Review

Diagnostic yield of non-invasive imaging in patients following non-traumatic out-of-hospital sudden cardiac arrest: A systematic review

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Abstract

Aim: To review data for non-invasive imaging in the diagnosis of non-traumatic out-of-hospital cardiac arrest (OHCA).

Data sources: We searched MEDLINE, EMBASE, Cochrane library, and clinicaltrials.gov databases from inception to January 2017 for studies utilizing non-invasive imaging to identify potential causes of OHCA [computed tomography (CT), ultrasound including echocardiography, and magnetic resonance (MRI)].

Study selection: Inclusion criteria were the following: (1) randomized control trials, cohort studies or observational studies; (2) contained a population ≥18 years old with non-traumatic OHCA who underwent diagnostic imaging with CT, MRI, echocardiography, or abdominal ultrasound; (3) imaging was obtained for diagnostic purposes; (4) patients were alive or were undergoing cardiopulmonary resuscitation at the time of imaging; (5) contained potential causes of OHCA. Endpoints studied were the number of potential OHCA causes identified, diagnostic accuracy measures (sensitivity, specificity, positive and negative predictive values), and diagnostic utility (number of imaging findings with reported changes in clinical management).

Results: Of the total 5722 studies identified, 17 (0.3%) met inclusion criteria. The majority of studies assessed the utility of CT in OHCA (n = 10), and potential causes of OHCA were found in 8–54% of patients following head, abdominal and/or chest CT. Only 1/17 (6%) studies reported diagnostic accuracy measures, and 9/17 (53%) studies included a time to imaging criteria within 24 h.

Conclusion: Although non-invasive imaging is commonly performed in patients after OHCA, its diagnostic utility remains poorly characterized. Prospective studies are needed for appropriate imaging selection and their potential impact on treatment and outcome.

Keywords: Sudden cardiac arrest, Out-of-hospital, Imaging, Computed tomography, Echocardiography, Magnetic resonance imaging

Introduction

Out-of-hospital cardiac arrest (OHCA) is a major cause of morbidity and mortality affecting about 350,000 patients annually in the USA.[1] Causes of sudden cardiac arrest are considered to be primarily from a cardiac origin in patients presenting with ventricular tachycardia (VT) or ventricular fibrillation (VF) by the Utstein method.[2,3] Current American Heart Association (AHA) guidelines recommend urgent coronary angiography in OHCA survivors suspected to have acute coronary syndrome (ACS), but have no recommendations on non-invasive imaging in the diagnosis of out-of-hospital cardiac arrest.[4,5] The European Resuscitation Council guidelines also suggest urgent coronary angiography, but recommend performing early echocardiography in all patients to detect myocardial dysfunction and CT of the head or chest for those without obvious causes for OHCA.[6] Subarachnoid hemorrhage (SAH), seizures, substance use disorders, trauma, and hemorrhage can also cause OHCA presenting with shockable (VT or VF) as well as non-shockable rhythms (pulseless electrical activity (PEA) or asystole) and require other laboratory testing or non-invasive imaging techniques for diagnosis. While significant advances have been made in pre- and post-hospital management of OHCA, the lack of non-invasive imaging data in OHCA survivors has led to indefinite patient guidelines and significant practice variation. To our knowledge, a formal literature review of diagnostic imaging to diagnose causes of OHCA in survivors of an event has not been performed.

In this review, we systematically reviewed diagnostic accuracy data on non-invasive imaging modalities following resuscitation from non-traumatic OHCA to inform and improve current diagnostic management algorithms. The primary aims of this study were to (1) assess potential causes of OHCA identified by non-invasive imaging modalities, (2) assess the diagnostic accuracy of non-invasive imaging modalities (sensitivity, specificity, positive and negative predictive values) to identify causes for OHCA, (3) and assess the imaging studies that led to reported changes in clinical management.

Methods

Data sources and search strategy

The database search strategy was verified by senior medical librarians experienced in systematic reviews (ALB, ND). We searched the MEDLINE and EMBASE databases from inception to January 12, 2017 for eligible articles (Fig. 1). The search included MEDLINE subject headings (MeSH) or EMBASE subject headings (Emtree) when possible, which were variations of the following terms: "cardiac arrest" or "out of hospital cardiac arrest" combined with "ultrasonography" or "computed tomography" or "echocardiography" or "magnetic resonance." The detailed search strategies are presented in Online Appendix A. We limited our search to studies published in English and those involving human subjects only. A subsequent manual review of the reference list of every study that passed inclusion/exclusion criteria was performed. Previous clinical trials were also searched for on the Clinicaltrials.gov website. This systematic review was performed following the PRISMA criteria.[7]

Study selection

To be eligible for this systemic review, studies had to fulfill the following inclusion criteria: (1) they were randomized control trials, cohort studies or observational studies; (2) they contained a population of adults (≥18 years old) with non-traumatic OHCA of unknown cause who underwent diagnostic imaging with CT, MRI, echocardiography, or abdominal ultrasound; (3) imaging was obtained either for diagnostic purposes, not only prognosis or physiologic measurements, or diagnostic imaging findings were reported in a paper with a different scope (4) patients were alive following return of spontaneous circulation or were actively undergoing CPR at the time of diagnostic imaging; (5) they contained a report of potential causes of OHCA (beyond organ system; cardiac/pulmonary/non-cardiac cause, or simply cardiac standstill in the case of echocardiogram) and not only CPR-related injuries. Exclusion criteria included non-English language, absence of a full published manuscript, case series/reports, review articles, unpublished data, studies of a subset of OHCA patients with a known diagnosis (hypertrophic cardiomyopathy, pulmonary embolism, aortic dissection, etc.) without rates of diagnosis from a larger OHCA cohort, and studies with only in-hospital cardiac arrest (IHCA) patients. While diagnostic neuro-imaging can also lead to prognostic information leading to withdrawal of care, studies whose goals included assessing the incidence or cause of intracranial pathology following OHCA were included. If the study was deemed eligible but not enough information was reported in the manuscript, the manuscripts' corresponding authors were contacted for additional information. A total of 4 authors provided unpublished data included in the manuscript.[8–11] The unpublished data was confirmed by personal communication and presented in Tables 1–4. The percentage of potential OHCA causes per non-invasive imaging modality was calculated using the studies passing inclusion criteria. For echocardiography, regional wall motion abnormalities, LV dysfunction, and hypovolemia could not be identified as a cause rather than an effect of OHCA so were not included in calculations. Similarly, for head CT, cerebral edema is likely to be an effect rather than cause of the OHCA and was excluded from analyses.

Data extraction and reporting

Two independent reviewers (BJP and KRB) assessed the results of the literature search by screening titles, abstracts, or full-texts to decide which studies to include. Each article with conflicting opinion from the initial reviewers was discussed with another reviewer (CLE) for final decision making. Two reviewers subsequently independently abstracted the study characteristics, patient characteristics, study design, and image-based clinical diagnoses reported among patients enrolled in all studies meeting the inclusion criteria (BJP and CLE). Outcome measures in this review for each manuscript included: (1) the number of potential OHCA causes identified, (2) diagnostic accuracy measures for individual imaging modalities (defined as sensitivity, specificity, negative and/or positive predictive values), and (3) number of imaging studies that resulted in a change in clinical management (changes in management as defined by individual papers).

Results

Overall, 17 (0.3%) studies met the final criteria for inclusion into the manuscript[8–24] (Fig. 1). Each imaging modality is reviewed below with the included manuscripts.
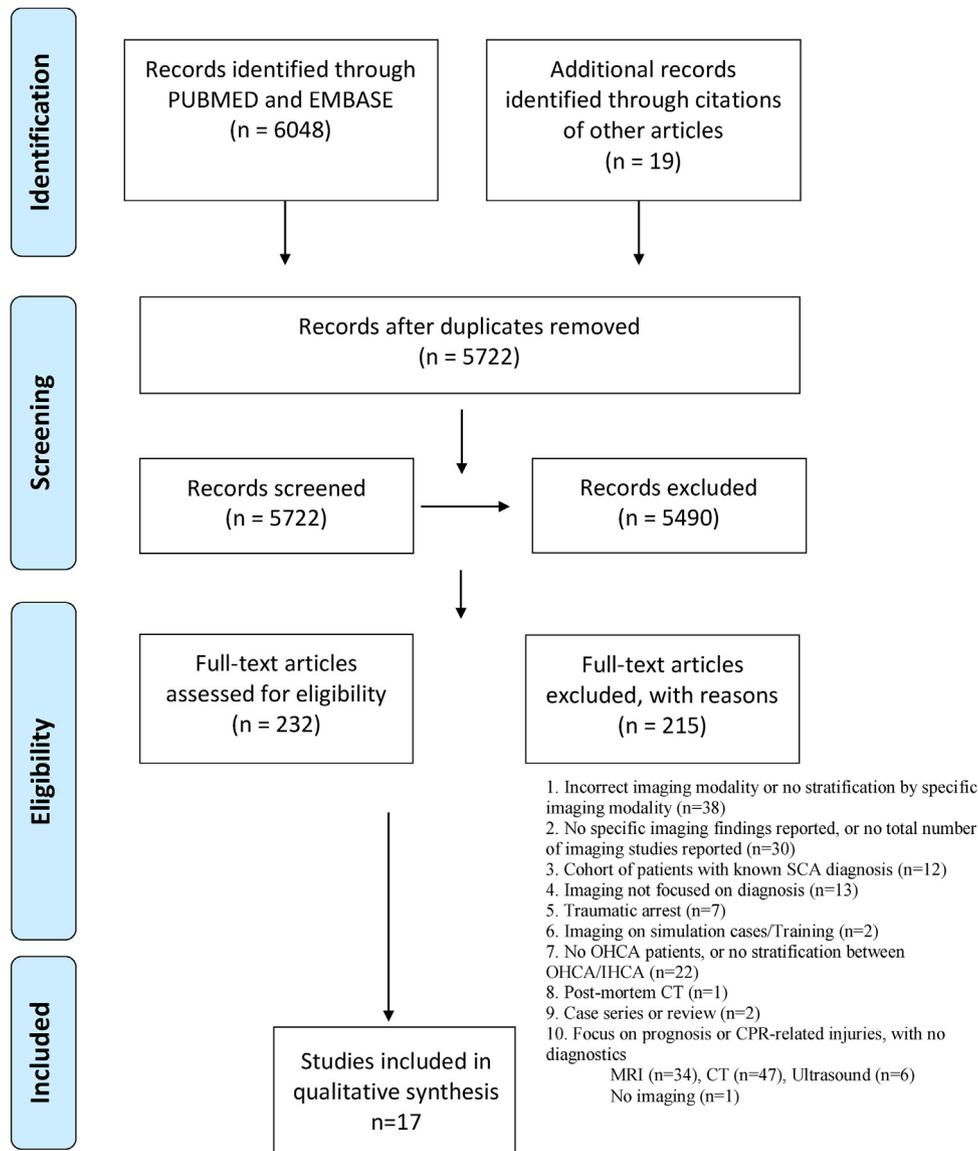
Fig. 1 – PRISMA flow diagram screening for eligibility of papers assessing diagnostic yield of non-invasive imaging following out-of-hospital cardiac arrest.

Computed tomography

Head computed tomography

Diagnoses from either contrast or non-contrast head CT scans in OHCA survivors were reported by 9 studies (Table 1). The two most common diagnoses reported in these patients were brain hemorrhage (16.9%, including intraparenchymal, intracranial or extra-axial hemorrhage) and acute stroke (11.8%, Table 1). Subarachnoid hemorrhage following return of spontaneous circulation (ROSC) was most often associated with a non-shockable presenting rhythm (95.7%), a prodromal headache before arrest (47.8%), and a negative cardiac troponin-T assay (94.7%).[17] In 10 patients with SAH, Mitsuma et al., reported that there were ECG abnormalities (ST-T changes and/or QT prolongation) in all patients following ROSC as well as abnormal echocardiographic findings in 3 patients.[19]

While most papers assessed the association between OHCA and subarachnoid hemorrhage, head CT was also included as a component in comprehensive diagnostic algorithms (that included echocardiography, angiography, ECG, or body CT) to diagnose OHCA etiology. Head CT as a component of these extensive workups provided a potential diagnosis in ~12% of patients.[12],[13] Naples et al. assessed the utility of head CT following any type of sudden death event (both in and out-of-hospital arrest) and reported that a head CT changed clinical management in 39% of studies (diagnostic alterations included: neurological consultation, ICP monitoring, a medication addition, additional diagnostic study, or life support withdrawal).[10]

The diagnostic accuracy (sensitivity, specificity, negative and/or positive predictive values) of head CT for identifying a probable cause of OHCA was not reported by any papers in this review. The rate of clinically significant findings after head CT in OHCA survivors was reported as 11.8% in the Cocchi et al. study,[18] and changes in clinical management were reported in 25% of OHCA cases undergoing head CT in the Christ et al. study.[13] A total of 4/9 (44%) studies reported a

Table 1 – Rates of diagnosis by head computed tomography for non-traumatic OHCA.

Head CT finding	Christ et al.[13] (n = 32)	Aliaga et al.[8] (n = 14)[a]	Inamasu et al.[17] (n = 142)[b]	Inamasu et al.[16] (n = 124)[b]	Cocchi et al.[18] (n = 51)	Naples et al.[10] (n = 33)[a]	Choi et al.[15] (n = 194)	Mitsuma et al.[19] (n = 67)	Chelly et al.[12] (n = 326)	Total[b]
Intracranial hemorrhage[c]	2 (6%)									2/32 (6%)
Intraparenchymal hemorrhage			3 (2%)	2 (2%)	1 (2%)	4 (12%)		2 (3%)		10/293 (3%)
Meningeal hemorrhage (Extra-axial)		2 (14%)	23 (16%)	10 (8%)	3 (6%)	5 (15%)	35 (18%)	10 (15%)		78/501 (16%)
1. Subdural					2 (4%)					2/51 (4%)
2. Subarachnoid			23 (16%)	10 (8%)	1 (2%)		35 (18%)	10 (15%)		69/454 (15%)
Stroke		1 (7%)				5 (15%)			38 (12%)	44/373 (12%)
Acute cerebral ischemia	2 (6%)									6/97 (6%)
Traumatic brain injury									2 (0.6%)	2/326 (0.6%)
Cerebral abscess									1 (0.3%)	1/326 (0.3%)
Cerebral edema	4 (13%)				6 (12%)	18 (55%)				28/116 (24%)
Hemorrhagic metastasis					1 (2%)					1/51 (2%)
Mass						1 (3%)				1/33 (3%)

Reported as N (%).

Definitions: CT = computed tomography, OHCA = out-of-hospital cardiac arrest.

[a] Unpublished data (confirmed through personal communication): Aliaga et al. reported that 14 patients had OHCA. There were 14 total head CT scans. Diagnoses made by CT scan were as listed above. Naples et al. confirmed that 33/98 patients undergoing head CT had OHCA in their study, with the results listed as above.

[b] Inamasu et al. published 2 papers in 2009 on CT imaging following OHCA, so only the largest cohort was included in total.[17]

[c] Type of intracranial hemorrhage (intraparenchymal vs. meningeal) was unspecified.

Table 2 – Rates of diagnosis by chest/abdomen computed tomography for non-traumatic OHCA.

Chest CT findings	Chelly et al.[12] (n = 195)	Christ et al.[13] (n = 31)	Choi et al.[14] (n = 77)	Aliaga et al.[8] (n = 7)[a]	Total
Pulmonary embolism	19 (10%)	3 (10%)	8 (10%)		30/303 (10%)
Pneumonia	3 (2%)	11 (35%)	4 (5%)		18/303 (6%)
Acute pulmonary edema	3 (2%)				3/195 (2%)
Pleural effusion	3 (2%)				3/195 (2%)
Pneumothorax	1 (1%)				1/195 (1%)
Tracheal compression	1 (1%)				1/195 (1%)
Aesotracheal fistula	1 (1%)				1/195 (1%)
Lung malignancy			3 (4%)		3/77 (4%)
Aortic dissection[b]			3 (4%)		3/77 (4%)
Myocardial infarction			2 (3%)		2/77 (3%)
Cardiac tamponade			1 (1%)		1/77 (1%)
Tension pneumothorax			1 (1%)		1/77 (1%)
Hemothorax		2 (6%)			2/31 (6%)
Tracheal rupture		1 (3%)			1/31 (3%)
Aortic thrombosis				1 (14%)	1/7 (14%)

Abdominal CT findings	Christ et al.[13] (n = 15)	Choi et al.[14] (n = 23)	Aliaga et al.[8] (n = 7)[a]	Total
Ruptured aortic aneurysm[c]	1 (7%)	1 (4%)		2/38 (5%)
Ruptured pseudoaneurysm of uterine artery		1 (4%)		1/23 (4%)
Acute cholecystitis	2 (13%)			2/15 (13%)
Paralytic ileus	1 (7%)			1/15 (7%)
Pneumoperitoneum	1 (7%)			1/15 (7%)
Mesenteric vascular occlusion	1 (7%)			1/15 (7%)
Hemoperitoneum			1 (14%)	1/7 (14%)
Iliac thrombosis			1 (14%)	1/7 (14%)

Reported as N (%).

Definitions: CT = computed tomography, OHCA = out-of-hospital cardiac arrest.

[a] Unpublished data (confirmed through personal communication): Aliaga et al. reported that 14 patients had OHCA. There were 7 whole body CT scans (including head, chest, abdomen). Diagnoses made by chest and abdominal CT are reported above.

[b] Aortic Dissection was assumed to be diagnosed by CT chest instead of abdomen/pelvis.

[c] Choi et al. reported an aortic rupture, which was assumed to be an abdominal aortic aneurysm.

Table 3 – Rates of diagnosis by cardiac magnetic resonance imaging for non-traumatic OHCA.

Cardiac MRI findings	Herman et al.[9] (n = 154)[a]	Marstrand et al.[11] (n = 11)[a]	Total
Myocarditis	3 (2%)		3 (2%)
Arrhythmogenic right ventricular cardiomyopathy	6 (4%)		6/154 (4%)
Dilated cardiomyopathy		2 (18%)	2/11 (18%)
Late gadolinium enhancement (myocardial infarction)		1 (9%)	1/11 (9%)

Reported as N (%).
Definitions: IHCA = in-hospital cardiac arrest, MRI = magnetic resonance imaging, OHCA = out-of-hospital cardiac arrest.
[a] Unpublished data (confirmed by personal communication): Herman et al. confirmed that all patients presented with OHCA, and all cases of myocarditis were diagnosed by cardiac MRI. The manuscript reported that cardiac MRI was the most effective form of clinical testing in 19% of patients, however, exact rates of diagnosis of coronary vasospasm and other cardiac MRI diagnoses than listed above were not reported in the manuscript and therefore not included in the table or final calculations; Marstrand et al. confirmed that 40/43 patients in the study had OHCA. Cardiac MRI was performed in 11 OHCA patients with the diagnoses listed above. The manuscript reports cardiomyopathy in 4/12 patients undergoing cardiac MRI (1 IHCA), however, some patients had the diagnosis of ischemic cardiomyopathy with cardiac catheterization prior to MRI. Marstrand et al. confirmed that cardiac MRI was the diagnostic test for 2/11 patients with cardiomyopathy as seen above.

Table 4 – Rates of diagnosis by transthoracic echocardiography for non-traumatic OHCA patients.

Echocardiographic findings	Kim et al.[22] (n = 48)	Lee et al.[23] (n = 135)	Chang et al.[24] (n = 58)	Chardoli et al.[21] (n = 50)[b]	Breitkrutz et al.[20] (n = 38)[c]	Marstrand et al.[11] (n = 40)[a]	Total
Regional wall motion abnormality	3 (6%)	53 (39%)	13 (22%)				69/241 (29%)
~LAD territory		11 (8%)					11/135 (8%)
~LCx territory		5 (4%)					5/135 (4%)
~RCA territory		12 (9%)					12/135 (9%)
~Multi-vessel territory		14 (10%)					14/135 (10%)
Acute myocardial infarction		41 (30%)[d]	10 (17%)				51/193 (26%)
Pericardial effusion				7 (14%)			7/50 (14%)
~Cardiac tamponade	1 (2%)				5 (13%)		6/86 (7%)
Hypovolemia				11 (22%)	2 (5%)		13/88 (15%)
Suspected pulmonary embolism (RV dilation)					4 (11%)		4/38 (11%)
LV dysfunction					22 (58%)		22/38 (58%)
Non-ischemic cardiomyopathy						5 (13%)	5/40 (13%)
Ischemic crdiomyopathy[d]						7 (18%)	7/40 (18%)

Reported as N (%).
Definitions: echo = echocardiography, LAD = left anterior descending artery, LCx = left circumflex artery, OHCA = out-of-hospital cardiac arrest, PEA = pulseless electrical activity, RCA = right coronary artery.
[a] Unpublished data (confirmed by personal communication): Marstrand et al. confirmed that 40/43 patients in the study had OHCA, with all undergoing echo (40/40). Echo findings are reported above.
[b] Included only patients with PEA arrest.
[c] Included only patients with pseudo-PEA (defined as no palpable pulse, but demonstration of cardiac motion by peri-resuscitation echocardiogram).
[d] Confirmed by coronary angiography.

specific time to imaging within 24 h, and 5/9 (56%) did not report a specific time criterion.

Chest and abdominal CT
Four studies evaluated chest and abdominal CT examinations after OHCA. Chest CT was performed in 310 patients, and common findings included pulmonary embolism (9.9%) and pneumonia (5.9%, Table 2). Abdominal CT was utilized less often (n = 45) than chest CT, and led to a variety of diagnoses including ruptured abdominal aortic aneurysm, acute cholecystitis, and abdominal vascular thromboses (Table 2). Chelly et al. implemented an early systematic imaging protocol following OHCA including coronary angiography (n = 745) and head and/or chest CT (n = 355) to assess for probable causes of

OHCA.[12] Head and chest CT led to a probable cause of OHCA in 20% of patients. Choi, et al. assessed the utility of chest (n = 77) and abdominal CT (n = 23) following OHCA, and reported that thoracoabdominal CT was the supportive (n = 3) or definitive test (n = 22) for identifying the probable cause of OHCA in 30% of patients.[14]

The diagnostic accuracy (sensitivity, specificity, negative and/or positive predictive values) of abdominal and chest CT for a possible cause of OHCA was only reported by Chelly et al. paper where the sensitivity of head and thoracic CT was 54%, specificity 86%, positive predictive value 26% and negative predictive value of 96% in 355 examined patients.[12] Clinically significant findings leading to changes in management following chest (n = 31) and abdominal CTs (n = 15) occurred in 54.3% of

cases in the Christ et al. paper.[13] A total of 3/4 (75%) studies reported a specific time to imaging within 24 h, and 1/4 (25%) did not report a specific time criterion.

Magnetic resonance imaging

Cardiac MRI

Two studies of cardiac MRI following OHCA met entry criteria. In these studies, cardiac MRI diagnosed several potential causes of OHCA including myocarditis, dilated cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy (ARVC), and late gadolinium enhancement suggestive of prior myocardial infarction (MI, Table 3). There were no reports of using MRI as the initial evaluation of OHCA survivors, therefore none of the MRI studies were in within 24 h from admission and cardiac MRI was utilized as part of a comprehensive imaging protocol in all studies. Potential cardiac MRI diagnoses were found in 6–27% of OHCA survivors (Table 3). Herman, et al. evaluated a systematic imaging protocol utilizing cardiac MRI and reported that cardiac MRI was the most effective form of clinical testing in 19% of patients,[9] including 6 patients with ARVC (4%) and 3 patients with myocarditis (2%). The diagnostic accuracy (sensitivity, specificity, negative and positive predictive values) of cardiac MRI for an OHCA diagnosis was not reported by any study. No studies reported the number of imaging studies that changed clinical management.

Echocardiography

Echocardiography

A total of six studies utilizing echocardiography following OHCA met criteria for inclusion (Table 4). Lee, et al. evaluated the accuracy of echocardiography to predict acute MI (confirmed by coronary angiography) in patients with OHCA.[23] They showed that regional wall motion abnormalities (RWMA) on echocardiography were more likely in patients with acute MI as a cause of OHCA than those with other causes of OHCA (64% vs. 18%, $p < 0.001$), but RWMA were seen in patients without angiographic evidence of CAD as well. The timing for echocardiography in this study was defined as the first interpretable data post-ROSC. Another study by Chang et al. evaluated the utility of echocardiography 6 h post-ROSC in OHCA survivors.[24] They found 13 (22%) patients with RWMA's and 10 (17%) of these were diagnosed with acute MI as the cause of OHCA. The overall rate of RWMAs for all included studies was 28.6%, and acute MI was 26.4% (Table 4).

In addition to RWMAs, enlarged left ventricular volumes may suggest chronicity of cardiac dysfunction and differentiate dilated cardiomyopathy from cardiac stunning following OHCA. Marstrand, et al. utilized a multimodality imaging strategy (echocardiography, coronary angiogram, cardiac MRI, and electophysiologic studies) on OHCA survivors and found that echocardiography identified non-ischemic cardiomyopathy in 12.5% (5/40), and angiographically-confirmed ischemic cardiomyopathy in 17.5% (7/40) of OHCA survivors.[11]

No articles reported diagnostic accuracy measures (sensitivity, specificity, negative and/or positive predictive values) specifically for echocardiography in identifying OHCA causes or changes in treatment based on imaging findings. Lee et al. reported that the presence of RWMAs or Troponin-T elevation along with ST-elevation was highly predictive of coronary artery disease (sensitivity = 90%, specificity = 29%, PPV = 55%, NPV = 74%), but did not separate between echocardiographic and laboratory and/or ECG analyses.[23] A total of 4/6 (67%) studies reported a specific time to imaging within 24 h, and 2/6 (33%) did not report a specific time criterion.

Summary of findings

Potential causes of OHCA were found in 10–45% of head CT scans (Table 1), 14–54% of chest CT scans (Table 2), 8–41% of abdominal CT scans (Table 2), 6–27% of cardiac MRI studies (Table 3), and 2–31% of echocardiographic studies (Table 4). Diagnostic accuracy was only reported in head and thoracic CT with a high specificity and negative predictive value, but not in cardiac MRI or echocardiography. Changes in clinical management following imaging were only reported for CT and varied from 25 to 60% depending on the organ studied. Only 1/17 (6%) studies reported diagnostic accuracy measures, and 9/17 (53%) studies included a time to imaging criteria within 24 h.

Discussion

This systematic review of OHCA survivors evaluated the ability and accuracy of non-invasive imaging to identify probable causes of OHCA events with the goal of refining current management paradigms. While such imaging was found to hold promise for improving diagnosis and treatment of these patients, this is accompanied by a critical knowledge gap. Multiple small to medium-sized studies primarily report observational data, but measures of robust diagnostic accuracy were lacking for nearly all non-invasive imaging modalities. Further, there are few prospective studies and no randomized controlled trials designed to assess the ability of non-invasive imaging modalities to identify probable causes of OHCA. Studies assessing systematic protocols for OHCA survivors that incorporate many imaging evaluations, including ECG, invasive coronary angiography, CT, echocardiography, and/or MRI, generally do not report the diagnostic contribution for each modality. Not surprisingly, the lack of non-invasive imaging data has manifested in a paucity of guideline recommendations for OHCA patients despite the need for rapid and accurate diagnoses when patient symptoms and past medical history are not available.[4],[5]

While OHCA is commonly assumed to be of cardiac origin,[25] there are many other possible causes that may require multiple, comprehensive modalities to make the correct diagnosis.[8–24] At present, most OHCA diagnostic data are derived from autopsy cohorts, but still support the assertion that non-cardiac causes for OHCA are common.[26] The relative rates of OHCA causes differ depending on presenting arrhythmia and some generalities are commonly applied including that VT or VF are primarily from a cardiac source and PEA is from hypoxia. Most studies in this review also do not stratify certain diagnoses with their associated presenting rhythm, making interpretation difficult. Overall, common cardiac diagnoses following OHCA arrest in this review included acute coronary syndrome and myocardial infarction, myocarditis, cardiac tamponade, arrhythmogenic right ventricular cardiomyopathy and dilated cardio-myopathy. These do not encompass the entirety of the cohort, however. Potential non-cardiac causes of OHCA by various imaging modalities in this review included SAH, pulmonary embolism, and ruptured aortic aneurysms. While these diagnoses were reported using multiple different imaging modalities, these data suffer from ascertainment bias where it is unclear if the imaging findings were the true cause of OHCA, or just secondary abnormal findings visible from the utilized imaging modality. Adjudication of OHCA causes are often lacking from observational studies, including those with systematic diagnostic evaluations.

Unfortunately, many more studies could have been included had the authors stratified data by out-of-hospital and in-hospital arrest in

the initial data collection, or had rates of a specific cause of adjudicated SCA been specified from a larger OHCA cohort. For example, Neilan et al. published a seminal study assessing the utility of cardiac MRI following sudden cardiac arrest of unknown etiology. However, they did not discriminate between OHCA and IHCA, so their results were not included.[27] The inclusion of both OHCA and IHCA patients has traditionally been an issue as many studies include both to increase power. Even though recruitment for OHCA cohorts can be much more difficult than IHCA cohorts, it is important to stratify the differences between the two because OHCA has been associated with different causes of arrest and worse clinical outcomes.[1]

Clinical implications

The lack of rigorous data regarding diagnostic accuracy of imaging after an OHCA event has resulted in little guidance and potential heterogeneity of practice. Based on the current review, obtaining an echocardiogram appears reasonable and may diagnose over one quarter of OHCA survivors with regional wall motion abnormalities or cardiac dysfunction. While echocardiographic abnormalities in the early resuscitation period may be transient, wall motion abnormalities or ventricular dilation may guide the patient toward a primary cardiac etiology and further evaluation with coronary angiography. However, our data suggest that many questions remain regarding the clinical application of CT, abdominal ultrasound and MRI in OHCA survivors to identify possible extra-cardiac causes of the event. CT may have secondary benefits including diagnosing injuries secondary to CPR and also guiding targeted temperature management (as a head CT can rule out intracranial bleeding which is a relative exclusion criterion). However, there are limited data on the diagnostic utility of CT. Routine use of most other imaging modalities is not clear. The decision on which patients and at what time point to consider imaging remains ill-defined, and further studies are needed to answer these important questions.

There are limitations to this analysis and clinical approaches that warrant discussion. Given the requirements applied to answer our questions, important studies were excluded. However, selection criteria were determined *a priori*, and we remained consistent in our approach to reduce bias and to address diagnostic accuracy. Second, diagnostic data were unavailable for virtually all studies such that this review was more akin to a scoping review rather than a systematic review. Third, different patient populations were studied within these manuscripts which included differing ages, OHCA rhythms, medical histories as well as selection bias as to who received a study and who did not. This led to heterogeneous patient groups and diagnoses for each study. This limitation would be overcome with a standardized protocol with a prospectively planned trial. Fourth, it is unclear if imaging findings were the actual cause of OHCA, as many studies did not have clear adjudicated diagnoses, so the rate of causes for OHCA may be skewed. Fifth, the primary aim for this paper was to assess the diagnostic ability of non-invasive imaging modalities. However, in the case of neuro-imaging, significant findings can also have prognostic value leading to withdrawal of care. We only included studies that assessed the incidence or intracranial cause of OHCA regardless of whether prognostic measures were reported. Finally, there was no time to imaging parameters in the inclusion criteria, and only 9/17 (53%) studies were confirmed to have a time to imaging within 24 h. This has clinical implications as the greatest potential benefits to imaging modalities like CT and echo are likely in the early post-ROSC period as these studies can be rapidly interpreted for acute changes in

clinical management. However, 8/17 (47%) studies did not specify a specific timeframe to imaging so could have been in the early post resuscitation period, and a strict time criterion would have excluded many studies (including all MRI) that help provide an overview of potential clinical utilities of these non-invasive imaging modalities following OHCA.

Conclusions

The current review suggests that there are scant data on the diagnostic ability of most non-invasive imaging modalities such as echocardiography, CT, ultrasound, or MRI to identify the cause for an OHCA event. In order to improve decision-making for OHCA survivors without an obvious cause, well-planned and executed studies are clearly needed. Data from these studies could foster development of comprehensive diagnostic and management algorithms that could then be incorporated into clinical guidelines. This would reduce care variation for OHCA survivors and may result in improved patient outcomes.

Conflicts of interest

None.

Source of funding

None.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.resuscitation.2018.09.004.

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