234-239.

End-tidal CO2 concentration (ETCO2) may serve as a simple noninvasive measurement of the blood flow generated by precordial compression during cardiopulmonary resuscitation (CPR). In a mechanically ventilated porcine preparation of ventricular fibrillation, onset of fibrillation was associated with a rapid decrease in ETCO2 from 4.0 +/- 0.2% to less than 0.7 +/- 0.2%. With precordial compression, it increased to 1.9 +/- 0.3%. Animals that were successfully defibrillated after 12 min of CPR demonstrated an immediate increase in

ETCO2. The ETCO2 increased from 1.9 +/- 0.3% to 4.9 +/- 0.3% over an interval of between 30 and 60 sec. These changes in ETCO2 were closely related to proportionally similar decreases and increases in cardiac output (CO), and a close correlation between ETCO2 and CO was demonstrated (r = .92). A similar highly significant correlation between ETCO2 and CO was also demonstrated during open-chest cardiac massage (r = .95). ETCO2 therefore serves as a noninvasive measure of pulmonary blood flow and therefore CO. In 17 successfully resuscitated animals. ETCO2 during precordial compression averaged 1.7 +/- 0.2%, whereas it was only 0.5 +/- 0.1% in five animals in whom resuscitation procedures were unsuccessful (p less than .001). Accordingly, ETCO2 prognosticates outcome during CPR and immediately identifies restoration of spontaneous circulation.

LOE 6

Supportive

Funding: Laerdal Foundation for Acute Medicine (Stavanger, Norway); Biomedical Research Support Grant Program, Division of Research Resources, National Institutes of Health; Critical Care Foundation (Beverly Hills, CA); Institute of Critical Care Medicine (Rancho Mirage, CA).

Key points: (22?) Minnesota minipigs; experimental study. Objective: to show that %ETCO2 may serve as a simple noninvasive measurement of the blood flow generated by precordial compression during CPR. Findings: Descriptively, noted that %ETCO2 dropped markedly at onset CPA, then increased with precordial compressions (t-5min %ETCO2 4.0 +/- 0.2SD; t+1min %ETCO2 1.0 +/- 0.2SD; t+9min %ETCO2 1.87 +/- 0.3SD). Found significant correlation between %ETCO2 and cardiac index (CI; $P < 0.001$). %ETCO2 could be used to predict CI. **%ETCO2 measured at 1, 3, 5, 9, and 11 minutes during CPCR was significantly different in animals that were resuscitated and those that were not ($P < 0.007$)**. Proportional changes in %ETCO2 and CI were also shown during open-chest direct cardiac compression in 5 animals; %ETCO2 and CI correlation coefficients were 0.91 – 0.98 (average 0.95 +/- 0.014SD). Concluded that %ETCO2 provides a competent and technically simple, noninvasive monitor that highly correlates with cardiac output under conditions of constant ventilation during experimental CPR.

11) Kalenda Z. The capnogram as a guide to the efficacy of cardiac massage. Resuscitation 1978;6:259-263.

Recordings from three patients in cardiac arrest are shown to illustrate the importance of monitoring pulmonary perfusion by means of the capnogram as a continuous guide to the cardiac output achieved by cardiac massage and resuscitation. Such monitoring allows the performance to be adjusted to obtain the maximal result.

LOE 6

Supportive

Funding: None stated.

Key points: 3 human patients; descriptive case series. Objective: to illustrate the importance of monitoring pulmonary perfusion by means of the capnogram as a continuous guide to the cardiac output achieved by cardiac massage and resuscitation. Findings: One slow-speed capnogram shows decreasing %ETCO2 (8 times) as each compressor tires, and an increase in %ETCO2 when that compressor is replaced with someone fresh who generates higher %ETCO2 again. Another capnogram in a man with massive PTE blocking both PA branches shows persistently low %ETCO2 even with ventricular complexes on the simultaneous ECG. Another shows variable but largely maintained %ETCO2 during internal cardiac massage prior to defibrillation, at which time %ETCO2 rises markedly. Concluded that %ETCO2 provides a valuable indicator of the efficacy of cardiac massage during CPCR.

12) Kern KB, Sanders AB, Voorhees WD, et al. Changes in expired end-tidal carbon dioxide during cardiopulmonary resuscitation in dogs: a prognostic guide for resuscitation efforts. J Am Coll Cardiol 1989;13:1184-1189.

Expired end-tidal carbon dioxide (PCO2) measurements made during cardiopulmonary resuscitation have correlated with cardiac output and coronary perfusion pressure when wide ranges of blood flow are included. The utility of such measurements for predicting resuscitation outcome during the low flow state associated with closed chest cardiopulmonary resuscitation remains uncertain. Expired end-tidal PCO2 and coronary perfusion pressures were measured in 15 mongrel dogs undergoing 15 min of closed chest cardiopulmonary resuscitation after a 3 min period of untreated ventricular fibrillation. In six successfully resuscitated dogs, the mean expired end-tidal PCO2 was significantly higher than that in nine nonresuscitated dogs only after 14 min of cardiopulmonary resuscitation (6.2 +/- 1.2 versus 3.4 +/- 0.8 mm Hg; p less than 0.05). No differences in expired end-tidal PCO2 values were found at 2, 7 or 12 min of cardiopulmonary resuscitation. A significant decline in end-tidal PCO2 levels during the resuscitation effort was seen in the nonresuscitated group (from 6.3 +/- 0.8 to 3.4 +/- 0.8 mm Hg; p less than 0.05); the successfully resuscitated group had constant PCO2 levels throughout the 15 min of cardiac arrest (from 6.8 +/- 1.1 to 6.2 +/- 1.2 mm Hg). Changes in expired PCO2 levels during cardiopulmonary resuscitation may be a useful noninvasive predictor of successful resuscitation and survival from cardiac arrest.

LOE 3

Supportive

Funding: American Heart Association, Arizona Affiliate, Flinn Foundation (Phoenix, AZ); National Heart, Lung, and Blood Institute (Bethesda, MD).

Key points: 15 dogs; experimental study. Objective: To determine whether PetCO2 measured during CPCR was useful for predicting long-term survival from cardiac arrest. Findings: At one time point during CPCR (14 minutes), PetCO2 was significantly different between resuscitated and nonresuscitated dogs. Nonresuscitated dogs had a significant decline in PetCO2 over the 15 min resuscitation effort (6.3 +/- 0.8 versus 3.4 +/- 0.8 mmHg; $p < 0.05$), whereas resuscitated dogs did not. PetCO2 $\geq$ 6mmHg had a positive predictive value of 75% for ROSC, whereas PetCO2 < 6 mm Hg had a negative predictive value of 80%. There was a positive correlation between PetCO2 and coronary perfusion pressure over the range of pressures achieved with standard closed chest compression cardiopulmonary resuscitation ($r = 0.306$; $p < 0.05$). Concluded that PetCO2 over the course of CPR appears to be a useful prognostic guideline for predicting successful resuscitation and long-term survival.

13) Kolar M, Krizmaric M, Klemen P, et al. Partial pressure of end-tidal carbon dioxide successful predicts cardiopulmonary resuscitation in the field: a prospective observational study. Crit Care 2008;12:R115.

INTRODUCTION: Prognosis in patients suffering out-of-hospital cardiac arrest is poor. Higher survival rates have been observed only in patients with ventricular fibrillation who were fortunate enough to have basic and advanced life support initiated soon after cardiac arrest. An ability to predict cardiac arrest outcomes would be useful for resuscitation. Changes in expired end-tidal carbon dioxide levels during cardiopulmonary resuscitation (CPR) may be a useful, noninvasive predictor of successful resuscitation and survival from cardiac arrest, and could help in determining when to cease CPR efforts. METHODS: This is a prospective, observational study of 737 cases of out-of-hospital cardiac arrest. The patients were intubated and measurements of end-tidal carbon dioxide taken. Data according to the Utstein criteria, demographic information, medical data, and partial pressure of end-tidal carbon dioxide (PetCO2) values were collected for each patient in cardiac arrest by the emergency physician. We hypothesized that an end-tidal carbon dioxide level of 1.9 kPa (14.3 mmHg) or more after 20 minutes of standard advanced cardiac life support would predict restoration of spontaneous circulation (ROSC). RESULTS: PetCO2 after 20 minutes of advanced life support averaged 0.92 +/- 0.29 kPa (6.9 +/- 2.2 mmHg) in patients who did not have ROSC and 4.36 +/- 1.11 kPa (32.8 +/- 9.1 mmHg) in those who did ($P < 0.001$). End-tidal carbon dioxide values of 1.9 kPa (14.3 mmHg) or less discriminated between the 402 patients with ROSC and 335 patients without. When a 20-minute end-tidal carbon dioxide value of 1.9 kPa (14.3 mmHg) or less was used as a screening test to predict ROSC, the

sensitivity, specificity, positive predictive value, and negative predictive value were all 100%. CONCLUSIONS: End-tidal carbon dioxide levels of more than 1.9 kPa (14.3 mmHg) after 20 minutes may be used to predict ROSC with accuracy. End-tidal carbon dioxide levels should be monitored during CPR and considered a useful prognostic value for determining the outcome of resuscitative efforts and when to cease CPR in the field.

LOE 6

Supportive

Funding: Not stated, but authors all declared no competing interests.

Key points: 737 human adults with nontraumatic, out-of-hospital, sudden cardiac arrest; prospective, observational study. Objective: to evaluate the hypothesis that PetCO2 can predict nonsurvival in an independent cohort of patients suffering out-of-hospital cardiac arrest. Findings: PetCO2(initial) was higher in patients who survived to discharge and in those who achieved ROSC (values expressed as kPa [mmHg]; surviving patients: 3.17 [23.8] ± 1.42 [10.7] vs. 2.34 [17.6] ± 1.95 [14.7]; ROSC patients 3.13 [23.5] ± 1.65 [12.4] vs. 2.54 [19.1] ± 2.43 [18.3]; $P < 0.001$). PetCO2(final) (kPa [mmHg]; surviving patients: 3.89 [29.3] ± 1.12 [8.4] vs. 1.99 [15.0 mmHg] ± 1.33 [10.0]; ROSC patients: 3.64 [27.4] ± 0.94 [7.1] vs. 0.97 [7.3] ± 0.33 [2.5]; $P < 0.001$) was also considerably higher in the surviving and ROSC patients. At 20 minutes into CPCR, PetCO2 ≤ 14.3mmHg used to predict death had 100% sensitivity, specificity, and positive and negative predictive values. At 15 minutes, PetCO2 ≤ 13.5 mmHg had a sensitivity and NPV of 100%, with high specificity and positive predictive value (98%). No patient with an initial, average, final, or maximum PetCO2 < 10 mmHg was resuscitated. In multivariate analysis, initial, average, 10-minute, 15-minute, 20-minute, maximum and final values of PetCO2 were all associated with ROSC; and initial, average, 10-minute, 15-minute, 20-minute, maximum and final PetCO2 values, and arrival time were associated with improved survival. Concluded that measurements of PetCO2 should be used to predict nonsurvival in CPA, and that PetCO2 monitoring should be incorporated into advanced cardiac life support algorithms.

14) Levine RL, Wayne MA, Miller CC. End-tidal carbon dioxide and outcome of out-of-hospital cardiac arrest. N Engl J Med 1997;337:301-306.

BACKGROUND: Survival after cardiac arrest occurring outside the hospital averages less than 3 percent. Unfortunately, the outcome of prolonged resuscitative attempts cannot be predicted. End-tidal carbon dioxide levels reflect cardiac output during cardiopulmonary resuscitation. We prospectively determined whether death could be predicted by monitoring end-tidal carbon dioxide during resuscitation after cardiac arrest. METHODS: We performed a prospective observational study in 150 consecutive victims of cardiac arrest outside the hospital who had electrical activity but no pulse. The patients were intubated and evaluated by mainstream end-tidal carbon dioxide monitoring. Our hypothesis was that an end-tidal carbon dioxide level of 10 mm Hg or less after 20 minutes of standard advanced cardiac life support would predict death. RESULTS: There was no difference in the mean age or initial end-tidal carbon dioxide level between patients who survived to hospital admission (survivors) and those who did not (nonsurvivors). After 20 minutes of advanced cardiac life support, end-tidal carbon dioxide (+/-SD) averaged 4.4+/-2.9 mm Hg in nonsurvivors and 32.8+/-7.4 mm Hg in survivors (P< 0.001). A 20-minute end-tidal carbon dioxide value of 10 mm Hg or less successfully discriminated between the 35 patients who survived to hospital admission and the 115 nonsurvivors. When a 20-minute end-tidal carbon dioxide value of 10 mm Hg or less was used as a screening test to predict death, the sensitivity, specificity, positive predictive value, and negative predictive value were all 100 percent. CONCLUSIONS: An end-tidal carbon dioxide level of 10 mm Hg or less measured 20 minutes after the initiation of advanced cardiac life support accurately predicts death in patients with cardiac arrest associated with electrical activity but no pulse. Cardiopulmonary resuscitation may reasonably be terminated in such patients.

LOE 6

Supportive

Funding: Not stated.
Key points: 150 human adults with out-of-hospital, nontraumatic, primary cardiac arrest with present electrical activity but no pulse (V fib and V tach excluded due to favorable prognosis); prospective, consecutive, observational study. Objective: to determine whether quantitative measurement of PetCO2 outside the hospital could be used to predict death in victims of CPA associated with electrical activity but no pulse. Findings: no significant difference in the *initial* PetCO2 between nonsurvivors and survivors to hospital admission. After 20 minutes of advanced cardiac life support, PetCO2 clearly discriminated between nonsurvivors and survivors to hospital admission, averaging 4.4 +/- 2.9 mmHg (range, 0 to 10) in nonsurvivors and 32.8 +/- 7.4 mm Hg (range, 18 to 58) in survivors ($P < 0.001$). The results of Fisher's exact test with 20-minute PetCO2s dichotomized at 10mmHg were also significant ($P < 0.001$). PetCO2 $\leq$ 10 mmHg had a sensitivity, specificity, positive predictive value, and negative predictive value of 100%. The PetCO2 during CPCR did not discriminate between patients who survived to hospital discharge and those who died in the hospital. Concluded that PetCO2 measured during resuscitative efforts can be a predictor of death from cardiac arrest in patients with electrical activity but no pulse.

15) Mauer D, Schneider T, Elich D, et al. Carbon dioxide levels during pre-hospital active compression--decompression versus standard cardiopulmonary resuscitation. Resuscitation 1998;39:67-74.
In a prospective randomized study we investigated end-tidal carbon dioxide levels during standard versus active compression-decompression (ACD) cardiopulmonary resuscitation (CPR) assuming that the end-tidal carbon dioxide reflects cardiac output during resuscitation. In each group 60 patients with out-of-hospital cardiac arrest were treated either with the standard or the ACD method. End-tidal CO2 (p(et)CO2, mmHg) was assessed with a side-stream capnometer following intubation and then every 2 min up to 10 min or restoration of spontaneous circulation (ROSC). There was no difference in p(et)CO2 between both patient groups. However, CO2 was significantly higher in patients who were admitted to hospital as compared to patients declared dead at the scene. All of the admitted patients had a p(et)CO2 of at least 15 mmHg no later than 2 min following intubation, none of the dead patients ever exceeded 15.5 mmHg. From these data we conclude that capnometry adds valuable information to the estimation of a patient's prognosis in the field (threshold, 15 mmHg), but we could not detect any difference in p(et)CO2 between ACD and standard CPR.
LOE 6
Supportive
Funding: None stated.
Key points: 120 humans of estimated body weight > 35kg with out-of-hospital, nontraumatic, primary cardiac arrest; prospective study with patients randomized to receive either standard or active compression-decompression (ACD) CPCR. Objective: to compare PetCO2 during ACD and standard CPCR, and to compare PetCO2 in surviving and non-surviving patients. Findings: Higher PetCO2 values were recorded in patients admitted to hospital than in the patients declared dead at the scene. The minimum PetCO2 in patients admitted to the hospital and surviving at least 6 hours was 15mmHg with most values ranging around 24mmHg; in those declared dead at the scene, PetCO2 never exceeded 15.5mmHg. Concluded that PetCO2 > 15 mmHg during the first minutes of CPR indicates a successful resuscitation in the form of hospital admission.

16) Nakatani K, Yukioka H, Fujimori M, et al. Utility of colorimetric end-tidal carbon dioxide detector for monitoring during prehospital cardiopulmonary resuscitation. Am J Emerg Med 1999;17:203-206.
The purpose of this study was to evaluate a colorimetric end-tidal CO2 (ETCO2) detector (EASY CAP) as a monitor during prehospital cardiopulmonary resuscitation (CPR) without tracheal intubation. This detector was used for 121 patients during CPR with a laryngeal mask airway or face mask by authorized emergency lifesaving technicians. At 7 to 15 minutes after the initiation of CPR, ETCO was <0.5% in 30 cases (group A), 0.5% to 2.0% in 46 cases (group B) and >2.0% in 45 cases (group C). The rate of return of spontaneous

circulation was 17% in group A, 24% in group B, and 48% in group C (groups A v C, P < .01). There was a significant difference in the rate of hospital admission between groups A and C. The ETCO2 value may be useful for monitoring during prehospital CPR with a laryngeal mask airway or face mask.
LOE 6
Supportive
Funding / material support: Nellcor-Puritan Bennett Japan (Tokyo, Japan).
Key points: 121 adult humans with nontraumatic, out-of-hospital cardiac arrest; prospective, multicenter, observational study. Objective: to evaluate the usefulness of a colorimetric ETCO2 detector as a monitor during prehospital CPR without tracheal intubation (i.e., with laryngeal mask or EGTA). Findings: There was a significant difference in the rate of ROSC between patients with %ETCO2 <0.5% and patients with %ETCO2 >2% (P < 0.05). There were significant differences in hospital admission rate between patients with %ETCO2 < 0.5% and those with %ETCO2 > 2%, and between patients with %ETCO2 of 0.5 – 2.0% and those with %ETCO2 >2%. %ETCO2s in patients admitted to the hospital were significantly higher than those in patients with no return of spontaneous circulation. Concluded that colorimetric ETCO2 detectors may be useful during prehospital CPR using laryngeal mask airway or face mask, as well as for patients who have undergone tracheal intubation. A significant difference was found in the both rate of ROSC and the rate of hospital admission between patients with ETCO2 values of <0.5% and those with values of >2% during CPR.

17) Ornato JP, Shipley JB, Racht EM, et al. Multicenter study of a portable, hand-size, colorimetric end-tidal carbon dioxide detection device. Ann Emerg Med 1992;21:518-523.
STUDY OBJECTIVES: To evaluate continuous, semiquantitative end-tidal carbon dioxide (ETCO2) monitoring in the prehospital and emergency department setting for confirming proper endotracheal tube placement and assessing prognosis and blood flow during CPR. TYPE OF PARTICIPANTS: Adult patients were included if an endotracheal tube was inserted by prehospital care providers or emergency physicians for cardiac arrest, respiratory arrest, respiratory insufficiency, or airway protection. DESIGN AND INTERVENTIONS: A small, portable, colorimetric ETCO2 detector was attached to the endotracheal tube immediately after each attempted endotracheal tube insertion. The color of the detector membrane was noted at the seventh breath following intubation. The color also was noted and recorded if there was return of spontaneous circulation (defined as a palpable pulse) immediately prior to and following conversion from manual to mechanical CPR. Survival to hospital admission was used as an end point to assess the prognostic value of the initial ETCO2 reading. MAIN RESULTS: A total of 227 patients (144 with cardiopulmonary arrest) were studied. In the 83 patients intubated but not in cardiopulmonary arrest, a reading on the ETCO2 detector signifying more than 0.5% ETCO2 was 100% sensitive and 93% specific in detecting proper endotracheal tube placement (100% specific with the endotracheal tube cuff inflated). In cardiac arrest patients, a longer period of estimated arrest appeared to be associated with a lower ETCO2 detector reading. A reading signifying more than 0.5% ETCO2 was 69% sensitive and 100% specific in detecting proper endotracheal tube placement. After proper endotracheal tube placement, all cardiac arrest patients who survived to hospital admission had an initial ETCO2 measurement signifying more than 0.5% ETCO2. Return of spontaneous circulation was usually accompanied by an improved ETCO2 value. Mechanical CPR always produced an ETCO2 value that was as high or higher than that produced by manual CPR. CONCLUSION: The colorimetric ETCO2 device is highly accurate for confirming endotracheal tube position in nonarrest patients. CONCLUSION: The colorimetric ETCO2 device is highly accurate for confirming endotracheal tube position in nonarrest patients. In cardiac arrest patients, a reading signifying more than 0.5% ETCO2 confirms correct endotracheal tube placement, while a value signifying less than 0.5% ETCO2 during resuscitation suggests that something is wrong (e.g. esophageal intubation, inadequate circulatory flow, prolonged down-time interval, hypothermia, or significant ventilation/perfusion mismatch).
LOE 6
Supportive

Funding: None stated
Key points: 227 adult humans requiring prehospital or in-hospital endotracheal intubation for CPA, respiratory arrest, respiratory insufficiency, or airway protection (144 of the subjects had CPA); prospective, multicenter, observational study. Objective: to evaluate continuous, semiquantitative ETCO2 monitoring in the prehospital and emergency department setting for confirming proper endotracheal tube placement and assessing prognosis and blood flow during CPR. Findings: All CPA patients who survived to hospital admission had %ETCO2 readings of either 0.5 – 2% or >2% on the semiquantitative capnometer; no CPA patients with %ETCO2 reading of <5% survived to hospital admission. Conclusions were all in reference to ET tube placement.

18) Salen P, O'Connor R, Sierzenski P, et al. Can cardiac sonography and capnography be used independently and in combination to predict resuscitation outcomes? Acad Emerg Med 2001;8:610-615.
OBJECTIVE: To measure the ability of cardiac sonography and capnography to predict survival of cardiac arrest patients in the emergency department (ED). METHODS: Nonconsecutive cardiac arrest patients prospectively underwent either cardiac ultrasonography alone or in conjunction with capnography during cardiopulmonary resuscitation at two community hospital EDs with emergency medicine residency programs. Cardiac ultrasonography was carried out using the subxiphoid view during pauses for central pulse evaluation and end-tidal carbon dioxide (ETCO(2)) levels were monitored by a mainstream capnograph. A post-resuscitation data collection form was completed by each of the participating clinicians in order to assess their impressions of the facility of performance and benefit of cardiac sonography during nontraumatic cardiac resuscitation. RESULTS: One hundred two patients were enrolled over a 12-month period. All patients underwent cardiac sonographic evaluation, ranging from one to five scans, during the cardiac resuscitation. Fifty-three patients also had capnography measurements recorded. The presence of sonographically identified cardiac activity at any point during the resuscitation was associated with survival to hospital admission, 11/41 or 27%, in contrast to those without cardiac activity, 2/61 or 3% ($p < 0.001$). Higher median ETCO(2) levels, 35 torr, were associated with improved chances of survival than the median ETCO(2) levels for nonsurvivors, 13.7 torr ($p < 0.01$). The multivariate logistic regression model, which evaluated the combination of cardiac ultrasonography and capnography, was able to correctly classify 92.4% of the subjects; however, of the two diagnostic tests, only capnography was a significant predictor of survival. The stepwise logistic regression model, summarized by the area under the receiver operator curve of 0.9, furthermore demonstrated that capnography is an outstanding predictor of survival. CONCLUSIONS: Both the sonographic detection of cardiac activity and ETCO(2) levels higher than 16 torr were significantly associated with survival from ED resuscitation; however, logistic regression analysis demonstrated that prediction of survival using capnography was not enhanced by the addition of cardiac sonography.
LOE 6
Supportive
Funding: Not stated
Key points: 102 humans with CPA (53 had capnography performed); prospective, convenience-sampled, observational study. Objective: to determine the feasibility of performing cardiac sonography during resuscitation and to evaluate the utility of cardiac sonography and capnography, both separately and together, as predictors of successful resuscitation of pulseless patients. Findings: median PetCO2 for survivors (39mmHg) was significantly greater than the median PetCO2 for nonsurvivors (13.7mmHg; $Z = 3.26$; $p < 0.01$). No patient with a PetCO2 of <16mmHg survived. PetCO2 was a significant predictor to hospital admission. For each increase of 1mmhg in PetCO2, the odds of surviving increased by 16% (odds ratio 1.16; 95% CI = 1.05 to 1.29). Concluded that PetCO2 > 16mmHg significantly associated with survival.

19) Sanders AB, Ewy GA, Bragg S, et al. Expired PCO2 as a prognostic indicator of successful resuscitation from cardiac arrest. Ann Emerg Med 1985;14:948-952. ("Sanders 1985a")

We performed a study to determine if the measurement of expired PCO2 during CPR for cardiac arrest could be used as a prognostic indicator of successful resuscitation. Twelve mongrel dogs were fibrillated electrically, and external chest massage and assisted ventilation were applied for 15 minutes. Expired PCO2 and aortic and right atrial pressures were monitored each minute of arrest. Coronary perfusion pressure (CPP) was calculated by subtracting the right atrial from the aortic diastolic pressure. Half the dogs received high-force chest compression (80 lb) and half received low-force chest compression (40 lb). The six dogs that received high-force compression were resuscitated successfully. The expired PCO2 was significantly higher in the successfully resuscitated dogs (expired PCO2 = 9.6 +/- 3.2 mm Hg) when compared to those dogs that died (expired PCO2 = 3.2 +/- 1.1 mm Hg, P less than .01). Expired PCO2 was highly correlated (r = 0.91, P less than .01) with the CPPs. The measurement of expired PCO2 during attempted CPR may be useful as a noninvasive indicator of CPP and adequate technique. Further studies on the use of this technique as an assessment criterion are warranted.

LOE 3

Supportive

Funding: American Heart Association, Arizona Affiliate

Key points: 12 healthy mongrel dogs; experimental study – fibrillation model, 6 dogs receiving high pressure external compressions and 6 dogs receiving low pressure external compressions. Objective: to determine if the measurement of PetCO2 during CPR could be used as a prognostic indicator of successful resuscitation from cardiac arrest in the animal model. Findings: The overall mean PetCO2 of resuscitated animals was 9.6 +/- 3.2mmHg, while the mean was 3.2 ± 1.1mmHg for animals not resuscitated. Significant differences were found at each minute that the data were examined. The relationship between PetCO2 and coronary perfusion pressure was determined using a linear regression analysis; the correlation coefficient was 0.91 ($P < .01$). Concluded that measurement of PetCO2 during CPR may be useful as a noninvasive indicator of CPP and successful resuscitation.

20) Sanders AB, Kern KB, Otto CW, et al. End-tidal carbon dioxide monitoring during cardiopulmonary resuscitation. A prognostic indicator for survival. JAMA 1989;262:1347-1351.

The effectiveness of ongoing cardiopulmonary resuscitation efforts is difficult to evaluate. Recent studies suggest that carbon dioxide excretion may be a useful noninvasive indicator of resuscitation from cardiac arrest. A prospective clinical study was done to determine whether end-tidal carbon dioxide monitoring during cardiopulmonary resuscitation could be used as a prognostic indicator of resuscitation and survival. Thirty-five cardiac arrests in 34 patients were monitored with capnometry during cardiopulmonary resuscitation during a 1-year period. Nine patients who were successfully resuscitated had higher average end-tidal carbon dioxide partial pressures during cardiopulmonary resuscitation than 26 patients who could not be resuscitated (15 +/- 4 vs. 7 +/- 5 mm Hg). The 3 patients who survived to leave the hospital had a higher average end-tidal carbon dioxide partial pressure than the 32 nonsurvivors (17 +/- 6 vs. 8 +/- 5 mm Hg). All 9 patients who were successfully resuscitated had an average end-tidal carbon dioxide partial pressure of 10 mm Hg or greater. No patient with an average end-tidal carbon dioxide partial pressure of less than 10 mm Hg was resuscitated. Data from this prospective clinical trial indicate that findings from end-tidal carbon dioxide monitoring during cardiopulmonary resuscitation are correlated with resuscitation from and survival of cardiac arrest.

LOE 6

Supportive

Funding: The Finn Foundation (Phoenix, AZ)

Key points: 34 adult humans undergoing 35 nontraumatic, in-hospital CPA events in which the patient was intubated and PetCO2 was monitored; prospective, convenience-sampled, observational, single-center study. Objective: to determine if end-tidal carbon dioxide monitoring during CPR could be used as a prognostic indicator for resuscitation and survival in patients. Findings: The 9 patients successfully resuscitated from CPA had significantly greater average PetCO2 (15 ± 4mmHg) than the average PetCO2 (7±5mmHg) for the 26

patients who could not be resuscitated (P<.001). All patients successfully resuscitated had average PetCO2 ≥10mmHg; no patient with an average PetCO2 < 10mmHg was resuscitated. The 3/35 patients that survived to leave the hospital had average PetCO2 > the average PetCO2 of the 32 nonsurvivors (17 ± 5mmHg vs. 8±5mmHg, P < 0.05). Patients who were resuscitated had values similar to nonresuscitated patients during the first 5 minutes of monitoring, but their values increased over time, while those of the nonresuscitated group decreased. Concluded that CPR is correlated with resuscitation from and survival of cardiac arrest. Such a prognostic indicator of resuscitation efforts should allow a more rational approach to the treatment of patients who are in cardiac arrest.

21) Sanders AB, Atlas M, Ewy GA, et al. Expired PCO2 as an index of coronary perfusion pressure. Am J Emerg Med 1985;3:147-149. ("Sanders 1985b")

Presently, there is no reliable noninvasive method of assessing the adequacy of cardiopulmonary resuscitation (CPR). Studies of animals have shown that during prolonged arrest the coronary perfusion pressure (CPP) is correlated with successful resuscitation. During previous studies it appeared that expired PCO2 correlated with CPP. To investigate this relationship, eight mongrel dogs (mean weight, 22.7 +/- 5.8 kg) were anesthetized with pentobarbital. Catheters were placed in the thoracic aorta and right atrium of each dog. Each animal was electrically fibrillated, and CPR was started using mechanical resuscitator. The PCO2 was determined at end expiration using a Hewlett Packard 47210A Capnometer with the electrode attached to the endotracheal tube. After 10, 15, 20, or 25 minutes of ventricular fibrillation and closed-chest massage, a thoracotomy was performed, and internal massage was begun. Coronary perfusion pressure was calculated at least each minute and correlated with the PCO2 values. A correlation coefficient of 0.78 was calculated based on 368 data points for eight dogs (P less than 0.01). The results of this study indicate that expired PCO2 is positively correlated with CPP in the canine model of CPR. Inasmuch as CPP correlates with survival in prolonged CPR, the noninvasive measurement of PCO2 may be a useful method of assessing the adequacy of CPR.

LOE 3

Supportive

Funding: American Heart Association, Arizona Affiliate

Key points: 8 healthy mongrel dogs; experimental study – fibrillation model. Objective: to determine the correlation of PetCO2 with the coronary perfusion pressure (CPP) during closed-chest massage after CPA in the animal model. Findings: Linear regression analysis revealed a correlation coefficient of +0.78 between PetCO2 and CPP (P < 0.01) during CPCR. Concluded that there is correlation of a noninvasive parameter (PetCO2) with calculated CPP in the canine model undergoing CPCR from fibrillatory arrest.

22) Sato S, Kimura T, Okubo N, et al. End-tidal CO2 and plasma lactate level: a comparison of their use as parameters for evaluating successful CPR. Resuscitation 1993;26:133-139.

Serial changes of end-tidal CO2 (ETCO2) and plasma lactate levels during CPR have been described as useful to investigate or evaluate the results of CPR. However, there have been no reports comparing these parameters in the same model. By inducing cardiopulmonary arrest (2-7 min) in 28 Wistar rats, ETCO2 and serum lactate levels were studied after and just before CPR, respectively. In the survived group (N = 16), ETCO2 was maintained in high levels (20.1-16.3 mmHg), however in the non-survived group (N = 12), ETCO2 showed an abrupt decline (6.0-2.0 mmHg). The lactate levels before CPR in two groups were significantly higher than those of control levels, however there was no significant difference just before the CPR between the two groups. ETCO2 during CPR is a useful indicator for determining the successful application of CPR. However, serum lactate levels sampled just before the onset of CPR did not prove to be a useful indicator of successful CPR in rats.

LOE 6

Supportive

Funding: Not stated

Key points: 28 Wistar rats; experimental study – fibrillation model. Objective: to determine whether plasma lactate levels just before CPR, or ETCO during CPR, can predict with greater certainty the success of CPR in rats. Findings: PetCO2 did not show any great differences between the ROSC and the non-ROSC groups immediately after CPR (0 min); however in rats that did not achieve ROSC, PetCO2 decreased strikingly. PetCO2 measured from 1 to 15 min during and after CPR in the ROSC group was significantly higher than in the non-ROSC group. Concluded that the real-time measurement of PetCO2 during CPCR is superior to serum [lactate] to determine successful CPCR.

23) Steedman DJ, Robertson CE. Measurement of end-tidal carbon dioxide concentration during cardiopulmonary resuscitation. Arch Emerg Med 1990;7:129-134.

End-tidal carbon dioxide concentrations were measured prospectively in 12 cardiac arrest patients undergoing cardiopulmonary resuscitation (CPR) in an accident and emergency department. The end-tidal carbon dioxide (CO2) concentration decreased from a mean (+/- SD) of 4.55 +/- 0.88% 1 min after chest compression and ventilation was established, to values ranging from 2.29 +/- 0.84% at 2 min to 1.56 +/- 0.66% following 8 min of CPR. Spontaneous circulation was restored in five patients. This was accompanied by a rapid rise in end-tidal CO2, which peaked at 2 min (3.7 +/- 1.08%). Changes in end-tidal CO2 values were often the first indication of return of spontaneous cardiac output. There was a significant difference in the end-tidal CO2 in patients undergoing CPR before return of spontaneous circulation (2.63 +/- 0.32%) and patients who failed to develop spontaneous output (1.64 +/- 0.89%) ($p < 0.001$). We conclude that measurement of end-tidal CO2 concentration provides a simple and non-invasive method of measuring blood flow during CPR and can indicate return of spontaneous circulation.

LOE 6

Supportive

Funding / material support: Ohmeda ("for the use of the CO2 analyser"; Louisville, USA)

Key points: 12 adult humans undergoing nontraumatic, normothermic CPA; prospective, observational study. Objective: to assess the clinical applicability of %ETCO2 measurement in patients undergoing cardiopulmonary resuscitation in an accident and emergency department. Findings: There was a significant difference between %ETCO2 in patients without ROSC (N=7, 1.64 + 0.89%) and %ETCO2 in patients prior to regaining ROSC (N=5, 2.63 ± 0.32%; $P < 0.001$). Concluded that ETCO2 measurement can provide a useful non-invasive monitor of blood flow produced by precordial compression during cardiac arrest.

24) Trevino RP, Bisera J, Weil MH, et al. End-tidal CO2 as a guide to successful cardiopulmonary resuscitation: a preliminary report. Crit Care Med 1985;13:910-911.

Utilizing a well-established porcine model of cardiac arrest, we found that end-tidal CO2 concentration (ETCO2) strikingly decreased to approximately 24% of control levels, immediately after cardiac arrest and before precordial compression. During precordial compression, ETCO2 progressively increased to 46% of control values in successfully resuscitated animals but only to 26% in animals that failed to respond to resuscitation efforts. After successful resuscitation, ETCO2 rapidly returned to baseline values. These data indicate that ETCO2 may be a useful monitor for assessing the adequacy of CPR.

LOE 6

Supportive

Funding: Not stated

Key points: 12 minipigs undergoing CPA; experimental study – CPA model not specified. Objective: to determine whether capnography serves as a reliable noninvasive monitor to assess efficacy of CPR. Findings: Within 90 seconds of starting precordial compressions, %ETCO2 increased to 46% of prearrest values in survivors and approximately 26% in nonsurvivors (statistical significance not stated). Concluded that under

conditions of constant ventilation, ETCO2 reflects circulatory status during and after CPR, and that thus ETCO2 is likely to be useful as a simple, noninvasive monitor to guide CPR.

25) Varon AJ, Morrina J, Civetta JM. Clinical utility of a colorimetric end-tidal CO2 detector in cardiopulmonary resuscitation and emergency intubation. J Clin Monit 1991;7:289-293.
The purposes of this study were to evaluate the clinical utility of a colorimetric end-tidal CO z (ETCO2) detector in confirming proper endotracheal intubation in patients requiring emergency intubation, to determine if this new device can be used as an adjunct to judge the effectiveness of cardiopulmonary resuscitation (CPR), and to determine whether the device can predict successful resuscitation from cardiopulmonary arrest. We studied prospectively 110 patients requiring emergency intubation for either respiratory distress (53 patients) or cardiopulmonary arrest (57 patients) by recording the color range of the indicator after the initial intubation.
In patients who suffered a cardiopulmonary arrest, the color range was also recorded during CPR after the endotracheal tube was confirmed to be in the tracheal position and perfusion optimized, and at the moment CPR was stopped. The ETCO 2 detector was 100% specific for correct endotracheal intubation in all patients. It was also highly sensitive (0.98) for correct endotracheal intubation in patients with respiratory distress. However, it was not sensitive (0.62) in patients with cardiopulmonary arrest and low perfusion. The sensitivity improved (0.88) when we used the ETCO 2 range obtained after attempts to increase perfusion. A low ETCO 2 color range in 19 patients undergoing CPR was interpreted as low cardiac output and prompted the physicians to attempt to increase perfusion. Of the patients who underwent CPR, no patient whose ETCO2 level remained less than 2% was successfully resuscitated. Those patients who had an ETCO2 level ->2% had a significantly higher incidence of successful resuscitation. We conclude that the colorimetric ETCO2 detector is reliable and provides reassurance of correct endotracheal tube placement in patients requiring emergency intubation for respiratory distress. This device helps identify patients with low perfusion during CPR and is a useful prognostic indicator of successful short-term resuscitation.
LOE 6
Supportive
Funding: Not stated
Key points: 110 humans (57 CPA, 53 resp distress); prospective, in-hospital, observational study. Objective: to determine if a colorimetric ETCO2 detector would be helpful in confirming proper endotracheal intubation in patients requiring emergency intubation for respiratory distress or CPA, to determine if this new device can also be used as an adjunct to assess the effectiveness of CPR efforts, and, finally, to determine whether the data provided can be used as a prognostic indicator of successful resuscitation. Pertinent findings: No patient who underwent CPR and had an %ETCO2 MAX or %ETCO2 FINAL < 2% was successfully resuscitated. Patients with %ETCO2 MAX (P = 0.04) or %ETCO2 FINAL (P = 0.002) ≥ 2% had a significantly higher incidence of successful resuscitation. Concluded that the colorimetric ETCO2 monitor helps identify patients with low perfusion during CPR and, if efforts directed at improving perfusion are successful, may improve the outcome of cardiac resuscitation. The data obtained from this device are a useful prognostic indicator of successful immediate resuscitation from cardiac arrest.

26) von Planta M, von Planta I, Weil MH, et al. End tidal carbon dioxide as an haemodynamic determinant of cardiopulmonary resuscitation in the rat. Cardiovasc Res 1989;23:364-368.
End tidal PCO2 (PETCO2) has been found to be a good prognostic indicator of successful resuscitation from cardiac arrest. To explore the value of this measurement further, we carried out a series of experiments during cardiac arrest and closed chest resuscitation in 14 mechanically ventilated Sprague-Dawley rats. Ventricular fibrillation (VF) was induced by a 10 mA current delivered to the right ventricular endocardium. After 4 min of VF, precordial compression was begun with a mechanical thumper and defibrillation was attempted 2 min later. PETCO2 decreased abruptly during cardiac arrest to 0.3 mm Hg (0.04 kPa). With precordial compression, it increased to 11 mm Hg (1.5 kPa). Within 3 min of successful defibrillation, there was an

overshoot in the PETCO2 to 44 mm Hg (5.8 kPa) with return to baseline levels approximating those of the pre-arrest control measurements over the 60 min that followed restoration of spontaneous circulation. The PETCO2 measurement during precordial compression predicted the success of defibrillation with return of spontaneous circulation. When PETCO2 exceeded 9 mm Hg (1.2 kPa), 7 of 8 animals were successfully resuscitated. When PETCO2 was less than 9 mm Hg during precordial compression, none of six animals were successfully resuscitated. The PETCO2 correlated with the mean aortic (r = 0.71) and coronary perfusion pressure (r = 0.80) generated during precordial compression. In corroboration of previously reported observations on pigs, dogs, and human patients, PETCO2 served as a non-invasive monitor of the effectiveness of precordial compression for maintaining coronary perfusion and therefore cardiac viability during CPR. The PETCO2 was also useful in that it promptly signaled restoration of spontaneous circulation.

******LOE 6 – please note I do not have a copy of this article – have only abstract to evaluate***

Supportive

Funding: *Unknown*

Key points: 14 mechanically ventilated Sprague-Dawley rats; experimental study – fibrillation model. Objective: to determine the value of PetCO2 as a prognostic indicator of successful resuscitation from cardiac arrest. Pertinent findings: The PetCO2 measurement during precordial compression predicted the success of defibrillation with ROSC. When PetCO2 exceeded 9 mm Hg (1.2 kPa), 7 of 8 animals were successfully resuscitated. When PetCO2 was less than 9 mm Hg during precordial compression, none of six animals were successfully resuscitated. The PetCO2 correlated with the mean aortic (r = 0.71) and coronary perfusion pressure (r = 0.80) generated during precordial compression. Concluded that .

27) Wayne MA, Levine RL, Miller CC. Use of end-tidal carbon dioxide to predict outcome in prehospital cardiac arrest. Ann Emerg Med 1995;25:762-767.

STUDY OBJECTIVE: End-tidal CO2 (ETCO2) measurement can be used to predict death in prehospital cardiac arrest patients with pulseless electrical activity (PEA). DESIGN: A prospective, observational study. SETTING: An urban and rural emergency medical services system in northwestern Washington state. PARTICIPANTS: Ninety consecutive victims of prehospital cardiac arrest with PEA. INTERVENTIONS: Patients were intubated in the field and treated using standard advanced cardiac life support protocols with online medical control. In addition, all patients were evaluated using mainstream ETCO2 monitoring. In this study, a hypothetical decision was made to cease resuscitative efforts based on an ETCO2 level of 10 mm Hg or less after 20 minutes of advanced cardiac life support. RESULTS: The study included 90 patients (61 were men) with a mean age of 67.6 +/- 13.6 years (range, 27 to 95 years). The initial ETCO2 averaged 11.7 +/- 6.6 mm Hg in nonsurvivors (range, 5 to 50 mm Hg) and 10.9 +/- 4.9 mm Hg in survivors (range, 5 to 24 mm Hg) (P > .672 [NS]). After 20 minutes of advanced cardiac life support, ETCO2 averaged 3.9 +/- 2.8 mm Hg (range, 0 to 12 mm Hg) in patients in whom the theoretical decision was made to cease field resuscitation. In contrast, survivors' ETCO2, just before restoration of circulation, averaged 31 +/- 5.3 mm Hg (range, 16 to 35 mm Hg) (P < .0001). Using an ETCO2 of 10 mm Hg or less as a theoretical threshold to predict death in the field successfully discriminated between the 16 survivors to hospital admission (those that achieved return of spontaneous circulation) and 75 prehospital deaths. Of the 16 survivors to hospital admission, 9 died in the hospital, and 7 were discharged from the hospital alive. In 13 of the 16 survivors, the first evidence of return of spontaneous circulation, before a palpable pulse or blood pressure, was a rising ETCO2. The logistic-regression parameters for the model are 4.4391 + ETCO2*-0.3624 (P < .0001). Sensitivity was 97.3%; specificity 100%; positive predictive value 100%; and negative predictive value 88.9%. CONCLUSION: This study suggests that a low ETCO2 (10 mm Hg or less) can be used to predict irreversible death in patients with pulseless electrical activity undergoing prehospital advanced cardiac life support. If future studies validate this model, use of ETCO2 may allow for triage decisions in the field.

LOE 6

Supportive

Funding: Not stated
Key points: 90 adult humans with normothermic, nontraumatic CPA that had pulseless electrical activity (V fib or V tach excluded); prospective, out-of-hospital, observational study. Objective: to evaluate the quantitative measurement of ETCO2 in the prehospital setting and to determine whether this value could be used as a marker to predict death. Pertinent findings: No difference in initial PetCO2 between those who achieved ROSC in the field and those that did not achieve ROSC prior to hospital arrival. PetCO2 averaged 3.9+/-2.8 mm Hg (range, 0 to 12 mm Hg) after 20 minutes of ACLS (at the time the decision to cease resuscitation was made) in patients who never achieved ROSC and 31+/-5.3 mm Hg (range, 16 to 35 mm Hg) just before ROSC in the other group (P<.0001). No patient in whom the decision would have been made to cease resuscitation on the basis of PetCO2 showed any evidence of ROSC during the additional period of ACLS after the hypothetical decision had been made. The OR for prediction of survival to hospital discharge for PetCO2 < 10mmHg versus ≥ 10mmHg was 957, with CI 43.9 to 20886.8 (P<.0001). Sensitivity was 97.3%; specificity, 100%; positive predictive value, 100%; and negative predictive value, 88.9%. Concluded that in this study of CPA victims with PEA, PetCO2 measured during resuscitative efforts appeared to be a marker of death. PetCO2 measurement is technically feasible for prehospital use and may help prevent unnecessary hospital transports.

28) Weil MH, Bisera J, Trevino RP, et al. Cardiac output and end-tidal carbon dioxide. Crit Care Med 1985;13:907-909.
Previous studies demonstrated selective increases in mixed venous carbon dioxide tension (PvCO2) during CPR in a porcine model of cardiac arrest. This was associated with a decrease in end-tidal carbon dioxide concentration (ETCO2), possibly due to a critical reduction in cardiac output and therefore pulmonary blood flow during CPR. We investigated the relationship between ETco2 and cardiac output before cardiac arrest and during CPR. Observations in 19 minipigs confirmed a high linear correlation between ETco2 and cardiac output. We conclude that the increase in Pvco2 and the concurrent decrease in ETco2 reflect a critical reduction in cardiac output, which reduces alveolar blood flow to the extent that carbon dioxide clearance by the lung fails to keep pace with systemic CO2 production.
LOE 6
Supportive
Funding: Not stated
Key points: 19 minipigs; experimental study – fibrillation model. Objective: to determine the relationship between ETCO2 and cardiac output before CPA and during CPR. Pertinent findings: regression equation based on 56 observations demonstrated a significant (P < 0.001) correlation between %ETCO2 and cardiac index. When CI was > 40mL/min kg, %ETCO2 was always ≥2.9%, and when CI was < 40mL/min kg, the maximum %ETCO2 was 2.3%. Concluded that there is a high correlation between %ETCO2 and cardiac output (pulmonary blood flow) during CPR. Thus, under conditions of constant ventilation, %ETCO2 reflects the circulatory status of the animal during CPR.