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Research Article

# Does Emergency Department Measured Cardiac Output Predict Organ Failure at 48 Hours? A Pilot Study

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## Abstract

**Background**: Cardiac performance is predictive of mortality in a wide range of conditions. We set out to study whether cardiac index predicts outcome in emergency department (ED) patients.

**Methods:** We performed a prospective observational study using a convenience sample of 58 patients presenting to the resuscitation area of an inner-city teaching hospital over 4 months. We measured cardiac index on initial presentation using an Ultrasonic Cardiac Output Monitor (USCOM™). We looked primarily at whether cardiac index predicts organ failure at 48 hours.

**Results:** Cardiac index was shown to be predictive of organ failure at 48 hours with an OR 4.71 95% CI 1.12 to 19.70 p=0.03.

**Conclusions:** This pilot data found that cardiac index measured using USCOM™ predicts 48-hour organ failure. However the study is limited in its conclusions by having only 58 full participants available for analysis.

**Keywords:** Cardiac Index; Uscom™; Prediction Tool; Emergency Department

**Abbreviations**
CO: Cardiac Output;
ECG: Electrocardiogram;
ED: Emergency Department;
GCS: Glasgow Coma Score;
OR: Odds Ratio;
PR: Pulse Rate;
SBP: Systolic Blood Pressure;
USCOM: Ultrasonic Cardiac Output Monitor

## Introduction

Cardiac performance is predictive of mortality in a wide range of conditions, including syncope, cardiac failure and sepsis [1-4]. Cardiac output (CO) is the major determinant of oxygen delivery and the prime focus for resuscitation [5]. Physiological scores (track and trigger systems) in use in the UK Emergency Departments (EDs) were developed for ward, not ED use [6]. Data is conflicted as to whether morbidity and mortality are improved by the medical response to physiological scores [7,8]. This is discussed further in our linked publication [9]. To our knowledge no ED based physiological score includes a measure of CO and the value of CO to predict outcome remains uncertain.

Our ED uses a non-invasive CO measurement obtained using a suprasternal Doppler probe (Ultrasonic Cardiac Output Monitor [USCOM™]) in the assessment of patients in the resuscitation area, so enabling cardiac index to be added to baseline physiological variables. USCOM™ uses continuous wave Doppler ultrasound to assess the velocity time integral for blood flowing through the aortic valve. The area of the valve is not measured but obtained from a height and weight based algorithm. The stroke volume is then calculated. Since the aortic valve is of a fixed size, any changes in measurements are consequent upon changes in blood flow. USCOM™ has been validated by several studies for use in the ED in adults [10,11]. There have also been several studies validating the USCOM™ for use in ICU settings and surgical patients[12-16].

USCOM™ (with its non-invasive approach, no expensive disposable parts and previous work suggesting that we could train a wide range of doctors and nurses in its use) would be ideally suited to an ED environment if it has the potential to influence management and outcome of unwell patients. We hypothesised that patients with an abnormal cardiac index would have a higher rate of organ failure and mortality and require a higher rate of escalation of care. As such, measurement of CO could thus represent a useful addition to the physiological assessment of patients presenting to the resuscitation area of the ED. We therefore set out to study whether cardiac index predicts outcome in ED patients.

## Materials and Methods

This data represents a subset of a larger study exploring the role of physiological and metabolic scoring in the ED setting [9]. Whether or not non-invasive CO could predict organ failure at 48 hours, or mortality, was an a priori aim of the study. Data is presented in two separate papers for clarity and simplicity and all data was collected prospectively.

### Setting

The study was carried out in the resuscitation area of an inner city teaching hospital and trauma centre. The annual census is around 120 000 patients, with approximately 3-5% cared for in the resuscitation area. Patients were admitted to the resuscitation area based on the discretion of senior nurse/clinician using clinical parameters or suspected diagnoses as discussed below.

### Study Participants & Design

We performed a prospective observational study using a convenience sample of 200 consecutive patients, which was determined by the time study team members were rostered to the resuscitation room, 24 hours a day and 7 days a week between 4th January and 21st April 2010. For reasons later explained, only 99 patients could be considered for use in our analysis and only 58 were actually entered for analysis. Our study participants were adults (> 17 years age) admitted to the resuscitation room due to one or more of: abnormal physiology (systolic blood pressure [SBP] <90mmHg, respiratory distress, pulse rate [PR] > 120, Glasgow Coma Score [GCS] < 14), acute myocardial ischemia, acute rhythm disturbance, cerebrovascular accident, lactate > 4 mmol/L, toxicological ingestion at risk of acute deterioration, acute gastrointestinal bleed, acute abdomen with abnormal physiology and severe sepsis.

We excluded patients admitted with traumatic injuries, in cardiac arrest, with 'do not resuscitate orders', with chest pain and normal initial troponin & electrocardiogram (ECG) and those patients who were in the resuscitation area for procedural sedation.

### Study Measurements

We obtained a non-invasive measurement of CO using the USCOM™ (Sydney, Australia). Trained nurses or doctors made all measurements within 30 minutes of the patients' arrival. Patients' height and weight were assessed by asking the patient or (if not known) height was measured by tape measure and weight was guestimated by nursing staff. All staff had been provided with dedicated training and had made at least 15 previous readings. Previous work in our department had demonstrated 15 readings were required to produce inter and intra-observer reliability of < 15% between readings, providing the trace quality score was ≥4/8. This reflects the accuracy of most CO measurement devices and is the threshold at which changes in CO in response to a fluid bolus determines a fluid responsive patient. Each reading required a score between 0 and 8 for quality of the trace. Only patients with a score ≥4 were included in the analysis. Details of the trace quality scores are provided in Appendix 1. Aortic windows (rather than the alternative pulmonary windows) were used in all cases.

For analysis we stratified cardiac index as normal, low or high using widely accepted physiological ranges and assigned normal as a score of "0" with low or high as a score of "1". Cardiac index was used as binary variable in the logistic regression

analysis with figures of <2.5L/min/$m^2$ or >4 L/min/$m^2$ (4 – 8 L/min) denoted as abnormal.

### Outcome Measures

Our primary outcome was new organ failure at 48 hours, which we defined using parameters adapted from the surviving sepsis campaign (Table 1). We considered this an appropriate end-point as we are looking at how initial status may predict outcome and therefore 48 hours seems a reasonable time frame over which initial physiological status may have a significant impact on outcome. Organ failure was considered to have developed if new abnormalities in these parameters had developed at 48 hours as compared to admission.

**Table 1.** Markers of new organ failure [based on 48h compared to arrival].

| |
|---|
| Reduction in GCS |
| New confusion as defined by disorientation in time, place and person |
| The need for non-invasive ventilation [either CPAP or PS or both] |
| The requirement for intubation |
| An escalation in Fi02 requirements since discharge from the ED to maintain SpO2>90% |
| New troponin rise [TnT rise, defined as > 0.03µg/L] |
| New left ventricular failure as evidenced by clinical syndrome of dyspnoea with new chest radiograph infiltrates reported as pulmonary oedema |
| The introduction of any inotrope or vasopressor by infusion |
| Any new arrhythmia diagnosed since discharge from ED to the ward areas. If the patient was known to have paroxysmal atrial fibrillation and had episodes of this while an inpatient this was not counted as a new arrhythmia |
| Doubling of creatinine or any value recorded >177µmol/L |
| Thrombocytopenia <100 x $10^9$/L |
| INR >1.5 [unless using anticoagulation] |
| APTT newly >60s [unless using anticoagulation] |

Our secondary outcomes were in-patient death and an escalation of care from level 1 care (ward-based) to level 2 care (high dependency, single organ failure) or from level 1 or 2 care to level 3 care (intensive care; 2 or more organs supported; invasive ventilation) within 48 hours of admission. Transfer to coronary care for non-invasive ventilation was included as an escalation to level 2 care.

All data was stored on a secure password protected NHS computer on a dedicated database (Microsoft Excel™ 2007 version).

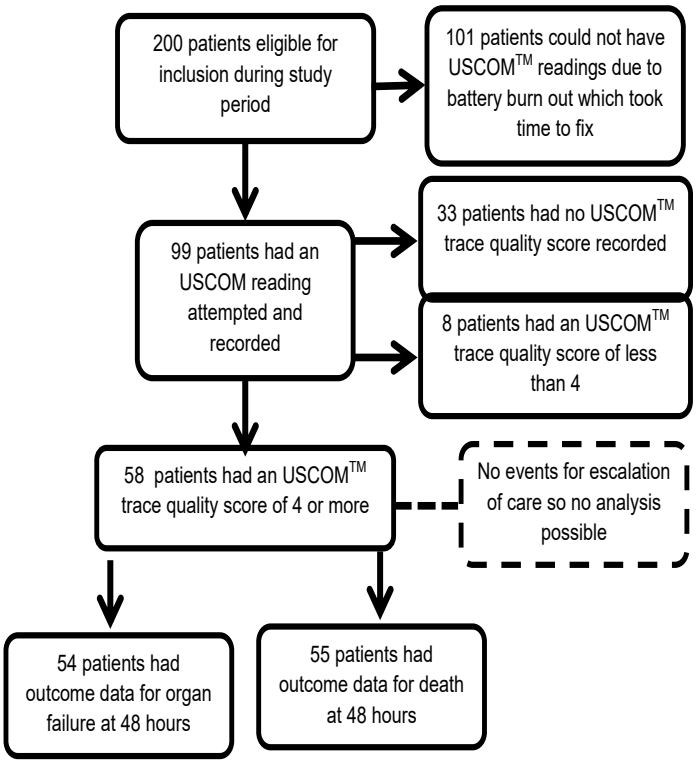
### Ethical Approval

The study was granted a waiver for consent by the Chair of ethics East London committee 2 as there were no interventions, no changes to patient care and no patient identifiable information. This was an observation of usual service delivery and the project was registered as a service evaluation along local guidelines. The data was anonymised.

## Statistical Analysis

STATA version 8.0 was used for all analyses. We described the data as means and standard deviations or numbers with percentages. Data on CO was available on 99 of 200 patients (due to technical failure of battery burn-out preventing a larger number of USCOM™ readings during the study period). We used logistic regression with organ failure as primary outcome and escalation of care and death as secondary outcomes. Our exposure was cardiac index. We analysed data on the reduced set of patients with a trace quality score recorded of 4 or more (n=58). This number would likely have been higher but unfortunately the trace quality score was omitted by our study team in some cases and was not retrievable retrospectively. See figure 1 for a full flow-diagram of included patients.

**Figure 1.** Flow-Diagram of Included Patients.



Our exposure variable was binary (0 if within the normal range i.e. greater than or equal to 2.5 and smaller than or equal to 4.5 and 1 if less than 2.5 or greater than 4.5). Data was presented as odds ratios (OR) with 95% confidence intervals. Results were deemed significant at the 5% level. Although the data-set total for analysis is 58, some of the outcome measure data was not available in all cases therefore table 5 shows totals less than 58.

## Results

Table 2 shows the baseline demographics of the potential participants in this part of the study alongside the reduced dataset.

Table 3 gives a summary of the baseline USCOM™ measurements on arrival in resuscitation area of the ED (as well as PR and SBP for those patients in which those readings were available) and table 4 shows the split of cardiac index readings.

Table 5 shows the odds of outcome by binary scoring of cardiac index. It is to be noted that the total number available for each outcome analysis is dependent on the outcome information being available. Our results show a significant relationship between cardiac index and 48-hour organ failure OR 4.71 95% CI 1.12 to 19.70 p=0.03. Our study does not show a statistically significant relationship between 48-hour escalation of care or death, the former OR could not be calculated due to no events

**Table 2.** Baseline characteristics adapted from Jafar et al [2014](9).

| **Socio-demographic characteristics** | N | **Mean [±standard deviation/SD] or N [%] Full dataset N= 99** | N | **Mean [±SD] or N [%] Reduced dataset [trace quality score recorded as 4 or more] N=58** |
|---|---|---|---|---|
| *Mean age in years* [SD] | 90 | 61 [±19] | 53 | 62 [±18] |
| *Age range* in years | 90 | 18-91 | 53 | 49-76 |
| *Ethnicity [%]* | 99 | | 58 | |
| white | | 46 [46] | | 25 [43] |
| south Asian | | 16 [16] | | 10 [17] |
| black | | 11 [11] | | 8 [14] |
| other or unknown | | 26 [26] | | 15 [26] |
| *Male sex [%]* | 98 | 66 [67] | 58 | 38 [66] |
| *Main anatomical presentation site [%]* | 97 | | 56 | |
| Cardiovascular | | | | |
| Respiratory | | 19 [20] | | 14 [25] |
| Neurological | | 21 [22] | | 11 [20] |
| Other or combination | | 15 [15] | | 10 [18] |
| | | 42 [43] | | 21 [38] |
| *Discharge destination [%]* | 83 | | 47 | |
| Ward | | 54 [65] | | 28 [60] |
| Coronary Care Unit (CCU) | | 13 [16] | | 9 [19] |
| Medical High Dependency Unit (HDU) | | 7 [8] | | 4 [9] |
| Discharge | | 2 [2] | | 1 [2] |
| Intensive Care Unit (ICU) | | 3 [4] | | 2 [4] |
| Majors | | 4 [5] | | 3 [6] |

**Table 3.** Baseline measurements.

| Clinical characteristics | N | Mean [±SD] |
|---|---|---|
| Systolic blood pressure (mmHg) | 56 | 126 [29] |
| Pulse rate (beats/minute) | 54 | 95 [30] |
| Stroke volume (ml) | 58 | 56 [20] |
| Cardiac output in (L/min) | 58 | 5.1 [1.9] |
| Cardiac index (L/min/$m^2$) | 58 | 2.8 [1.1] |

**Table 4.** Split of cardiac index.

| Cardiac index categories | N | % of total |
|---|---|---|
| Cardiac index<2.5 (L/min/$m^2$) | 28 | 47 |
| Cardiac index 2.5 – 4.5 (L/min/$m^2$) [reference] | 27 | 48 |
| Cardiac index>4.5 (L/min/$m^2$) | 3 | 5 |

**Table 5.** Impact of binary cardiac index on outcome.

| Outcome | N patients with outcome data available [n] event number | OR [95% CI] | P value |
|---|---|---|---|
| **Organ failure at 48 hours** | 54 *[13]* | 4.71 [1.12-19.70] | 0.03 |
| **Escalation of care at 48 hours** | No events* | No events* | NA |
| **Death at 48 hours** | 55 *[6]* | 1.92 [0.32-11.47] | 0.47 |

*No events in group if cardiac index >2.5 and <4.5 so unable to calculate odds ratios.

in the abnormal cardiac index group, the latter OR 1.92 95% CI 0.32 to 11.47 p=0.47 us clearly not significant. It must be noted that the absolute number of outcomes (6 in this case) are very small.

## Discussion

Our results suggest that cardiac index measured by Doppler technology (USCOM™) may have a role in identifying those patients cared for in the ED resuscitation room who are at increased risk of organ failure at 48 hours. The results however do not support the hypothesis that cardiac index may predict death or escalation of care at 48 hours but the event numbers in this study are too small for truly meaningful analysis.

In this paper we grouped patients as having either an abnormal or normal CO, whether in a high or low output state, regardless of cause. Our primary outcome was organ failure at 48 hours and we set out to test the hypothesis that abnormal CO was associated with new organ failure. Organ failure in shock results predominantly from hypoperfusion and consequent tissue hypoxia, regardless of the aetiology. Our results support an association between abnormal CO and new organ failure. However patients with low or high CO may not be equivalent groups. For example it may be that patients with sepsis and low CO fail to increase their CO to meet increased oxygen requirements and consequently have a greater risk of organ failure as compared to those with a moderate increase in CO. We had insufficient data to explore this hypothesis.

In those patients where a trace quality score was recorded, 88% had a trace quality score of 4 or more. There may be bias in this percentage if in those 33 cases no trace quality score was recorded this was because it was a poor trace or similarly because it was very good trace. The study team observed that it was most challenging to obtain good quality traces in the sicker patients. This was due to respiratory distress (previously reported to affect USCOM™ readings[17]) with tracheal tug clouding readings, inability of some patients to lay flat, agitation and tremor. This may bias our results as we did not always get good readings in the patient group most likely to have a value that denoted prognosis. We also noted that the traces obtained in patients in high output states were consistently better quality than low output states. This is a result of the better signal to noise ratio on the display screen at higher COs. Given that around 60-70% shock seen in the ED is secondary to sepsis the low proportion of patients with high CO is surprising. This may reflect selection bias with sicker patients requiring resuscitation based on hypotension alone not being included in the study because acuity dictated that care took priority. Our readings were obtained early on in the patients' journey and the study was performed in winter so temperature dependent peripheral vasoconstriction may have skewed our findings.

Having no events of escalation of care in the abnormal cardiac index group is likely due to small overall numbers combined with small event numbers. However, it may either be that those with abnormal cardiac index were already originally admitted to an appropriate level of care, hence there were no escalation events (approximately 30% of those with abnormal cardiac index were admitted to at least level 2 care, whereas this figure is only 15% for those with normal cardiac index). Conversely it may be that in current practice we are not detecting those who really need escalation of care. A larger study would be useful to further answer this question.

USCOM™ has been validated in several studies in adults and children [10-16, 18-22]. There is no data to support USCOM™ or any other non invasive CO device improving outcomes when used in the ED. Despite excellent laboratory precision clinical experience has produced conflicting data of precision, accuracy and inter-observer relaibility [23,24]. We used no second device to asess CO. Larger studies with a wide range of users are required and different methods of assessing cardiac ultra-

sound are also required.

## Limitations

The limitations to this study based on the larger data-set from which it was derived is discussed in detail in our linked paper [9]. We highlight the possibility that the sickest patients may have been those in whom less data was available as data-collection competed with patient care (which must take priority). We also note the high number of males and non-white patients in our study group as well as the young mean age, which may have implications for generalisability. More specifically, due to technical problems with battery burn-out we obtained data on just under half of our original full study group (99 patients), so raising the question of type II error which may account for our lack of association with secondary outcomes. 33 patients unfortunately had no trace quality score recorded, which reduced our numbers further (as we cannot guarantee the trace quality score was of an acceptable quality in these patients): this was an omission noted only once data was being analysed and therefore was impossible to retrospectively rectify. 8 patients with a cardiac index tracing score <4 were excluded from the analysis because we deemed trace quality scores this low to be unreliable.

We did not record patient medication history or past medical history as this information is often not readily or accurately available in the first instance. We accept that medication and medical history may have an impact on the USCOM™ reading and that this may be considered a limitation of the study.

We did not evaluate interobserver reliability within this study because previous work in the department showed that 15 readings were required to produce an acceptable inter and intra-observer reliability. However this may be deemed a limitation of the study. Furthermore, since this study was carried out, another research group has recommended a higher number of assessed scans to achieve competence [25]. We also relied on patient-reported height/weight in some circumstances and nurse-estimated weight in other circumstances. This may have introduced an element of error into our measurements. We grouped our cardiac index readings into binary results i.e. normal or abnormal which, as we have commented upon in the discussion, is a limitation to the interpretation of our results as there may be value in looking separately at low, normal and high readings if participant numbers are increased.

## Conclusions

Our pilot data provides some evidence that cardiac index measured by USCOM™ may be useful in predicting 48-hour organ failure in patients admitted from the ED resuscitation room. This, and the trend towards abnormal CO predicting death,-suggest that a further larger study may be warranted. Any future studies may, if large enough, explore the differences in organ failure for different shock aetiologies. It may be that assessment of cardiac index using Doppler technology is best performed later during the resuscitation phase as readings of CO were not able to be measured in a high proportion of patients upon arrival, presumably deemed as unnecessary by clinicians. Our data is too small to make any firm conclusions with regard to the role that CO can play in a physiological screen in the ED. We believe that further work would be of value in order to further assess the utility of CO as a predictor of outcome in ED patients.

## Competing Interests

The authors have no conflicts of interests to declare.

### Authors' Contributions

AJNJ and TRH conceived the idea for the study. KM, CH, EG, AJNJ and TRH developed the methodology or for the study. KM, CH, EG, AJNJ and TRH collected data for and coordinated the study. CJ and SK performed the statistical analysis. CJ, SK, TRH and AJNJ drafted the text of the manuscript. All authors AJNJ, CJ, SK, CH, KM, EG and TRH approved the final manuscript.

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