



## Clinical paper

## The association between intra-arrest arterial blood pressure and return of spontaneous circulation in out-of-hospital cardiac arrest

Shadman Aziz<sup>a,b,\*</sup>, Jon Barratt<sup>a,c,d</sup>, Zachary Starr<sup>a</sup>, Kate Lachowycz<sup>a</sup>, Rob Major<sup>a</sup>,  
Ed B.G. Barnard<sup>a,c,e</sup>, Paul Rees<sup>a,b,f,g</sup>

<sup>a</sup> Department of Research, Audit, Innovation, and Development (RAID), East Anglian Air Ambulance, Norwich, UK

<sup>b</sup> Blizard Institute, Queen Mary University of London, London, UK

<sup>c</sup> Academic Department of Military Emergency Medicine, Royal Centre for Defence Medicine (Research & Clinical Innovation), Birmingham, UK

<sup>d</sup> Emergency Department, University Hospitals of North Midlands NHS Trust, Stoke-on-Trent, UK

<sup>e</sup> Emergency and Urgent Care Research in Cambridge (EURECa), PACE Section, Department of Medicine, Cambridge University, Cambridge, UK

<sup>f</sup> Academic Department of Military Medicine, Royal Centre for Defence Medicine (Research & Clinical Innovation), Birmingham, UK

<sup>g</sup> Barts Heart Centre, Barts Health NHS Trust, London, UK

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## ABSTRACT

**Background:** The optimal haemodynamic parameter for goal-directed resuscitation in out-of-hospital cardiac arrest (OHCA) remains uncertain. This study aimed to characterise the association between invasive blood pressure (IBP) measurements and return of spontaneous circulation (ROSC) in adult OHCA patients, to identify this parameter.

**Methods:** A retrospective observational study was conducted at East Anglian Air Ambulance (EAAA). Adult ( $\geq 18$  years) medical OHCA patients attended by EAAA between 01/02/2015 and 01/02/2024, who had arterial IBP measurement during chest compressions were included. The initial, minimum, maximum, average (mean) and  $\Delta$  (maximum-initial) were calculated for systolic (SBP), diastolic (DBP) and mean arterial (MAP) components of IBP. Logistic regression and receiver operating characteristic curves tested the association between IBP variables and ROSC.

**Results:** During the study period, 4363 OHCA patients were attended and 80 met inclusion criteria. Thirty-four patients (42.5 %) achieved ROSC and 4 (5.0 %) survived to discharge. The maximum, average and  $\Delta$  DBP; and maximum and average MAP were positively associated with ROSC. Maximum DBP had an AUC of 0.83 (95 % CI 0.74–0.92) with an optimal cut-off of 35 mmHg (sensitivity 94.1 %; specificity 58.7 %) for predicting ROSC. The odds ratio for ROSC was 1.05 (95 % CI 1.03–1.08) for every 1 mmHg increase in maximum DBP.

**Conclusions:** This study supports the use of arterial DBP as an important haemodynamic parameter for goal-directed resuscitation in adult OHCA. Maximising DBP may increase the chances of ROSC. These data suggest that a DBP threshold of 35 mmHg is optimal for identifying patients who may achieve ROSC with continued resuscitation.

## Introduction

Survival after out-of-hospital cardiac arrest (OHCA) remains poor in the UK, with fewer than one in ten patients (9 %) surviving to hospital discharge<sup>1</sup>. Efforts to improve outcomes from OHCA emphasise education around cardiopulmonary resuscitation (CPR) and access to public access defibrillators<sup>2</sup>. However, providers are taught to deliver CPR in a uniform manner; with a fixed rate, depth, and position. This approach

does not consider anatomical and physiological differences between patients<sup>3</sup>. Furthermore, when prehospital teams arrive at a patient in OHCA, resuscitation follows the advanced life support (ALS) algorithms, which have largely remained unchanged over the last decade<sup>4</sup>. In order to further improve outcomes from OHCA, strategies are needed which might allow clinicians on scene to deliver nuanced resuscitation; targeted for individual patients.

Direct measurement of the haemodynamic response to CPR is possible during OHCA. Coronary perfusion occurs primarily during the

\* Corresponding author at: Department of Research, Audit, Innovation, and Development (RAID), East Anglian Air Ambulance, Norwich, UK.

E-mail addresses: [shadman.aziz@eaaa.org.uk](mailto:shadman.aziz@eaaa.org.uk) (S. Aziz), [jon.barratt@eaaa.org.uk](mailto:jon.barratt@eaaa.org.uk) (J. Barratt), [zachary.starr@eaaa.org.uk](mailto:zachary.starr@eaaa.org.uk) (Z. Starr), [kate.lachowycz@eaaa.org.uk](mailto:kate.lachowycz@eaaa.org.uk) (K. Lachowycz), [rob.major@eaaa.org.uk](mailto:rob.major@eaaa.org.uk) (R. Major), [edward.barnard@eaaa.org.uk](mailto:edward.barnard@eaaa.org.uk) (E.B.G. Barnard), [paul.rees@eaaa.org.uk](mailto:paul.rees@eaaa.org.uk) (P. Rees).

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| Abbreviation |                                             | IQR   | Interquartile range                                       |
|--------------|---------------------------------------------|-------|-----------------------------------------------------------|
| AED          | Automated external defibrillator            | MAP   | Mean arterial pressure                                    |
| ALS          | Advanced life support                       | OHCA  | Out-of-hospital cardiac arrest                            |
| AoDBP        | Aortic diastolic blood pressure             | OR    | Odds ratio                                                |
| AUC          | Area under the curve                        | PEA   | Pulseless electrical activity                             |
| CCP          | Critical care paramedic                     | RAP   | Right atrial pressure                                     |
| CI           | Confidence interval                         | ROC   | Receiver operating characteristic                         |
| CPP          | Coronary perfusion pressure                 | ROSC  | Return of spontaneous circulation                         |
| CPR          | Cardiopulmonary resuscitation               | SBP   | Systolic blood pressure                                   |
| DBP          | Diastolic blood pressure                    | SD    | Standard deviation                                        |
| EAAA         | East Anglian Air Ambulance                  | SPEAR | Specialist Percutaneous Endovascular Aortic Resuscitation |
| EEAST        | East of England Ambulance Service NHS Trust | SVR   | Systemic vascular resistance                              |
| HEMS         | Helicopter Emergency Medical Services       | TOR   | Termination of resuscitation                              |
| IBP          | Invasive blood pressure                     | VF    | Ventricular fibrillation                                  |
|              |                                             | VT    | Ventricular tachycardia                                   |

decompression phase of external chest compressions, which is the equivalent of diastole during cardiac arrest<sup>5–6</sup>. This blood flow is driven by the diastolic pressure gradient between the proximal aorta (AoDBP) and right atrium (RAP), developing a resultant coronary perfusion pressure (CPP)<sup>7</sup>. If invasive arterial catheters are in situ during cardiac arrest, the afferent component of the CPP can be estimated by measuring the arterial diastolic blood pressure (DBP)<sup>6</sup>.

Higher DBP has been associated with increased chances of achieving return of spontaneous circulation (ROSC)<sup>7–13</sup>. International guidelines on CPR quality have recommended ‘goal-directed’ titration of chest compression parameters and/or vasopressor administration to an DBP of > 25 mmHg, where invasive blood pressure (IBP) monitoring is present<sup>6</sup>. However, other studies have proposed that a DBP of at least 40 mmHg is required for successful resuscitation<sup>8–9</sup>. Furthermore, there is conflicting evidence suggesting that systolic blood pressure (SBP) or mean arterial blood pressure (MAP) may be better parameters for goal-directed resuscitation.<sup>11</sup> Lastly, there remains a paucity of data on the association between IBP and outcomes in OHCA, likely due to the perceived difficulties of initiating arterial IBP monitoring in the pre-hospital environment<sup>14</sup>. Accordingly, the optimal haemodynamic parameter for goal-directed resuscitation in OHCA remains undetermined.

The East Anglian Air Ambulance (EAAA) has used arterial IBP monitoring during OHCA since 2014<sup>15–16</sup>. Using physiological data recorded from this cohort, this retrospective observational study aimed to characterise the association between intra-arrest arterial IBP measurements and the primary outcome (ROSC) in adult OHCA patients; and to establish a potential optimal IBP parameter to inform prehospital goal-directed resuscitation.

## Methods

### Study design and setting

A retrospective observational study was conducted of all OHCA patients attended by EAAA between the introduction of the service electronic patient record (HEMSbase, MedicOne Systems Ltd, UK) on 1 February 2015 to 1 February 2024 (latest patient outcome data).

EAAA is a helicopter emergency medical service (HEMS) operating in the East of England, UK. The East of England is a geographical area of 20,000 km<sup>2</sup> with a population of approximately 6.4 million. The statutory ambulance service operating in this area is the East of England Ambulance Service Trust (EEAST)<sup>17</sup>. Resuscitation is attempted by EEAST in approximately 3000 OHCA patients per annum. Of these, approximately 17 % are attended by EAAA<sup>18</sup>. The HEMS team consists of at least one physician and one critical care paramedic (CCP), dispatched from bases in Norwich and Cambridge. They respond either by

helicopter or rapid response vehicle, depending on patient location and weather conditions<sup>19</sup>.

In addition to standard ALS, the EAAA team provides enhanced decision making and delivers the following prehospital critical care interventions: prehospital emergency anaesthesia, mechanical ventilation, central venous access, vasoactive infusions, oesophageal temperature monitoring, point-of-care ultrasonography, and arterial blood gas analysis<sup>4,18</sup>. Arterial catheterisation has been performed by EAAA clinicians since 2014 and is utilised in select cases of OHCA to monitor IBP during external chest compressions<sup>15</sup>. This allows for modification of chest compression position to maximise DBP, and to monitor the effect of vasopressor administration. Radial and brachial arterial catheterisation are performed via palpation or ultrasound-guidance using a 20G over-the-needle arterial cannula with flow-switch blood control (Becton, Dickinson and Company, New Jersey, USA). Since September 2021, a dedicated programme of ultrasound-guided percutaneous femoral arterial catheterisation using 5Fr vascular access sheaths (MERIT Prelude®, Merit Medical, Utah, USA) entitled Specialist Percutaneous Emergency Aortic Resuscitation (SPEAR), was started at EAAA in order to improve physiological monitoring intra-arrest and deliver nuanced, goal-directed resuscitation in OHCA patients<sup>16</sup>. The intra-arrest use of arterial catheters is described in further detail in Supplementary Appendix 1.

### Inclusion and exclusion criteria

A consecutive sample of adult (>18 years old) medical OHCA patients attended by EAAA, with arterial IBP measured during ongoing resuscitation were included in the study. Patients were excluded if IBP measurements were obtained only after ROSC.

### Data collection

Patient data from the electronic patient record (HEMSbase, MedicOne Systems Ltd, UK) were collated in a data spreadsheet (Microsoft® Excel® for Microsoft 365, v2308), and stored in a secure data environment. Physiological data, recorded by time-calibrated monitors (X Series®, ZOLL Medical Corporation, Runcorn, UK) and automatically uploaded to HEMSbase at two-minute intervals, or directly extracted from the ZOLL monitor JSON file at 30-second intervals; were collected and interrogated by two trained data abstractors. Patient outcome data is regularly obtained from EEAST and supplemented by outcome information collected by the EAAA Aftercare Team.

The following variables were collected: age, sex, aetiology, bystander CPR, witnessed arrest, initial rhythm, type of CPR (mechanical or manual), arterial catheter site (femoral, radial or brachial), pH, base deficit, end-tidal CO<sub>2</sub>, IBP measurements (SBP, DBP and MAP),

ROSC achieved and survival to hospital discharge (or transfer). Only IBP measurements during the period of external chest compressions were analysed. The initial, maximum, minimum, average and the  $\Delta$  (difference between the initial and maximum measurements) in IBP measurements were determined for the three components of IBP (SBP, DBP and MAP) in each patient.

### Outcome measures

The primary outcome was prehospital ROSC, defined as clinical evidence of signs of life comprising a palpable pulse or generating a blood pressure (i.e., a self-sustained pulsatile IBP waveform), achieved at any time before arrival to a hospital facility<sup>20</sup>. Survival to hospital discharge (or transfer) was a secondary outcome.

### Data analysis

Manipulation of data and statistical analyses were performed in RStudio (Version 2023.12.1.402.1, Posit Software, PBC, Boston, MA) using the R statistical programming language (R Foundation for Statistical Computing, Vienna, Austria)<sup>21</sup>.

Sample characteristics were described using number (percentage) for categorical variables and mean ( $\pm$ standard deviation (SD)) for continuous variables. The Chi-square test was used to compare proportions unless there was a cell count  $< 5$ , in which case Fisher's exact test was used. The Two-sample *t*-test was used to compare means. A pre-defined significance value of  $p < 0.05$  was used throughout. P-values for the comparisons of IBP data between groups were Bonferroni-adjusted for multiple (fifteen) comparisons.

Univariate logistic regression was used to test the association between IBP measurements and ROSC. Odds ratios (ORs) and 95 % confidence intervals (95 % CIs) were computed for every 1 mmHg increase in IBP measurements. The P-values indicating the statistical significance of ORs were also Bonferroni-adjusted for multiple (fifteen) comparisons. The receiver operating characteristic (ROC) area under the curve (AUC) values were also calculated for each IBP variable in order to evaluate their ability to discriminate ROSC. AUCs were compared using the DeLong method<sup>22</sup>. To identify the optimal threshold for achieving ROSC, the ROC cut-off point that maximised sensitivity whilst

preserving specificity was calculated for the IBP variable with the highest AUC point estimate. Lastly, in order to test the robustness of the findings, a pre-planned sensitivity analysis was conducted. This excluded IBP measurements from the two minutes prior to ROSC, as these data may represent intrinsic cardiac contraction (i.e., unrecognised ROSC) rather than external chest compressions.

### Ethical review

Ethical approval for the study was granted by Queen Mary University of London (ERM\_0007). It is reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines<sup>23</sup>.

### Results

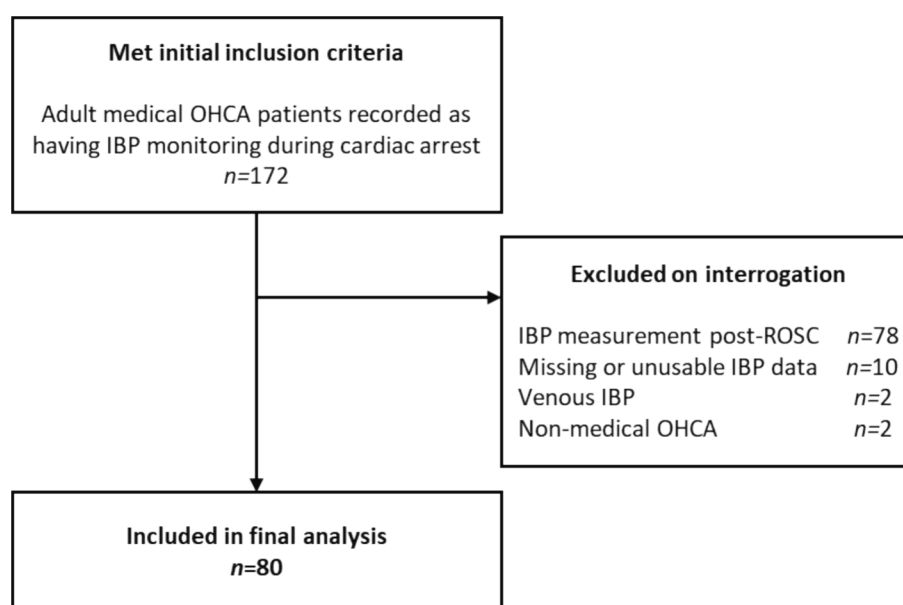
During the study period, 4363 OHCA patients were attended by EAAA. After exclusions, 80 patients were included in the final analysis (Fig. 1).

Due to the study inclusion criteria, there were no missing IBP measurements. Therefore, a complete case analysis was utilised, and multiple imputation was not required. The prevalence of intra-arrest IBP monitoring was 1.8 %. Patient characteristics are presented in Table 1.

The mean age was  $59 \pm 13$  and the majority of patients were male ( $n = 60$ , 75 %). ROSC was achieved in 34 patients (42.5 %). Only four patients (5.0 %) survived to hospital discharge, precluding any statistical analysis of this secondary outcome. Patients who achieved ROSC had a longer mean time interval from arrest to IBP initiation ( $54.7 \pm 15.0$  min) than those who did not ( $46.9 \pm 9.4$  min;  $p = 0.010$ ). However, the time interval from first IBP to maximum DBP showed no significant difference between ROSC ( $10.9 \pm 11.4$  min) and non-ROSC groups ( $9.2 \pm 11.7$  min;  $p = 0.50$ ). (Table S1 in Supplementary Appendix 2).

The maximum and average DBP, and maximum and average MAP were significantly higher in patients who achieved prehospital ROSC compared to those who did not (Table 2).

This statistical significance persisted in the sensitivity analysis excluding IBP measurements from the two-minutes prior to ROSC (Table S3 in Supplementary Appendix 3). Notably, the maximum DBP generated during the phase of external chest compressions was



**Fig. 1.** Study flow diagram of adult medical out-of-hospital cardiac arrest patients with intra-arrest invasive blood pressure monitoring, attended by East Anglian Air Ambulance between 1 February 2015 and 1 February 2024. Abbreviations: IBP: Invasive blood pressure; OHCA: out-of-hospital cardiac arrest; ROSC: return of spontaneous circulation.

**Table 1**  
Patient characteristics in adult medical out-of-hospital cardiac arrest patients with intra-arrest invasive blood pressure monitoring, attended by East Anglian Air Ambulance between 1 February 2015 and 1 February 2024.

| Characteristic                               | Overall<br>n = 80 | No ROSC<br>n = 46 | ROSC<br>n = 34 | p-value             |
|----------------------------------------------|-------------------|-------------------|----------------|---------------------|
| Age, years <sup>1</sup>                      | 59 (13)           | 59 (14)           | 58 (13)        | 0.86 <sup>‡</sup>   |
| Sex                                          |                   |                   |                | 0.79 <sup>‡</sup>   |
| Male                                         | 60 (75 %)         | 34 (74 %)         | 26 (76 %)      |                     |
| Female                                       | 20 (25 %)         | 12 (26 %)         | 32 (24 %)      |                     |
| Aetiology                                    |                   |                   |                | 0.61 <sup>§</sup>   |
| Myocardial infarction                        | 39 (49 %)         | 22 (48 %)         | 17 (50 %)      |                     |
| Pulmonary embolism                           | 10 (13 %)         | 5 (11 %)          | 5 (15 %)       |                     |
| Arrythmia                                    | 3 (3.8 %)         | 1 (2.2 %)         | 2 (5.9 %)      |                     |
| Hypoxia                                      | 2 (2.5 %)         | 2 (4.3 %)         | 0 (0 %)        |                     |
| Metabolic                                    | 2 (2.5 %)         | 1 (2.2 %)         | 1 (2.9 %)      |                     |
| Aortic dissection                            | 1 (1.3 %)         | 1 (2.2 %)         | 0 (0 %)        |                     |
| Hypothermia                                  | 1 (1.3 %)         | 1 (2.2 %)         | 0 (0 %)        |                     |
| Hypovolaemia                                 | 1 (1.3 %)         | 0 (0 %)           | 1 (2.9 %)      |                     |
| Neurological                                 | 1 (1.3 %)         | 0 (0 %)           | 1 (2.9 %)      |                     |
| Toxic                                        | 1 (1.3 %)         | 0 (0 %)           | 1 (2.9 %)      |                     |
| Unknown / not recorded                       | 19 (24 %)         | 13 (28 %)         | 6 (18 %)       |                     |
| Bystander CPR                                | 61 (76 %)         | 38 (83 %)         | 23 (68 %)      | 0.12 <sup>‡</sup>   |
| Witnessed arrest                             | 66 (83 %)         | 36 (78 %)         | 30 (88 %)      | 0.25 <sup>‡</sup>   |
| Initial rhythm                               |                   |                   |                | 0.28 <sup>§</sup>   |
| VF                                           | 29 (36 %)         | 13 (28 %)         | 16 (47 %)      |                     |
| Asystole                                     | 16 (20 %)         | 12 (26 %)         | 4 (12 %)       |                     |
| PEA                                          | 14 (18 %)         | 8 (17 %)          | 6 (18 %)       |                     |
| AED – Shockable                              | 12 (15 %)         | 7 (15 %)          | 5 (15 %)       |                     |
| AED – Non-shockable                          | 8 (10 %)          | 6 (13 %)          | 2 (5.9 %)      |                     |
| VT (pulseless)                               | 1 (1.3 %)         | 0 (0 %)           | 1 (2.9 %)      |                     |
| Type of CPR                                  |                   |                   |                | 0.63 <sup>§</sup>   |
| Mechanical CPR initiated                     | 76 (95 %)         | 43 (93 %)         | 33 (97 %)      |                     |
| Manual CPR only                              | 4 (5.0 %)         | 3 (6.5 %)         | 1 (2.9 %)      |                     |
| Arterial catheter site                       |                   |                   |                | 0.51 <sup>§</sup>   |
| Femoral                                      | 37 (46 %)         | 24 (52 %)         | 13 (38 %)      |                     |
| Radial                                       | 33 (41 %)         | 16 (35 %)         | 17 (50 %)      |                     |
| Brachial                                     | 6 (7.5 %)         | 4 (8.7 %)         | 2 (5.9 %)      |                     |
| Unknown                                      | 4 (5.0 %)         | 2 (4.3 %)         | 2 (5.9 %)      |                     |
| pH <sup>1</sup>                              | 6.81 (0.19)       | 6.81 (0.19)       | 6.81 (0.19)    | 0.93 <sup>‡</sup>   |
| Missing                                      | 22                | 13                | 9              |                     |
| Base deficit <sup>1</sup>                    | −20 (6)           | −19 (6)           | −21 (6)        | 0.21 <sup>‡</sup>   |
| Missing                                      | 26                | 16                | 10             |                     |
| End-tidal CO <sub>2</sub> , kPa <sup>1</sup> | 3.58 (1.72)       | 3.49 (1.53)       | 3.67 (1.96)    | 0.76 <sup>‡</sup>   |
| Missing                                      | 44                | 27                | 17             |                     |
| TOR at scene                                 | 61 (76 %)         | 45 (98 %)         | 16 (47 %)      | <0.001 <sup>‡</sup> |
| Survival to discharge                        | 4 (5.0 %)         | 0 (0 %)           | 4 (12 %)       | 0.029 <sup>§</sup>  |

Data are expressed as n= (%) unless otherwise stated. <sup>1</sup>Mean (SD).  
Abbreviations: AED: automated external defibrillator; CPR: cardiopulmonary resuscitation; PEA: pulseless electrical activity; ROSC: return of spontaneous circulation; SD: standard deviation; TOR: termination of resuscitation; VF: ventricular fibrillation; VT: ventricular tachycardia.  
<sup>‡</sup> Two-sample *t*-test; <sup>‡</sup>Chi-squared test; <sup>§</sup>Fisher's exact test. P-values below 0.10 are reported to 3 decimals for clarity.

**Table 2**  
Comparison of intra-arrest invasive blood pressure variables between patients with and without return of spontaneous circulation during the total time of external chest compressions.

| Measurement                     | Overall<br>n = 79 | No ROSC<br>n = 46 | ROSC<br>n = 33 | p-value <sup>‡</sup> |
|---------------------------------|-------------------|-------------------|----------------|----------------------|
| <b>Systolic blood pressure</b>  |                   |                   |                |                      |
| Initial SBP                     | 88 (54)           | 77 (53)           | 101 (54)       | 0.78                 |
| Minimum SBP                     | 55 (40)           | 51 (42)           | 60 (37)        | >0.99                |
| Maximum SBP                     | 136 (69)          | 118 (67)          | 160 (64)       | 0.09                 |
| Average SBP                     | 93 (49)           | 84 (51)           | 105 (43)       | 0.81                 |
| Δ SBP                           | 49 (49)           | 41 (44)           | 59 (53)        | >0.99                |
| <b>Diastolic blood pressure</b> |                   |                   |                |                      |
| Initial DBP                     | 22 (17)           | 18 (13)           | 27 (21)        | 0.42                 |
| Minimum DBP                     | 12 (12)           | 9 (6)             | 17 (17)        | 0.18                 |
| Maximum DBP                     | 48 (28)           | 36 (22)           | 65 (27)        | <0.001               |
| Average DBP                     | 28 (18)           | 21 (13)           | 37 (20)        | 0.003                |
| Δ DBP                           | 27 (25)           | 18 (20)           | 38 (27)        | 0.011                |
| <b>Mean arterial pressure</b>   |                   |                   |                |                      |
| Initial MAP                     | 47 (25)           | 40 (19)           | 57 (28)        | 0.06                 |
| Minimum MAP                     | 33 (20)           | 28 (14)           | 40 (24)        | 0.15                 |
| Maximum MAP                     | 73 (36)           | 59 (29)           | 92 (36)        | <0.001               |
| Average MAP                     | 52 (25)           | 44 (20)           | 63 (26)        | 0.012                |
| Δ MAP                           | 26 (27)           | 19 (22)           | 35 (31)        | 0.22                 |

Data are expressed as mean (SD).  
*Abbreviations:* DBP: diastolic blood pressure; IQR: interquartile range; MAP: mean arterial pressure; ROSC: return of spontaneous circulation; SBP: systolic blood pressure.  
<sup>‡</sup> Two-sample *t*-test. P-values are Bonferroni adjusted for multiple (fifteen) comparisons. P-values below 0.10 are reported to 3 decimals for clarity.

significantly higher in patients who achieved ROSC (mean difference 28 mmHg; 95 % CI 17–40; *p* < 0.001).  
The associations between all IBP measurements and ROSC are presented in [Table 3](#). Using a univariable logistic regression model, maximum, average and Δ DBP; and the maximum and average MAP had a significant association with ROSC. The maximum and average

**Table 3**  
Unadjusted odds ratio and area under the receiver operating curve for the association between invasive blood pressure and return of spontaneous circulation during the total time of external chest compressions.

| Measurement                     | OR (95 % CI)     | p-value <sup>‡</sup> | AUC (95 % CI)    |
|---------------------------------|------------------|----------------------|------------------|
| <b>Systolic blood pressure</b>  |                  |                      |                  |
| Initial SBP                     | 1.01 (1.00–1.02) | 0.90                 | 0.64 (0.52–0.77) |
| Minimum SBP                     | 1.01 (1.00–1.02) | >0.99                | 0.60 (0.48–0.73) |
| Maximum SBP                     | 1.01 (1.00–1.02) | 0.14                 | 0.69 (0.57–0.81) |
| Average SBP                     | 1.01 (1.00–1.02) | >0.99                | 0.66 (0.54–0.78) |
| Δ SBP                           | 1.01 (1.00–1.02) | >0.99                | 0.62 (0.49–0.75) |
| <b>Diastolic blood pressure</b> |                  |                      |                  |
| Initial DBP                     | 1.03 (1.01–1.07) | 0.37                 | 0.62 (0.48–0.75) |
| Minimum DBP                     | 1.07 (1.02–1.13) | 0.17                 | 0.62 (0.49–0.76) |
| Maximum DBP                     | 1.05 (1.03–1.08) | <0.001               | 0.83 (0.74–0.92) |
| Average DBP                     | 1.07 (1.03–1.11) | 0.013                | 0.77 (0.67–0.88) |
| Δ DBP                           | 1.04 (1.02–1.06) | 0.022                | 0.73 (0.60–0.85) |
| <b>Mean arterial pressure</b>   |                  |                      |                  |
| Initial MAP                     | 1.03 (1.01–1.06) | 0.067                | 0.69 (0.57–0.81) |
| Minimum MAP                     | 1.04 (1.01–1.07) | 0.16                 | 0.65 (0.53–0.78) |
| Maximum MAP                     | 1.03 (1.02–1.05) | 0.005                | 0.77 (0.67–0.87) |
| Average MAP                     | 1.04 (1.02–1.06) | 0.028                | 0.73 (0.62–0.84) |
| Δ MAP                           | 1.02 (1.01–1.05) | 0.24                 | 0.66 (0.53–0.79) |

*Abbreviations:* AUC: area under the receiver operating curve; DBP: diastolic blood pressure; MAP: mean arterial pressure; OR: odds ratio; SBP: systolic blood pressure.  
<sup>‡</sup> P-values for odd ratios are Bonferroni adjusted for multiple (fifteen) comparisons. P-values below 0.10 are reported to 3 decimals for clarity.

measurements remained statistically significant in the sensitivity analysis excluding IBP measurements from the last two minutes before ROSC (Table S4 in Supplementary Appendix 3). Maximum DBP had the largest AUC point-estimate for discriminating ROSC (0.83; 95 % CI 0.74–0.92) with an optimal cut-off of 35 mmHg [sensitivity 94.1 % (95 % CI 80.3 %–99.3 %); specificity 58.7 % (95 % CI 43.2 %–73.0 %)] for predicting ROSC (Fig. 2). However, there was no significant difference between the AUC of maximum DBP compared to average DBP, Δ DBP and maximum MAP respectively (Table S2 in Supplementary Appendix 2).

The odds ratio for ROSC was 1.05 (95 % CI 1.03–1.08;  $p < 0.001$ ) for every 1 mmHg increase in maximum DBP. No patients with a maximum DBP below 28 mmHg achieved ROSC (Fig. 3).

Discussion

This study has demonstrated that intra-arrest arterial IBP measurement is achievable in the prehospital setting and provides useful information about the haemodynamic response to CPR. The average DBP, maximum DBP, Δ DBP, average MAP and maximum MAP generated by CPR were significantly higher in patients who achieved ROSC compared to those who did not. Maximum DBP had an AUC of 0.83 for the primary outcome, with an increase in the odds of ROSC of 5 % for every 1 mmHg increase in maximum DBP.

These results agree with previous animal and human studies that found that arterial DBP is a useful surrogate for the afferent component of CPP and is associated with ROSC<sup>8,11–13</sup>. However, no previous studies have demonstrated this relationship in the early prehospital phase of OHCA. CPP remains the ideal haemodynamic parameter for goal-directed resuscitation, as it considers both the driving pressure from the AoDBP, and the resistance to flow from the RAP. However, measurement of CPP is generally not practical prehospitally, as insertion of aortic and upper-thoracic central venous catheters might presents significant technical challenges in the context of ongoing resuscitation. Furthermore, most portable monitors cannot display CPP in real-time. In view of this, the findings of this study support the measurement of DBP as a suitable alternative parameter for goal-directed resuscitation in the prehospital environment.

This study also investigated various methods to report and analyse DBP variables to help outline which might be most meaningful to resuscitation teams. The average DBP had the highest OR for ROSC, but maximum DBP showed greater precision and AUC. However, this difference in AUC was not statistically significant. In this cohort, the optimal cut-off for the maximum DBP in predicting ROSC was 35 mmHg. This DBP threshold was chosen as it maximised sensitivity whilst preserving specificity; which is optimal for identifying patients who may

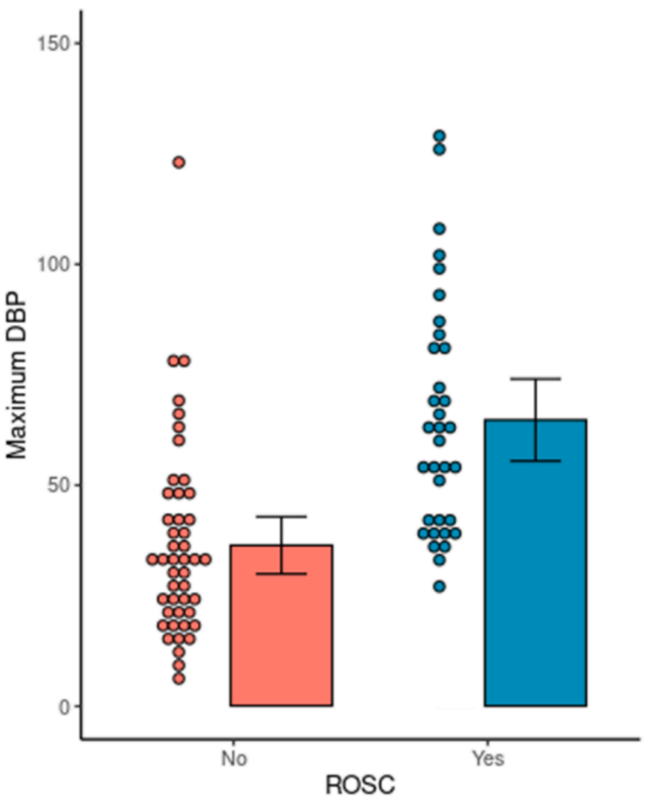


Fig. 3. Distribution of maximum intra-arrest diastolic blood pressures among patients who achieved ROSC (right) and those who did not achieve ROSC (left). Each dot represents a patient. Bar chart shows mean (95% CI).Abbreviations: DBP: diastolic blood pressure; ROSC: return of spontaneous circulation.

achieve ROSC with continued resuscitation, whilst minimising prolonged invasive resuscitation in patients who are unlikely to be successfully resuscitated.

No significant association was detected between the initial measurements of DBP and ROSC, consistent with previous findings<sup>11</sup>. The minimum DBP also had no association with ROSC, which is understandable, as this may capture DBP measurements during pulse checks and other pauses in CPR. Notably, there was initially a significant association between the Δ DBP measurements and ROSC in this cohort, but this did not persist in the sensitivity analysis. This suggests that the Δ

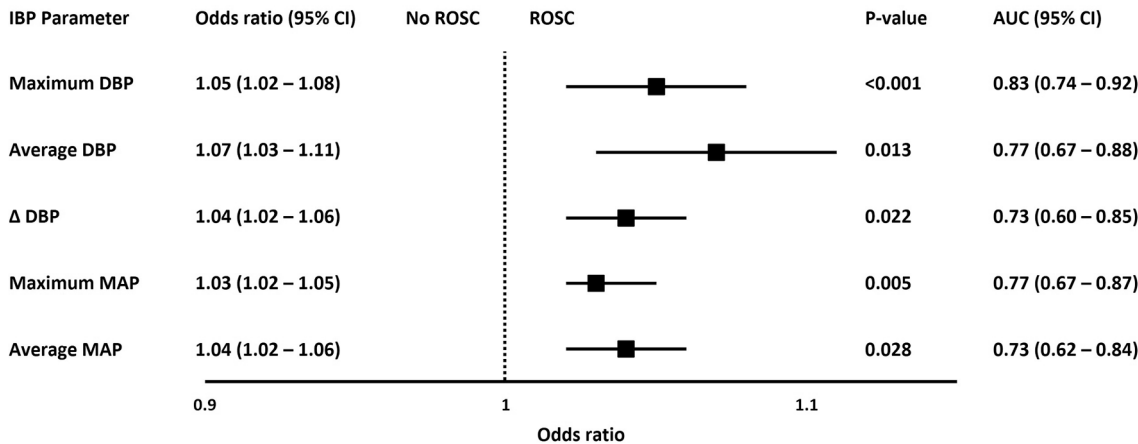


Fig. 2. Forest plot demonstrating the odds ratio (95% CI) and AUC for IBP variables with statistically significant associations with ROSC.Abbreviations: AUC: area under the curve; CI: confidence interval; DBP: diastolic blood pressure; IBP: Invasive blood pressure; MAP: mean arterial pressure; OR: odds ratio; SBP: systolic blood pressure; ROSC: return of spontaneous circulation.

DBP from the initial measurement has a smaller effect size than rapidly achieving an overall higher maximum DBP and maintaining this over the duration of CPR (higher average DBP).

Higher average and maximum MAP were also associated with ROSC, although their association was weaker than average and maximum DBP, respectively. As DBP is a determinant of the MAP, it is logical that MAP is also associated with ROSC. Koyama *et al.* identified an association between MAP and ROSC in a large cohort of patients transported to Japanese Emergency Departments after non-traumatic OHCA<sup>11</sup>. However, they also found an association between the SBP and ROSC, which was not observed in this study; and found that both MAP and SBP had a stronger association with ROSC compared to DBP.

One potential explanation is that measured or displayed DBP values only represent the blood pressure at the nadir of the arterial waveform. It has been suggested that although this point accurately represents end-diastolic pressure during spontaneous cardiac contractions, it may actually represent the reformation of the aortic outflow tract during the early decompression phase of CPR<sup>24</sup>. Coronary perfusion may occur at any point when the pressure in the aortic root exceeds the pressure within the ventricles, which may not be accurately represented by the DBP value displayed on IBP monitors during CPR, leading to type II error. Additionally, in the case of the right ventricle, perfusion predominantly occurs during systole, as the systolic pressure in the aortic root likely exceeds the right ventricular systolic pressure<sup>25</sup>. Therefore, MAP, which is the average calculated blood pressure throughout the cardiac cycle; and SBP, which is measured at the peak of the arterial waveform and determines MAP; may also be important determinants of myocardial perfusion, and therefore ROSC. Although this study supports the use of DBP for goal-directed resuscitation, the overall evidence remains conflicted, and clinicians must be aware of the caveats with the DBP value displayed on the monitor.

#### Future directions

Although this study found significantly higher average DBP values in patients who achieved ROSC compared to those who did not, it cannot comment on the specific circumstances that led to this difference. DBP during cardiac arrest is the result of complex relationships between chest compression parameters and systemic vascular resistance (SVR), both of which can be modulated during resuscitation<sup>26</sup>. The next logical step for research could be to use IBP monitoring to prospectively evaluate interventions that can be used to augment DBP in goal-directed resuscitation.

Current resuscitation guidelines recommend uniform rate, depth and hand position for delivery of 'high-quality CPR' to optimise blood pressure, perfusion and outcomes<sup>3</sup>. However, these uniform parameters do not account for anatomical and physiological differences between patients. Multiple studies have identified suboptimal compression of the left ventricle, or compression of the left ventricular outflow tract, when CPR is performed on the lower half of the sternum<sup>27–32</sup>. Recent studies have also demonstrated improvement of left ventricular compression by using ultrasound to change hand position during CPR<sup>28,32</sup>. These results highlight that blind, uniform application of CPR parameters may be harmful; and where possible, 'customised' resuscitation utilising IBP monitoring should be considered in order to improve quality of CPR.

Another major determinant of DBP is SVR, which is augmented during cardiac arrest through administration of vasopressors such as adrenaline. Current ALS guidelines recommend that the adrenaline administration interval should be every 3–5 min<sup>4</sup>. However, the haemodynamic response to adrenaline is known to be variable and diminishes with time<sup>33</sup>. Drumheller *et al.* recently demonstrated the feasibility of using goal-directed resuscitation to titrate the administration of vasopressors to DBP in refractory OHCA<sup>9</sup>. Further research is required to develop nuanced protocols that move away from fixed-interval, supra-physiological boluses of vasopressors to those utilising goal-directed titration of vasopressors to DBP in order to optimise

coronary perfusion and improve patient outcomes.

#### Limitations

This was a single centre, retrospective observational cohort study and relied on accurate record keeping. The definition of the phase of external chest compression was based on the timings in the patient record form, which may be subject to recall or recording bias. The generalisability of this study to all OHCA is also limited, as it only included patients attended by single HEMS service, who are predominantly dispatched to patients with favourable OHCA characteristics. Conversely, the prevalence of intra-arrest IBP monitoring was low, as it was only initiated in patients who were in refractory OHCA despite optimal ALS. The small sample size and low survival rate also precluded analysis of the association between IBP and the secondary outcome measure of survival to hospital discharge. The regression model did not adjust for other well-known predictors of ROSC; however, baseline characteristics did not differ significantly between groups, and it was agreed that a univariate approach would better mirror how IBP parameters would be interpreted in practice. Further research is required in larger cohorts to confirm the validity of this study, and to investigate the relationship between IBP and other outcomes such as survival to hospital discharge and neurological outcomes.

#### Conclusion

This study supports the use of arterial DBP as an important haemodynamic parameter for goal-directed resuscitation in adult OHCA. Maximising DBP may increase the chances of ROSC. These data suggest that a DBP threshold of 35 mmHg is optimal for identifying patients who may achieve ROSC with continued resuscitation.

#### CRedit authorship contribution statement

**Shadman Aziz:** Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jon Barratt:** Writing – original draft, Visualization, Supervision, Methodology, Conceptualization. **Zachary Starr:** Writing – review & editing, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Kate Lachowycz:** Writing – original draft, Visualization, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rob Major:** Writing – review & editing, Methodology, Conceptualization. **Ed B.G. Barnard:** Writing – review & editing, Methodology, Conceptualization. **Paul Rees:** Writing – original draft, Visualization, Supervision, Methodology, Conceptualization.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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#### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.resuscitation.2024.110426>.

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