Resuscitation xxx (2020) xxx–xxx

Contents lists available at ScienceDirect

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

Review

Prognostication with point-of-care echocardiography during cardiac arrest: A systematic review

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ARTICLE INFO

Article history:
Received 12 March 2020
Received in revised form 27 April 2020
Accepted 1 May 2020

Keywords:
Cardiac arrest
Cardiopulmonary resuscitation
Echocardiography
Point-of-care ultrasound
Prognostication
Systematic review

ABSTRACT

Aim: To conduct a prognostic factor systematic review on point-of-care echocardiography during cardiac arrest to predict clinical outcomes in adults with non-traumatic cardiac arrest in any setting.
Methods: We conducted this review per PRISMA guidelines and registered with PROSPERO (ID pending). We searched Medline, EMBASE, Web of Science, CINAHL, and the Cochrane Library on September 6, 2019. Two investigators screened titles and abstracts, extracted data, and assessed risks of bias using the Quality in Prognosis Studies (QUIPS) template. We estimated prognostic test performance (sensitivity and specificity) and measures of association (odds ratio). Grading of Recommendations Assessment, Development and Evaluation (GRADE) methodology evaluated the certainty of evidence.
Results: In total, 15 studies were included. We found wide variation across studies in the definition of 'cardiac motion' and timing of sonographic assessment. Most studies were hindered by high risks of bias from prognostic factor measurement, outcome measurement, and lack of adjustment for other prognostic factors. Ultimately, heterogeneity and risk of bias precluded meta-analyses. We tabulated ranges of prognostic test performance and measures of association for 5 different combinations of definitions of 'cardiac motion' and sonographic timing, as well as other miscellaneous sonographic findings. Overall certainty of this evidence is very low.
Conclusions: The evidence for using point-of-care echocardiography as a prognostic tool for clinical outcomes during cardiac arrest is of very low certainty and is hampered by multiple risks of bias. No sonographic finding had sufficient and/or consistent sensitivity for any clinical outcome to be used as sole criterion to terminate resuscitation.

Introduction

Out-of-hospital cardiac arrest (OHCA) affects over 350,000 individuals in the United States[1] and 275,000 individuals in Europe[2,3] each year. Additionally, in-hospital cardiac arrest (IHCA) occurs in an estimated 290,000 patients per year in the United States.[4] A bedside test to prognosticate clinical outcomes during cardiac arrest resuscitation is a desirable clinical tool.

In addition to screening for evidence of specific etiologies of cardiac arrest, point-of-care echocardiography is increasingly used as a decision aid for termination of resuscitation: the absence of cardiac motion is associated with the absence of return of spontaneous circulation (ROSC).[5] However, the potential for misinterpretation is under-recognized. For example, prognostic tests that influence clinical care or are utilized within clinical

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https://doi.org/10.1016/j.resuscitation.2020.05.004
0300-9572/

decisions to terminate resuscitation are highly susceptible to bias from 'self-fulfilling prophecy', in which clinicians involved with the decision to terminate resuscitation are not blinded to the results of the test in question. Additionally, the timing of point-of-care echocardiography during the course of resuscitation likely influences its ability to successfully predict clinical outcome.

Given the widespread incorporation of point-of-care echocardiography into current clinical practice, a comprehensive and rigorous summary of its intra-arrest prognostic capabilities would provide valuable information to both the resuscitation science community and treating clinicians. Our aim was to perform a prognostic factor systematic review on point-of-care echocardiography during cardiac arrest to inform the 2020 update to international resuscitation guidelines.

Methods

Protocol and registration

The protocol for the current study was prospectively submitted to the International Prospective Register of Systematic Reviews (PROSPERO) on October 2, 2019 (ID pending) and is provided in Supplementary Appendix. This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[6] The PRISMA checklist is provided in Supplementary Appendix. This review was conducted by the Advanced Life Support Task Force of the International Liaison Committee on Resuscitation (ILCOR).

Eligibility criteria, outcomes, and definitions

The study question was framed using the PICOST (Population, Intervention, Comparator, Outcome, Study Design, Timeframe) format: In adults in any setting in non-traumatic cardiac arrest (P), does a particular finding on point-of-care echocardiography during CPR (I), compared to the absence of that finding or a different finding on point-of-care echocardiography during CPR (C) prognosticate clinical outcomes (O). Human randomized and non-randomised studies (both prospective and retrospective), prognosis studies based on RCT data, and case-control studies were eligible for inclusion. Animal studies, ecological studies, case series, case reports, narrative reviews, editorials, comments, letters to the editor, and unpublished studies (e.g., conference abstracts, trial protocols) were excluded (S). There were no limitations on publication period or manuscript language, provided there was an English abstract (T).

The ILCOR Advanced Life Support Task Force prioritized the clinical outcomes ROSC (important), survival to hospital admission (important), survival to hospital discharge (critical), favorable neurologic outcome at hospital discharge (critical), survival beyond hospital discharge (critical), and favorable neurologic outcome beyond hospital discharge (critical).

Point-of-care echocardiography encompassed all means of sonographically viewing of the heart during CPR across the spectrum of sonographic modalities: transthoracic sonography with a multi-purpose bedside ultrasound, formal transthoracic echocardiography, and transesophageal echocardiography. We expected a priori that most prognostic factors would center primarily around 'cardiac activity', indicating spontaneous myocardial/valvular contraction or movement. We anticipated this could be variably defined across studies along a spectrum of observed degree of 'cardiac activity'.

Literature search

After collaboratively developing the search strategy (Supplementary Appendix) to capture each component of the PICO question, an information specialist searched the following electronic bibliographic databases on September 6, 2019: Medline, EMBASE, Web of Science, CINAHL, and the Cochrane Library. We also reviewed the references of both included studies and identified systematic reviews pertinent to this topic.

Study selection

Two investigators, using pre-defined screening criteria, independently screened all titles and abstracts retrieved by the systematic search. After resolving disagreements regarding inclusion and exclusion of articles by discussion or adjudication with a third investigator, they independently reviewed the articles retained for full-text assessment. Disagreements regarding eligibility were resolved by discussion. We calculated Kappa statistics for inter-rater agreement during screening and final inclusion.

Data collection

Two investigators used a pre-defined and piloted standardized data tool to independently extract data pertinent to the PICOST question. These data elements were driven by the Checklist for Critical Appraisal and Data Extraction for Systematic Review of Prediction Modeling Studies (CHARMS-PF) checklist (Supplementary Appendix)[7] for critical appraisal and data extraction for systematic review of prognostic factors. Discrepancies in the extracted data were identified and resolved via discussion.

Bias assessment

Two investigators independently reviewed the risk of bias of individual studies and disagreements were resolved via discussion. We used the Quality in Prognosis Studies (QUIPS) template to assess risk of bias across six domains: study participation, study attrition, prognostic factor measurement, outcome measurement, study confounding, and statistical analysis/reporting.[8] The signaling questions and criteria used to rate risk of bias are in Supplementary Appendix. QUIPS contains similar elements to Quality Assessment of Diagnostic Accuracy Studies Version 2 (QUADAS-2), which is used for diagnostic test accuracy systematic reviews.[9] We also considered industry sponsorship as a potential source of bias.

In addition to this standardized risk of bias assessment, we especially considered two sources of bias related to prognostication during resuscitation of cardiac arrest. First, 'self-fulfilling prophecy', when clinicians involved with the decision to terminate resuscitation are not blinded to the results of point-of-care echocardiography, was a key consideration when reviewing studies for risk of bias. We considered this a critical risk of bias that precluded pooling studies. Operationally, we determined a priori that this would include studies with point-of-care echocardiography performed immediately prior to termination of resuscitation, studies in which clinicians were not blinded to sonographic findings, or studies with other evidence of self-fulfilling prophecy. Second, the timing of point-of-care echocardiography during resuscitation was another key confounder since restoring cardiac motion is a primary goal of resuscitative therapies. For example, resuscitative interventions could lead to the restoration of cardiac motion, or cardiac motion could cease over the course of an unsuccessful resuscitation. The timing of a prognostic test assessing cardiac motion could artificially improve or lower its prognostic estimates.

Please cite this article in press as: Reynolds JC, et al. Prognostication with point-of-care echocardiography during cardiac arrest: A systematic review. Resuscitation (2020), https://doi.org/10.1016/j.resuscitation.2020.05.004

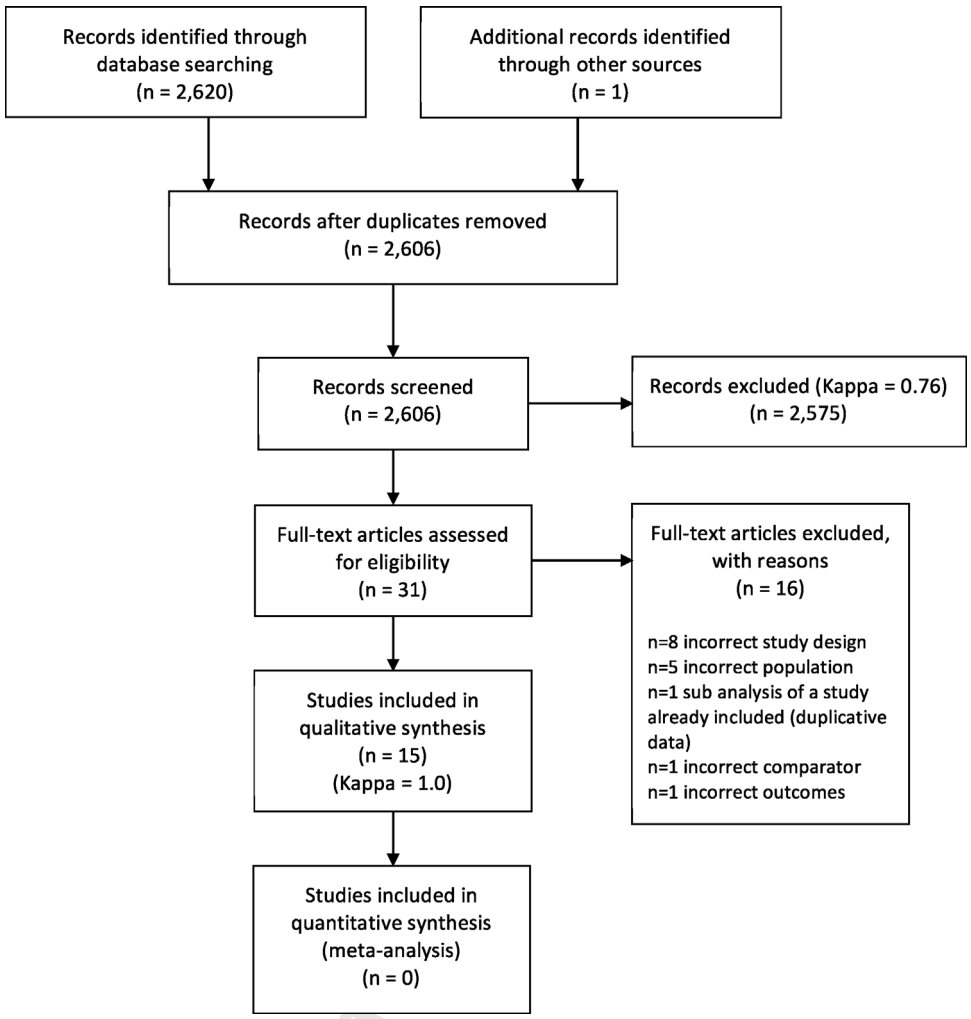

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram illustrating the selection of articles.

Data analysis and synthesis

Although the Cochrane Prognosis Working Group recommends estimating odds ratios or risk ratios in a prognostic factor systematic review,[10] the binary nature of the clinical outcomes lends itself well to consideration in a standard 2 × 2 tabular format. While this is not a systematic review of diagnostic test accuracy, elements of test performance have clinical applications in the prognostication of clinical outcomes (i.e. ROSC) with a bedside tool (i.e. point-of-care echocardiography). In addition, we believe that consideration of the true- and false-positive rates of point-of-care echocardiography is more useful to clinicians than traditional measures of association (e.g. odds ratio). Nonetheless, we provide both estimates of test performance and traditional measures of association for interpretation. Test positive denotes presence of the sonographic finding in question (e.g. cardiac motion). Disease positive denotes presence of the clinical outcome in question (e.g. ROSC).

Studies were assessed for clinical, methodological, and statistical heterogeneity. A *p*-value of <0.10 or *I*-squared statistic of >50% indicated substantial statistical heterogeneity.[11] Sufficiently homogenous studies without critical risk of bias were eligible for pooling with a random effects meta-analysis, as per the Cochrane Collaboration Prognosis Working Group, since unexplained heterogeneity is likely to remain in prognostic factor systematic reviews.[10] We planned the following a priori subgroups: witnessed vs. unwitnessed collapse, shockable vs. nonshockable initial cardiac rhythm, and in-hospital vs. out-of-hospital cardiac arrest.

Using guidance documents from the Cochrane Prognosis Methods Group,[12] we assessed the certainty of the overall evidence using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) methodology ranging from very low certainty of evidence to high certainty of evidence.[13] We used GRADEpro software (McMaster University, 2014) to tabulate detailed assessment of overall risk of bias, inconsistency, imprecision, and indirectness.

Results

Study selection

The search identified 2606 unique titles and abstracts, of which 2575 were excluded after initial review (Kappa 0.75) (Fig. 1). After reviewing 31 full-text articles for eligibility, an additional 16 were excluded leaving 15 manuscripts for inclusion (Kappa 1.0). All included studies were observational in nature.

Summary of studies

Altogether, 15 observational studies enrolled 2091 subjects between 1999–2017 (four studies did not specify years of enrollment) and were published between 1997–2019, of which 10 were conducted in the Emergency Department, two in the prehospital setting, two in the inpatient setting, and one with mixed settings of enrollment.[14–28] There were seven studies from North America,

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five from Asia, two from Europe, and one from South America. Most (14/15) studies utilized the subxiphoid view, nine utilized the apical 4-chamber view, nine utilized a parasternal view, and one utilized transesophageal views as needed. There was wide variability between studies in the reported training and credentials of sonographers (Table 1).

Upon reviewing the included articles, we discovered wide variability in the definitions of 'cardiac motion' pertaining to anatomy (i.e. left ventricular contractions with associated valvular opening, myocardial contractions, any ventricular movement, any myocardial movement, any movement [including isolated valvular fluttering], or unspecified) and timing (initial, every, any, or subsequent point-of-care echocardiogram; or unspecified) (Supplementary Appendix). Ultimately, we classified studies describing cardiac motion as organized contractility vs. non-organized and/or unspecified motion. We classified studies describing echocardiogram timing as the initial echocardiogram, every echocardiogram, any echocardiogram, a subsequent echocardiogram, or unspecified timing. We collated sonographic evidence of treatable pathology (evidence of hypovolemia, pericardial effusion, cardiac tamponade, or right ventricular dilation) into one category. Two studies report multiple sonographic findings within a given category on the same subjects.[18,28] To collate complete data, these are tabulated as the composite variable 'subject-assessments'. Finally, we report other described miscellaneous sonographic findings.

Bias assessment

Studies tended to have high risks of bias related to prognostic factor measurement, outcome measurement, and lack of adjustment for other prognostic factors (Table 2). Notably, prospective studies either enrolled a convenience sample of subjects or did not specify consecutive subject sampling. No study specified if outcome assessors were blinded to sonographic findings. No industry sponsorships were identified.

Two studies contained evidence of self-fulfilling prophecy. In both Atkinson et al. and Gaspari et al., subjects with cardiac motion received longer durations of CPR than those without (Atkinson et al.: 27 min vs. 12 min; Gaspari et al.: 18 min vs. 12 min).[15,21] Furthermore, subjects in Atkinson et al. with cardiac motion were more likely to be treated with endotracheal intubation (95% vs. 47%) and epinephrine (100% vs. 82%) than those without.[15]

Four studies contained evidence of efforts to avoid confounding from self-fulfilling prophecy.[18,20,22,23] In Chardoli, et al., treating clinicians were blinded to sonographic results but made aware of other findings that could influence clinical treatment.[18] In Flato, et al., subjects without cardiac motion (median 12 cycles CPR) had longer durations of CPR than subjects with cardiac motion (median 6 cycles CPR), even though the treating team was not blinded to sonographic findings.[20] In both Kim et al. and Lien et al., all subjects received mandatory prespecified 30 min of CPR beyond sonographic assessment prior to termination of resuscitation.[22,23]

The timing of sonographic assessment varied greatly between studies (Table 1 and Supplementary Appendix). Since no more than 4 studies addressed any one combination of sonographic finding and timing, we did not assess for publication bias.

Meta-analyses

Ultimately, no combination of studies assessing a particular sonographic finding with particular timing had sufficiently low risk of bias to perform meta-analyses (Table 2 and Supplementary Appendix).

Certainty of evidence

The overall certainty of evidence was rated as very low for all outcomes primarily due to risk of bias, inconsistency, or imprecision (Table 3 and Supplementary Appendix). The individual studies were at substantial risk of bias due to prognostic factor measurement, outcome measurement, adjustment for prognostic factors, or residual confounding. Because of this and a high degree of clinical heterogeneity, individual studies are difficult to interpret.

Main results

Presence of organized cardiac motion (unspecified echocardiogram timing)

One observational study of 49 IHCA subjects reported sensitivity (1.00; 95% CI 0.40–1.00), specificity (0.49; 95% CI 0.34–0.64), and OR (8.62; 95% CI 0.44–169.38) for survival to 180 days.[20] Two observational studies of 229 IHCA and OHCA subjects reported ranges of sensitivity (0.67 to 1.00), specificity (0.51 to 0.89), and odds ratio (13.60 to 16.63) for survival to hospital discharge.[15,20] Two observational studies of 349 OHCA subjects reported ranges of sensitivity (0.39 to 1.00), specificity (0.91 to 0.91) (identical point estimates), and odds ratio (6.73 to 414.56) for survival to hospital admission.[15,16] Two observational studies of 229 IHCA and OHCA subjects reported ranges of sensitivity (0.34 to 0.79), specificity (0.68 to 0.96), and odds ratio (8.07 to 13.21) for ROSC. [15,20]

Presence of non-organized and/or unspecified cardiac motion on initial echocardiogram

One observational study of 42 OHCA subjects reported sensitivity (1.0; 95% 0.03–1.00), specificity (0.78; 95% CI 0.62–0.89), and odds ratio (10.26; 95% CI 0.39–273.09) for good neurologic outcome at hospital discharge.[14] Three observational studies of 1171 IHCA and OHCA subject-assessments reported ranges of sensitivity (0.06 to 0.91), specificity (0.49 to 0.94), and odds ratio (0.38 to 17.00) for survival to hospital discharge.[21,27,28] Four observational studies of 1295 IHCA and OHCA subject-assessments reported ranges of sensitivity (0.11 to 0.92), specificity (0.55 to 0.85), and odds ratio (0.75 to 27.56) for survival to hospital admission.[14,21,24,28] Three observational studies of 861 IHCA and OHCA subjects reported ranges of sensitivity (0.25 to 0.64), specificity (0.78 to 1.00), and odds ratio (6.33 to 16.11) for ROSC.[21,22,27]

Presence of non-organized and/or unspecified cardiac motion on every echocardiogram

Two observational studies of 134 OHCA subjects reported ranges of sensitivity (0.50 to 0.80), specificity (0.92 to 1.00), and odds ratio (45.33 to 148.20) for survival to hospital admission.[14,24]

Presence of non-organized and/or unspecified cardiac motion (unspecified echocardiogram timing)

One observational study of 49 IHCA subjects reported sensitivity (1.00; 95% CI 0.40–1.00), specificity (0.49; 95% CI 0.34–0.64), and odds ratio (8.62; 95% CI 0.44–169.38) for good neurologic outcome at 180 days.[20] One observational study of 70 OHCA subjects reported sensitivity (1.0; 95% 0.03–1.00), specificity (0.86; 95% CI 0.75–0.93), and odds ratio (17.00; 95% CI 0.65–446.02) for good neurologic outcome at hospital discharge.[25] One observational study of 177 OHCA subjects reported sensitivity (0.48; 95% CI 0.28–0.69), specificity (0.77; 95% CI 0.69–0.83), and odds ratio (3.09; 95% CI 1.29–7.37) for survival to hospital discharge.[23] Three observational studies of 291 OHCA subjects reported ranges of sensitivity (0.72 to 0.86), specificity (0.60 to 0.84), and odds ratio (9.14 to 14.00) for survival to hospital admission.[17,19,24] Four observational studies of 317 OHCA subjects reported ranges of sensitivity

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Table 1
Characteristics of included studies. **US**: ultrasound. **ROSC**: return of spontaneous circulation. **TOR**: termination of resuscitation. **OHCA**: out of hospital cardiac arrest. **ED**: emergency department. **ICU**: intensive care unit. **IHCA**: in hospital cardiac arrest. **Min**: minutes. **PEA**: pulseless electrical activity. **DNR**: do not resuscitate. **FEEL**: focused echocardiographic evaluation in life support.

Author/year	Subjects/ setting/ country	Years of enrollment	Inclusion criteria	Exclusion criteria	Sonographer	Timing of sonographic assessment	Collapse-to-US (min)	US-to-ROSC/ TOR (min)	Kappa provided	Mean/Median Age (years)	Sex (% male)	Rhythm (% shockable)
Aichinger 2012[14]	*n* = 42 Prehospital Austria	2009–2010	Adult OHCA	Trauma	Emergency physician; 2-h course in focused echocardiography (video demonstration and hands-on training)	After initial defibrillation, endotracheal intubation, vascular access	Mean no-flow 9.8 min Mean low-flow 17.4 min	–	–	70	71%	26%
Atkinson 2019[15]	*N* = 180 ED Canada	2010–2014	Adult OHCA	TOR due to end-of-life decisions	Competent personnel with experience in point-of-care ultrasound	During designated pauses (e.g. pulse check, rhythm check, other procedures)	–	27 min for subjects with cardiac activity 12 min for subjects without cardiac activity	–	65	67%	–
Blaivas 2001[16]	*n* = 169 ED United States	1999–2000	Adult OHCA	Trauma; obvious non-cardiac etiology of collapse	Ultrasound-trained and credentialed emergency physicians	Shortly after ED arrival; during pulse checks	Mean no-flow 5.6 min Mean combined no-flow & low-flow 13.6 min	15 min for survivors 17 min for non-survivors	–	71	–	39%
Breitkreutz 2010[17]	*n* = 88 Prehospital Germany	2002–2007	Adult OHCA	–	Emergency physician trained in peri-resuscitation echocardiography (standard FEEL training program)	90% of sonographic exams performed after airway management	–	–	–	65	61%	12%
Chardoli 2012[18]	*n* = 50 ED Iran	2009	Adult OHCA; PEA	–	Emergency Medicine resident physician participating in ultrasound training course (training/credentials not described)	During initial pulse check (allowed up to 3 exams during subsequent pulse checks q2 min)	–	–	–	60	60%	0%
Chua 2017[19]	*n* = 104 ED Singapore	2015–2016	Age > 20 years; OHCA	Pregnancy; terminal illness	Emergency physicians (senior resident or above) that passed training course (lecture, hands-on, simulation, live patients, multiple choice test, approved live scans)	During pulse checks	–	–	–	71	68%	16%
Flato 2015[20]	*n* = 49 ICU Brazil	2013–2014	Adult IHCA; nonshockable rhythm	DNR order	*n* = 2 intensivists with formal training/certification in echocardiography ("levels 2 and 3")	During pulse/rhythm checks	Median 1 min	Median 18 min	Kappa 0.93	58	55%	0%
Gaspari 2016[21]	*n* = 793 ED United States & Canada	2011–2014	Adult OHCA; nonshockable rhythm	Resuscitative efforts < 5 min; TOR after initial ultrasound; TOR due to DNR order	Emergency physician credentialed for bedside US by their hospital	During pulse/rhythm checks	Median 34 min	Median 18 min for subjects with cardiac activity Median 12 min for subjects without cardiac activity	Kappa 0.63	64	62%	0%
Kim 2016[22]	*n* = 48 ED Korea	2013–2015	Adult OHCA	Trauma; Poisoning	Emergency physicians or residents "well-trained" in peri-resuscitation echocardiography with minimum 3 years experience	During rhythm check	Mean 23 min	30 min for all subjects	–	64	71%	17%

Please cite this article in press as: Reynolds JC, et al. Prognostication with point-of-care echocardiography during cardiac arrest: A systematic review. Resuscitation (2020), https://doi.org/10.1016/j.resuscitation.2020.05.004

Table 1 (*Continued*)

Author/year	Subjects/ setting/ country	Years of enrollment	Inclusion criteria	Exclusion criteria	Sonographer	Timing of sonographic assessment	Collapse-to-US (min)	US-to-ROSC/ TOR (min)	Kappa provided	Mean/Median Age (years)	Sex (% male)	Rhythm (% shockable)
Lien 2018[23]	*n* = 177 ED Taiwan	2016–2017	Adult OHCA	Trauma; pregnancy; neck tumor or operation; DNR order	Emergency physicians with basic ultrasound training and additional 4-h focused training session	During pulse/rhythm checks	Mean 8 min	Mean 22.5 min for subjects with ROSC Mean 23.6 min for subjects without ROSC	–	71	63%	18%
Salen 2001[24]	*n* = 102 ED United States	–	Adult OHCA or ED cardiac arrest	Trauma	4-h ultrasound course	During pulse/rhythm checks	–	–	–	–	–	11%
Salen 2005[25]	*n* = 70 ED United States	–	Adult OHCA or ED cardiac arrest	Trauma	–	On arrival to ED; then during pulse/rhythm checks	Range 5–77 min	<12 min for 85% of subjects	–	–	61%	0%
Tayal 2003[26]	*n* = 20 ED United States	–	Adult OHCA; PEA	Trauma	Emergency physicians with 20-h course including training on echocardiography and pericardial effusion states	–	–	–	–	57	60%	–
Varriale 1997[27]	*n* = 20 IHCA United States	–	Adult IHCA	–	Designated members of a cardiology team	Ultrasound arrival to subject bedside	Mean 3.9 min	–	–	76	60%	15%
Zengin 2016[28]	*n* = 179 Mixed Turkey	2013–2014	Age > 16 years; OHCA or IHCA	Trauma	Senior residents with 16 h echocardiography training plus 8 h basic emergency ultrasound training	During pulse checks or defibrillator charging	–	–	–	63	58%	–

[a] All included studies had an observational study design.
[b] Prospective studies utilized either convenience sampling or did not specify sampling strategy.
[c] No-flow denotes elapsed interval from collapse to onset of chest compressions.
[d] Low-flow denotes elapsed interval from onset of chest compressions to return of spontaneous circulation or termination of resuscitation.

Table 2
Risk of bias assessment using the Quality In Prognostic Factor Studies (QUIPS) rubric.

Author/year	Study participation	Study attrition	Prognostic factor measurement	Outcome measurement	Adjustment for other prognostic factors		Statistical analysis and reporting
					Shorter Term Outcomes	Longer Term Outcomes	
Aichinger 2012[14]	Moderate[a]	Low	Low	Moderate[b,c]	Low	High[d]	Moderate[e]
Atkinson 2019[15]	Low	Low	High[f]	High[c,g]	High[d]	Moderate[e]	
Blaivas 2001[16]	Moderate[a]	Low	Low	High[c,g]	Low	Low	
Breitkreutz 2010[17]	Low	Low	High[h,i]	High[c,g]	Low	Low	
Chardoli 2012[18]	Moderate[a]	Low	High[h,j]	Moderate[c,k]	Low	Low	
Chua 2017[19]	Moderate[a]	Low	Moderate[h,l]	High[c,g]	Low	Low	
Flato 2015[20]	Moderate[a]	Low	Low	Moderate[b,c]	Low	High[d]	Low
Gaspari 2016[21]	Low	Low	High[f]	High[c,g]	Low	Low	
Kim 2016[22]	Moderate[a]	Low	Low	Moderate[b,c]	Low	Low	
Lien 2018[23]	Moderate[a]	Low	Moderate[i]	Moderate[b,c]	Low	Moderate[e]	
Salen 2001[24]	Moderate[a]	Low	High[h,i]	High[c,g]	Low	Low	
Salen 2005[25]	Moderate[a]	Low	High[h,j]	High[c,g]	High[d]	Moderate[e]	
Tayal 2003[26]	Moderate[a]	Low	High[h,j]	High[c,g]	Low	Low	
Varriale 1997[27]	Moderate[a]	Low	High[h,j]	High[c,g]	High[d]	Moderate[e]	
Zengin 2016[28]	Moderate[a]	Low	Moderate[h]	High[c,g]	High[d]	Moderate[e]	

[a] Enrolled convenience sample of subjects.
[b] Treating clinicians not blinded to ultrasound findings, but either a protocolized delay between ultrasound and termination of resuscitation, or granular data indicate lack of self-fulfilling prophecy.
[c] Unspecified if outcome assessors blinded to ultrasound findings.
[d] Clinical outcomes beyond return of spontaneous circulation not adjusted for other prognostic factors.
[e] No measures of association for clinical outcome beyond survival to hospital admission.
[f] Granular data indicate presence of self-fulfilling prophecy.
[g] Treating clinicians not blinded to ultrasound findings.
[h] Unspecified timing of ultrasound in relation to termination of resuscitation.
[i] Imprecise or unclear definition of ultrasound finding.
[j] Unclear credentials of the sonographer.
[k] Treating clinicians blinded to sonographic finding of 'cardiac motion', but were advised of other findings that might prompt specific interventions.
[l] Missing data.

(0.62 to 1.00), specificity (0.33 to 0.98), and odds ratio (23.18 to 289.00) for ROSC.[18,23,25,26]

Return of organized cardiac motion on subsequent echocardiogram

One observational study of 20 IHCA subjects reported sensitivity (0.50; 95% CI 0.01–0.99), specificity (0.79; 95% CI 0.54–0.94), and odds ratio (3.75; 95% CI 0.19–74.06) for survival to hospital discharge.[27] One observational study of 20 IHCA subjects reported sensitivity (0.67; 95% CI 0.22–0.96), specificity (1.00; 95% CI 0.77–1.00), and odds ratio (52.50; 95% CI 2.10–1300.33) for ROSC.[27]

Presence of coalescent echo contrast (i.e. visible clotted intra-cardiac blood) after 20–30 min CPR

One observational study of 20 IHCA subjects reported sensitivity (0.00; 95% CI 0.00–0.84), specificity (0.45; 95% CI 0.23–0.68), and odds ratio (0.13; 95% CI 0.01–3.11) for survival to hospital discharge.[27] One observational study of 20 IHCA subjects reported sensitivity (0.00; 95% CI 0.00–0.46), specificity (0.21; 95% CI 0.05–0.51), and odds ratio (0.02; 95% CI 0.00–0.53) for ROSC.[27]

Sonographic evidence of treatable pathology

Three observational studies totaling 1130 IHCA and OHCA subject-assessments reported ranges of sensitivity (0.00 to 0.15), specificity (0.89–0.98), and odds ratio (1.32 to 4.25) for survival to hospital discharge.[21,27,28] One observational study with 531 IHCA and OHCA subject-assessments reported ranges of sensitivity (0.03 to 0.04), specificity (0.95 to 0.99), and odds ratio (0.61 to 4.70) for survival to hospital admission.[28] Four observational studies totaling 317 IHCA and OHCA subject-assessments reported ranges of sensitivity (0.00 to 1.00), specificity (0.84 to 0.94), and odds ratio (0.38 to 125.00) for ROSC.[18,23,26,27]

Additional findings

One study reported time-dependent test performance data.[23] As CPR duration increased from <4 min to 14–16 min, sensitivity for ROSC increased from 0% (95% CI 0–46%) to 100% (95% CI 3–100%) and specificity for ROSC increased from 88% (95% CI 47–100%) to 100% (95% CI 16–100%). Both estimates peaked at 10–12 min, which corresponded to the greatest numbers of subjects in any given quantile: sensitivity 100% (95% CI 79–100%) and specificity 100% (89–100%). Only two studies provided estimates of inter-rater reliability for the sonographic finding under investigation (Kappa 0.93 and 0.63, respectively).[20,21]

Discussion

We conducted a prognostic factor systematic review of point-of-care echocardiography during resuscitation of adults with non-traumatic cardiac arrest in any setting to predict clinical outcomes. Ultimately, clinical heterogeneity and risk of bias precluded meta-analyses, the certainty of evidence was uniformly very low, and individual studies are difficult to interpret.

The most striking finding of this systematic review was the widely inconsistent definitions and terminology around sonographic evidence of cardiac motion, which included wide variation in the classification of anatomy, type of motion, and timing of point-of-care echocardiography. This finding is consistent with a recent prospective survey study conducted by Hu et al.[29] Among 127 emergency medicine, critical care, and cardiology physician sonographers shown sonographic video clips from a sample of 15 cases of cardiac arrest, there was only moderate agreement (Krippendorff's α 0.47) of what constituted cardiac standstill. Within subject subgroups by specialty, level of training, and self-reported sonographic skill, agreement ranged from 0.43 to 0.55. Cases with myocardial contractions but profound bradycardia, and valvular fluttering from

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Table 3
Estimated prognostic test performance and prognostic association for sonographic findings on point-of-care echocardiography during cardiac arrest to predict clinical outcomes. Certainty of evidence was assessed with the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach. **CI**: confidence interval. **IHCA**: in-hospital cardiac arrest. **OHCA**: out-of-hospital cardiac arrest.

Outcome	Author (year)	Subjects (*n*)/location/study design	Sensitivity range or 95% CI	Specificity range or 95% CI	Odds ratio range or 95% CI	Certainty of evidence
Organized cardiac motion (unspecified echocardiogram timing)						
Survival 180 days	Flato (2015)[20]	49 IHCA Observational	1.0 (95% CI 0.4–1.0)	0.49 (95% CI 0.34–0.64)	8.62 (95% CI 0.44–169.38)	Very low
Survival to Hospital Discharge	Atkinson (2019)[15] Flato (2015)[20]	229 IHCA & OHCA Observational	0.67 to 1.00	0.51 to 0.89	13.60 to 16.63	Very low
Survival to Hospital Admission	Atkinson (2019)[15] Blaivas (2001)[16]	349 OHCA Observational	0.39 to 1.00	0.91 to 0.91	6.73 to 414.56	Very low
ROSC	Atkinson (2019)[15] Flato (2015)[20]	229 IHCA & OHCA Observational	0.34 to 0.79	0.68 to 0.96	8.07 to 13.21	Very low
Non-organized and/or unspecified cardiac motion on initial echocardiogram						
Good neurological outcome at discharge	Aichinger (2012)[14]	42 OHCA Observational	1.00 (95% CI 0.03–1.00)	0.78 (95% CI 0.62–0.89)	10.26 (95% CI 0.39–273.09)	Very low
Survival to Hospital Discharge	Gaspari (2016)[21] Varriale (1997)[27] Zengin (2016)[28]	1,171[b] IHCA & OHCA Observational	0.06 to 0.91	0.49 to 0.94	0.38 to 17.00	Very low
Survival to Hospital Admission	Aichinger (2012)[14] Gaspari (2016)[21] Salen (2001)[24] Zengin (2016)[28]	1,295[b] IHCA & OHCA Observational	0.11 to 0.92	0.55 to 0.85	0.75 to 27.56	Very low
ROSC	Gaspari (2016)[21] Kim (2016)[22] Varriale (1997)[27]	861 IHCA & OHCA Observational	0.25 to 0.64	0.78 to 1.00	6.33 to 16.11	Very low
Non-organized and/or unspecified cardiac motion on every echocardiogram						
Survival to Hospital Admission	Aichinger (2012)[14] Salen (2001)[24]	134[a] OHCA Observational	0.50 to 0.80	0.92 to 1.00	45.33 to 148.20	Very low
Non-organized and/or unspecified cardiac motion (unspecified echocardiogram timing)						
Good neurological outcome at 180 days	Flato (2015)[20]	49 IHCA Observational	1.00 (95% CI 0.40–1.00)	0.49 (95% CI 0.34–0.64)	8.62 (95% CI 0.44–169.38)	Very low
Good neurological outcome at discharge	Salen (2005)[25]	70 OHCA Observational	1.00 (95% CI 0.03–1.00)	0.86 (95% CI 0.75–0.93)	17.00 (95% CI 0.65–446.02)	Very low
Survival to Hospital Discharge	Lien (2018)[23]	177 OHCA Observational	0.48 (95% CI 0.28–0.69)	0.77 (95% CI 0.69–0.83)	3.09 (95% CI 1.29–7.37)	Very low
Survival to Hospital Admission	Breitkreutz (2010)[17] Chua (2017)[19] Salen (2001)[24]	291[a] OHCA Observational	0.72 to 0.86	0.60 to 0.84	9.14 to 14.00	Very low
ROSC	Chardoli (2012)[18] Lien (2018)[23] Salen (2005)[25] Tayal (2003)[26]	317 OHCA Observational	0.62 to 1.00	0.33 to 0.98	23.18 to 289.00	Very low
Return of organized cardiac motion on subsequent echocardiogram						
Survival to Hospital Discharge	Varriale (1997)[27]	20 IHCA Observational	0.50 (95% CI 0.01–0.99)	0.79 (95% CI 0.54–0.94)	3.75 (95% CI 0.19–74.06)	Very low

Table 3 (*Continued*)

Outcome	Author (year)	Subjects (*n*)/location/study design	Sensitivity range or 95% CI	Specificity range or 95% CI	Odds ratio range or 95% CI	Certainty of evidence
Return of Spontaneous Circulation	Varriale (1997)[27]	20 IHCA Observational	0.67 (95% CI 0.22–0.96)	1.00 (95% CI 0.77–1.00)	52.50 (95% CI 2.10–1300.33)	Very low
Coalescent echo contrast (i.e. visible clotted intra-cardiac blood) after 20–30 min CPR						
Survival to Hospital Discharge	Varriale (1997)[27]	20 IHCA Observational	0.00 (95% CI 0.00–0.84)	0.45 (95% CI 0.23–0.68)	0.13 (95% CI 0.01–3.11)	Very low
Return of Spontaneous Circulation	Varriale (1997)[27]	20 IHCA Observational	0.00 (95% CI 0.00–0.46)	0.21 (95% CI 0.05–0.51)	0.02 (95% CI 0.00–0.53)	Very low
Sonographic evidence of treatable pathology						
Survival to Hospital Discharge	Gaspari (2016)[21] Varriale (1997)[27] Zengin (2016)[28]	1130[b] IHCA & OHCA Observational	0.00 to 0.15	0.89 to 0.98	1.32 to 4.25	Very low
Survival to Hospital Admission	Zengin (2016)[28]	531[b] IHCA & OHCA Observational	0.03 to 0.04	0.95 to 0.99	0.61 to 4.70	Very low
Return of Spontaneous Circulation	Chardoli (2012)[18] Lien (2018)[23] Tayal (2003)[26] Varriale (1997)[27]	317[b] IHCA & OHCA Observational	0.00 to 1.00	0.84 to 0.94	0.38 to 125.00	Very low

[a] Studies did not report these data for all enrolled subjects; *n* is lower than the total of all subjects enrolled.

[b] Gaspari, et al. and Zengin, et al. report multiple sonographic findings within a given category on the same subjects; *n* reflects composite variable 'subject-assessments'.

Please cite this article in press as: Reynolds JC, et al. Prognostication with point-of-care echocardiography during cardiac arrest: A systematic review. Resuscitation (2020), https://doi.org/10.1016/j.resuscitation.2020.05.004

mechanical ventilation or weak myocardial contractions generated the most disagreement. We strongly encourage the Utstein working group, the World Interactive Network Focused on Critical Ultrasound (WINFOCUS), or other ultrasound and diagnostic imaging professional societies to establish uniform definitions and terminology describing sonographic findings of cardiac activity during cardiac arrest.

Additionally, most of the identified studies suffer from high risk of bias related to prognostic factor measurement, outcome measurement, lack of adjustment for other prognostic factors, and confounding from self-fulfilling prophecy and unspecified timing of point-of-care echocardiography. The evidence supporting use of point-of-care echocardiography as a prognostic tool during cardiac arrest is uniformly of very low certainty due to these risks of bias, inconsistency, and imprecision. Clinicians should interpret sonographic findings during cardiac arrest in light of these limitations. We strongly encourage subsequent investigations of point-of-care echocardiography during cardiac arrest to employ robust methodology that mitigates risks of bias unique to prognostic factor studies, to report the precise credentials of sonographers, to report inter-rater reliability, and to report uniform timing of sonographic assessment. Given the heterogenous nature of cardiac arrest, standardizing the timing of sonographic assessment is challenging. Assessment intervals could be normalized to assorted clinical milestones such as activation of the prehospital emergency response system, arrival of prehospital personnel, or arrival to the Emergency Department.

The primary goal of prognostication during cardiac arrest is to predict clinical outcomes with both classification accuracy and certainty. Operationally, this results in continuing resuscitation efforts in patients with a possibility of survival and terminating resuscitation in futile cases. In this systematic review, we found wide variability in both the point estimates and certainty around these point estimates to prognosticate clinical outcomes. A few sonographic findings (any cardiac activity on initial assessment, return of organized cardiac activity on subsequent assessment, and evidence of treatable pathology) tended to have higher ranges of specificity for the short-term clinical outcomes of ROSC and survival to hospital admission, but the certainty of this evidence is very low. No sonographic finding had sufficient and/or consistent sensitivity for any clinical outcome to be used a sole criterion to terminate resuscitative efforts. It is generally considered more acceptable to continue resuscitation efforts that prove futile than to erroneously terminate resuscitation in a patient who would have otherwise survived. In either case, the prognostic implications of sonographic findings during cardiac arrest are at high risk of over-interpretation or providing false reassurance.

Two forthcoming studies may add to the findings of this systematic review. Javaudin, et al. propose a prospective, multicenter observational study of early point-of-care focused echocardiography as a predictive factor for absence of ROSC after out-of-hospital cardiac arrest.[30] Additionally, investigators from Nantes University Hospital (Nantes, France) propose a prehospital, prospective cohort study of sonographic asystole within the first minutes of chest compressions as a predictor for absence of ROSC (ClinicalTrials.gov NCT03494153).

Despite its non-invasive nature, point-of-care echocardiography is not necessarily a benign modality. Several investigations report the introduction of additional interruptions in chest compressions with a transthoracic approach.[31,32] One proposed strategy to limit this adverse effect is to record brief sonographic video clips during pulse/rhythm checks which may then be viewed and interpreted during resumption of chest compressions. Additionally, sonographers may serially assess for specific findings on subsequent pulse/rhythm checks instead of extending the duration of an individual pulse/rhythm check for a comprehensive assessment.[33] Alternatively, the transesophageal approach may mitigate this concern.[34]

Point-of-care echocardiography may still have utility to diagnose treatable etiologies of cardiac arrest, to guide the optimal anatomic location for chest compressions, to suggest prudent therapies, and to intermittently assess response to resuscitative treatments. These applications are not within the scope of this particular systematic review. However, echocardiographic findings associated with treatable etiologies may not necessarily indicate the same pathology during cardiac arrest. For example, isolated right ventricular dilation is an uncertain diagnostic indicator of massive pulmonary embolism. Right ventricular dilation begins a few minutes after onset of cardiac arrest as blood shifts from the systemic circulation to the right heart along its pressure gradient.[35,36] Additionally, right ventricular dilation has been uniformly observed in a porcine model of cardiac arrest across various etiologies of hypovolemia, hyperkalemia, and primary arrhythmia.[37]

Our methodology differs somewhat compared to other systematic reviews on this topic.[38–43] Notably, we did not restrict the target population to subjects with a nonshockable initial cardiac rhythm but did restrict it to subjects with non-traumatic cardiac arrest. Additionally, we utilized methodology standards for a systematic review of prognostic factor studies, not diagnostic test accuracy studies; the data extraction, bias assessment, and certainty of evidence assessment tools all differ. Finally, we were more stringent than other systematic reviews in our assessments for heterogeneity and risk of bias, which ultimately precluded meta-analyses. Other systematic reviews have estimated pooled test performance and measures of association for cardiac activity and clinical outcomes. Given the inherent limitations and biases we identified in this systematic review, those pooled estimates should be interpreted with caution.

Conclusions

The evidence for using point-of-care echocardiography as a prognostic tool for clinical outcomes during cardiac arrest is of very low certainty with significant risks of bias in prognostic factor and outcome measurements, lack of adjustment for other prognostic factors, and confounding. The establishment of uniform definitions and terminology describing sonographic findings of cardiac activity during cardiac arrest would greatly facilitate the interpretation of future studies.

Conflict of interest

None of the authors declared conflicts of interest for this systematic review. Dr. Paiva was a co-author on one of the studies included in this systematic review but did not participate in the study selection or risk of bias assessment processes. He did review the findings of this systematic review and participate in Task Force discussions on the interpretation of these data as a Task Force member.

Acknowledgments

The authors extend appreciation to Dr. David Lee Osterbur, information specialist at the Harvard Countway Library of Medicine, Boston, MA, United States, for preparing and conducting the systematic searches. Additionally, Dr. Eddy Lang provided methodologic expertise.

Please cite this article in press as: Reynolds JC, et al. Prognostication with point-of-care echocardiography during cardiac arrest: A systematic review. Resuscitation (2020), https://doi.org/10.1016/j.resuscitation.2020.05.004

Appendix A. International Liaison Committee on Resuscitation Advanced Life Support Task Force Collaborators

Members of the International Liaison Committee on Resuscitation Advanced Life Support Task Force who met the criteria as a collaborator include:

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Bernd W. Böttiger
Clifton W. Callaway
Charles D. Deakin
Michael Donnino
Cindy H. Hsu
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Jerry P. Nolan
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Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.resuscitation.2020.05.004.

References

1 Benjamin EJ, Muntner P, Alonso A, et al. Heart disease and stroke statistics-2019 update: a report from the American Heart Association. Circulation 2019. CIR0000000000000659.
2 Berdowski J, Berg RA, Tijssen JG, Koster RW. Global incidences of out-of-hospital cardiac arrest and survival rates: systematic review of 67 prospective studies. Resuscitation 2010;81:1479–87.
3 Gräsner JT, Lefering R, Koster RW, et al. EuReCa ONE-27 Nations, ONE Europe, ONE Registry: a prospective one month analysis of out-of-hospital cardiac arrest outcomes in 27 countries in Europe. Resuscitation 2016;105:188–95.
4 Holmberg M, Ross C, Fitzmaurice G, et al. Annual incidence of adult and pediatric in-hospital cardiac arrest in the United States. Circ: Cardiovasc Qual Outcomes 2019.
5 Long B, Alerhand S, Maliel K, Koyfman A. Echocardiography in cardiac arrest: an emergency medicine review. Am J Emerg Med 2018;36:488–93.
6 Moher D, Liberati A, Tetzlaff J, Altman DG, PRIMSA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ 2009;339:b2535.
7 Moons KGM, de Groot JAH, Bouwmeester W, et al. Critical appraisal and data extraction for systematic reviews of prediction modelling studies: the CHARMS checklist. PLoS Med 2014;11:e1001744.
8 Hayden JA, van der Windt DA, Cartwright JL, Cote P, Bombardier C. Assessing bias in studies of prognosis factors. Ann Intern Med 2013;158:280–6.
9 Whiting PF, Rutjes AW, Westwood ME, et al. QUADAS-2 Group. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. Ann Intern Med 2011;155:529–36.
10 Riley RD, Moons KGM, Snell KIE, et al. A guide to systematic review and meta-analysis of prognostic factor studies. BMJ 2019;364:k4597.
11 Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analysis. BMJ 2003;327:557–60.
12 Iorio A, Spencer FA, Falavigna M, et al. Use of GRADE for assessment of evidence about prognosis: rating confidence in estimates of event rates in broad categories of patients. BMJ 2015;350:h870.
13 Guyatt GH, Oxman AD, Vist GE, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ 2008;336:924–6.
14 Aichinger G, Zechner PM, Prause G, et al. Cardiac movement identified on prehospital echocardiography predicts outcome in cardiac arrest patients. Prehosp Emerg Care 2012;16:251–5.
15 Atkinson PR, Beckett N, French J, Banerjee A, Fraser J, Lewis D. Does point-of-care ultrasound use impact resuscitation length, rates of intervention, and clinical outcomes during cardiac arrest? A study from the sonography in hypotension and cardiac arrest in the emergency department (SHoC-ED) investigators. Cureus 2019;11:e4456.
16 Blaivas M, Fox JC. Outcome in cardiac arrest patients found to have cardiac standstill on the bedside emergency department echocardiogram. Acad Emerg Med 2001;8:616–21.
17 Breitkreutz R, Price S, Steiger HV, et al. Emergency Ultrasound Working Group of the Johann Wolfgang Goethe-University Hospital, Frankfurt am Main. Focused echocardiographic evaluation in life support and peri-resuscitation of emergency patients: a prospective trial. Resuscitation 2010;81:1527–33.
18 Chardoli M, Heidari F, Rabiee H, Sharif-Alhoseini M, Shokoohi H, Rahimi-Movaghar V. Echocardiography integrated ACLS protocol versus conventional cardiopulmonary resuscitation in patients with pulseless electrical activity cardiac arrest. Chin J Traumatol 2012;15:284–7.
19 Chua MT, Chan GW, Kuan WS. Reversible causes in cardiovascular collapse at the emergency department using ultrasonography (REVIVE-US). Ann Acad Med Singap 2017;46:310–6.
20 Flato UA, Paiva EF, Carballo MT, Buehler AM, Marco R, Timerman A. Echocardiography for prognostication during the resuscitation of intensive care unit patients with non-shockable rhythm cardiac arrest. Resuscitation 2015;92:1–6.
21 Gaspari R, Weekes A, Adhikari S, et al. Emergency department point-of-care ultrasound in out-of-hospital and in-ED cardiac arrest. Resuscitation 2016;109:33–9.
22 Kim HB, Suh JY, Choi JH, Cho YS. Can serial focused echocardiographic evaluation in life support (FEEL) predict resuscitation or termination of resuscitation (TOR)? A pilot study. Resuscitation 2016;101:21–6.
23 Lien WC, Hsu SH, Chong KM, et al. US-CAB protocol for ultrasonographic evaluation during cardiopulmonary resuscitation: validation and potential impact. Resuscitation 2018;127:125–31.
24 Salen P, O'Connor R, Sierzenski P, et al. Can cardiac sonography and capnography be used independently and in combination to predict resuscitation outcomes? Acad Emerg Med 2001;8:610–5.
25 Salen P, Melniker L, Chooljian C, et al. Does the presence or absence of sonographically identified cardiac activity predict resuscitation outcomes of cardiac arrest patients? Am J Emerg Med 2005;23:459–62.
26 Tayal VS, Kline JA. Emergency echocardiography to detect pericardial effusion in patients in PEA and near-PEA states. Resuscitation 2003;59:315–8.
27 Varriale P, Maldonado JM. Echocardiographic observations during in hospital cardiopulmonary resuscitation. Crit Care Med 1997;25:1717–20.
28 Zengin S, Yavuz E, Al B, et al. Benefits of cardiac sonography performed by a non-expert sonographer in patients with non-traumatic cardiopulmonary arrest. Resuscitation 2016;102:105–9.
29 Hu K, Gupta N, Teran F, Saul T, Nelson BP, Andrus P. Variability in interpretation of cardiac standstill among physician sonographers. Ann Emerg Med 2018;71:193–8.
30 Javaudin F, Pes P, Montassier E, et al. Early point-of-care focused echocardiographic asystole as a predictive factor for absence of return of spontaneous circulatory in out-of-hospital cardiac arrests: a study protocol for a prospective, multicentre observational study. BMJ Open 2019;9:e027448.
31 Huis In't Veld MA, Allison MG, Bostick DS, et al. Ultrasound use during cardiopulmonary resuscitation is associated with delays in chest compressions. Resuscitation 2017;119:95–8.
32 Clattenburg EJ, Wroe P, Brown S, et al. Point-of-care ultrasound use in patients with cardiac arrest is associated prolonged cardiopulmonary resuscitation pauses: a prospective cohort study. Resuscitation 2018;122:65–8.
33 Clattenburg EJ, Wroe PC, Gardner K, et al. Implementation of the Cardiac Arrest Sonographic Assessment (CASA) protocol for patients with cardiac arrest is associated with shorter CPR pulse checks. Resuscitation 2018;131:69–73.
34 Teran F. Resuscitative cardiopulmonary ultrasound and transesophageal echocardiography in the emergency department. Emerg Med Clin North Am 2019;37:409–30.
35 Querellou E, Leyral J, Brun C, et al. In and out-of-hospital cardiac arrest and echography: a review. Ann Fr Anesth Reanim 2009;28:769–78.
36 Blanco P, Volpicelli G. Common pitfalls in point-of-care ultrasound: a practical guide for emergency and critical care physicians. Crit Ultrasound J 2016;8:15.
37 Aagaard R, Granfeldt A, Bøtker MT, Mygind-Klausen T, Kirkegaard H, Løfgren B. The right ventricle is dilated during resuscitation from cardiac arrest caused by hypovolemia: a porcine ultrasound study. Crit Care Med 2017;45:e963–70.
38 Blyth L, Atkinson P, Gadd K, Lang E. Bedside focused echocardiography as predictor of survival in cardiac arrest patients: a systematic review. Acad Emerg Med 2012;19:1119–26.
39 Bøtker MT, Jacobsen L, Rudolph SS, Knudsen L. The role of point of care ultrasound in prehospital critical care: a systematic review. Scand J Trauma Resusc Emerg Med 2018;26:51.
40 Lalande E, Burwash-Brennan T, Burns K, et al. SHoC Investigators. Is point-of-care ultrasound a reliable predictor of outcome during atraumatic, non-shockable cardiac arrest? A systematic review and meta-analysis from the SHoC investigators. Resuscitation 2019;139:159–66.
41 Tsou PY, Kurbedin J, Chen YS, et al. Accuracy of point-of-care focused echocardiography in predicting outcome of resuscitation in cardiac arrest patients: a systematic review and meta-analysis. Resuscitation 2017;114:92–9.
42 Wu C, Zheng Z, Jiang L, et al. The predictive value of bedside ultrasound to restore spontaneous circulation in patients with pulseless electrical activity: a systematic review and meta-analysis. PLOS ONE 2018;13:e0191636.
43 Kegan I, Ciozda W, Palatinus JA, Palatinus HN, Kimchi A. Prognositic value of point-of-care ultrasound during cardiac arrest: a systematic review. Cardiovasc Ultrasound 2020;18:1.

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