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ORIGINAL CONTRIBUTION

Early head-to-pelvis computed tomography in out-of-hospital circulatory arrest without obvious etiology

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Abstract

Objectives: Patients resuscitated from an out-of-hospital circulatory arrest (OHCA) commonly present without an obvious etiology. We assessed the diagnostic capability and safety of early head-to-pelvis computed tomography (CT) imaging in such patients.

Methods: From November 2015 to February 2018, we enrolled 104 patients resuscitated from OHCA without obvious cause (idiopathic OHCA) to an early sudden-death CT (SDCT) scan protocol within 6 h of hospital arrival. The SDCT protocol included a noncontrast CT head, an electrocardiogram-gated cardiac and thoracic CT angiogram, and a nongated venous-phase abdominopelvic CT angiogram. Patients needing urgent cardiac catheterization or hemodynamically unable to tolerate SDCT were excluded. Cardiac CT analyses were blinded, but other SDCT findings were clinically available. Primary endpoints were the number of OHCA causes identified by SDCT compared to the adjudicated cause and critical diagnoses identified by SDCT, including resuscitation complications. Safety endpoints were acute kidney injury (AKI) and inappropriate treatments based on SDCT findings. Acute coronary syndrome was the presumed etiology if any major coronary artery had a >50% stenosis without another OHCA cause.

Results: SDCT scans occurred within 1.9 ± 1.0 h of hospital arrival and identified 39% (41/104) of all OHCA causes and 95% (39/41) of causes potentially identifiable by SDCT. Critical findings were identified by SDCT in 98% (43/44) of patients that included potentially life-threatening resuscitation complications of liver or spleen laceration (n = 6); pneumothorax or thoracic organ laceration (n = 8); and mediastinal, pericardial, or vascular hemorrhage (n = 3). SDCT exclusively identified 13 (13%) OHCA causes that would otherwise not be identified without SDCT imaging. No inappropriate treatments resulted from SDCT findings. AKI was common (28%) but only one (1%) patient required new dialysis.

Presented, in part, at the European Society of Cardiology Congress, Paris, France, August 2019.

Clinical study registration (clinicaltrials.gov): NCT 03111043.

Conclusions: This observational cohort study suggests that early SDCT scanning is safe, can expedite the diagnosis of potential causes, and can meaningfully change clinical management after idiopathic OHCA.

KEYWORDS
abdominal CT, cardiac arrest, cardiac computed tomography, cardiac CT, CT angiography, observational cohort, out of hospital cardiac arrest, resuscitation complication, sudden death, sudden death diagnosis

INTRODUCTION

Out-of-hospital circulatory arrest (OHCA) is a devastating event that occurs annually in approximately 140 per 100,000 persons in the United States.[1] For patients resuscitated from an OHCA event without an obvious cause (idiopathic OHCA) causes of the event are varied and are frequently difficult to determine on presentation due to a lack of medical history and communication barriers from patient endotracheal intubation and/or obtundation.[2] Current guidelines recommend a number of tests to evaluate causes of OHCA, including electrocardiogram, chest radiograph, echocardiogram, and serologic evaluation,[3-5] although these may not establish the probable cause for OHCA in greater than 10% of cases.[6,7]

In patients without obvious causes for OHCA, computed tomography (CT) has the ability to rapidly evaluate for numerous etiologies of an OHCA event. CT scanning can evaluate head and neck, thorax (including the lungs and vascular system), heart (including coronary arteries), and abdominal organs and structures.[8,9] Current guidelines recommend use of coronary CT angiography (CCTA) in patients resuscitated from OHCA,[3-5] although CCTA data in this population are scarce.[10,11] If CT scanning were to extend from head to pelvis, up to 75% to 86% of potential anatomic diagnoses could potentially be ascertained based on causes of death identified on autopsy.[12] In a recent retrospective study, whole-body CT identified acute pathology in a majority of patients that included potential etiologies of OHCA as well as cardiopulmonary resuscitation–related injuries.[13]

This prospective cohort study was designed to evaluate early use (≤6 h from hospital arrival) of head-to-pelvis sudden-death CT (SDCT) in patients resuscitated from an OHCA event. We hypothesized that early SDCT scanning after idiopathic OHCA is feasible and safe, can expedite the diagnosis of potential OHCA causes, and can meaningfully change clinical management.

METHODS

Study design and setting

This prospective, observational pilot study evaluated a head-to-pelvis SDCT scan protocol in patients admitted to the hospital after OHCA (NCT 03111043). Patients were to be prospectively enrolled to undergo early (<6 h from hospital arrival) SDCT in addition to standard postarrest care. Informed consent was obtained by a research nurse from a legally authorized patient representative or the patient before the SDCT or, if the SDCT was ordered clinically, consent was obtained after the scan. If the patient expired but no family members could be identified, clinically obtained data were accessed under minimal risk criteria provisions. The academic centers human subject division approval was obtained and the study adhered to all HIPAA requirements. This study was supported by a research grant from the Medic One Foundation (Seattle, WA, USA).

Selection of participants

Patients that survived an OHCA event between December 2015 and February 2018 and presented to one of two academic medical centers were eligible for recruitment (Figure 1). Research inclusion criteria were: 1) SDCT scanning ≤ 6 h from the OHCA event, 2) no obvious cause for OHCA identifiable upon emergency department arrival, and 3) sufficient clinical stability for performance of SDCT per treating physicians. Candidates included patients who had received endotracheal intubation, those requiring sedation for scanning, and recipients of targeted temperature management, if deemed appropriate. Exclusion criteria were 1) acute ST elevation myocardial infarction (ST elevation ≥ 1 contiguous lead or new or unknown duration left bundle branch block on ECG) or other clinical indication for urgent invasive angiography; 2) known nonrevascularized coronary artery disease or coronary stent < 2.5 mm; 3) known severe renal dysfunction (eGFR < 30 mL/h/1.73 m^2, creatinine > 1.7 mg/dL) unless ordering physicians believed that SDCT scanning warranted regardless of creatinine; 4) implantable defibrillator, due to metal artifact from a defibrillator coil potentially compromising image quality; 5) known iodinated contrast allergy; and 6) known hospice patient or terminal disease with expected < 3 months' survival. All patients received clinically directed imaging and treatments by their health care providers before and after SDCT.

SDCT scan and coronary evaluation

The SDCT scan was performed on either a dual-source CT (FORCE, Siemens Medical Solutions, Forchheim, Germany) or a wide single-detector CT (REVOLUTION, GE Healthcare, Waukesha, WI). Due to

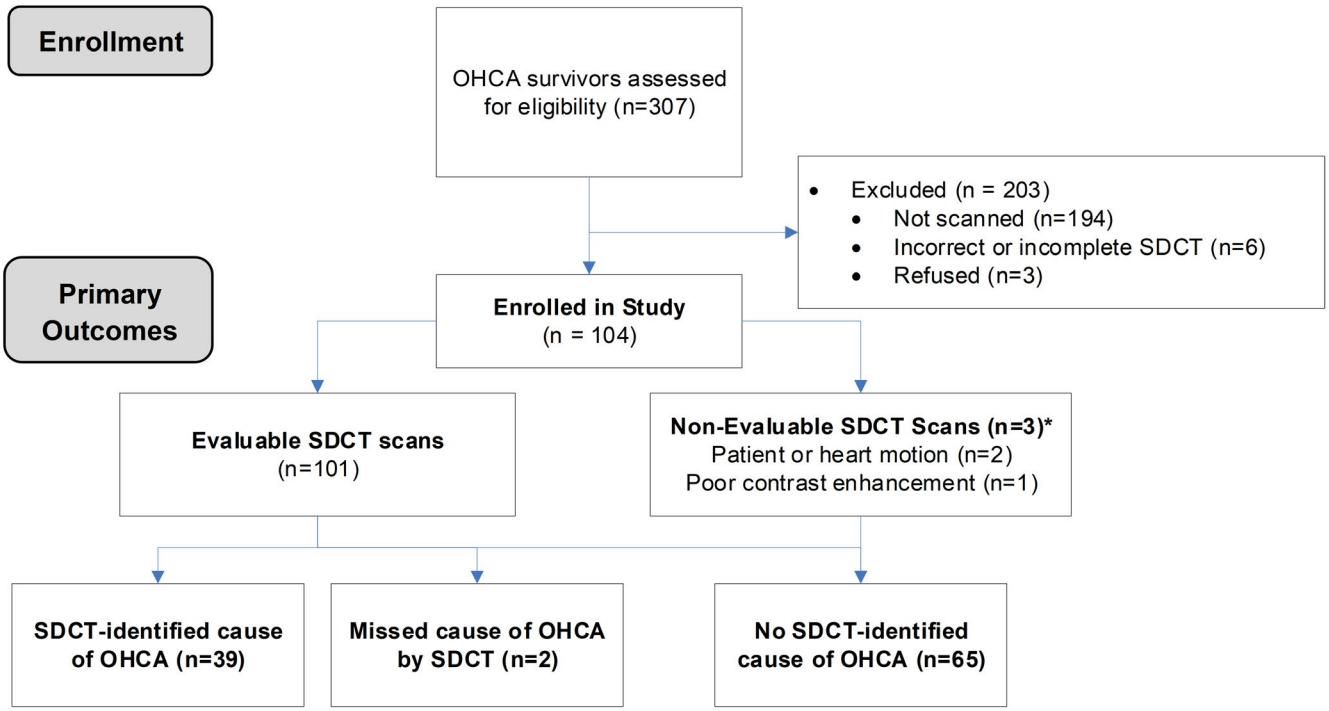

FIGURE 1 CONSORT diagram of patient enrollment. *SDCT images were unevaluable only for the coronary CT images. All other imaging was deemed evaluable. OHCA, out-of-hospital circulatory arrest; SDCT, sudden-death computed tomography

the possibility of hemodynamic instability after OHCA, beta blocker and nitroglycerin were not prescribed for SDCT scanning. SDCT was conducted in a manner similar to that of whole-body CT for trauma patients[14] and consisted of 1) noncontrast head CT from the top of the head to below the mandible, 2) ECG-gated CT scan of the thorax, and 3) a non–ECG-gated venous-phase CT scan extending from the diaphragm to just below the pelvis. SDCT scans were generally performed during mechanical ventilation. Patients were positioned supine with arms up and SDCT scan settings are outlined in the Table S1 (available as supporting information in the online version of this paper, which is available at http://onlinelibrary.wiley.com/doi/10.1111/acem.14228/full). Automatic kVp and mA determinations were used to minimize radiation dose. Total radiation dose was the summation of all dose-length products in mGy*cm from each CT scan as reported from the imaging console.

The thoracic CT was either retrospective ECG-gated for the dual-source CT (FORCE, Siemens, Forchheim, Germany) or prospective ECG-triggered for the wide-detector CT (REVOLUTION, Waukesha, WI). A triple-phase iodinated contrast injection (iohexol 350 or iodixanol 320, Chicago, IL) was administered by intravenous (IV) power injection at 5 mL/s[15] and contrast bolus detection at the level of the ascending aorta determined peak arterial enhancement. To ensure the highest likelihood of a diagnostic CCTA scan and to determine biventricular function, the first 25 thoracic CT scans (as part of the SDCT) imaged from systole to diastole (20%–90% of the R–R interval) of the cardiac cycle. Due to high radiation dose, thorax CT beam on time was shortened for all subsequent patients to ~30% to 80% of the R–R interval during the study. Since patients were not optimized for CCTA, cardiac and CCTA information was not disclosed to care providers but were only read as research data. All other thoracic and abdominopelvic SDCT findings were read clinically and provided to treating providers.

SDCT scan interpretation

Two board-certified imagers (M.G. and R.E., with 25 and 9 years' experience, respectively) were blinded to patient clinical data and independently assessed cerebral, thoracic, and abdominal anatomy for pathologic findings. Any discrepancies in CT findings were resolved by consensus.

CCTA images were blinded and independently reviewed by two trained providers (K.R.H.B. and R.B. with 15 and 2 years of CCTA experience, respectively) who were also blinded to the clinical data. Coronary arteries were evaluated using axial images and processed using automated software into curvilinear reformatted images, using manual adjustment when required (AW Server, GE Healthcare, Waukesha, WI). Using a modified AHA 20 segment coronary model, coronary artery quality was graded using an ordinal scale (0 = non-diagnostic/unevaluable, 4 = excellent quality)[16] and a categorical stenosis severity was determined.[17] Any discrepancies in stenosis severity were resolved with automated quantitative coronary artery analysis (AW Server, GE Healthcare, Waukesha, WI) and any other discrepancies by consensus between the readers. The highest degree of stenosis for each coronary segment determined the degree of coronary segmental stenosis.

Adjudication of cause for OHCA event

An emergency physician and a cardiologist (M.O.G. and K.R.H.B.) independently reviewed all clinical information, including clinical SDCT readings, but exclusive of blinded research cardiac and CCTA data, to generate a ranked list of likely causes for the OHCA event. Any discrepancies between readers were subsequently resolved by consensus. The highest ranked adjudicated diagnosis was considered the primary cause for OHCA and the mode of diagnosis along with the time when performed were recorded. If no cause of sudden death could be determined, the adjudicated diagnosis was coded as "unknown" and the time of diagnosis defaulted to the date of death or discharge.

Study outcomes

Primary goals of this study were to assess the capability of SDCT to detect possible causes of an OHCA event and affect changes in clinical care as well as to assess the relative safety of SDCT. Primary study outcomes were 1) the number of OHCA causes the SDCT protocol detected compared to the adjudicated cause of OHCA event as the reference standard and 2) the frequency at which the SDCT identified time-critical findings that did or should affect clinical treatments. Time-critical findings included those where treatment within 6 h is indicated, such as acute coronary syndrome, pulmonary embolism, aortic dissection, abdominal rupture, and pneumonia. Since the cardiac and coronary CT data were blinded from the treating physicians, diagnostic ability and changes in care ascribed to cardiac and coronary CT findings were inferred. This includes "possible acute coronary syndrome" that was inferred if there was obstructive CAD (a ≥ 50% stenosis in a major coronary artery) on SDCT identified by researchers. The 50% stenosis is a conservative stenosis threshold used for acute chest pain and in diagnostic accuracy CCTA studies.[18,19] Exploratory analyses included 1) estimating of the number of OHCA causes diagnosed exclusively with SDCT information and 2) the time to diagnosis. To determine the number of causes of the OHCA event only SDCT identified or would identify, all imaging, clinical, and serologic data as part of their clinical care were reviewed. We included the blinded cardiac data into this analysis. SDCT exclusively identified an OHCA cause only if a patient's clinical care did not identify the correct OHCA diagnosis by other means.

Safety of SDCT

Safety endpoints for the SDCT scan were 1) the incidence of contrast nephropathy, 2) rate of SDCT scan findings that resulted in inappropriate treatment or unwarranted further testing as deemed by the adjudicated reviewers, and 3) allergic reactions or other complications related to SDCT. All SDCT findings were reviewed and any changes in treatment or additional were tabulated. Incident acute renal dysfunction and contrast nephropathy was defined using the Acute Kidney Injury Network definition of an absolute serum creatinine increase of ≥0.3 mg/dL, a percentage increase in serum creatinine of ≥50% (1.5-fold above baseline), or urine output reduced to ≤0.5 mL/kg/h for at least 6 h within 72 h of hospital arrival.[20] Patient data were stratified for those with contrast from SDCT alone and those with additional contrast exposure from invasive coronary angiogram (ICA). Allergic contrast reactions were identified if they fit American College of Radiology criteria.[21] Any complications during SDCT, such as contrast extravasation or hypotension requiring addition or increase in pressors, were also tabulated.

Data analysis

Baseline patient data were tabulated using the total number and percentage for binary variables and either mean and standard deviation or median and interquartile ratio (IQR) for continuous variables based on the distribution of the data (SPSS, Chicago, IL). No further statistical analyses were performed for this observational cohort. The clinically available SDCT data introduced information bias to the adjudicated causes for OHCA so formal diagnostic accuracy measures were not performed. Per journal guidelines, the manuscript followed STROBE guidelines for reporting (Table S1).

RESULTS

Over the time of enrollment from November 2015 to February 2018, a total of 307 patients presented with OHCA to the two centers (Figure 1). A total of 111 nonsequential patients were included into the study after clinical SDCT scanning. Due to difficulty in obtaining consent early after OHCA, no patients were consented prior to CT scanning. Seven patients were excluded due to incorrect SDCT protocol (n = 4) or refusing enrollment after awakening (n = 3) leaving 104 patients remaining in this observational study. Patient characteristics are shown in Table 1. For the CCTA scans, 3% (3/104) were deemed to have nonevaluable coronary arteries due to poor contrast enhancement (n = 1) or cardiac or subject motion (n = 2). Total CT radiation dose by dose-length product was 2388 ± 975 mGy*cm.

Adjudicated causes for the OHCA event and the SDCT findings are listed in Table 2. The primary endpoints were as follows. SDCT scans identified 39% (41/104) of the adjudicated causes for OHCA and 95% (41/43) of OHCA causes that were potentially identifiable with a head-to-pelvis CT. The SDCT missed a significant coronary stenosis in one patient due to a poor-quality scan and missed a patient with cardiomyopathy due to the left ventricular size being normal. Of the 44 patients with time-critical diagnoses that required a change or expedited treatments (including resuscitation complications), SDCT identified 98% (Table 3). For the exploratory analyses, SDCT identified life-threatening resuscitation complications in 16% (17/104) of patients (Table 3). Causes of OHCA were determined exclusively by SDCT in 13% (13/104) of cases that would not have been identified by the standard of care without CT scanning.

TABLE 1 Known baseline characteristics (*N* = 104)

Characteristic	n/N (%) or mean ± SD value
Age (y)	56 ± 15
Female gender	32/104 (31%)
Medical history	
Hypertension	38/95 (40%)
Dyslipidemia	15/95 (16%)
Heart failure	12/95 (13%)
LV ejection fraction < 40%	13/38 (27%)
Diabetes mellitus	19/95 (20%)
History of coronary artery disease	11/95 (12%)
History of cardiac arrest	2/95 (2%)
Prior ICD implantation	—
History of PTCA/stent	5/95 (5%)
Prior valvular disease	5/95 (5%)
Prior stroke	6/95 (6%)
History of renal insufficiency	12/95 (13%)
Race	
White	63/104 (61%)
Black	17/104 (16%)
Native American	3/104 (3%)
Asian	9/104 (9%)
Other/unknown	12/104 (12%)
Witnessed arrest	51/87 (59%)
Bystander CPR	48/86 (60%)
Initial rhythm	
VF/VT	30/104 (29%)
Asystole	26/104 (25%)
Pulseless electrical activity	40/104 (38%)
Other	8/104 (8%)

Ninety-five of 104 (91%) patients had complete past medical history obtained during the hospitalization.

Abbreviations: ICD, implantable cardioverter defibrillator; PCTA, percutaneous transluminal coronary angioplasty; VF/VT, ventricular fibrillation/ventricular tachycardia.

These included acute coronary syndrome (*n* = 1), pulmonary embolism (*n* = 5), pneumonia (*n* = 1), hemorrhagic cerebrovascular accident (*n* = 2), necrotizing mediastinal mass (*n* = 1), and abdominal catastrophe (*n* = 3; Figures 2-4). The mean time to SDCT scanning from hospital arrival was 1.8 ± 0.8 h, and the median time to diagnosis of time-critical diagnoses by SDCT was 1.4 (IQR = 1.0–2.3) h from hospital arrival. The median time to any OHCA diagnosis was 3.1 (IQR = 1.4–12.9) h.

For the primary safety endpoints, average creatinine on presentation and after 48 h are in Table 1. Most patients (57 [55%]) had elevated creatinine upon presentation and approximately one-quarter of patients undergoing SDCT with or without ICA met criteria for incident acute kidney injury (AKI) by the Acute Kidney Injury Network (Table 4). However, only 30 (28%) had elevated creatinine after 48 h and only one patient (1%) required initiation of renal replacement therapy during hospitalization. The patient had a baseline type III chronic kidney disease and required pressors during the hospitalization. We did not identify any cases in which inappropriate treatments or procedures were undertaken due to an SDCT result (Table 4). There were no allergic reactions and only one contrast IV extravasation during SDCT scanning.

DISCUSSION

This prospective observational study demonstrated that a head-to-pelvis SDCT protocol performed within 6 h of hospital arrival (mean = 1.9 h) had high diagnostic yield to identify and rule out causes for idiopathic OHCA. SDCT discovered the likely cause for OHCA in 39% of patients, identified 95% of adjudicated OHCA diagnoses that could be made by with head-to-pelvis CT scan, and changed clinical care in 98% of patients with time critical diagnoses on SDCT. In 13% of cases, SDCT alone identified the cause for OHCA. In addition, SDCT identified potentially life-threatening resuscitation complications in 16% of subjects. SDCT appeared safe overall and did not result in inappropriate treatments or procedures.

Current imaging guidelines for resuscitated patients recommend a chest radiograph as well as echocardiography[3-5] although additional imaging, such as other ultrasound, CT, or magnetic resonance imaging, have little diagnostic imaging data to support routine use.[22] Sedation and intubation after OHCA resuscitation also hinder ascertainment of symptoms prior to the event, past medical history, and other important clinical information. Given these limitations, a comprehensive, morphologic assessment of potential causes for OHCA may be a logical addition to the current standard of care in these unresponsive, high-risk patients. CT is a rapid, readily available imaging tool that can evaluate the head and neck, thoracic and cardiac structures (including coronary arteries), and abdominal organs and structures for a myriad of causes for idiopathic OHCA.[8,9]

However, there are few data on the use of CT scanning in OHCA.[22] The Parisian Region Out of Hospital Cardiac Registry (PROCAT) studied 355 resuscitated patients that showed that a clinical head CT head or CT pulmonary angiography showed a cause for OHCA in 72 of 355 (20%) patients with a sensitivity of 54% and specificity of 86%.[23] Another study showed that of 1,061 resuscitated patients that underwent "perimortem" noncontrast CT scanning of head and/or thorax, noncardiac causes of death were diagnosed in 66% of patients and of these, 22% were diagnosed exclusively by CT scan.[24] While these retrospective data were encouraging, further data are needed.

Our study was designed to prospectively test feasibility and safety of the head-to-pelvis SDCT in addition to routine diagnostic imaging and clinical care. The SDCT protocol was developed from the whole-body CT used routinely in major trauma patients,[14,25] which have similar limitations for obtaining clinical history and symptoms as our patients. We incorporated ECG gating of thorax into the trauma CT protocol to allow assessment of coronary

TABLE 2 SDCT diagnostic yield compared to adjudicated cause for OHCA

	Adjudicated cause of OHCA event (*N* = 104), *n* (%)	SDCT diagnosis of OHCA cause, *n* /*N* (%)
Diagnosable by SDCT (*n* = 41)	41 (39%)	39/41(37%)
Acute coronary syndrome	14[a]	13/14 (95%)
Pneumonia	9	9/9 (100%)[b]
Hemorrhagic stroke	2	2/2 (100%)
Pulmonary embolism	5	5/5 (100%)
Abdominal catastrophe	3	3/3 (100%)
Perforated viscus	2	2 (100%)
Mesenteric ischemia	1	1 (100%)
Heart failure	6	5/6 (83%)
Not diagnosable by SDCT (*n* = 63)		
Substance use	23	—
Seizure	6	—
Unknown	8	—
Asthma	5	—
Electrolyte disorder	6	—
Valvular heart disease	2	—
Other	15	—

N, number of adjudicated causes for the OHCA event in each row.

Abbreviations: OHCA, out-of-hospital circulatory arrest; SDCT, sudden-death computed tomography.

[a]All but one case of acute coronary syndrome was diagnosed by a rising troponin during hospitalization and an invasive coronary angiogram with at least one major coronary artery with ≥ 50% stenosis. Nine of 14 of these patients underwent percutaneous coronary revascularization and one of 14 underwent coronary artery bypass. Two of 14 cases were deferred due to coronary complexity or chronic total occlusion. One of 14 invasive angiograms were deferred by the clinical service due to repeated codes and one of 14 patients had a 50% stenosis that was treated medically.

[b]One of nine patients had pneumonia diagnosed only by SDCT while eight of nine were diagnosed by chest radiograph or SDCT.

artery and myocardial anatomy and function, data that are critical in the resuscitated OHCA patient. The SDCT protocol performed well for cardiac pathology and correctly identified all 13 of 14 patients with acute coronary syndrome and five of six patients with cardiomyopathy. An acute coronary syndrome patient was missed due to an uninterpretable thoracic CT scan, and the one missed patient with cardiomyopathy had normal left ventricular size and did not have the entire cardiac cycle for analysis. A previously published subset of 28 of our patients demonstrated a high sensitivity (85%) and specificity (88%) for SDCT to identify obstructive coronary artery disease compared to ICA.[10] These data suggest incremental benefit of cardiac analysis for that could augment or replace early echocardiography or ICA for certain patients resuscitated after OHCA.

SDCT also identified critical noncardiac diagnoses that necessitate further evaluation or changes in clinical care as well as significant complications from cardiopulmonary resuscitation (Figures 2 and 3; Table 3). Taken together, the cumulative critical SDCT findings inform specific and sometimes disparate treatments or procedures, such as when urgent surgical consultation is needed or when antithrombotic therapy may be strictly indicated (e.g., pulmonary embolism or coronary stenosis) or contraindicated (e.g., hemorrhagic stroke or organ laceration). In summary, our data suggest that incorporating SDCT into standard care may rapidly identify causes for OHCA and triage of patients to specific clinical services, identify important and potentially life-threatening resuscitation-induced injury, and target treatments and procedures to potentially improve patient outcomes.

SDCT safety

The benefits of SDCT need to be weighed against any potential harmful effects as measured by our safety outcomes of contrast nephropathy, inappropriate care based on SDCT findings, and the SDCT procedure itself. Prior studies in patients resuscitated from an OHCA event suggest that renal dysfunction on hospital arrival is common (40%–50%), likely transient and related to the OHCA event,[26-28] and may not be exacerbated by exposure to iodinated contrast.[27,29]

However, concerns that contrast may worsen renal dysfunction persist despite substantial data showing low overall risk with IV contrast.[30] In our patients, the first creatinine obtained after arrival to the hospital was elevated in over half of patients and the primary prespecified safety outcome of AKI at 48 h was seen in 25% of our patients. However, the elevation was transient for most patients with only one patient requiring renal replacement therapy. In patients who had iodinated contrast from the SDCT scan as well as invasive coronary angiography, renal function did not deteriorate at higher rates (Table 4). Thus, SDCT with contrast appears to be relatively safe even with elevated creatinine upon arrival, but further data are needed.

TABLE 3 Time-critical diagnoses[a] identified by SDCT

Diagnoses[a]	Identified by SDCT, n/N (%) or N
Total subjects with critical diagnoses[a]	44/104 (44%)
Critical diagnosis diagnosed by SDCT	43/44 (98%)[b]
Critical diagnoses causing OHCA	
Acute coronary syndrome	13[b]
Pulmonary embolism	5
Pneumonia	9
Pulmonary hemorrhage	1
Hemorrhagic stroke	2
Abdominal catastrophe	2
Presumed resuscitation complication	17
Liver/spleen laceration	6
Pneumothorax	5
Mediastinal hemorrhage	1
Pericardial hemorrhage	1
Pulmonary laceration	3
Vascular access hemorrhage	1

Abbreviations: OHCA, out-of-hospital circulatory arrest; SDCT, sudden-death computed tomography.

[a]Subjects could have more than one critical diagnosis.

[b]One acute coronary syndrome was missed by the SDCT.

For our other safety outcomes, we did not identify any cases where an SDCT finding inappropriately altered clinical care and there were no other significant complications during the SDCT scan itself. Radiation dose from the SDCT (which included ECG-gated imaging through most of the cardiac cycle) was relatively high, but comparable to other similar chest to pelvis imaging, such as transcatheter valve implantation.[31,32]

STRENGTHS AND LIMITATIONS

Strengths of this article include being the first study, to our knowledge, of prospectively applying a head-to-pelvis SDCT scan to patients resuscitated from OHCA. Limitations include the fact that our patients were not randomized and were not sequential. In addition, all patients included in this study underwent a clinical SDCT rather than having a waiver of consent or a signed consent prior to the SDCT due to difficulties in identifying and consenting the next of kin. These selection biases likely affected our findings by possibly inflating the yield of the SDCT and our data should be interpreted and generalized accordingly. Our patients also had a high prevalence

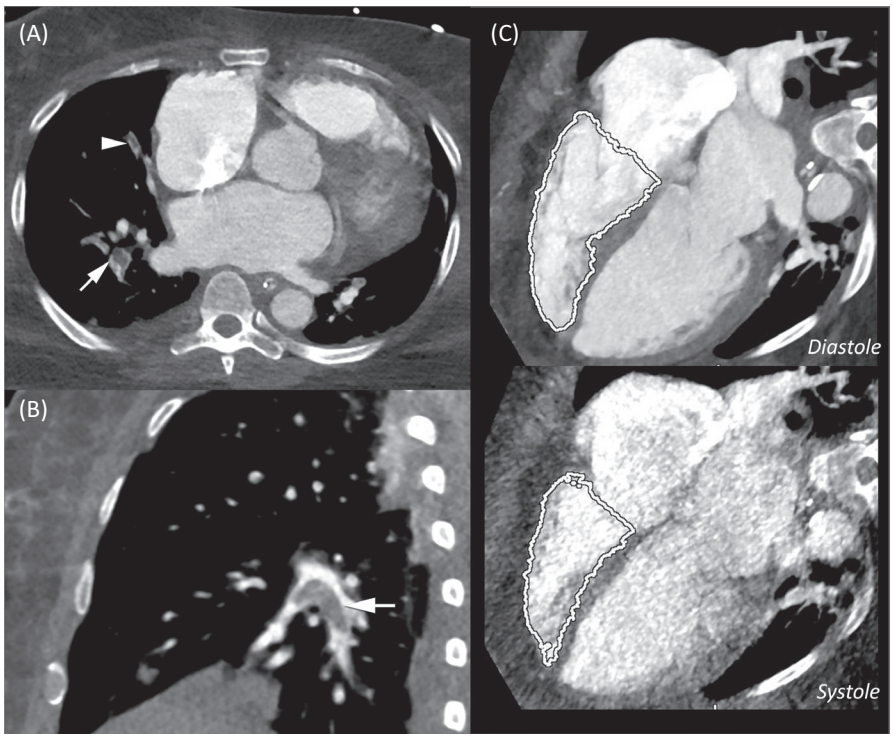

FIGURE 2 (A) SDCT following resuscitation of a 49-year-old woman with known idiopathic cardiomyopathy (left ventricular ejection fraction of 25%) found down with asystole. Pulmonary emboli in right middle (*arrowhead*) and lower (*arrow*) lobe pulmonary arteries in axial (A) and sagittal (B) CT images. (C) Severely enlarged right ventricle (end diastolic volume indexed for body mass index at 140 mL/m^2 mL) with mildly reduced systolic function with a 3D ejection fraction of 53%. Severely enlarged left ventricle (end diastolic volume index 138 mL/m^2 mL) with moderately reduced function and a 3D ejection fraction of 31%. Thrombolytics were deferred. Treated with IV heparin and transitioned to apixaban for lifelong therapy. SDCT, sudden-death computed tomography

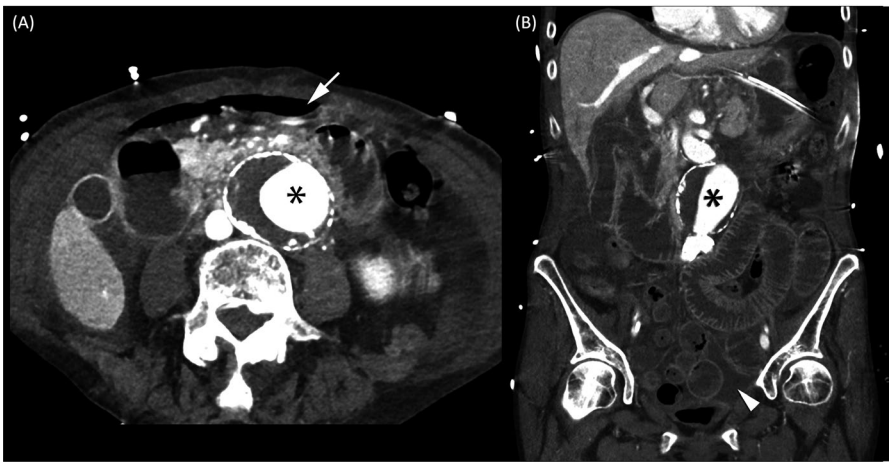

FIGURE 3 SDCT following resuscitation of a 67-year-old woman with unknown medical history found down with pulseless electrical activity. Axial (A) and coronal (B) images show extensive intraperitoneal gas (*arrow*) and fluid (*arrowhead*). A chronic abdominal aortic aneurysm (*asterisk*) was also present. Surgical exploration demonstrated a ruptured stomach ulcer. SDCT, sudden-death computed tomography

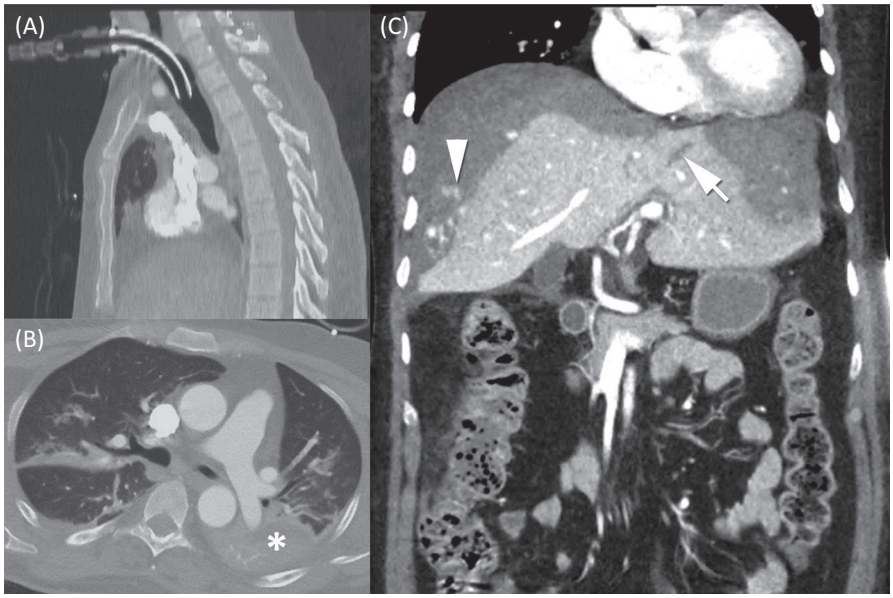

FIGURE 4 SDCT following resuscitation for 50-year-old with progressive sensorimotor axonal polyneuropathy and tracheostomy presenting with pulseless electrical activity. (A) Tracheostomy in place without mucus plug. (B) Left lower lobe consolidation (*asterisk*) consistent with pneumonia treated with IV vancomycin and piperacillin/tazobactam. (C) Liver lacerations (*arrow*) with active contrast extravasation (*arrowheads*) due to resuscitation. Treated conservatively due to poor prognosis with 4 units of red blood cells, 3 units of platelets, 3 units of fresh-frozen plasma, and 1 unit of cryoprecipitate with abdominal compartment syndrome and autotamponade of bleeding. SDCT, sudden-death computed tomography

of drug and alcohol use as a cause for OHCA, and these may not reflect other patient populations. Cardiac and coronary CTA data were not clinically available to treating physicians and the standard of care was not affected by these data so that benefit is inferred from these data. Since all other SDCT data were clinically available, SDCT readings informed the adjudicated cause for OHCA events for many patients. This informational bias may artificially inflate the SDCT diagnostic ability and, thus, we opted to not quantify diagnostic accuracy measures. Finally, incident contrast-induced AKI can only be inferred rather than measured as there was no comparator group to ascertain AKI in those without contrast exposure. A prospective randomized trial would address most of these limitations.

CONCLUSIONS

Early head-to-pelvis sudden-death computed tomography shows significant promise for identifying causes of idiopathic out-of-hospital circulatory arrest without overt safety concerns. Time-critical diagnoses, including significant resuscitation complications, were identified within 2 h of sudden-death computed tomography evaluation and resulted in substantive changes to clinical care. An OHCA cause was only identified by sudden-death computed tomography in 13% of cases. No sudden-death computed tomography findings resulted in inappropriate evaluations or changes in care. These data suggest that early sudden-death computed tomography

TABLE 4 Safety analyses: incident AKI and inappropriate treatments due to SDCT

Group	>0.3 mg/dL increase	>50% increase	Incident AKI[a]	Dialysis
AKI with SDCT with or without ICA				
All (*n* = 104)	26 (25%)	16 (15%)	27 (26%)	1 (1%)
SDCT only (*n* = 75)	20 (26%)	14 (18%)	21 (25%)	1 (1%)
Both SDCT and ICA (*n* = 29)	6 (21%)	2 (7%)	6 (21%)	0 (0%)
SDCT complications			*N* (%)	
Inappropriate procedures based on SDCT scan			0 (0%)	
Complications during SDCT			1 (1%)[b]	

Abbreviations: AKI, acute kidney injury; ICA, invasive coronary angiography; SDCT, sudden-death computed tomography.

[a]Incident nephropathy defined as >0.3 mg/dL or >50% increase in creatinine from baseline to maximum 48-h reading.

[b]One patient required renal replacement dialysis therapy.

scanning in resuscitated OHCA patients is safe, expedites diagnoses of OHCA causes, and can meaningfully change clinical management.

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CONFLICT OF INTEREST

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AUTHOR CONTRIBUTIONS

Kelley R. H. Branch, Peter J. Kudenchuk, Michael R. Sayre, and Medley O. Gatewood conceived the study, designed the trial, and obtained research funding. Kelley R. H. Branch, Robin Brusen, Peter J. Kudenchuk, Bradley J. Petek, Jared Strote, Medley O. Gatewood, David Carlbom, Jeffrey L. Probstfield, and Martin Gunn supervised the conduct of the trial and acquisition of data. Kelley R. H. Branch and Medley O. Gatewood chaired the data oversight committee. Kelley R. H. Branch drafted the manuscript, and all authors contributed critical revisions of the manuscript for important intellectual content. Charles Maynard and Catherine Counts provided statistical advice on study design and analyzed the data. Kelley R. H. Branch takes responsibility for the paper as a whole.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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