Can Cardiac Sonography and Capnography Be Used Independently and in Combination to Predict Resuscitation Outcomes?

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Abstract. 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 (ETCO₂) 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 ETCO₂ levels, 35 torr, were associated with improved chances of survival than the median ETCO₂ 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 ETCO₂ 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. Key words: cardiac sonography; capnography; prediction; survival; outcomes; cardiac arrest. ACADEMIC EMERGENCY MEDICINE 2001; 8:610–615

The absence of a palpable central pulse does not always reflect cardiac standstill during cardiac resuscitation. Inefficient cardiac contractions occur as a result of many factors, including pericardial tamponade, pulmonary embolism, and pneumothorax. Because some causes of pulselessness are more reversible than others, the early identification of groups of pulseless patients with higher likelihood of successful resuscitations might be useful. Research has suggested that cardiac sonography may be beneficial in identifying patients with potentially treatable conditions and therefore better prognosis when central pulses are not palpable. Since end-tidal carbon dioxide (ETCO₂) levels are dependent on the cardiac output generated by cardiopulmonary resuscitation in cardiac arrest victims, capnography represents another potential predictor of survival or death after cardiac arrest. Both cardiac sonography and capnography are well suited to bedside emergency department (ED) practice in the care of critically ill patients because both tests are rapidly performed, noninvasive, and easily available. The objectives of this study were to determine the feasibility of per-
forming 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.

**METHODS**

**Study Design.** This was a prospective clinical observation study of nonconsecutive cardiac arrest patients undergoing cardiac ultrasonography alone or in conjunction with capnography. The goal was to measure the ability of these noninvasive techniques to predict survival after cardiac arrest. Informed consent was waived because of the patients' critical condition and the noninvasive character of cardiac sonography and capnography.

**Study Setting and Population.** This study was conducted at two community hospital EDs with emergency medicine residency programs. Pulseless ED patients were enrolled in a prospective and nonconsecutive fashion. The minimal required experience for performing ultrasonography on study participants was a four-hour trauma sonography course during which focused cardiac sonography, using the subxiphoid view, was taught and practiced on a series of different human and mannequin simulator models. Participating emergency physicians, residents and attendings, performed and interpreted the cardiac sonography studies during the pulse check pause of the Advanced Cardiac Life Support (ACLS) algorithm.

**Study Protocol.** Focused cardiac sonography was performed primarily by the subxiphoid view; the apical view was used as an adjunct in obese subjects (Fig. 1). St. Luke's Hospital physicians used the Pie Medical Scanner 200 (Pie Medical, Maastricht, The Netherlands) and Christiana Hospital physicians used the General Electric RT3200 Advantage II (General Electric, Milwaukee, WI); both used a 3.5-MHz curvilinear transducer. The capnography monitor, available only at Christiana Hospital, was a mainstream capnograph with infrared analysis of ETCO₂ that provided quantitative capnographic waveforms and measurements. Patient data, including cardiac rhythm, sonographic findings, impression of the clinical utility of cardiac sonography, and capnography results, were recorded. The study protocol recommended that cardiac sonography should be performed in less than 10 seconds and that it should not interfere with ACLS-mandated interventions. Cardiac sonography was carried out during the pulse evaluation and with any change in cardiac electrical rhythm; the number of scans was determined by the progress of the resuscitation. Capnography was performed upon patient arrival in the ED if the subject was an out-of-hospital-intubated cardiac arrest victim, or immediately after intubation in the ED. Capnography levels were noted simultaneous to cardiac sonography exams; only peak ETCO₂ levels are reported.

**Data Analysis.** Chi-squared analysis was used to compare survival rates in groups with and without sonographically detected cardiac activity. Survival was defined as survival to admission to the hospital. The Mann-Whitney test was used to compare the differences in medians between capnography data for survivors and nonsurvivors. The point-biserial correlation coefficient tested the strength of association between the capnographic data and survival. Alpha was set at 0.05, two-tailed. Multivariate logistic regression, which evaluated cardiac ultrasonography and ETCO₂ results, was used to construct a multivariate model predicting survival to hospital admission based on ETCO₂ levels and the presence of sonographically identified cardiac activity. Stepwise multivariate logistic regression generated significant predictors.
RESULTS

Table 1 documents the cardiac rhythms, the presence of cardiac activity, the survival status, and the capnography data of the 102 subjects enrolled over 12 months. Subjects underwent a mean of 1.8 cardiac ultrasound scans during the resuscitation, with a range of one to five examinations. Patients with sonographically identified cardiac activity at any time during the resuscitation were more likely to survive to hospital admission, (11/41 or 27%) than those without cardiac activity (2/61 or 3%; $\chi^2 = 12.2; \phi = 0.35; p < 0.001$). Among pulseless electrical activity (PEA) patients with no sonographic detection of contractions, only one of 24 (4%) survived to admission compared with eight of 31 (26%) of patients with contractions ($\chi^2 = 4.6; \phi = 0.3; p < 0.05$). Sonographic detection of cardiac activity on the first sonographic evaluation in the resuscitation was associated with survival (12/39 or 31%), as compared with those without cardiac activity (1/63 or 2%; $\chi^2 = 18.5; \phi = 0.6; p < 0.001$). Of patients with sonographically identified contractions present throughout resuscitation, (i.e., every time the heart was sonographically identified, it was contracting), 100% (6/6) survived to admission. Of those who lacked contractions on at least one sonographic evaluation, 7.0% (6/86) survived to hospital admission ($\chi^2 = 42.8; \phi = 0.7; p < 0.001$). Two patients (1 PEA, 1 asystole) without sonographically identified contractions survived to admission. Cardiac sonography, used eight times to confirm or refute transcutaneous or transvenous pacemaker capture, confirmed pacemaker capture of cardiac electrical activity in one subject and refuted capture in seven subjects. Of 11 subjects who were noted to have either ventricular tachycardia or ventricular fibrillation, seven had sonographically identified cardiac activity. Pericardial effusions were identified in four subjects.

The median ETCO$_2$ level for survivors (39 torr) was significantly elevated compared with the median ETCO$_2$ level for nonsurvivors (13.7 torr; $Z = 3.26; p < 0.01$). The point-biserial correlation between ETCO$_2$ levels and survival was 0.53. Figure 2 is a box-and-whisker plot that demonstrates the association between ETCO$_2$ and survival. Although elevations of up to 48 torr were noted in nonsurvivors, no patient with an ETCO$_2$ less than 16 torr survived. Of 22 subjects with ETCO$_2$ levels less than 16 torr and the absence of sonographically detectable cardiac activity, none survived; seven subjects with ETCO$_2$ less than 16 torr had cardiac activity detected and none survived. Of 19 subjects with ETCO$_2$ higher than 16 torr and sonographically detectable cardiac activity, five survived; five subjects with ETCO$_2$ higher than 16 torr had no sonographically detectable cardiac activity, only one survived.

Results of the multivariate logistic regression model reveal that sonographically identified cardiac activity was not a significant predictor of survival (odds ratio 1.09; 95% CI = 0.07 to 16.4). However, ETCO$_2$ was a significant predictor to hospital admission. For each increase of 1 torr in ETCO$_2$, the odds of surviving increased by 16% (odds ratio 1.16; 95% CI = 1.05 to 1.29). The model was able to correctly classify 92.4% of the subjects as a predicted probability cut value of 0.50 (sensitivity 50%; specificity 98%; positive predictive value 75%; negative predictive value 94%). Summary statistics for the entire model suggest that it fit the data well (Hosmer-Lemeshow goodness of fit = 4.8; $p = 0.8$; McFadden $r^2 = 0.4$). The results of the stepwise logistic regression model are summarized by

Table 1. Data Summary of Cardiac Sonography and Capnography Correlated with Survival*  

<table>
<thead>
<tr>
<th>+Cardiac Activity</th>
<th>−Cardiac Activity</th>
<th>End-Tidal CO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEA</td>
<td>Asystole</td>
<td>V Tach</td>
</tr>
<tr>
<td>Died</td>
<td>23</td>
<td>3</td>
</tr>
<tr>
<td>Survived</td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

*CO$_2$ = carbon dioxide; PEA = pulseless electrical activity; V Tach = ventricular tachycardia; V Fib = ventricular fibrillation.
the ROC curve in Figure 3, with an area under the curve of 0.9, which demonstrates that ETCO₂ is an outstanding predictor of survival.

Clinicians reported successfully identifying the heart sonographically in all 102 cases. Figure 4 demonstrates the self-reported degree of the difficulty in identifying the heart sonographically. On a one-to-five Likert scale (1 = easy to 5 = difficult), the performance of cardiac sonography was graded as 1 or 2 in 73% of cases. On the post-resuscitation questionnaire, clinician participants reported cardiac sonography to be helpful in their management of 96% of cases and unhelpful in 4%.

DISCUSSION

An increasing body of evidence suggests that capnography can be used to predict survival or to determine when ACLS can be discontinued.²⁻⁷⁻¹¹ There is also evidence suggesting that cardiac sonography may be a useful adjunct in cardiopulmonary resuscitation and in terms of predicting survival.¹²⁻¹³ This study was conducted to determine whether cardiac sonography either alone or in combination with capnography in pulseless patients undergoing resuscitation is predictive of survival.

Overall, sonographically detected cardiac activity was noted in 40% (41/102) of pulseless subjects (Table 1). The sonographic identification of cardiac activity was associated with increased survival as opposed to those without sonographically identified cardiac activity (p < 0.001). The presence of cardiac activity on the first sonographic evaluation was also associated with survival (p < 0.001). Furthermore, there was a moderately strong association between survival and the presence of sonographically detected contractions throughout the resuscitation as opposed to those who had one or more episodes in which cardiac sonography did not detect activity (p < 0.001). Previous research has demonstrated that as many as 87% of patients in PEA have myocardial wall and valve motion.³ Our data confirm that a large percentage, 56%, of subjects with PEA do have cardiac activity and these PEA victims may be the most amenable to resuscitative therapy; the association between survival and sonographically detected cardiac activity in PEA subjects as compared with no cardiac activity was significant (p < 0.05). Our data support the hypothesis that the demonstration of cardiac standstill is associated with an unsuccessful resuscitation, whereas the detection of cardiac output is associated with an improved likelihood of survival.¹¹⁻¹³

Cardiac sonography may have other uses in the evaluation of cardiac arrest patients. There have been case reports regarding cardiac sonography in the evaluation of pacemaker capture of cardiac electrical activity, in the evaluation of pericardial effusion in pulseless electrical tachycardia patients, and in the detection of ventricular fibrillation.²⁻⁴⁻⁶ In our study, cardiac sonography refuted pacemaker capture in seven cases and confirmed capture in one case by either transcutaneous or transvenous pacemaker. Historically, postmortem presence of pericardial effusion was found in 1% to 14% of pulseless patients who underwent cardiopulmonary resuscitation for nontraumatic cardiac arrest;⁴⁻⁵ we identified a rate of 4% of pericardial effusion in pulseless victims. Finally, of 11 victims of pulseless ventricular tachycardia or ventricular fibrillation, seven had sonographically detected cardiac activity (Table 1). This finding of sonographically detected cardiac activity in ventricular fibrillation patients adds credence to two case reports in which echocardiography identified cardiac activity in subjects with ventricular fibrillation.⁵⁻¹²
Higher ETCO2 values have been associated with return of spontaneous circulation.\(^7\)\(^,\)\(^{11,13}\) Our capnography results (Table 1) add to this evidence base by demonstrating that higher ETCO2 values are associated with better prognosis. Median ETCO2 for survivors (35 torr) was significantly higher than for nonsurvivors (13.7 torr). The median ETCO2 value of 35 torr in this study mirrors mean ETCO2 levels in survivors in prior studies, which ranged from 31 torr to 33 torr.\(^{11,13}\) In comparison with previous studies in which nonsurvivors had mean ETCO2 levels ranging from 4.4 torr to 20.6 torr, nonsurvivors in our study had a median ETCO2 level of 13.7 torr.\(^{11,13}\) An ETCO2 value of 16 torr or less successfully discriminated between the survivors and nonsurvivors in our study because no patient survived with an ETCO2 less than 16 torr. Our logistic regression model further showed that for every increase of 1 torr in ETCO2, the odds of surviving increased by 16%.

Both the sonographic demonstration of cardiac activity and ETCO2 higher than 16 torr were significantly associated with survival. Of the two correlation coefficients, \(\phi\) of 0.35 for cardiac sonography and point-biserial coefficient of 0.53 for capnography, elevated ETCO2 levels were more strongly associated with survival than the presence of sonographically detected cardiac activity. The multivariate logistic regression model combining cardiac sonography and capnography correctly classified 92.4% of subjects. However, only capnography was found to be a significant predictor; cardiac sonography did not enhance the predictive accuracy of the model. Furthermore, the results of the stepwise logistic regression model not only confirmed the multivariate logistic regression model, but also demonstrated that capnography alone is an outstanding predictor of survival.

Clinicians did not report any instances in which cardiac sonography appeared to interfere with resuscitation, and the responses of the clinician participants demonstrated that cardiac sonography could be carried out with relative ease during the performance of cardiopulmonary resuscitation (Fig. 3). Furthermore, the impression that cardiac ultrasound provided useful information about the resuscitation was reported by 96% of the clinician participants.

LIMITATIONS AND FUTURE QUESTIONS

This study used a convenience sample because of several methodological constraints. The ultrasound scanner was occasionally in use for other indications. Sometimes there were no trained emergency physician sonographers available during the resuscitation. Additionally, use of cardiac sonography in resuscitation was not mandatory. It also should be noted that this study did not attempt to quantify the vigor with which the sonographically identified heart was beating. Future studies might attempt to quantify the strength of sonographically identified cardiac contractions. In this study, survival was defined as survival to admission; follow-up studies may want to evaluate the long-term outcome of the survivors. Although we cannot exclude the possibility that, for example, the absence of cardiac activity coupled with low ETCO2 shortened the duration of resuscitation efforts, we believe that all the resuscitations in this study were carried out according to ACLS guidelines. Finally, our modest sample size may account for the fact that cardiac sonography was not a predictor of survival in our logistic regression analysis, and further study with larger cohorts may be warranted.

CONCLUSIONS

Sonographic observation of cardiac activity and ETCO2 levels higher than 16 torr were both significantly associated with survival from ED resuscitation; however, logistic regression analysis demonstrated that prediction of survival using ETCO2 higher than 16 torr was not enhanced by cardiac sonography. Clinician participants perceived that cardiac sonography could be performed with relative ease at the bedside without hampering cardiopulmonary resuscitation efforts.

References


REFLECTIONS

For Jonathan (at 5 Years)

We are but older children, dear,
Who fret to find our bedtime near.
—Lewis Carroll

Who made the sky? Playing basketball
On a cloudless day, you ask, between shots.
I, who should know better, say I don’t know.
You persist.
Grandma and grandpa later tell you, “God made the sky.”
You look at me and shrug.
Metaphysics is a children’s primer:
Who made the first day?
What’s the last number?
Who was the first person?
Eternity, infinity, and creation pass in your mind
casually, while you push a toy truck, or
at bedtime, or on the way to school.
My answers are weak rockets I send up—they
sputter, then fall to the ground.
The flames of philosophy, theology, and science
crackle in young minds, energized by wonder.
Only grown-ups think they have the answer.
But they’ve forgotten the questions.
Fundamental questions asked in life’s foundation—
The most basic by the most basic of minds.
Years etch trivialities into concerns: mutual funds and mortgages,
politics and gossip, schedules bordered by deadlines—
All push back the early questions.
Until we turn the curve to the end, and the heart slows, the brain
falters, the joints freeze. Only then the questions of children
rush in a flood: The why of who we are, and how we came to be.
Some lean on religion, or philosophy, or the latest trend.
Some learn new Eastern meditations, adapt special diets,
discover herbs and roots with medicinal import.
Some find love again, others leave, some come back:
All together in a heap at the end, asking the same questions
of children, mindless of destiny, shooting baskets on cloudless
days, hours before bedtime.

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Reference