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Clinical paper

Electrical and mechanical recovery of cardiac function following out-of-hospital cardiac arrest☆

Daniel P. Davis[a,*], Rebecca E. Sell[b], Nathan Wilkes[a], Renee Sarno[a], Ruchika D. Husa[c], Edward M. Castillo[a], Brenna Lawrence[a], Roger Fisher[d], Criss Brainard[d], James V. Dunford[a,d]

[a] Division of Emergency Medicine, Department of Medicine, UC San Diego, San Diego, CA, United States
[b] Division of Pulmonary and Critical Care Medicine, Department of Medicine, UC San Diego, San Diego, CA, United States
[c] Division of Cardiology, Department of Medicine, UC San Diego, San Diego, CA, United States
[d] San Diego Medical Services Enterprise, United States

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ABSTRACT

Background: Compression pauses may be particularly harmful following the electrical recovery but prior to the mechanical recovery from cardiopulmonary arrest.
Methods and results: A convenience sample of patients with out-of-hospital cardiac arrest (OOHCA) were identified. Data were exported from defibrillators to define compression pauses, electrocardiogram rhythm, PetCO2, and the presence of palpable pulses. Pulse-check episodes were randomly assigned to a derivation set (one-third) and a validation set (two-thirds). Both an unweighted and a weighted receiver–operator curve (ROC) analysis were performed on the derivation set to identify optimal thresholds to predict ROSC using heart rate and PetCO2. A sequential decision guideline was generated to predict the presence of ROSC during compressions and confirm perfusion once compressions were stopped. The ability of this decision guideline to correctly identify pauses in which pulses were and were not palpated was then evaluated. A total of 145 patients with 349 compression pauses were included. The ROC analyses on the derivation set identified an optimal pre-pause heart rate threshold of >40 beats min^{-1} and an optimal PetCO2 threshold of >20 mmHg to predict ROSC. A sequential decision guideline was developed using pre-pause heart rate and PetCO2 as well as the PetCO2 pattern during compression pauses to predict and rapidly confirm ROSC. This decision guideline demonstrated excellent predictive ability to identifying compression pauses with and without palpable pulses (positive predictive value 95%, negative predictive value 99%). The mean latency period between recovery of electrical and mechanical cardiac function was 78 s (95% CI 36–120 s).
Conclusions: Heart rate and PetCO2 can predict ROSC without stopping compressions, and the PetCO2 pattern during compression pauses can rapidly confirm ROSC. Use of a sequential decision guideline using heart rate and PetCO2 may reduce unnecessary compression pauses during critical moments during recovery from cardiopulmonary arrest.

1. Introduction

Sudden cardiac arrest is a leading cause of mortality, with over 300,000 deaths annually in North America alone.[1,2] Survival rates remain poor despite recent advances in our understanding of the pathophysiology of cardiopulmonary arrest.[2,3] Factors associated with improved survival from out-of-hospital cardiac arrest (OOHCA) include: younger age, initial rhythm of ventricular fibrillation (VF) or ventricular tachycardia (VT), bystander witnessed arrest, bystander cardiopulmonary resuscitation (CPR), and early defibrillation.[4,5] In addition, high quality chest compressions with full chest recoil provide the foundation for cardiac arrest resuscitation by improving perfusion to vital organs, repleting myocardial ATP stores, and removing metabolic byproducts.[3,5,6]

Minimizing interruptions in chest compressions has emerged as a critical objective for high quality resuscitation, with recent data documenting a linear relationship between the chest compression fraction (the percentage of time spent performing chest compressions) and outcome from OOHCA.[7–10] Unfortunately, data from inpatient and prehospital arrests suggest that chest compression fractions are suboptimal.[10–12] Thus, the 2005 ILCOR guidelines recommend uninterrupted CPR for 2-min intervals followed by a pause for rhythm analysis and pulse check.[1]

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* Corresponding author. Tel.: +1 619 543 3829.
E-mail address: davismd@cox.net (D.P. Davis).

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Even when separated by 2-min intervals, these pauses may be excessive due to challenges in pulse palpation in critical patients.[13,14] While a prolonged pause for pulse assessment is not harmful if spontaneous perfusion has resumed, withholding compressions for any period of time in a non-perfusing patient is potentially catastrophic. This may be particularly true in the presence of organized ECG complexes but prior to ROSC, which may represent a critical juncture in cardiac recovery from arrest.

Quantitative capnometers measure end-tidal carbon dioxide (PetCO2) with relative accuracy, even during cardiopulmonary arrest. In states of normal perfusion, PetCO2 is influenced primarily by alveolar ventilation. However, in states of low perfusion, PetCO2 is limited by pulmonary blood flow and, therefore, cardiac output whether by manual compression or spontaneous circulation.[15,16] A relationship between persistently low PetCO2 values and resuscitation futility has been described.[16,17] Over two decades ago, Falk and colleagues described the ability of PetCO2 to reflect return of spontaneous circulation (ROSC), concluding that "...precordial compression need not be interrupted in order to confirm that spontaneous circulation has been restored.".[18]

We hypothesized that ROSC following OOHCA would follow a predictable pattern of electrical recovery followed by mechanical recovery of cardiac function.[19,20] Furthermore, we hypothesized that the electrical recovery of cardiac function can be defined by an increase in heart rate above a threshold value and that the mechanical recovery of cardiac function can be defined by an increase in PetCO2 above a threshold value while compressions are performed and sustained with cessation of compressions. Lastly, we anticipated that continuing ventilations during compression pauses would allow identification of absent perfusion as reflected by a rapid decline in PetCO2 values.

2. Methods

2.1. Design

This was an observational analysis using prospectively collected data from OOHCA victims in the City of San Diego. Waiver of informed consent was granted from our Investigational Review Board.

2.2. Setting and protocols

This study was performed in a large, urban emergency medical services (EMS) system serving the City of San Diego, with a population of about 1.2 million. Both first-responding and transport vehicles provide advanced life support (ALS) care. During the study period, EMS personnel performed continuous, manual chest compressions with synchronized ventilations interposed between compressions at a ratio of 10:1. The identical ventilation strategy is performed following intubation, which generally occurs after the initial rhythm analysis has been performed and vascular access achieved. No mechanical devices were employed to either perform or enhance compressions. A pause for rhythm analysis and pulse check is performed every 2 min. Defibrillation is performed using Zoll M Series defibrillators (Zoll Medical Inc., Chelmsford, MA) in manual mode, with compressions performed immediately before and after defibrillation attempts.

Capnography is performed immediately upon initiation of bag-valve-mask (BVM) ventilation and continued following endotracheal (ET) intubation. This approach establishes proper capnography function and allows a baseline PetCO2 value to be recorded prior to intubation, both of which assist in confirmation of ET tube placement. While paramedics have access to capnography data during resuscitation, protocols during the study period did not include use of PetCO2 values to guide the decision to pause for pulse check or help determine the presence of ROSC.

2.3. Subjects

Data for all adult OOCHA victims are maintained in a quality assurance database. All cardiopulmonary arrest patients with available defibrillator and PetCO2 data were identified over a two-month period. An approximately equal number of patients with and without ROSC maintained until arrival to the emergency department were included.

2.4. Data collection

Data are retrieved from defibrillators for all cardiopulmonary arrests by quality assurance personnel. Code Review software (Zoll Medical Corp, Chelmsford, MA) is used to abstract data by trained data analysts, with "real-time" review of multiple input channels of physiologic data (ECG, impedance, breath-to-breath PetCO2, ventilation rate). When combined with audio recording, this technique allows for reliable identification of chest compression intervals as well as simultaneous abstraction of heart rate and PetCO2 values.[21,22] Clinical events, such as intubation, defibrillation, administration of epinephrine, and palpation of a pulse, are also identified using the audio channel and the electronic patient care record.

Specific data points for this analysis included prepause heart rate and PetCO2 values as well as PetCO2 values recorded during and immediately after any compression pauses. Ventilation rates with CPR and during pauses were also calculated. In addition, the pre-pause rhythm and the duration of each pause were determined. If the pre-pause rhythm could not be defined due to compression artifact, then the rhythm present immediately upon cessation of compressions was used. Finally, insertion of an advanced airway (endotracheal tube or Combitube), attempted defibrillation, and epinephrine administration were abstracted.

2.5. Data analysis

The primary objectives of this analysis were: (1) to identify threshold values for pre-pause heart rate and PetCO2 to predict ROSC, (2) to describe the PetCO2 pattern during compression pauses, and (3) to combine these into an algorithm allowing pre-pause ROSC prediction and rapid ROSC confirmation during compression pauses. Such an algorithm would minimize compression pauses during cardiac arrest resuscitation. Mean PetCO2 values immediately before, during, and immediately after pauses in which a pulse was palpated were compared to those in which a pulse was not palpated.

One-third of the compression pauses were assigned to the derivation group. Receiver–operator curve (ROC) analysis was used to identify the threshold heart rate and PetCO2 values below which ROSC, as defined by the presence of a palpable pulse, was unlikely. Both unweighted and weighted analyses were performed because of the potential to use more than one compression pause from an individual patient. Area under the curve (AUC) was used to quantify the predictive ability of the ROC analyses. An optimal threshold value was selected by the statistical software based on the greatest distance from the line with slope of 1. The threshold heart rate and PetCO2 values were then used to calculate the mean latency period between recovery of electrical function and mechanical function.

The PetCO2 pattern during compression pauses with and without palpable pulses was defined using linear regression. ROC analysis was performed to identify the optimal PetCO2 threshold during the compression pause to identify the absence of a