Review

Goldilocks in cardiac arrest: A scoping review of invasive hemodynamic monitoring in the pre-hospital setting for getting adrenaline dosing just right

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Abstract

Introduction

A one-size-fits-all approach to adrenaline dosing is likely to be sub-optimal for out-of-hospital cardiac arrest given the diverse nature of patient age, bodyweight, frailty and intra-arrest coronary perfusion pressure. An individualised adrenaline dosing approach to cardiac arrest using invasive blood pressure monitoring has been shown to increase rates of return of spontaneous circulation in the hospital setting, but evidence for this approach has not yet been reviewed in the pre-hospital setting.

Methods

A scoping review was undertaken using Science Direct, ProQuest, PubMed, CINAHL Complete and GALE Health and Wellness databases with the search terms 'arterial line', 'pre-hospital', 'cardiac arrest' and similar derivatives. Subject matter experts and authors of articles meeting inclusion criteria were also consulted to help identify further relevant studies. Articles were included if they pertained to the use of arterial lines in cardiac arrest in the pre-hospital field, and excluded if they related to traumatic cardiac arrest, in a language other than English, Dutch or French, or not retrievable as a full text.

Results

A total of 1408 articles were identified using the search method, of which three remained after de-duplication, use of inclusion and exclusion criteria, and full text appraisal. The current pre-hospital literature is lacking and avenues for further research to improve the evidence for hemodynamic guided resuscitation were identified.

Conclusion

Paramedic-initiated invasive arterial monitoring presents a new, but as yet unproven, intervention for improving cardiac arrest outcomes.

Keywords:

out-of-hospital cardiac arrest (OHCA); invasive blood pressure (IBP); arterial line; guided adrenaline dosing; paramedicine

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Introduction

The outcomes of out-of-hospital cardiac arrest (OHCA) have been dramatically improved by early defibrillation and widespread public knowledge of cardiopulmonary resuscitation, but unfortunately the use of anti-arrhythmic drugs has not yielded similar results (1-4). Although the PARAMEDIC-2 trial did demonstrate increased rates of return of spontaneous circulation (ROSC) and survival to hospital discharge, it also showed an increased rate of survivors with severe neurological impairment (5). One possible explanation for these lacklustre outcomes is the one-dose-fits-all approach of the adult advanced life support algorithms, where all patients are given 1 milligram of intravenous adrenaline at regular intervals, irrespective of age, bodyweight, frailty or coronary perfusion pressure (CPP). Individualised pharmacotherapy has already demonstrated its benefit in a range of other clinical contexts, such as with analgesia, antiplatelet therapy and psychotherapy (6-8). The positive effects of adrenaline in cardiac arrest on CPP need to be balanced with the deleterious dose-dependent effects of increasing myocardial oxygen consumption, arrhythmogenicity and potentially decreasing cerebral microcirculatory flow (9-12).

Tailoring pharmacological interventions during resuscitation according to hemodynamic parameters has been suggested as early as the 1980s (13,14), and more recently an individualised adrenaline dosing approach to cardiac arrest using invasive blood pressure (IBP) monitoring has been shown to increase rates of ROSC in a hospital setting (15). Coronary perfusion pressure can be calculated by measuring the aortic diastolic blood pressure and subtracting the right atrial pressure (9). If a central venous pressure is not available, an aortic diastolic blood pressure can be used as a surrogate marker for CPP. Consensus guidelines suggest titrating resuscitation efforts to an arterial diastolic blood pressure of 25–30 mmHg when invasive arterial blood pressure monitoring, but no central venous blood pressure monitoring, is in place before onset of cardiac arrest (16). No specific consensus guidelines have been produced regarding the initiation of invasive monitoring during cardiac arrest, but this is being practised by some resuscitation experts (17).

Arterial line placement for hemodynamic monitoring is ubiquitous in intensive care and surgical settings, however its use is not yet widespread in the paramedic profession (18,19). End-tidal carbon dioxide is the only widely available hemodynamic measurement in cardiac arrest, albeit suggestive at best, and likely inferior to invasive endpoints for making treatment decisions (20). Intra-arrest arterial line placement is notably more challenging without the use of ultrasonography (21). In the New Zealand setting, ambulances do not typically carry an ultrasound machine, and paramedics are not yet trained in their use.

The aim of this scoping review is to evaluate the current evidence for the placement of arterial lines and hemodynamic monitoring by paramedics to guide adrenaline dosing in OHCA.

Methods

A scoping review was undertaken using the Science Direct, ProQuest, PubMed, CINAHL Complete, and GALE Health and Wellness databases using the search terms 'arterial line', 'pre-hospital', 'cardiac arrest', the Boolean operator 'AND', as well as similar keywords (Table 1). Reference lists of studies meeting the inclusion criteria were evaluated for relevant publications. Due to the niche nature of the topic, subject matter experts and authors of articles meeting inclusion criteria were also consulted to help identify further relevant studies.

This search strategy was purposefully designed to capture as many relevant articles as possible. Studies were included if they discussed the use of an arterial line, involved the pre-hospital setting, and related to patients in cardiac arrest. Studies were excluded if the full text was not available, pertained to traumatic cardiac arrest or in a language other than English, French or Dutch (Table 2). No time limiters were applied.

All search results were stored and de-duplicated using the reference management software Endnote (Version X9.3.3). Articles meeting inclusion criteria were then assessed using the Critical Appraisal Skills Programme qualitative research checklist (22). Data was then extracted, including interventions undertaken, insertion techniques, time for cannulation and preparation of the IBP set, and any patient-related outcomes.

Table 1. Search terms used

Arterial line	Pre-hospital	Cardiac arrest
Invasive blood pressure	Out-of-hospital	Cardiopulmonary resuscitation
Hemodynamic monitoring	Paramedic	Resuscitation

Table 2. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Use of invasive blood pressure monitoring	Full text not available
Pre-hospital setting	Not available in English, French or Dutch
Patient in cardiac arrest	Cardiac arrest secondary to trauma

Results

The search created a total of 1408 results, and after review using the inclusion criteria and removal of duplicates, 14 eligible articles were found. On further review and appraisal of the full texts, three articles remained (Table 3). The main reasons for exclusion were articles not meeting one of the three search domains: not in a pre-hospital setting, no use of invasive hemodynamic monitoring, or not relating to cardiac arrest (Figure 1).

The overall level of evidence was low, and heterogenous in nature, with two of the studies being observational and one being a singular case study. All the articles were published between 2010 and 2013. No randomised-controlled trials were found. The studies predominantly focussed on the feasibility of IBP monitoring in OHCA and were not designed to investigate the titration of adrenaline dosing specifically. The critical appraisal checklist highlighted one study with a disclosed potential conflict of interest (23).

Multiple benefits of pre-hospital arterial lines

A case report by Wildner et al (23) makes the point that common pre-hospital hemodynamic monitoring modalities only provide delayed secondary measurements such as end-tidal carbon dioxide monitoring. The success of their prolonged resuscitation was attributed to being able to visualise the arterial blood pressure measurement. In addition to titrating adrenaline, continuous hemodynamic monitoring was used to guide effectiveness of compressions. The arterial line also allowed for blood gas analysis, which guided ventilation parameters.

Time taken and potential implications

Arterial cannulation and preparation of the transducer set can be completed pre-hospitally in times comparable to in-hospital settings (19). A prospective observational study resulted in a median time for successful arterial cannulation of 2 minutes (range 30–600 seconds), and preparation of the IBP set of 3 minutes (range 30–600 seconds) (19). The overwhelming majority of arterial cannulations in this study were completed by a physician well versed in the procedure. It is worthwhile noting that some of these cannulations were performed by especially trained emergency medical technicians under supervision.

A retrospective feasibility study showed that a specially prepared sterile pack can reduce time to prepare the transducer and pressure lines by a physician to just 1 minute (24). The time to place an aortic catheter through the femoral artery using a Seldinger technique was reported as “approximately 5 minutes or less in the majority of cardiac arrest patients”.

One study was excluded as it did not pertain to a patient

Figure 1. Flow diagram of records retrieved, excluded and analysed

in cardiac arrest, but used a mechanical model to evaluate the accuracy and practicality of a minimised flush system to measure invasive arterial blood pressure in the pre-hospital environment (25). A minimised flush system was concluded as being simpler, quicker to prepare, and able to provide accurate measurements in an experimental model when compared to a conventional pressurised transducer set (observations within 5% of conventional method in n=63/64 (98.4%)); but has unknown effects on long-term cannula patency.

Adverse effects related to hemodynamic monitoring

Wildner et al (19) reported that arterial line insertion disturbed the patient care process in three cases, but does not elaborate further as to the nature or extent of disturbance caused. No other complications were identified. Similarly, Manning (24) describes no complications as a direct result of hemodynamic monitoring and chest radiographs in patients who arrived at the hospital with ROSC confirmed appropriate catheter placement. No complications were reported as a result of the one patient who required a surgical cutdown technique for femoral artery access.

Discussion

This review highlighted the feasibility of pre-hospital arterial lines placed by physicians in cardiac arrest. Although no

literature specific to the pre-hospital initiation of arterial lines by paramedics was found, one observational study supported the possibility of especially trained paramedics performing cannulation under physician supervision (19). The literature identified a range of advantages from arterial cannulation in cardiac arrest, including the ability to initiate hemodynamic monitoring and arterial blood gas analysis. These in turn were employed in a pleiotropic fashion to titrate adrenaline dosing, as well as assess efficacy of chest compressions and alter ventilation parameters.

None of the studies included in this scoping review refer to the total dose of adrenaline given to patients in their respective cohorts. As such, it is not possible to infer if hemodynamic monitoring decreases the total dose of adrenaline given pre-hospitally. In large cohort studies, an association has been demonstrated between giving a greater total dose of adrenaline and poor neurological outcome (26,27). This may be confounded by longer resuscitation times and survival bias. Studies comparing high dose adrenaline with standard dose showed no appreciable difference in patient-centred outcomes such as survival to hospital discharge (28,29).

All the included studies make specific mention to completion of proven conventional life support measures such as defibrillation

Table 3. Study characteristics

Reference	Methods and sample size	Location and setting	Interventions and technique	Outcomes
Wildner et al (2010)	Case report (n=1)	Austria; physician-staffed unit	Radial arterial line; technique not stated ABG analysis Compression effectiveness tailored Adrenaline doses tailored Not stated if ultrasound was used	ROSC and survival to hospital discharge without neurological deficit, after almost 2 hours of prolonged resuscitation
Wildner et al (2011)	Prospective observational study (n=50)	Austria; physician-staffed unit with a small number of the interventions completed by trained emergency medical technicians under supervision	Mostly radial arterial line (75.2%), some brachial (5.1%) or femoral (3.6); non-wire guided Ultrasound not used	ROSC or survival to hospital discharge not specifically recorded Median time for successful arterial cannulation 2 minutes (range: 30-600s) Median time for preparation of IBP set 3 minutes (range: 30-600s) Cannulation success rate 48.9% on first attempt, 80.3% after three attempts
Manning (2013)	Retrospective observational study (n=22)	US; physician responder unit dispatched in conjunction with emergency medical services	Aortic catheterisation via femoral artery; blind Seldinger technique, with one surgical cutdown Ultrasound not used	ROSC with survival to hospital admission in 50% of patients (n=22) None survived to hospital discharge Time for successful aortic catheterisation reported as "approximately 5 minutes or less in most cardiac arrest patients" Time for preparation of IBP set "approximately 1 minute" Cannulation attempt numbers and success rates not specifically stated

and compressions before initiation of arterial cannulation. A potential complication of employing IBP monitoring in cardiac arrest is that it may interfere with other higher priority resuscitation efforts. Adrenaline administration has been shown to be more effective when given early in a resuscitation, especially in the circulatory as opposed to metabolic phase of cardiac arrest (30). Conversely, adrenaline administration in the metabolic phase of cardiac arrest has been associated with harmful outcomes (31). It is possible that preparation and initiation of IBP monitoring may delay the first dose of adrenaline if these actions are performed sequentially as opposed to in parallel.

A possible justification for initiating invasive hemodynamic monitoring before intravenous access would be if the information was used to tailor compression efficacy. While generic guidance regarding compression depth, speed and recoil is widely promulgated, invasive monitoring would give real-time feedback about the compression efficacy for an individual patient. Rieke et al (32) performed a study that showed improved quality of chest compressions in a simulated environment with IBP feedback. Conversely it was also shown that even fit compressors did not maintain quality compressions without real-time feedback (32).

Key differences between the pre-hospital and in-hospital environments include the number of people, expertise and equipment rapidly available (33). Increasing the complexity and number of tasks, without increasing available resources, can decrease the likelihood of all procedures being performed correctly (34). Recent advances in OHCA have been made using a team focussed, or 'pit-crew', approach to resuscitation (35). Invasive blood pressure monitoring represents a step towards increasing complexity, as seen in intensive care unit settings, and away from the simplification of pit-crew resuscitation. In order to be successful, acquiring the knowledge and skills for pre-hospital invasive hemodynamic monitoring in cardiac arrest would need to be done with a focus on communication and leadership (36).

One commonly used key performance indicator used in the pre-hospital environment is time spent on scene. Scene time was not stated in the papers included in this scoping review, but one study which did measure the effect of arterial cannulation on scene time suggested a significant positive correlation (increase of 34.4 min, 95% CI 26.1–42.8) (37). These patients were however not in cardiac arrest, and time may have been well spent with interventions such as fluids and vasopressors. As shown, arterial cannulation and preparation of the IBP set can be completed in a much shorter timeframe (19,24). As pre-hospital treatment becomes more sophisticated and focussed, scene time may become less relevant as a key performance indicator.

It is not known what effect paramedic arterial cannulation would have on success rate, procedural time taken or rate of complications. Aortic catheterisation as demonstrated by

Manning (24) has obvious similarities in terms of insertion technique to resuscitative endovascular balloon occlusion of the aorta (REBOA). While theorised to be possible for intensive care paramedics to perform, studies involving pre-hospital REBOA have only been done with doctors or surgeons as the interventionist (38,39). Radial artery cannulation using a non-wire guided technique would be most comparable to the intravenous cannulation technique already used by paramedics. With training and an appropriate protocol, it is likely that paramedics can safely insert radial arterial catheters (19,40).

None of the studies included used ultrasound to guide arterial cannulation. Arterial cannulation has been shown to be far more likely to be successful on first attempt with the use of ultrasound, and decrease complication rates, and be achieved more quickly (21). As the articles included in this scoping review have been published, high level evidence has been produced suggesting that ultrasound guided arterial cannulation is best practice (41). Ultrasound techniques can be rapidly taught to paramedics with no prior experience and with high competency (42,43).

Limitations

The studies identified in this scoping review have limited cohort numbers and have been undertaken in two locations in total. While feasibility of aortic and arterial catheterisation has been shown, when undertaken by an experienced clinician in a Franco-German ambulance model, it is not known if this can be replicated by a paramedic practitioner working in an Anglo-American model. Furthermore, due to the paucity of evidence available it is not possible to address questions regarding the therapeutic efficacy of hemodynamic guided resuscitation in the pre-hospital field, only procedural feasibility.

Conclusion

Pre-hospital hemodynamic monitoring has the potential to maximise therapeutic effects when used in conjunction with interventions that are already widely used in OHCA. Paramedic initiated invasive arterial monitoring presents a new, but as yet unproven, avenue for improving cardiac arrest outcomes. Pre-hospital feasibility studies with paramedics, and randomised multi-centre trials with patient-oriented outcomes, are required before paramedic practice recommendations can be made regarding hemodynamic guided resuscitation.

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Competing interests

The author declares no competing interests. The author of this paper has completed the ICMJE conflict of interest statement.

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