Chest wall injuries due to cardiopulmonary resuscitation and the effect on in-hospital outcomes in survivors of out-of-hospital cardiac arrest

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BACKGROUND: This study aimed to assess the prevalence of chest wall injuries due to cardiopulmonary resuscitation for out-of-hospital cardiac arrest (OHCA) and to compare in-hospital outcomes in patients with versus without chest wall injuries.

METHODS: A retrospective cohort study of all intensive care unit (ICU)–admitted patients who underwent cardiopulmonary resuscitation for OHCA between January 1, 2007, and December 2019 was performed. The primary outcome was the occurrence of chest wall injuries, as diagnosed on chest computed tomography. Chest wall injury characteristics such as rib fracture location, type, and dislocation were collected. Secondary outcomes were in-hospital outcomes and subgroup analysis of patients with good neurological recovery to identify those who could possibly benefit from the surgical stabilization of rib fractures.

RESULTS: Three hundred forty-four patients were included, of which 291 (85%) sustained chest wall injury. Patients with chest wall injury had a median of 8 fractured ribs (P_{25}–P_{75}, 4–10 ribs), which were most often undisplaced (on chest computed tomography) (n = 1,574 [72.1%]), simple (n = 1,948 [89.2%]), and anterior (n = 1,785 [77.6%]) rib fractures of ribs 2 to 7. Eight patients (2.3%) had a flail segment, and 136 patients (39.5%) had an anterior flail segment. Patients with chest wall injury had fewer ventilator-free days (0 days [P_{25}–P_{75}, 0–16 days] vs. 13 days [P_{25}–P_{75}, 2–22 days]; $p = 0.006$) and a higher mortality rate (n = 102 [54.0%] vs. n = 8 [22.2%]; $p < 0.001$) than those without chest wall injury. For the subgroup of patients with good neurological recovery, the presence of six or more rib fractures or a single displaced rib fracture was associated with longer hospital and ICU length of stay, respectively.

CONCLUSION: Cardiopulmonary resuscitation–related chest wall injuries in survivors of OHCA and especially rib fractures are common. Patients with chest wall injury had fewer ventilator-free days and a higher mortality rate. Patients with good neurological recovery might represent a subgroup of patients who could benefit from surgical stabilization of rib fractures. (*J Trauma Acute Care Surg.* 2021;91: 966–975. Copyright © 2021 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Therapeutic, level IV; Epidemiological, Level IV.

KEY WORDS: Rib fracture; cardiopulmonary resuscitation; out-of-hospital cardiac arrest; outcome; surgical stabilization of rib fractures.

Sudden cardiac arrest is associated with poor survival rates, ranging from 2% to 11% after out-of-hospital cardiac arrest (OHCA) and up to 25% after in-hospital cardiac arrest.[1,2] Cardiopulmonary resuscitation (CPR) is vital for the survival of these patients, and chest compressions are key in providing oxygenation to the brain and heart.[3,4] While chest compressions are considered the most important component of CPR, this mechanism also causes traumatic injuries.[5,6] For example, rib fractures are the most often sustained bony injury after blunt chest trauma with a prevalence of 40%, but following CPR, rib fractures have been found in more than 80% of patients.[4,7–9] Multiple rib fractures after CPR are mostly anterior fractures of three or more adjacent ribs of the second to seventh rib, often studied in postmortem subjects or as diagnosed on chest radiography.[8–12] Besides the number and location of rib fractures, there is relatively little information on CPR-related rib fracture severity characteristics such as fracture type and degree of dislocation.

Pneumonia is the most common infectious complication after OHCA, and rates of approximately 25% have been described, which is most likely due to the extensive iatrogenic pulmonary contusion and aspiration of stomach contents.[13–17] Sustaining traumatic rib fractures has been associated with a high risk of pneumonia and consequent high morbidity and mortality rates. Following thoracic trauma, the risk of pneumonia increases with age or a higher number of fractured ribs.[18–20] As a result, the already vulnerable patient because of the OHCA might be at increased risk of developing pneumonia after sustaining CPR-related rib fractures and consequently has an increased risk of poor in-hospital outcome and mortality. To our knowledge, the effect of chest wall injury severity characteristics on in-hospital outcomes has not previously been described in survivors of OHCA. The use of surgical stabilization of rib fractures (SSRF) for severe chest wall injury has increased exponentially over the last decade and established ground in a broadening trauma population in terms of shorter hospital and intensive care unit (ICU) length of stay (LOS) and mitigation of pulmonary morbidity such as pneumonia, in comparison with nonoperative management.[21–24] The practice of SSRF in patients with chest wall injuries due to CPR has only been described in small case series after failure of nonoperative management.[25,26]

The primary aim of this study was to assess the prevalence of chest wall injuries due to CPR after OHCA with no obvious traumatic or extracardiac cause in patients admitted to the ICU. The secondary aim was to compare in-hospital outcomes in patients with versus without chest wall injuries due to CPR after OHCA and to identify a possible subgroup of patients who might benefit from SSRF.

PATIENTS AND METHODS

Design and Participants

A multicenter retrospective cohort study was performed at two hospitals, a level 1 and level 2 trauma center. The study was exempted by the local Medical Research Ethics Committee. All patients who had CPR after OHCA with no obvious traumatic or extracardiac cause between January 1, 2007, and December 31, 2019, and were admitted to the ICU with return of spontaneous circulation (ROSC) within 24 hours after CPR were included in the study. Eligible patients were identified by a local OHCA resuscitation or ICU database. Patients with any of the following criteria were excluded: (1) chest wall injury sustained within

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3 months before CPR; (2) use of ventricular support device (i.e., extracorporal membrane oxygenation, left ventricular assist device, Impella device, or intra-aortic balloon pump) because of the risk of iatrogenic intrathoracic or abdominal injury due to placement. Given the exploratory nature of this study, a formal sample size calculation was not made.

Data Collection and Outcome Measures

Data were extracted from the patient's medical files. The primary outcome measure was the occurrence of chest wall injuries, as diagnosed on chest computed tomography (CT) (i.e., rib fracture(s) including number of total fractured ribs, rib fracture location, dislocation, and type; presence of a flail segment; sternum fracture; and anterior flail segment). In case of an additional CPR setting, the last chest CT was used. All definitions on rib and chest wall injury characteristics were derived from the Chest Wall Injury Society international taxonomy paper.[27] The location of fracture per rib was defined as costochondral, anterior, lateral, posterior, or paravertebral. The degree of dislocation was defined as undisplaced (>90% cortical contact), offset (<90% cortical contact), or displaced (no cortical contact). Type of fracture per rib was defined as simple, wedge, or complex. The presence of a flail segment (three or more consecutive ribs fractured in two or more places) and anterior flail segment or flail sternum (three bilateral consecutive anterior rib or costochondral fractures) were radiological diagnoses. Collected intrathoracic injury characteristics were occurrence of pneumothorax, hemothorax, unilateral or bilateral pulmonary contusion, pneumomediastinum, intrathoracic arterial blush, abdominal injury, and intrapulmonary aspiration at admission (defined as the presence of abnormal fluids or infiltrative consolidations at the time of the initial chest CT, as reported by the radiologist). The secondary outcomes were mechanical ventilation requirement, ventilator-free days (number of days the patient breathed without pulmonary assistance) during hospitalization, ICU LOS and hospital length of stay (HLOS) during primary admission, the occurrence of thoracic complications requiring medicinal or surgical interventions (i.e., pneumonia, pleural empyema, retained hemothorax, or tracheostomy requirement), and in-hospital mortality. Patients were intubated and received targeted temperature management in case of a Glasgow Coma Scale (GCS) score of <8 according to international guidelines or if a patient had a motor GCS of <5.[28] Also, to identify if a select patient group might benefit from SSRF over nonoperative management, subgroup analysis was performed to assess in-hospital outcomes in patients with good neurological recovery after targeted temperature management for OHCA, defined as a motor GCS of 5 or 6, and presence versus absence of increasing chest wall injury.

In addition, the following variables were collected: patient characteristics (i.e., age, sex, smoking status at age of OHCA, presence of cardiovascular comorbidities, previous cardiac interventions), OHCA-related characteristics (i.e., cause of arrest, time between OHCA and CPR, time between OHCA and ROSC, and GCS at presentation), CPR-related variables (i.e., manual or mechanical CPR, CPR performed by bystander, (helicopter) emergency medical service [(H)EMS], or a combination), and treatment-related variables (e.g., SSRF, video-assisted thoracoscopic surgery [VATS], or thoracotomy performed).

Statistical Analysis

Data were analyzed using the Statistical Package for the Social Sciences version 25 (SPSS, Chicago, IL). Normality of continuous variables was tested with the Shapiro-Wilk test, and homogeneity of variances was tested using the Levene's test. A *p* value of lower than 0.05 was considered statistically significant, and all tests were two-sided. Descriptive analysis was performed to report the data for the entire study population and for patients with or without chest wall injury. For continuous data, the median and percentiles (nonparametric data) were reported. Categorical data are reported as numbers and frequencies. Statistical significance of differences between patients with and without chest wall injuries was assessed using Mann-Whitney *U* test (two groups) for continuous data and χ^2 or Fisher's exact test for categorical data, as applicable.

Subgroup analysis of patients with good neurological recovery was performed to evaluate the effect of increasing severity of chest wall injury (increasing number of rib fractures, presence and increasing number of displaced rib fractures, and presence of any type of flail segment) on the in-hospital outcomes, as compared with patients in which these characteristics were absent.

RESULTS

In total, 344 of 386 eligible patients (89%) were included for analysis (Supplemental Digital Content, Supplementary Fig. 1, http://links.lww.com/TA/C117). The median age was 66 years (P_{25}–P_{75}, 54–74 years), 259 (75.3%) were male, and the median GCS at admission was 3 (P_{25}–P_{75}, 3–5; range, 3–15) with an acute myocardial infarction as the most prevalent cause of the OHCA (n = 177 [51.5%]) (Table 1). The median time of OHCA to ROSC was 10 minutes (P_{25}–P_{75}, 6–17 minutes) with CPR initiation at a median of 0 minutes (P_{25}–P_{75}, 0–5 minutes) after OHCA.

Of the included patients, 291 (85%) had sustained chest wall injury due to CPR, and rib fractures were the most common chest wall injury (n = 285 [83%]; Table 2). Patients with chest wall injury had a median of 8 fractured ribs (P_{25}–P_{75}, 4–10 ribs), which were most often undisplaced (n = 1,574; 72%), simple (n = 1,948; 89%), and anterior (n = 1,785; 78%) fractures of ribs 2 to 7 (Fig. 1). Of ribs 2 to 7, the rate of displaced rib fractures ranged from 4.0% to 13.4%. A total of 98 patients (28.5%) had a concomitant sternum fracture, and 136 (39.5%) had an anterior flail segment.

Patients with chest wall injury were older (median [P_{25}–P_{75}], 67 [57–75] years vs. 50 [40–63] years; $p < 0.001$; Table 3) and less often had congenital heart disease (n = 4 [1.9%] vs. n = 3 [10.3%]; $p = 0.038$) than patients without chest wall injury. Other baseline characteristics were similar across the two groups. The two groups had similar time from OHCA to start of CPR and median GCS at admission, but the duration from OHCA to ROSC was significantly longer in patients with chest wall injury (median [P_{25}–P_{75}], 10 [6–18] minutes vs. 4 [1–6] minutes; $p = 0.001$). In addition, the distribution of CPR performed by (H)EMS or bystander was similar, but for patients with chest wall injury, the duration of CPR performed by (H)EMS was significantly longer than in those without chest wall injury (median [P_{25}–P_{75}], 8 [4–13] minutes vs. 4 [2–9] minutes; $p = 0.003$). With regard

TABLE 1. Demographics, OHCA, and CPR Characteristics in Admitted Patients Who Underwent CPR After OHCA

	n*	Overall (n = 344)
Patient demographics		
Age, y	344	66 (54–74)
Sex (male)	344	259 (75.3%)
Smoking at age of CPR	241	90 (37.3%)
Hypertension	244	150 (61.5%)
Diabetes mellitus	244	68 (27.9%)
COPD	244	35 (14.3%)
Pulmonary embolism	244	6 (2.5%)
Cerebrovascular accident	244	16 (6.6%)
Previous MI	244	72 (29.5%)
Cardiomyopathy	244	33 (13.5%)
Congenital heart disease	244	7 (2.9%)
Chronic heart failure	244	54 (22.1%)
Arrhythmia	244	63 (25.8%)
Cardiac valve disease	244	18 (7.4%)
Cardiac intervention	344	80 (23.3%)
Congenital heart disease operation	80	3 (3.8%)
Cardiac valve disease operation	80	10 (12.5%)
Previous PCI	80	54 (67.5%)
Previous CABG	80	24 (30.0%)
ICD or pacemaker in situ	80	17 (21.3%)
OHCA and CPR characteristics		
OHCA cause		
Acute MI	344	177 (51.5%)
Old MI/scar tissue	344	60 (17.4%)
Cardiomyopathy	344	42 (12.2%)
Primary rhythm disorder	344	48 (14.0%)
Intoxication	344	4 (1.2%)
Unknown	344	13 (3.8%)
GCS at presentation	331	3 (3–5)
OHCA to CPR duration, min	267	0.0 (0.0–5.0)
OHCA to ROSC duration, min	242	10.0 (6.0–17.3)
Bystander	253	0.0 (0.0–5.0)
(H)EMS	316	6.0 (4.0–12.0)
CPR mode		
Manual	344	344 (100.0%)
Manual + mechanical	344	19 (5.5%)
Type of compressor		
Bystander	344	27 (8.0%)
(H)EMS	344	137 (40.5%)
Combination	344	174 (51.5%)
Additional CPR setting	344	54 (15.7%)
<24 h	54	46 (85.2%)
>24 h	54	8 (14.8%)
Chest CT performed		
After first CPR setting	344	315 (91.6%)
After additional CPR setting	344	29 (8.4%)

Data are shown as median (P_{25}–P_{75}) or as n (%).
*Provides the exact number of patients for whom data were available.
CABG, coronary artery bypass graft; COPD, chronic obstructive pulmonary disease; CWI, chest wall injury; ICD, implantable cardioverter defibrillator; MI, myocardial infarction; PCI, percutaneous coronary intervention.

to intrathoracic injuries, patients with chest wall injury more frequently sustained a hemothorax (n = 84 [28.9%] vs. n = 7 [13.2%]; p = 0.018) and pulmonary contusion (n = 155 [53.3%] vs. n = 19 [35.8%]; p = 0.025) than those without chest wall injury. Other intrathoracic injury rates were similar across the two groups. The radiologically diagnosed abdominal injuries were two kidney hemorrhages, one spleen hemorrhage, one ureter hemorrhage, one adrenal gland hemorrhage, one colon injury, and one concomitant kidney and liver infarction in the chest wall injury group versus one spleen hemorrhage in the group without chest wall injury (p = 0.818).

In the chest wall injury group, seven patients (2.4%) underwent SSRF, because of insufficient respiratory function, after a median of 5 days (P_{25}–P_{75}, 2–5 days) following hospital admission. In these patients, a median of five ribs (P_{25}–P_{75}, 5–7 ribs) were surgically stabilized, totaling a ratio of ribs repaired to fractured (rib fixation ratio) of 0.70 (P_{25}–P_{75}, 0.38–0.83). In one patient, SSRF was complicated by a postoperative bleeding, which required a thoracotomy, and another patient required a VATS because if a retained hemothorax. No surgical site infection or hardware failure was reported during hospitalization. All patients underwent SSRF in 2019, and all were discharged alive.

Of the entire cohort, 119 patients (34.6%) were transferred to another hospital during primary admission. In-hospital outcomes were evaluated for patients with complete data regarding their primary hospital stay (n = 225; Table 4). Median ventilator-free days

TABLE 2. Chest Wall Injury Characteristics in Admitted Patients After CPR for OHCA

Chest Wall Injury Characteristics	Overall (n = 344)
Rib fracture	285 (82.9%)
No. ribs fractured	8 (4–10)
Bilateral rib fractures	240 (84.2%)
No. rib fractures	2,300
Rib fracture location	
Costochondral	117 (5.1%)
Anterior	1,785 (77.6%)
Lateral	376 (16.3%)
Posterior	21 (0.9%)
Costovertebral	1 (0.04%)
Rib fracture dislocation	
Undisplaced	1,578 (72.2%)
Offset	434 (19.9%)
Displaced	175 (8.0%)
Rib fracture type	
Simple	1,952 (89.3%)
Wedge	122 (5.6%)
Complex	113 (5.2%)
Flail segment	8 (2.3%)
Sternal fracture	98 (28.5%)
Anterior flail segment/flail sternum	136 (39.5%)

Data are shown as median (P_{25}–P_{75}) or as n (%). There were no missing data.
Undisplaced fracture, >90% cortical contact; offset, <90% cortical contact; displaced, no cortical contact. Flail segment, three or more consecutive ribs fractured in two or more places; anterior flail segment or flail sternum, three bilateral consecutive anterior rib or costochondral fractures. Complex fractures were evaluated for degree of dislocation once.

A

			Left side				Right side					
Σ	PV	P	L	A	CC	Rib	CC	A	L	P	PV	Σ
14	0	0	2	7	5	1	3	11	1	1	0	16
139	1	0	10	126	2	2	3	125	3	1	0	132
205	0	0	28	177	0	3	2	173	28	2	0	205
233	0	0	47	185	1	4	6	185	36	3	0	230
228	0	1	45	175	7	5	13	168	46	2	0	229
186	0	1	35	134	16	6	20	147	33	2	0	202
122	0	1	19	86	16	7	15	69	22	1	0	107
21	0	0	11	7	3	8	4	10	6	2	0	22
3	0	0	2	0	1	9	0	0	2	1	0	3
1	0	1	0	0		10		0	0	1	0	1
1	0	1	0			11			0	0	0	0
0	0	0				12				0	0	0
Σ 1153	1	5	199	897	51		66	888	177	16	0	1147

B

		Left side			Right side			
Σ	C	W	S	Rib	S	W	C	Σ
14	1	2	11	1	11	4	1	16
136	5	16	115	2	105	19	4	128
199	6	16	177	3	177	13	8	198
225	11	11	203	4	196	14	10	220
218	13	7	198	5	194	9	14	217
176	10	7	159	6	169	2	15	186
100	6	0	94	7	94	0	6	100
21	1	0	20	8	19	1	1	21
3	0	0	3	9	1	0	1	2
1	0	0	1	10	1	0	0	1
1	0	1	0	11	0	0	0	0
0	0	0	0	12	0	0	0	0
Σ 1094	53	60	981		967	62	60	1089

C

		Left side			Right side			
Σ	D	O	U	Rib	U	O	D	Σ
14	0	3	11	1	12	3	1	16
136	8	30	98	2	94	22	12	128
199	11	31	157	3	141	42	15	198
225	21	57	147	4	151	43	26	220
218	16	60	142	5	149	39	29	217
176	13	32	131	6	137	38	11	186
100	4	14	82	7	82	14	4	100
21	2	2	17	8	17	3	1	21
3	0	1	2	9	2	0	0	2
1	1	0	0	10	1	0	0	1
1	0	0	1	11	0	0	0	0
0	0	0	0	12	0	0	0	0
Σ 1094	76	230	788		786	204	99	1089

Figure 1. Heat map displaying the location (*A*), type (*B*), and degree of dislocation (*C*) per rib. Thick borders around specific ribs represent hotspots, which comprise ≥50% of the total number of rib fracture location, type, or dislocation degree. A, anterior; C, complete; CC, costochondral, D, displaced; L, lateral; O, offset; P, posterior; PV, costovertebral; S, simple; U, undisplaced; W, wedge.

were significantly lower in those with chest wall injury (0 days; P_{25}–P_{75}, 0–16 days) than in patients without chest wall injury (13 days; P_{25}–P_{75}, 2–22 days; $p = 0.006$). A total of 102 patients (54.0%) died in the group with chest wall injury, while 8 patients (22.2%) died in the group without chest wall ($p < 0.001$). The ICU LOS, rate of mechanical ventilation requirement, and thoracic complications were similar for both groups.

In subgroup analysis, the effect of a specific chest wall injury characteristic (indicator) on in-hospital outcomes was evaluated as compared with patients without this characteristic (reference), in patients with good neurologic recovery (motor GCS of 5 or 6). A motor GCS of 5 or 6 after targeted temperature management versus a motor GCS of 1 to 4 was associated with a higher number of ventilator-free days (15 days [P_{25}–P_{75}, 11–22

TABLE 3. Demographics, OHCA, CPR, and Intrathoracic Injury Characteristics in Admitted Patients Who Underwent CPR After OHCA, Stratified for Presence or Absence of CWI

	n*	With CWI (n = 291)	n*	Without CWI (n = 53)	p
Patient demographics					
Age, y	291	67 (57–75)	53	50 (40–63)	**<0.001**
Sex (male)	291	221 (75.9%)	53	38 (71.7%)	0.494
Smoking at age of CPR	198	76 (38.4%)	43	14 (32.6%)	0.602
Hypertension	215	134 (62.3%)	29	16 (55.2%)	0.543
Diabetes mellitus	215	62 (28.8%)	29	6 (20.7%)	0.508
COPD	215	31 (14.4%)	29	4 (13.8%)	1.000
Pulmonary embolism	215	4 (1.9%)	29	2 (6.9%)	0.151
Cerebrovascular accident	215	14 (6.5%)	29	2 (6.9%)	1.000
Previous MI	215	65 (30.2%)	29	7 (24.1%)	0.665
Cardiomyopathy	215	27 (12.6%)	29	6 (20.7%)	0.247
Congenital heart disease	215	4 (1.9%)	29	3 (10.3%)	**0.038**
Chronic heart failure	215	50 (23.3%)	29	4 (13.8%)	0.342
Arrhythmia	215	55 (25.6%)	29	8 (27.6%)	0.823
Cardiac valve disease	215	17 (7.9%)	29	1 (3.4%)	0.704
Cardiac intervention	291	70 (24.1%)	53	10 (18.9%)	0.482
Congenital heart disease operation	70	1 (1.4%)	10	2 (20.0%)	**0.040**
Cardiac valve disease operation	70	9 (12.9%)	10	1 (10.0%)	1.000
Previous PCI	70	47 (67.1%)	10	7 (70.0%)	1.000
Previous CABG	70	22 (31.4%)	10	2 (20.0%)	0.715
ICD or pacemaker in situ	70	16 (22.9%)	10	1 (10.0%)	0.680
OHCA and CPR characteristics					
OHCA cause					
Acute MI	291	155 (53.3%)	53	22 (41.5%)	**0.018**
Old MI/scar tissue	291	55 (18.9%)	53	5 (9.4%)	
Cardiomyopathy	291	35 (12.0%)	53	7 (13.2%)	
Primary rhythm disorder	291	33 (11.3%)	53	15 (28.3%)	
Intoxication	291	3 (1.0%)	53	1 (1.9%)	
Unknown	291	10 (3.4%)	53	3 (5.7%)	
GCS at presentation	278	3 (3–5)	53	3 (3–6)	0.215
OHCA to CPR duration, min	222	0 (0–5)	45	0 (0–5)	0.777
OHCA to ROSC duration, min	207	10 (6–18)	35	4 (1–6)	**0.001**
Bystander	217	0 (0–5)	36	0 (0–5)	0.847
(H)EMS	266	8 (4–13)	50	4 (2–9)	**0.003**
CPR mode					
Manual	291	291 (100.0%)	53	53 (100.0%)	1.000
Manual + mechanical	291	17 (5.8%)	53	2 (3.8%)	0.749
Type of compressor					
Bystander	285	21 (7.4%)	53	6 (11.3%)	0.539
(H)EMS	285	118 (41.4%)	53	19 (35.8%)	
Combination	285	146 (51.2%)	53	28 (52.8%)	
Additional CPR setting	291	49 (16.8%)	53	5 (9.4%)	0.219
<24 hours	49	41 (83.7%)	5	5 (100.0%)	1.000
>24 hours	49	8 (16.3%)	5	0 (0.0%)	
Chest CT performed					
After first CPR setting	291	264 (90.7%)	53	51 (96.2%)	0.281
After additional CPR setting	291	27 (9.3%)	53	2 (3.8%)	
Intrathoracic injury					
Pneumothorax	291	19 (6.5%)	53	1 (1.9%)	0.334
Hemothorax	291	84 (28.9%)	53	7 (13.2%)	**0.018**
Pulmonary contusion	291	155 (53.3%)	53	19 (35.8%)	**0.025**
Unilateral	291	28 (18.1%)	53	6 (31.6%)	0.216
Bilateral	291	127 (81.9%)	53	13 (68.4%)	

Continued next page

TABLE 3. *(Continued)*

	n*	With CWI (n = 291)	n*	Without CWI (n = 53)	*p*
Pneumomediastinum	291	7 (2.4%)	53	1 (1.9%)	1.000
Intrathoracic arterial blush	291	4 (1.4%)	53	0 (0.0%)	1.000
Abdominal injury	291	7 (2.4%)	53	1 (1.9%)	1.000
Aspiration at admission	291	36 (12.4%)	53	3 (5.7%)	0.236
Chest tube drainage	291	20 (6.9%)	53	1 (1.9%)	0.221

Data are shown as median (P_{25}–P_{75}) or as n (%); bold *p* values are considered statistically significant.
*Provides the exact number of patients for whom data were available.
CABG, coronary artery bypass graft; COPD, chronic obstructive pulmonary disease; CWI, chest wall injury; ICD, implantable cardioverter defibrillator; MI, myocardial infarction; PCI, percutaneous coronary intervention.

days] vs. 0 days [P_{25}–P_{75}, 0–11 days]; $p < 0.001$) and lower mortality rate (n = 3 [2.2%] vs. n = 89 [57.4%]; $p < 0.001$) (Table 5 and Supplemental Digital Content, Supplementary Table 1, http://links.lww.com/TA/C118). In this subgroup of patients with good neurological recovery, sustaining one to five rib fractures was not associated with any difference in in-hospital outcomes, but sustaining six or more rib fractures as compared with one to five rib fractures was associated with a longer HLOS (22 days [P_{25}–P_{75}, 17–31 days] vs. 18 days [P_{25}–P_{75}, 12–22 days]; $p = 0.040$). The rate of pneumonia in patients with rib fractures was 30.9% (n = 17) versus 9.1% (n = 2) in patients without rib fractures ($p = 0.077$).

The presence of one or more displaced rib fractures as compared with having only undisplaced rib fractures was associated with longer ICU LOS (10 days [P_{25}–P_{75}, 3–12 days] vs. 5 days [P_{25}–P_{75}, 4–6 days]; $p = 0.023$). No effect was seen of the presence of the different number of rib fractures, number of displaced rib fractures, or a flail chest on mortality rate. Patients with a flail segment (anterior or flail sternum or other flail segment) had more ventilator-free days and longer HLOS as compared with those without any flail segment, but outcomes were not significantly different.

DISCUSSION

This retrospective review is the first to assess CPR-related chest wall injuries in detail based on the validated taxonomy for rib fracture classification and evaluate the effect of these injuries on in-hospital outcomes in survivors of CPR. In this population of patients who are admitted following CPR for OHCA, chest wall injuries are common. The most prevalent injury were rib fractures, present in over 8 of every 10 patients, with a median of 8 rib fractures per patient. These rib fractures were most often bilateral, anterior, and undisplaced simple rib fractures of ribs 2

TABLE 4. In-Hospital Outcomes and Thoracic Complications in Patients With ROSC After CPR for OHCA, Stratified for Presence or Absence of CWI

	Overall (n = 344)	With CWI (n = 291)	Without CWI (n = 53)	*p*
Transferred to other hospital	119 (34.6%)	102 (35.1%)	17 (32.1%)	0.755
HLOS, d	12 (4–23)	10 (4–23)	16 (8–25)	**0.024**
HLOS (survivors), d	23 (16–30)	23 (17–32)	21 (13–27)	0.125
ICU LOS, d	5 (3–8)	5 (3–8)	3 (1–5)	0.871
Mechanical ventilation	217 (96.4%)	184 (97.4%)	33 (91.7%)	0.119
Ventilator-free days	5 (0–18)	0 (0–16)	13 (2–22)	**0.006**
Thoracic complication	75 (33.3%)	66 (34.9%)	9 (25.0%)	0.335
Tracheostomy	11 (4.9%)	11 (5.8%)	0 (0.0%)	0.219
Pneumonia	45 (20.0%)	39 (20.6%)	6 (16.7%)	0.657
Pleural empyema	0 (0.0%)	0 (0.0%)	0 (0.0%)	1.000
Retained hemothorax	1 (0.4%)	1 (0.5%)	0 (0.0%)	1.000
Mortality	110 (48.9%)	102 (54.0%)	8 (22.2%)	**<0.001**
Mortality, d	3 (1–6)	3 (1–6)	4 (2–8)	0.388
Mortality cause				
Postanoxic neurological damage	72 (65.5%)	66 (64.7%)	6 (75.0%)	0.696
Cardiogenic shock	14 (12.7%)	14 (13.7%)	0 (0.0%)	
Respiratory insufficiency	4 (3.6%)	4 (3.9%)	0 (0.0%)	
Multiorgan failure	14 (12.7%)	12 (11.8%)	2 (25.0%)	
DNR/DNI status	2 (1.8%)	2 (2.0%)	0 (0.0%)	
Unknown	4 (3.6%)	4 (3.9%)	0 (0.0%)	

Data are shown as median (P_{25}–P_{75}) or as n (%); bold *p* values are considered statistically significant. There were no missing data.
CWI, chest wall injury; DNR/DNI, do not resuscitate/do not intubate.

TABLE 5. Effect of Neurological Status and Chest Wall Injury on In-hospital Outcomes After CPR for OHCA

		Ventilator-Free Days		ICU LOS		HLOS		Pneumonia		Mortality	
Indicator	Reference	Indicator	Reference	Indicator	Reference	Indicator	Reference	Indicator	Reference	Indicator	Reference
GCS-M 5 or 6	GCS-M 1–4	**15 (11–22)**	**0 (0–11)****	5 (3–7)	6 (4–9)	**18 (13–25)**	**7 (4–19)****	19 (24.7%)	25 (20.5%)	**3 (2.2%)**	**89 (57.4%)****
≥1 RF	0 RF	15 (11–21)	16 (11–24)	5 (4–8)	5 (3–6)	19 (14–25)	16 (12–26)	17 (30.9%)	2 (9.1%)	3 (2.9%)	0 (0.0%)
≥3 RF	1–2 RF	15 (11–21)	15 (7–22)	6 (4–9)	4 (3–6)	20 (15–25)	17 (9–26)	15 (34.9%)	2 (16.7%)	3 (3.4%)	0 (0.0%)
≥4 RF	1–3 RF	15 (12–23)	14 (9–18)	6 (4–10)	5 (3–6)	22 (16–27)	16 (10–21)	13 (36.1%)	4 (21.1%)	3 (3.8%)	0 (0.0%)
≥5 RF	1–4 RF	15 (12–23)	14 (9–19)	6 (4–10)	5 (3–7)	22 (16–30)	18 (12–23)	11 (35.5%)	6 (25.0%)	3 (4.3%)	0 (0.0%)
≥6 RF	1–5 RF	15 (13–24)	14 (9–19)	6 (4–10)	5 (3–7)	**22 (17–31)**	**18 (12–22)***	11 (36.7%)	6 (24.0%)	3 (4.8%)	0 (0.0%)
≥1 displaced RF	No displaced RF	14 (8–17)	15 (11–23)	**10 (3–12)**	**5 (4–6)***	21 (16–24)	18 (13–25)	6 (40.0%)	13 (21.0%)	2 (7.1%)	1 (0.9%)
≥2 displaced RF	1 displaced RF	15 (13–17)	12 (7–19)	8 (3–23)	10 (3–12)	22 (17–35)	19 (14–25)	1 (20.0%)	5 (50.0%)	0 (0.0%)	2 (12.5%)
≥3 displaced RF	1–2 displaced RF	17 (15–17)	13 (7–16)	10 (8–10)	10 (3–13)	21 (17–21)	21 (16–28)	0 (0.0%)	6 (46.2%)	0 (0.0%)	2 (8.7%)
Flail segment	No flail segment	19 (13–26)	14 (11–21)	5 (4–8)	5 (3–7)	22 (17–28)	18 (12–24)	6 (27.3%)	13 (23.6%)	1 (2.2%)	2 (2.1%)

Data are shown as median (P_{25}–P_{75}) or as n (%); bold values are considered statistically significant.
*$p < 0.05$.
**$p < 0.001$.
GCS-M, Glasgow Coma Scale-Motor score; RF, rib fracture.

to 7. Patients with chest wall injury had significant longer time from OHCA to ROSC and CPR performed by (H)EMS as well as higher intrathoracic injury rates of hemothorax and pulmonary contusion as compared with patients without chest wall injury. In-hospital outcomes differed between groups regarding mortality rates, which were higher (54% vs. 22%), and ventilator-free days, which were lower (0 vs. 13) in the chest wall injury group. For the subgroup of patients with good neurological recovery, a single displaced rib fracture was associated with longer ICU LOS. The same holds true for the HLOS in patients with six or more rib fractures, irrespective of the amount of dislocation.

The majority of chest wall injuries are still evaluated only at autopsy and most large-scale studies on chest wall injuries after CPR comprise postmortem subjects.[7,29–31] Chest wall injuries and more specifically rib fractures due to CPR are common in survivors too with previously diagnosed rib fracture rates similar to our findings (80–85%).[4,32,33] One of these studies also assessed the rate of displaced rib fractures and found a rate of 10%, which is similar to the 9% in our cohort.[4] The mentioned study did however only include 39 patients. The current study is the first to describe rib fracture severity according to the validated taxonomy of the Chest Wall Injury Society in ICU-admitted patients who had CPR for OHCA with an available chest CT.[27,34]

Iatrogenic rib fractures as sustained after CPR are associated with longer HLOS and a higher mortality rate than blunt traumatic rib fractures.[35] Delineating chest wall injuries such as rib fractures is important because the presence and number of rib fractures as well as the degree of dislocation or presence of a flail segment after chest trauma have been associated with increased rates of mortality and pulmonary morbidity.[20,36–38] In this cohort, patients with chest wall injury had worse in-hospital outcomes than their counterparts without chest wall injury regarding less ventilator-free days and a higher mortality rate. This suggests that there is a relationship between the presence of CPR-related chest wall injury and worse in-hospital outcomes, thus highlighting the importance of correctly identifying this injury. However, further prospective research is required to evaluate possible causality between chest wall injury and outcomes such as mechanical ventilation requirement.

Good motor GCS after targeted temperature management was associated with higher ventilator-free days, longer HLOS, and lower mortality. This might suggest that the neurological status after targeted temperature management is more predictive of worse in-hospital outcomes than the degree of chest wall injury severity. Age and duration from OHCA to ROSC were different among patients with and without chest wall injury in this study and have previously been shown to increase the risk of chest wall injury.[39–41] A higher age and longer OHCA setting might therefore, besides increasing chest wall injury risk, also precipitate a higher risk of neurological damage and result in worse in-hospital outcomes.

Within the group of patients with chest wall injury with good motor GCS (5 or 6) after targeted temperature management, the effect of the presence or absence of specific chest wall injuries on in-hospital outcomes was less clear. Sustaining six rib fractures, as opposed to one to five, or one or more displaced rib fractures as compared with only undisplaced rib fractures was associated with longer HLOS and ICU LOS, respectively. Also, although being nonsignificant, some differences in in-hospital outcomes between patients with and without specific chest wall injuries might be clinically relevant. For example, patients with rib fractures and good motor GCS recovery had a three times higher (31% vs. 9%) rate of pneumonia than those without rib fractures ($p = 0.077$).

The practice of SSRF in patients with chest wall injuries due to CPR has been evaluated with good outcomes, improving chest wall stability and aiding ventilator support weaning.[25,26] These studies, however, are case reports or series with no control group with patients undergoing SSRF at a late stage (>10 days) of hospitalization. Early SSRF (≤72 hours of admission) is associated with improved in-hospital outcomes as compared with nonoperative treatment, but late salvage rib fixation has actually been shown to be inferior to nonoperative treatment.[42,43] In this cohort, seven patients underwent SSRF at a median of 5 days after their sudden cardiac arrest, and all survived until discharge without perioperative complications with one patient requiring a VATS for retained hemothorax. Since SSRF has been shown to be safe in patients with traumatic brain injury and associated with a lower risk of pneumonia, SSRF (preferably in the early window) might also be safe and improve respiratory function in patients with severe chest wall injury due to CPR and possible OHCA-related post–anoxic brain injury.[44] Patients with good neurological recovery following targeted temperature management and severe chest wall injuries might represent a subgroup that could benefit from early SSRF. In these patients, the presence and increasing number of rib fractures or one displaced rib might be factors to be taken into account when considering SSRF to improve outcomes. The overall long HLOS, ICU LOS, and high rate of pneumonia in patients with chest wall injury due to CPR indicate that room for possibly clinically relevant improvements of these outcomes exists. Future comparative studies should focus on the effect of SSRF and nonoperative treatment in patients with chest wall injuries, which are currently deemed SSRF indications. While it is possible that these accepted SSRF indications do not apply to CPR-related chest wall injuries, chest wall injuries require identification and, if followed by good neurological recovery, might warrant further delineation regarding number of fractures and degree of dislocation, and consideration of SSRF to improve clinical outcomes.

When interpreting these results, several limitations should be considered. First, this was a retrospective study that might have introduced information bias through missing data. With a median admission GCS of 3, almost all patients (96%) requiring mechanical ventilation, and a mortality rate of 49% in the total cohort, missing data rates were possibly higher than in other original studies. Second, the analyses of in-hospital outcomes in the subgroups with good neurological recovery should be interpreted with caution because of the small sample sizes, which were possibly too low to detect small but clinically relevant differences in outcomes between groups. This could be attributable to the inclusion criterion of an available chest CT, which is the golden standard for diagnosis and delineation of rib fractures.[45] About half of the total number of patients had to be excluded because of no available chest CT. This might be explained because there was no standardized protocol for performing a chest CT in these patients during the study period, the acute care most often centered around cardiac and neurologic recovery requiring other diagnostic modalities, and this number of chest CTs might have been higher if patients had an unknown or noncardiac cause (e.g., pulmonary embolism or intracranial hemorrhage) of the sudden cardiac arrest. While this could have introduced selection bias, it was not possible with this retrospective data to evaluate why patients did or did not receive a chest CT and, consequently, whether patients without a chest CT had lower rates of chest wall injuries. However, as one of the largest studies on CPR-related injuries in survivors of OHCA with data of two hospitals, the available data mimic current daily practice. We recommend performing a chest CT at a low threshold in the acute setting to adequately assess chest wall injuries. Third, only univariate subgroup analysis was performed because of the small sample sizes of the subgroups. As a result, differences in patient and OHCA characteristics between the two groups such as age and duration of CPR could not be corrected for while these might have impacted in-hospital outcomes. In addition, the effect of neurological motor recovery appeared to be more strongly associated with adverse outcomes than specific chest wall injuries. These small sample sizes of patients with good neurological recovery show that poor in-hospital outcomes might be multifactorial and require a multidisciplinary approach.

In summary, CPR-related chest wall injuries in survivors of OHCA have a high prevalence. Multiple, bilateral, anterior, and undisplaced simple rib fractures of ribs 2 to 7 are most common. The presence of chest wall injuries is associated with worse in-hospital outcomes such as less ventilator-free days and higher mortality. Patients with good neurological recovery and chest wall injury still have lengthy ICU LOS and high rates of pneumonia. While this study does not prove causality between chest wall injury and in-hospital outcomes, it does demonstrate an association, warranting further large-scale prospective investigation and identification of a subgroup of patients who might benefit from SSRF to restore chest wall function and respiratory capacity following CPR for OHCA.

AUTHORSHIP

J.T.H.P., E.M.M.V.L., C.A.D.U., J.V., M.H.J.V., and M.M.E.W. participated in the study design. J.T.H.P., S.F.M.V.W., N.T.B.S., C.A.D.U., and J.V. participated in data provision and collection. J.T.H.P. and E.M.M.V.L. performed the data analysis. J.T.H.P., E.M.M.V.L., and M.M.E.W. participated in data interpretation. J.T.H.P. and E.M.M.V.L. drafted the article. E.M.M.V.L., S.F.M.V.W., N.T.B.S., C.A.D.U., J.V., M.H.J.V., and M.M.E.W. participated in critical revisions. All authors approved the final article version for submission.

DISCLOSURE

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