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Clinical paper

Diagnostic yield, safety, and outcomes of Head-to-pelvis sudden death CT imaging in post arrest care: The CT FIRST cohort study

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Abstract

Aim: Our aim was to test whether a head-to-pelvis CT scan improves diagnostic yield and speed to identify causes for out of hospital circulatory arrest (OHCA).

Methods: CT FIRST was a prospective observational pre-/post-cohort study of patients successfully resuscitated from OHCA. Inclusion criteria included unknown cause for arrest, age >18 years, stability to undergo CT, and no known cardiomyopathy or obstructive coronary artery disease. A head-to-pelvis sudden death CT (SDCT) scan within 6 hours of hospital arrival was added to the standard of care for patients resuscitated from OHCA (post-cohort) and compared to standard of care (SOC) alone (pre-cohort). The primary outcome was SDCT diagnostic yield. Secondary outcomes included time to identifying OHCA cause and time-critical diagnoses, SDCT safety, and survival to hospital discharge.

Results: Baseline characteristics between the SDCT (N = 104) and the SOC (N = 143) cohorts were similar. CT scans (either head, chest, and/or abdomen) were ordered in 74 (52%) of SOC patients. Adding SDCT scanning identified 92% of causes for arrest compared to 75% (SOC-cohort; p value < 0.001) and reduced the time to diagnosis by 78% (SDCT 3.1 hours, SOC alone 14.1 hours, $p < 0.0001$). Identification of critical diagnoses was similar between cohorts, but SDCT reduced delayed (>6 hours) identification of critical diagnoses by 81% ($p < 0.001$). SDCT safety endpoints were similar including acute kidney injury. Patient survival to discharge was similar between cohorts.

Discussion: SDCT scanning early after OHCA resuscitation safely improved the efficiency and diagnostic yield for causes of arrest compared to the standard of care alone.

Clinical Trials Number: NCT03111043.

Keywords: Out of hospital cardiac arrest, Resuscitation, Cardiac computed tomography, Head computed tomography, Abdominopelvic computed tomography, Standard of care, Cohort study, Acute kidney injury, Diagnostic testing

Introduction

Out of hospital circulatory arrest (OHCA) is common, occurring in approximately 89 per 100,000 individuals in the Unites States.[1] After successful resuscitation, past medical history, prodromal and ongoing symptoms are often unknown due to obtundation and intubation.[2] In patients without an obvious cause for OHCA on hospital arrival, termed idiopathic OHCA, guideline-based standard of care includes electrocardiogram (ECG), chest radiography, metabolic evaluation, head CT, and echocardiography.[3–6] More recently, the European Society of Cardiology guidelines suggest that chest CT should also be considered when this initial evaluation are not consistent with a cardiac cause.[7] Additional evaluations including imaging are ordered at the discretion of the treating physicians, including CT scans.[8–10]

Abbreviations: CT, computed tomography, CT, FIRST - CT Feasibility In Resuscitated patients for Sudden death Triage, ECG, electrocardiogram, IQR, i'nterquartile ratio, OCHA, out of hospital cardiac arrest, SDCT, sudden death CT scan, SOC, standard of care

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https://doi.org/10.1016/j.resuscitation.2023.109785
Received 16 January 2023; Received in Revised form 8 March 2023; Accepted 26 March 2023

While this approach allows for tailored clinical evaluation, heterogenous patient evaluation can adversely affect diagnosis and treatment decisions in these critically ill individuals.

The CT Feasibility In Resuscitated patients for Sudden death Triage (CT FIRST) observational study prospectively enrolled 104 patients to undergo a head-to-pelvis sudden death CT (SDCT) scan and identified a cause for OHCA in 39% of patients as well as a high proportion of patients with resuscitation complications.[11–13] However, the incremental benefit and safety of routine SDCT scanning compared to a contemporary standard of care (SOC) cohort has not been explored.

The current study was a planned prospective pre-/post-analysis of successfully resuscitated patients with idiopathic OHCA. The study compared the standard of care alone (Pre-cohort or SOC-cohort) to the addition of an SDCT scan within 6 hours of hospital arrival (Post-cohort or SDCT-cohort) in addition to the standard of care. The primary endpoint of this study was diagnostic SDCT scan yield. Secondary outcomes included and time to diagnosis, SDCT scan safety, and patient survival and neurologic outcome at hospital discharge.

Methods

The CT FIRST study design was a prospective observational pre- and post-cohort study of patients successfully resuscitated from an idiopathic OHCA event (NCT 03111043. https://clinicaltrials.gov/ct2/show/NCT03111043). The pre-cohort (SOC alone) cohort included patients successfully resuscitated from OHCA from January 2014 to December 2015 and treated with standard post-arrest care in two academic hospitals. The post- or SDCT-cohort included patients that underwent a head-to-pelvis SDCT scan in addition to the standard of care from December 2015 to February 2018. Post-arrest treatment protocols otherwise remained similar during the 2014–2018 study period. Consent was obtained from the patient or the next of kin, or waived if subsequently never awakening and without an identifiable legally authorized representative. Consent was waived for the SOC-cohort under minimal risk criteria. This study was conducted in accordance with the amended Declaration of Helsinki, adhered to HIPAA requirements, and was approved by the University Human Subjects Division. This study was supported by a research grant from the Medic One Foundation (Seattle, WA, USA).

Inclusion and Exclusion Criteria. Inclusion and exclusion criteria were reviewed previously (Supplemental Table 1).[11] Important inclusion criteria were 1) patients successfully resuscitated from OHCA upon reaching the Emergency Department and 2) had a SDCT (SDCT-cohort) or could undergo SDCT scanning (SOC-cohort) in the judgement of the research team within 6 hours of hospital arrival. Exclusion criteria included 1) obvious cause for OHCA prior to SDCT or on hospital arrival (SOC-cohort), 2) indication for emergent invasive coronary angiography or had invasive coronary angiography within 1 hour of arrival (SOC-cohort), 3) known obstructive coronary disease or known coronary stent <2.5 mm if previously successfully treated for obstructive coronary disease, 4) known cardio defibrillator, 4) known pre-existing Do Not Resuscitate order. Severe renal dysfunction (estimated glomerular filtration rate 1–30 ml/min/1.73 m^2) was an exclusion criteria for the SDCT-cohort, although patients could undergo a clinical CT scan at the judgement of their treating physicians. A substantial number of patients had eGFR from 1 to 30 mg/min/1.72 m^2 that underwent a clinically ordered SDCT (n = 14/104). To control for this in the SOC-cohort, we included a similar number of renal dysfunction patients who would otherwise be potential candidates for SDCT scanning, essentially removing this exclusion from the SOC-cohort. The CONSORT diagram of study patients is outlined in Fig. 1.

SDCT scanning and analysis. The SDCT scan protocol has been reviewed in detail previously.[14] SDCT scanning was performed on either a dual source CT (FORCE, Siemens Medical Solutions, Forcheim, Germany) or a wide single detector CT (REVOLUTION, GE Healthcare, Waukesau, WI). Given the potential for hemodynamic instability, there was no pre-treatment with beta blockade nor nitroglycerin for coronary CT evaluation. The SDCT scan protocol consisted of three CT scans: 1) a non-contrast head CT, 2) retrospective ECG-gated thoracic CT contrast angiogram for most of the cardiac cycle (initially 20–90% and later 30–80% of the cardiac cycle to reduce radiation dose), and 3) a venous phase, non-ECG gated, spiral abdominal and pelvis CT. A triple phase iodinated intravenous contrast protocol with either iodixanol or iohexol was used to enhance the coronary arteries, pulmonary arteries, and thoracic aorta.[15] Cardiac CT results, including coronary CT angiographic data, were not provided to the treating physicians due to inability to optimize coronary CT imaging. All other CT data were clinically available to the radiologists and treating physicians in real time. Head, coronary, cardiac, thoracic and abdominopelvic CT scans were read independently by 2 physicians (cardiac CT K.R.B. and R.B with 15 and 2 years' experience, all other CT's M.G, R.E. with 15 and 12 years of experience respectively). All physicians were blinded to the patient history and reading discrepancies were resolved by consensus. The physicians generated a adjudicated list of causes for OHCA based on SDCT scan data; the most likely cause was deemed the SDCT cause for OHCA.

Clinical data. Clinical data were obtained from the prehospital and hospital medical records. Other than the SDCT scan in the SDCT-cohort, there were other no other recommended treatment protocols. Patient characteristics, resuscitation parameters, selected laboratory values (including cardiac troponin-I and lactate levels), target temperature management, and any post-arrest hospital treatments and procedures were abstracted. All imaging data, including any other CT scan data, were also abstracted.

Potential causes for the OHCA event were adjudicated by two physicians (K.R.B. and M.G.) with access to all records, including the SDCT scan. The most likely diagnosis by adjudication was considered the presumed clinical diagnosis for the OHCA event. "Time-critical" diagnoses were defined *a priori* to the study and included acute coronary syndrome or obstructive coronary artery disease (≥50% coronary stenosis in a major coronary artery), pulmonary embolism, aortic dissection, pneumothorax, cerebrovascular accident (hemorrhagic or thrombotic), abdominal catastrophe, pneumonia (excluding presumed resuscitation aspiration), and critical resuscitation complications of internal or organ bleeding.

The primary outcome measure was the diagnostic yield of SDCT protocol compared to the standard of care to identify the cause for OHCA event. Diagnostic yield was defined as the number of patients with an adjudicated diagnosis that was the presumed cause for OHCA. Secondary outcomes included the time to adjudicated OHCA diagnosis, percentage of correct diagnoses by SDCT or by any CT scan as part of the standard of care, diagnosis of time critical diagnoses by SDCT scan compared to the standard of care, any delayed diagnosis >6 hours from hospital arrival and safety of SDCT scanning. The time to diagnosis was defined at the time at which a labo-

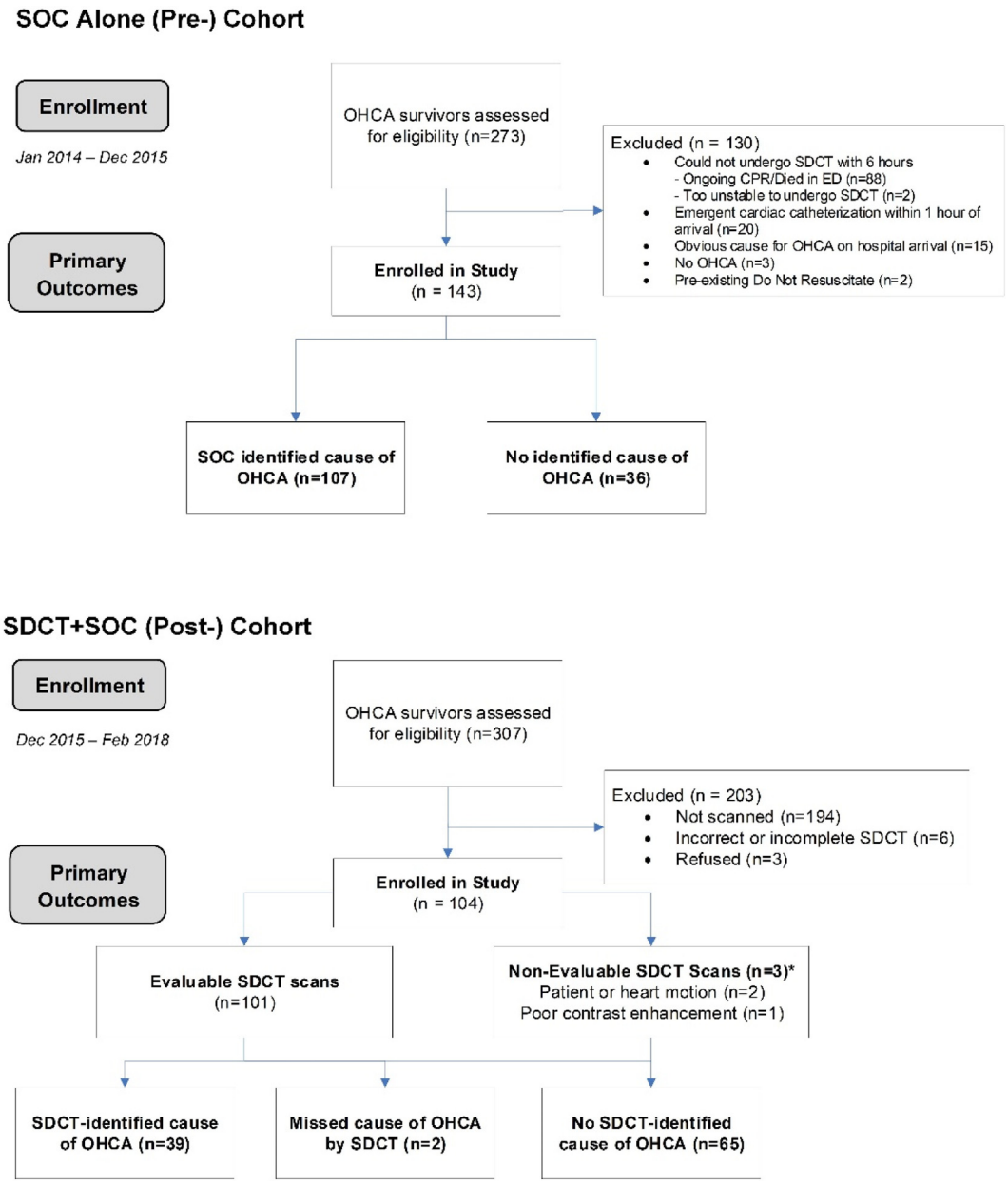

Fig. 1 – Diagram of patients included in the SOC- and SDCT-cohorts.

ratory value, procedure, or scan was completed that led to the OHCA cause or the time of a progress note listing the diagnosis. If no diagnosis was made, then the time of discharge or death was used. The safety of SDCT scanning was defined as the combination of either acute kidney injury at 48 hours as defined by Acute Kidney Injury Network,[16] allergic contrast reactions[17] or CT complications (e.g., extubation or line extravasation), and CT findings leading to inappropriate treatments. Pre-specified secondary analyses examined hospital outcomes including survival to and neurologic status by Cerebral Performance Category at hospital discharge.

Statistical analysis. Continuous variables were reported as mean and standard deviation or median and interquartile ratio (IQR) depending on the normality of data. Binary variables were reported as number and percent. The Student t-test and the Wilcoxon rank sum test were used for comparing continuous variables by dichotomous variables (such as SDCT versus SOC-cohort); the former was used for normally distributed variables and the latter for non-normally distributed variables. The Chi-square statistic was used to compare independent categorical variables and dependent categorical variables. Diagnostic yield results for SDCT were tabulated by comparing the most likely diagnosis for OHCA by physician adjudication as compared to the diagnosis by SDCT. Linear regression was used for time to diagnosis and logistic regression for survival to hospital discharge. The outcomes of time to OHCA diagnosis and survival to hospital discharge underwent prespecified regression adjustment for patient age, gender, initial cardiac rhythm, and witnessed or non-witnessed OHCA status. SPSS version 19 was used for statistical analysis. $P < 0.05$ was considered statistically significant. Analyses were not adjusted for multiple comparisons.

Results

The cohort diagram outlines subject inclusion in Fig. 1. For the SOC-cohort, of the 273 patients admitted after resuscitation from OHCA, 143 met criteria for idiopathic OHCA and could have undergone SDCT scanning. These included 29 (20%) of otherwise eligible patients with low eGFR of 1–30 ml/min/1.73 m^2. For the SDCT-cohort, of the 307 patients admitted after resuscitation from OHCA, 111 patients underwent SDCT. After exclusion of 7 patients, 104 patients were included in the SDCT-cohort. These included 14 (13%) of clinically scanned patients with low eGFR of 1–30 ml/min/1.73 m^2. Because the SDCT scans were clinically ordered, some eligible patients were not scanned in the SDCT-cohort. Baseline characteristics are in Table 1. Subjects were well matched overall although the SDCT-cohort had significantly higher proportion of patients with prior valvular heart disease, higher rate of bystander CPR, and different locations of arrest. The baseline labs were well matched between cohorts (Supplemental Table 2).

Post-arrest care was similar between the cohorts (Table 2), with all patients having at least one ECG and nearly all having echocardiography. Invasive coronary angiography was performed more commonly in the SDCT-cohort despite the cardiac CT data being blinded, but procedure utilization was otherwise similar between cohorts. At least one type of CT imaging was ordered clinically in over half of patients in the SOC-cohort, with most patients having a non-contrast head CT. No patients in the SOC-cohort had the equivalent of an SDCT scan protocol. Adjudicated presumed causes of OHCA are listed by cohort in Table 3.

Primary and Secondary Outcomes: The primary and secondary outcomes are listed in Table 4 and graphically in Fig. 2. For the primary outcome, the combination of SDCT and the SOC identified 92% of presumptive causes for OHCA, 17% more than the SOC alone (diagnostic yield of 75% to identify causes of OHCA; unadjusted p value < 0.0001, adjusted p value < 0.001). SDCT identified causes for OHCA in 40 (38%) patients and only SDCT identified causes for OHCA in 13 (13%) of patients. In the SOC-cohort, 24

Table 1 – Baseline Characteristics for SDCT and SOC-cohorts.

Characteristic	**SDCT-cohort (*n* = 104)*** *N (%) or mean (SD)*	**SOC-cohort (*n* = 143)*** N *(%) or mean (SD)*	**P-value**
Age (years)	55[15]	52[14]	0.12
Female	30 (29%)	52 (36%)	0.22
Medical History			
Hypertension	38/96 (40%)	54/129 (42%)	0.93
Dyslipidemia	15/96 (16%)	10/129 (8%)	0.17
Known heart failure	12/96 (12%)	18/129 (14%)	0.44
Left ventricular ejection fraction < 40%	13/72 (18%)	26/96 (27%)	0.17
History of long QT	1/95 (1%)	0/129 (0%)	-
Diabetes mellitus	19/96 (20%)	24/129 (19%)	0.95
Smoking (Current/Former)	—	—	
History of coronary artery disease	12/96 (12%)	16/129 (12%)	0.32
Prior myocardial infarction	7/96 (7%)	10/129 (8%)	0.56
History of coronary revascularization or stent	5/96 (5%)	4/129 (3%)	0.45
History of cardiac arrest	2/96 (2%)	5/129 (4%)	0.57
Prior valvular disease	5/96 (5%)	1/129 (0.8%)	0.043
Prior stroke	6/96 (6%)	10/129 (8%)	0.89
History of chronic kidney disease	12/96 (12%)	12/129 (9%)	0.17
Race			0.10
White	61 (59%)	95 (66%)	
Black	15 (14%)	17 (12%)	
Native American	3 (3%)	6 (4%)	
Asian	8 (8%)	16 (11%)	
Other/unknown	17 (16%)	9 (6%)	
Location of arrest			<0.0001
Home	43 (43%)	56 (39%)	
Public	17 (17%)	33 (23%)	
Nursing home	28 (28%)	41 (29%)	
Medical facility	8 (8%)	8 (6%)	
Other	3 (3%)	55 (4%)	
Witnessed arrest	59/99 (60%)	84/143 (59%)	0.95
Bystander CPR	57/99 (58%)	57/143 (40%)	0.007
Initial rhythm			0.53
VF/VT	30 (29%)	44 (31%)	
Asystole	26 (25%)	39 (27%)	
Pulseless electrical activity	40 (39%)	55 (38%)	
Other/Unknown	8 (8%)	5 (4%)	

*Complete data were available only for 102 CT FIRST and 137 Control cohort patients. CPR = cardiopulmonary resuscitation; VF/VT = ventricular fibrillation/ventricular tachycardia.

Table 2 – Procedures performed during hospitalization.

	SDCT-cohort (*n* = 104)	SOC-cohort (*n* = 143)	P-value
Procedure	*N (%)*	*N (%)*	
Any CT scan (contrast or non-contrast)	104 (100%)	120 (84%)	<0.0001
CT head	104 (100%)	116 (81%)	<0.0001
CT chest	104 (100%)	52 (36%)	<0.0001
CT abdomen	104 (100%)	26 (18%)	<0.0001
Mechanical CPR device	28 (27%)	25 (17%)	0.06
Targeted temperature management	77 (74%)	105 (73%)	0.91
Electrocardiogram	104(100%)	143 (100%)	—
Echocardiogram	72 (69%)	96 (67%)	0.90
Coronary angiogram	31 (30%)	30 (21%)	0.11
Brain MRI	37 (36%)	51 (36%)	0.82

CT = computed tomography, CPR = cardiopulmonary resuscitation, MRI = magnetic resonance imaging, SDCT = sudden death computed tomography, SOC = standard of care.

Table 3 – Adjudicated OHCA Etiology.

Etiology (final diagnosis)	SDCT-cohort (*n* = 104)	SOC-cohort (*n* = 143)
Diagnosable by SDCT	*N (%)*	*N (%)*
Myocardial infarction	14 (13%)	18 (13%)
Pulmonary embolism	5 (5%)	3 (2%)
Aortic dissection	0 (0%)	1 (1%)
Pneumonia	9 (9%)	4 (3%)
Heart failure	6 (6%)	12 (8%)
Valvular	2 (2%)	0 (0%)
Embolic cerebral vascular accident	0 (0%)	4 (3%)
Hemorrhagic cerebral vascular accident	2 (2%)	3 (2%)
Abdominal catastrophe	3 (3%)	1 (1%)
Not Diagnosable by CT		
Asthma	5 (5%)	4 (3%)
Overdose-alcohol	5 (5%)	4 (3%)
Overdose-drugs	18 (17%)	34 (24%)
Seizure	6 (6%)	1 (1%)
Electrolyte	6 (6%)	4 (3%)
Other	15 (14%)	12 (8%)
Not specified	0 (0%)	2 (1%)
Unknown Etiology	8 (8%)	36 (25%)

SDCT = sudden death computed tomography, SOC = standard of care.

(17%) of OHCA causes were identified from the selective, clinically ordered head, thoracic, or abdominopelvic CT scan. Secondary outcome of identification of time critical diagnoses was similar between cohorts but the number of delayed (>6 hours) time-critical diagnoses was reduced by 81% in the SDCT-cohort (unadjusted $p < 0.0001$, adjusted 0.001). The time to diagnosis (minutes) was reduced 78% compared to SOC alone (adjusted $p < 0.0001$). There was no difference in survival to hospital discharge for those in the SDCT-cohort (42%) compared to the SOC-cohort (44%; $p = 0.78$, Supplemental Table 3). There were no other differences in hospital outcomes or neurologic recovery although there was slightly better categorical neurologic status at discharge in the SOC-cohort ($p = 0.02$, Supplemental Table 3).

Safety Outcomes. Median creatinine levels upon ED arrival were similar at 1.26 (IQR 0.97,1.62) for the SDCT-cohort and 1.32 (IQR 1.05,2.15) for the SOC-cohort (p-value = 0.16; Supplemental Table 2). There were no significant differences in the median 48 hour and peak creatinine levels (Supplemental Table 2) and no difference in acute kidney injury between the SDCT- and the SOC-cohorts (Table 4). New renal replacement therapy was rare and there was no difference between cohorts. There were also no differences in renal function for those that received contrast compared to those that did not (Supplemental Table 5) even in those receiving both intravenous (SDCT) and intraarterial (invasive coronary angiography) contrast. In patients with severe renal dysfunction on hospital arrival (eGFR 1–30 ml/min/1.73 m^2), acute kidney injury was similar between cohorts (SDCT cohort: $n = 5/14$, 36%. SOC cohort: $n = 11/29$, 38%, $p = 0.89$). Not surprisingly, the incidence of acute kidney injury was numerically higher for those with lower eGFR but there was no difference whether patients received contrast or not (Supplemental Table 6). No allergic contrast reactions occurred in either cohort, and there were no SDCT scan complications or inappropriate treatments based on SDCT scan findings identified.

Table 4 – Primary and Secondary Outcomes.

Outcome	SDCT-cohort (*n* = 104) *Median (IQR) or N (%)*	SOC-cohort (*n* = 143) *Median (IQR) or N (%)*	Unadjusted p-value	Adjusted p-value*
Primary Outcome				
Identified diagnosis for OHCA†	96 (92%)	107 (75%)	<0.0001	0.001
Secondary Outcomes				
Time to diagnosis (hours)	3.1 (1.4,12.9)	14.1 (2.2, 69.5)	<0.0001	<0.0001
Identified time-critical diagnosis	33 (32%)	34 (24%)	0.16	0.33
OHCA diagnosis by any CT scan†	39 (39%)	24 (17%)	—	—
Delayed ascertainment (>6hrs) of time critical diagnosis‡	4/33 (12%)	21/34 (62%)	<0.0001	0.001
Survival to hospital discharge	44 (42%)	63 (44%)	0.78	0.50
Safety Outcomes				
Acute Kidney Injury	27 (26%)	34 (24%)	0.69	—

† The SDCT-cohort included likely OHCA diagnoses identified by the SDCT scan protocol as well as the SOC. SDCT diagnosed an OHCA cause exclusively in 30 (30%) of patients. Time critical diagnoses include myocardial infarction, pulmonary embolism, aortic dissection, pneumonia, embolic CVA, hemorrhagic CVA, and abdominal catastrophe. ‡Delayed clinical ascertainment of time critical diagnoses by >6 hours from arrival. *Data were adjusted for age, sex, initial rhythm, and witness status using linear regression statistical modeling. Acute kidney injury defined as >0.3 mg/dL or >50% increase in creatinine from baseline to maximum 48 hour reading.[16] CT = computed tomography, OHCA = out of hospital circulatory arrest, SDCT = sudden death computed tomography, SOC = standard of care.

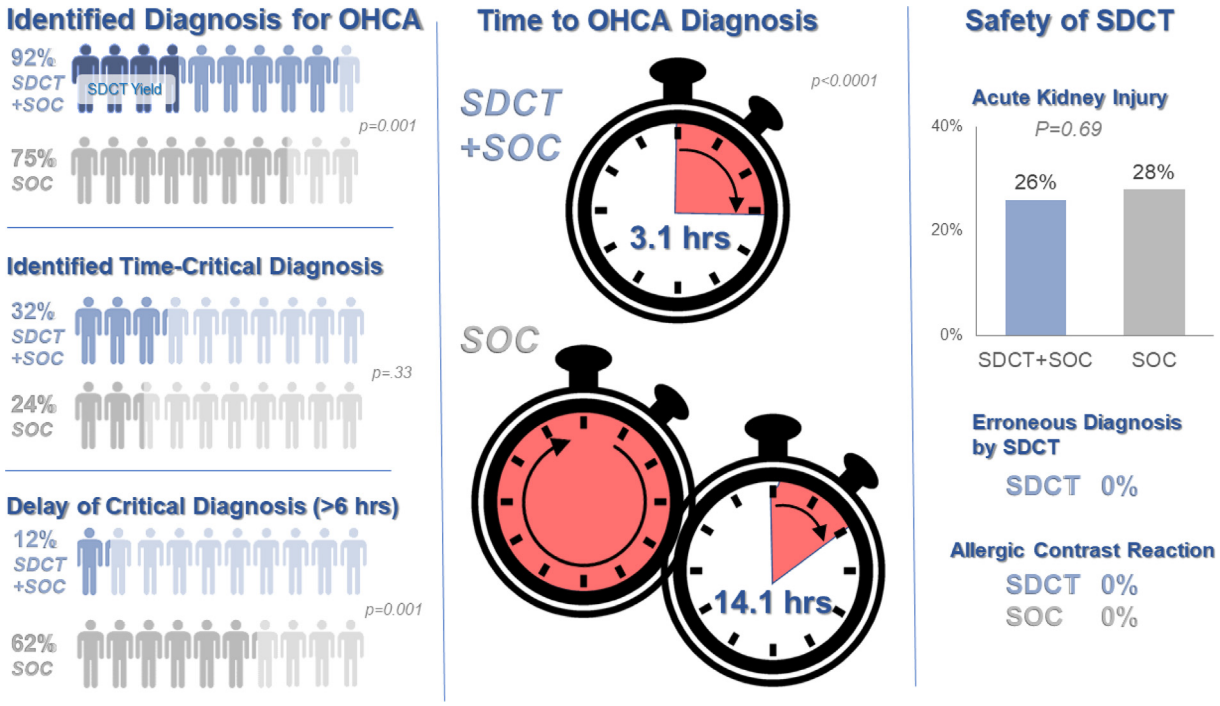

Fig. 2 – Primary outcome of diagnostic yield to identify a diagnosis for the cause of OHCA (including the overall SDCT diagnostic yield of 38%). Secondary outcomes were time to diagnosis, number of delayed critical diagnosis greater than 6 hours, and safety of SDCT-cohort compared to SOC-cohort. OHCA = out of hospital cardiac arrest, SDCT = sudden death computed tomography, SOC = standard of care.

Discussion

The CT FIRST observational cohort study showed that adding an early SDCT scan to the standard of care increased the identification of causes for OHCA and a significantly shortened time to OHCA diagnosis to 3 hours compared to 14 hours. Identification of time critical diagnoses was similar although SDCT scanning decreased the number of delayed (>6 hours) time-critical diagnoses by 81%. There was no significant difference on survival to hospital discharge for the SDCT-cohort. These data suggest that the addition of SDCT to the standard of care can add significant and actionable information in the acute post-arrest care setting.

Patients successfully resuscitated from an OHCA event have a high morbidity and mortality from both the underlying cause of OHCA as well as complications from circulatory arrest and resuscitation.[1] Guidelines for post-arrest care recommend ECG, laboratory analyses, chest radiography, head CT, and echocardiography[3–6] and most recently, chest CT when a cardiac cause is not suspected after initial evaluation.[7] However, there are few data on the accuracy of these and other imaging modalities to identify causes of OHCA.[18] Most of our understanding of causes of OHCA arise from autopsy data, but whether these data are similar to those that survive OHCA is not clear. In addition, a substantial number of patients have an unknown cause for OHCA at discharge with the current standard of care highlighting an unmet need.[19–20] Thus, post-arrest imaging to identify causes of OHCA as well inform further evaluation and treatment with the current standard of care remains suboptimal.

CT scanning has been used to augment diagnostic yield in patients resuscitated from OHCA. The Parisian Region Out of Hospital Cardiac Registry (PROCAT) showed that a clinically-indicated CT head and CT pulmonary angiogram identified 20% of potential OHCA causes.[8] The CT scan specificity to identify OHCA causes of was 86% while sensitivity was more modest at 54%. In patients that survived resuscitation and initiated on extracorporeal membrane oxygenation, a chest and pelvis CT scan identified findings in 75% of patients that led to changes in care.[21] More recently, Adel and colleagues and Hwang and colleagues reported their use of cross sectional CT imaging in 225 and 316 patients respectively showing a relatively high yield for potential causes for OHCA as well as resuscitation complications.[9–10] Moriwaki, et al, performed "peri-mortem" non-contrast head and/or thorax CT scans in 849 idiopathic sudden death survivors and found non-cardiac causes of death in 66% of patients and of these, 22% were diagnosed only with CT scanning. These yields are similar to our 30% yield with the SDCT scan alone and 17% yield with clinically ordered CT scans in the SOC-cohort.[22] In a meta-analysis of post-mortem CT scans, whole body CT identified causes of death with reasonable sensitivity of 79% compared with autopsy.[23] These data are encouraging and correlate to our findings, although no studies utilized a head-to-pelvis scan protocol that included ECG-gated CT coronary angiography, nor were they compared to a standard of care population.

Our study showed that compared to a contemporary historical SOC-cohort, the addition of an SDCT scan to the SOC safely increased the diagnostic yield for causes and complications of OHCA. The 78% reduction in time to diagnosis and the reduction in delayed time-critical diagnoses, allowed rapid initiation of appropriate treatments. In addition, SDCT demonstrated a large number of patients without significant morphologic disease. The SDCT informed and reassured providers that they are not missing important pathology and can appropriately withhold ineffectual or potentially harmful treatments. Despite these potential benefits, our study did not demonstrate improvements in hospital survival or neurologic outcome by adding SDCT protocol to the standard of care even after adjustment for important baseline characteristics. These data emphasize the complexity in post-arrest care and specifically the minimal effect of SDCT on affecting brain death, the most common cause of post-arrest mortality. There is a clear need for a randomized study to further explore the potential benefits of the SDCT versus other imaging approaches.

Higher diagnostic yield and efficiency of SDCT could also advancements investigational post-arrest care including inpatient arrest. SDCT may identify reversible or alterable disease states that impact post-arrest care, such as the time-critical diagnoses above, organ bleeding, sternal fracture, or a flail chest, that would not be readily detected with SOC.[11–13] Even non-time critical diagnoses, such as significant rib fractures or chest wall injuries, might impact downstream post-arrest critical care such as decisions regarding ventilator management and liberation. These findings reduce the likelihood that untreated causes and complications of OHCA will confound survival analyses with future clinical investigations. In addition, SDCT data should reduce the misclassification of patients into a default "cardiac" cause for OHCA. The San Francisco autopsy study demonstrated frequent misclassification for OHCA,[24] but the extent to which this occurs in survivors of OHCA is not known. Thus, SDCT evaluation can also inform the taxonomy of causes for OHCA and is an important topic for further study.

SDCT Safety. A primary safety concern of CT angiography in post-arrest care is the possibility of contrast-associated renal dysfunction. Prior studies of survivors of OHCA demonstrated that up to 50% of patients have renal dysfunction early in post-arrest setting although most recover.[25–27] However, prior observational studies by our group and others suggested that contrast associated nephropathy was uncommon.[26,28] The data demonstrated that although post-arrest renal dysfunction was common, the incidence was the same for SDCT and SOC cohorts and unchanged for those with and without iodinated contrast exposure. There were no SDCT complications nor erroneous findings from the SDCT that led to inappropriate treatments.

Limitations of the current analysis include the relatively small sample sizes and lack of randomization to SDCT scanning with a reliance on clinical CT ordering. Referral bias for both SDCT scanning and other CT scans is inevitable although the patients appeared well matched overall for baseline characteristics between cohorts. A substantial number of patients also underwent at least one type of CT scan in the SOC-cohort thereby obfuscating the incremental benefit of the more comprehensive SDCT scanning. The adjudication for causes of OHCA in the SDCT-cohort were also affected by the clinical SDCT scan readings if they served as self-fulfilling for some patients, may inflate the diagnostic yield of the SDCT protocol. A planned prospective trial will address many of these limitations.

Conclusions

In this study comparing two cohorts, SDCT scan protocol added to post-OHCA standard of care early after resuscitation safely improved the time and overall diagnostic ability to determine causes for OHCA compared to the standard of care alone. Identification of time-critical diagnoses was similar but delayed identification of time-critical diagnosis was reduced with SDCT scanning. However, this did not result in improved survival. Implementation of SDCT scanning to the critically ill resuscitated patient could focus appropriate care and restrict potentially detrimental treatments and well-designed prospective trials are needed to confirm these findings.

Conflicts of Interest

The authors have no conflicts of interest for the current manuscript. KRHB reports grant money to University of Washington to conduct research conceived and sponsored Bayer, Sanofi, Eli Lilly, Kestra and has received funding personally from Bayer and Janssen for

consulting. JLP reports grant money to University of Washington to conduct research conceived and sponsored Bayer, Sanofi, Eli Lilly. J MOG, PJK, CM, MRS, DJC, RME, CRC, JLP, RB, NJ, MLG report no conflict of interest. The study was supported by a grant from the Medic One Foundation. The Medic One Foundation had no input or contributions to the research or current manuscript.

CRediT authorship contribution statement

Kelley R.H. Branch: Conceptualization, Methodology, Validation, Resources, Data curation, Writing – original draft, Supervision. **Medley O. Gatewood:** Methodology, Validation, Investigation, Data curation, Writing – review & editing. **Peter J. Kudenchuk:** Conceptualization, Writing – review & editing. **Charles Maynard:** Methodology, Data curation, Formal analysis, Writing – review & editing. **Michael R. Sayre:** Methodology, Writing – review & editing. **David J. Carlbom:** Methodology, Writing – review & editing. **Rachel M. Edwards:** Data curation, Writing – review & editing. **Catherine R. Counts:** Data curation, Writing – review & editing. **Jeffrey L. Probstfield:** Methodology, Writing – review & editing, Visualization. **Robin Brusen:** Methodology, Data curation, Writing – review & editing, Visualization. **Nicholas Johnson:** Methodology, Writing – review & editing. **Martin L. Gunn:** Conceptualization, Methodology, Validation, Resources, Data curation, Writing – original draft, Supervision.

Acknowledgements

We would like to thank Deborah Fly, RN and Michelle Olsufka, RN and the additional staff of the Medic One foundation for their assistance and expertise with data review, abstraction, and data entry.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resuscitation.2023.109785.

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REFERENCES

1. Tsao CW, Aday AW, Almarzooq ZI, Alonso A, Beaton AZ, Bittencourt MS, et al. Heart disease and stroke statistics 2022 Update: A report from the American Heart Association. Circulation 2022;145: e153–639. https://doi.org/10.1161/CIR.0000000000001052.
2. Pokorna M, Necas E, Skripsky R, Kratochvil J, Andrlik M, Franek O. How accurately can the aetiology of cardiac arrest be established in an out-of-hospital setting? Analysis by Concordance in Diagnosis Crosscheck Tables. Resuscitation 2011;82:391–7. https://doi.org/10.1016/j.resuscitation.2010.11.026.
3. Al-Khatib SM, Stevenson WG, Ackerman MJ, Bryant WJ, Callans DJ, Curtis AB, et al. 2017 AHA/ACC/HRS Guideline for Management of Patients With Ventricular Arrhythmias and the Prevention of Sudden Cardiac Death. Circulation 2018;138:e272–391. https://doi.org/10.1161/CIR.0000000000000549.
4. Yannopoulos D, Bartos JA, Aufderheide TP, Callaway CW, Deo R, Garcia S, et al. The evolving role of the cardiac catheterization laboratory in the management of patients with out-of-hospital cardiac arrest: A scientific statement From the American Heart Association. Circulation 2019;139:e530–52. https://doi.org/10.1161/CIR.0000000000000630.
5. Panchal AR, Bartos JA, Cabañas JG, Donnino MW, Drennan IR, Hirsch KG, et al. Part 3: Adult Basic and Advanced Life Support: 2020 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation. 2020;142:S366–468. https://doi.org/10.1161/cir.0000000000000916.
6. Collet JP, Thiele H, Barbato E, Barthélémy O, Bauersachs J, Bhatt DL, et al. 2020 ESC Guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation. Eur Heart J 2021;42:1289–367. https://doi.org/10.1093/eurheartj/ehaa575.
7. Zeppenfeld K, Tfelt-Hansen J, de Riva M, Winkel BG, Behr ER, Blom NA, et al. 2022 ESC Guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death: Developed by the task force for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death of the European Society of Cardiology (ESC) Endorsed by the Association for European Paediatric and Congenital Cardiology (AEPC). Eur Heart J 2022;43:3997–4126. https://doi.org/10.1093/eurheartj/ehac262.
8. Chelly J, Mongardon N, Dumas F, Varenne O, Spaulding C, Vignaux O, et al. Benefit of an early and systematic imaging procedure after cardiac arrest: insights from the PROCAT (Parisian Region Out of Hospital Cardiac Arrest) registry. Resuscitation 2012;83:1444–50. https://doi.org/10.1016/j.resuscitation.2012.08.321. PubMed PMID: 22922264.
9. Adel J, Akin M, Garcheva V, Vogel-Claussen J, Bauersachs J, Napp LC, et al. Computed-Tomography as First-line Diagnostic Procedure in Patients With Out-of-Hospital Cardiac Arrest. Front Cardiovasc Med 2022;9. https://doi.org/10.3389/fcvm.2022.799446.
10. Hwang CW, Chowdhury MAB, Curtis DZ, Agarwal A, Climenhage BP, et al. A descriptive analysis of cross-sectional imaging findings in patients after non-traumatic sudden cardiac arrest. Resusc Plus 2021;5:100077. https://doi.org/10.1016/j.resplu.2021.100077.
11. Branch KR, Hira R, Brusen R, Maynard C, Kudenchuk PJ, Petek BJ, et al. Diagnostic accuracy of early computed tomographic coronary angiography to detect coronary artery disease after out-of-hospital circulatory arrest. Resuscitation 2020;153:243–50. https://doi.org/10.1016/j.resuscitation.2020.04.033.
12. Karatasakis A, Sarikaya B, Liu L, Gunn ML, Kudenchuk PJ, Gatewood MO, et al. Prevalence and patterns of resuscitation-associated injury detected by head-to-pelvis computed tomography after successful out-of-hospital cardiac arrest resuscitation. J Am Heart Assoc 2022;11(3). https://doi.org/10.1161/jaha.121.023949.
13. Champigneulle B, Haruel PA, Pirracchio R, Dumas F, Geri G, Arnaout M, et al. Major traumatic complications after out-of-hospital cardiac arrest: Insights from the Parisian registry. Resuscitation 2018;128:70–5. https://doi.org/10.1016/j.resuscitation.2018.04.022.
14. Branch KRH, Strote J, Gunn M, Maynard C, Kudenchuk PJ, Brusen R, et al. Early head-to-pelvis computed tomography in out-of-hospital circulatory arrest without obvious etiology. Acad Emerg Med 2021;28:394–403. https://doi.org/10.1111/acem.14228.

15. Mitsumori LM, Wang E, May JM, Lockhart DW, Branch KR, Dubinsky TJ, et al. Triphasic contrast bolus for whole-chest ECG-gated 64-MDCT of patients with nonspecific chest pain: Evaluation of arterial enhancement and streak artifact. Am J Roentgenol 2010;194: W263–71. https://doi.org/10.2214/ajr.09.2788.
16. Mehta RL, Kellum JA, Shah SV, Molitoris BA, Ronco C, Warnock DG, et al. Acute Kidney Injury Network: report of an initiative to improve outcomes in acute kidney injury. Crit Care 2007;11:R31. https://doi.org/10.1186/cc5713.
17. ACR Manual on Contrast Media: American College of Radiology; 2022 [cited 2023 01/13/2023].
18. Petek BJ, Erley CL, Kudenchuk PJ, Carlbom D, Strote J, Gatewood MO, et al. Diagnostic yield of non-invasive imaging in patients following non-traumatic out-of-hospital sudden cardiac arrest: A systematic review. Resuscitation 2018. https://doi.org/10.1016/j.resuscitation.2018.09.004.
19. Hawkes C, Booth S, Ji C, Brace-McDonnell SJ, Whittington A, Mapstone J, et al. Epidemiology and outcomes from out-of-hospital cardiac arrests in England. Resuscitation 2017;110:133–40. https://doi.org/10.1016/j.resuscitation.2016.10.030.
20. Sharifzadehgan A, Gaye B, Bougouin W, Narayanan K, Dumas F, Karam N, et al. Lack of early etiologic investigations in young sudden cardiac death. Resuscitation 2022;179:197–205. https://doi.org/10.1016/j.resuscitation.2022.06.023.
21. Yang KJ, Wang CH, Huang YC, Tseng LJ, Chen YS, Yu HY. Clinical experience of whole-body computed tomography as the initial evaluation tool after extracorporeal cardiopulmonary resuscitation in patients of out-of-hospital cardiac arrest. Scand J Trauma Resusc Emerg Med 2020;28(1):54. https://doi.org/10.1186/s13049-020-00746-5.
22. Moriwaki Y, Tahara Y, Kosuge T, Suzuki N. Etiology of out-of-hospital cardiac arrest diagnosed via detailed examinations including perimortem computed tomography. J Emerg, Trauma, Shock 2013;6:87–94. https://doi.org/10.4103/0974-2700.110752.
23. Ampanozi G, Halbheer D, Ebert LC, Thali MJ, Held U. Postmortem imaging findings and cause of death determination compared with autopsy: a systematic review of diagnostic test accuracy and meta-analysis. Int J Legal Med. 2020;134:321–37. https://doi.org/10.1007/s00414-019-02140-y.
24. Tseng ZH, Olgin JE, Vittinghoff E, Ursell PC, Kim AS, Sporer K, et al. Prospective countywide surveillance and autopsy characterization of sudden cardiac death. Circulation 2018;137:2689–700. https://doi.org/10.1161/CIRCULATIONAHA.117.033427.
25. Hasper D, von Haehling S, Storm C, Jörres A, Schefold JC. Changes in serum creatinine in the first 24 hours after cardiac arrest indicate prognosis: an observational cohort study. Crit Care 2009;13:R168. https://doi.org/10.1186/cc8144.
26. Rundgren M, Ullén S, Morgan MPG, Glover G, Cranshaw J, Al-Subaie N, et al. Renal function after out-of-hospital cardiac arrest; the influence of temperature management and coronary angiography, a post hoc study of the target temperature management trial. Crit Care. 2019;23(1):163. https://doi.org/10.1186/s13054-019-2390-0.
27. Tujjar O, Mineo G, Dell'Anna A, Poyatos-Robles B, Donadello K, Scolletta S, et al. Acute kidney injury after cardiac arrest. Crit Care 2015;19:169. https://doi.org/10.1186/s13054-015-0900-2.
28. Petek BJ, Bravo PE, Kim F, de Boer IH, Kudenchuk PJ, Shuman WP, et al. Incidence and risk factors for postcontrast acute kidney injury in survivors of sudden cardiac arrest. Ann Emerg Med 2015. https://doi.org/10.1016/j.annemergmed.2015.07.516.