Eur Radiol (2018) 28:4122–4127
https://doi.org/10.1007/s00330-017-5117-0

CrossMark

EMERGENCY RADIOLOGY

Use of whole body CT to detect patterns of CPR-related injuries after sudden cardiac arrest

Gregor M. Dunham[1] · Alexandre Perez-Girbes[2] · Ferdia Bolster[3] · Kellie Sheehan[1] · Ken F. Linnau[1]

Received: 4 March 2017 / Revised: 26 September 2017 / Accepted: 3 October 2017 / Published online: 9 November 2017

Abstract

Aims and objectives We have recently implemented a dedicated sudden cardiac arrest (SCA) - whole-body computed tomography (WBCT) protocol to evaluate SCA patients with return of spontaneous circulation (ROSC) following cardiopulmonary resuscitation (CPR). The aim of this study is to evaluate the number and pattern of CPR-related injuries in ROSC patients with SCA-WBCT.

Methods and materials Single-centre retrospective review of 39 patients (13 female; 20 male, mean age 51.8 years) with non-traumatic, out-of-hospital SCA and ROSC and evaluation with dedicated SCA-WBCT over a 10-month period.

Results In-hospital mortality was 54%. CPR-related injuries were detected in 85% (33/39).

Chest injuries were most common on WBCT: 85% (33) subjects had rib fractures (mean of 8.5 fractures/subject); 31% (12) sternal fractures; 13% (5) mediastinal haematoma; 10% (4) pneumothorax; 8% (3) pneumomediastinum and 3% (1) haemothorax. Three subjects (8%) had abdominal injuries on WBCT, including one hepatic haematoma with active haemorrhage.

Conclusion CPR-related injuries on WBCT after ROSC are common, with serial rib fractures detected most commonly. An unexpectedly high rate of abdominal injuries was detected on SCA-WBCT. Radiologists need to be attuned to the spectrum of CPR-related injuries in WBCT, including abdominal injuries and subtle rib fractures.

Key Points

- *CPR frequently causes injuries.*
- *Radiologists should be aware of the spectrum of CPR related injuries.*
- *Rib fractures are frequent and radiologic findings often subtle.*
- *Clinically unexpected abdominal injuries may be present.*

Keywords Cardiopulmonary resuscitation · Tomography, X-Ray computed · Wounds and injuries · Emergencies · Radiology

Introduction

Cardiopulmonary resuscitation (CPR) is vital for the survival of patients with sudden cardiac arrest (SCA). Chest compressions are the key component for providing flow of oxygenated blood to the brain and heart [1]. However, chest compressions are also traumatic. Previously reported CPR-related injuries range from non-complicated rib fractures to life-threatening injuries such as large pneumothorax or mediastinal haemorrhage [2–4].

Imaging after return of spontaneous circulation (ROSC) is being increasingly utilised to identify clinically occult causes of SCA. Although improving, the rate of survival to discharge remains low for those with ROSC following SCA. Only 10.8% of patients with out-of-hospital cardiac arrest and 22.3–25.5% of in-hospital cardiac arrest survive to discharge [1]. The goal of imaging is to identify a treatable cause of SCA and to rule out potentially complicating pathology, such as intracranial haemorrhage. Additionally, imaging may identify unexpected traumatic injuries related to CPR. It is unknown to

✉ Gregor M. Dunham
gmdunham@uw.edu

1 Department of Radiology, University of Washington, 1959 N.E. Pacific Street, Seattle, WA 98195-7117, USA

2 University and Polytechnic Hospital La Fe, Valencia, Spain

3 Mater Misericordiae Hospital, Dublin, Ireland

what extent the injuries may affect survival in this patient population. The aim of this study is to assess traumatic injuries related to CPR in patients undergoing the non-traumatic SCA imaging protocol in our institution.

Materials and methods

The institutional review board (IRB) approved this HIPAA-compliant single-centre retrospective study with data acquired between January and September of 2016. The inclusion criteria were adult, non-traumatic, out-of-hospital SCA with ROSC who underwent SCA imaging protocol in our institution.

The SCA imaging protocol includes a WBCT including a retrospective ECG-gated CT arteriography of the chest, CT of the abdomen and pelvis in portal venous phase, and non-enhanced CT of the head. All CT images were acquired with a dual source dual energy CT, Siemens SOMATOM Force (Siemens Medical Systems, Erlangen, Germany). Chest CT was acquired in single energy mode and abdomen CT acquired in dual energy mode. Scan variables were as follows: 120 kVp (chest), Care KV modulation (abdomen); modulation mAs with reference of 160 (chest), 150 (abdomen); slice thickness 0.5mm (chest), 3mm (abdomen); rotation time 0.25s (chest), 0.5s (abdomen). Routinely, coronal and sagittal reconstructions were performed.

Study data was collected and managed using REDCap electronic data capture tools hosted at our institution [5]. REDCap (Research Electronic Data Capture) is a secure, web-based application designed to support data capture for research studies. The following data was collected from medical records: age, gender, height, weight, body mass index (BMI), use of anticoagulants prior to arrest, cause of SCA, duration of CPR and survival to discharge. Statistical analysis was made using R Commander (Fox, J., and Bouchet-Valat, M. (2017). Rcmdr: R Commander. R package version 2.3-2). CT images were reviewed by two senior radiology residents together and by consensus to evaluate for traumatic injuries, including: location, number and type of rib fractures, sternal fracture, pneumothorax, haemothorax, aspiration, pneumomediastinum, mediastinal haemorrhage, haemopericardium, cardiac injuries, great vessel injuries and abdominal injuries. Rib fracture types included incomplete, complete non-displaced, and displaced. An incomplete fracture was defined as acute angulation without discrete fracture line. Displacement was defined by as at least one cortical width separation of fracture fragments.

Results

During the study period, 39 patients (13 female, 26 male) aged 23 through 83 years (mean 51.8) were enrolled. Twenty-three of the patients (59%) had non-cardiac cause of SCA and the remaining 16 (41%) had cardiac origin (Table 1). ROSC was achieved after less than 10 minutes of CPR in 17 patients (44%); 10 (26%) patients needed 10–20 min and in 11 (28%) more than 20 minutes of CPR was performed. According to clinical records, all patients underwent manual CPR. No use of mechanical chest compression devices was recorded. Eighteen patients (46%) survived to discharge and 21 (54%) deceased during hospitalisation. Detailed demographic variables are shown in Table 1.

Rib fractures were the most common injuries (Fig. 1), present in 33 patients (85%). A total of 279 rib fractures were recorded. Rib fractures ranged from 0 to 13 per patient with a mean of 8.5 fractures per patient. Of these, 26 rib fractures (9%) were segmental. Patients with 7 or more fractures were significantly older than patients with less than 7 fractures, 56.16 vs. 46.57 years (p=0.046). Patients with segmental fractures were significantly older than patients without segmental fractures 67.5 vs 50.0 years (p=0.003). (Table 2).

CT findings of CPR-related rib fractures follows a spectrum of severity and can be further classified in three categories (Fig. 2): a) incomplete rib fractures, 206 (74%); complete non-displaced fracture, 43 (15%); displaced fractures, 27 (10%). Also, 5 (2%) chondral fractures were noted. Distribution of the rib fractures is summarised in Table 3.

Additional chest injuries were present including: 12 patients (31%) had sternal fracture, 5 (13%) mediastinal haemorrhage, 4 (10%) pneumothorax, 3 (8%) pneumomediastinum and 1 haemothorax. Also, abdominal injuries were found in three patients (8%). All three had liver injuries: one had American Association for the Surgery of Trauma (AAST) [6] grade II laceration, one a grade III laceration and the other one a grade III subcapsular haematoma with active bleeding and haemoperitoneum (Fig. 3). All detected injuries are included in Table 4.

Discussion

Traumatic injuries frequently result from CPR, most commonly rib and sternal fractures. A review by Hoke et al. [7] reported an incidence of rib fractures ranging from 13 to 97% and sternal fractures from 1 to 43%. More recent studies [3, 8–10] utilising post-mortem or post-resuscitation CT also show a wide variability with rib fractures present in 26.8–70% and sternal fractures in 4.2–30%. The reason for the variability is not known and likely multifactorial. Kim et al. [8] showed wide variation in the frequency of rib fractures among different hospitals. The incidence and outcome of cardiac arrest has been found to have significant regional differences [11]. The contributing variables such as training level of emergency medical services (EMS), time from call to EMS arrival, distance to hospital, prevalence of bystander CPR, and aetiology

Table 1 Patient demographics

	Female (n=13)	Male (n=26)	Total (n=39)
Age, mean (IQR) years	53.1 (23)	51.2 (24)	51.8 (22)
BMI, mean (IQR) kg/m^2	29.5 (13)	24.8 (4)	26.4 (7)
Taking ACO prior to arrest, n (%)			
Yes	0 (0)	4 (15)	4 (11)
No	13 (100)	22 (85)	35 (89)
Cause of SCA, n (%)			
Cardiac	7 (54)	9 (35)	16(41)
CNS	1 (8)	3 (12)	4(10)
Pulmonary	2 (15)	5 (19)	7(18)
Sepsis	1 (8)	3 (12)	4(10)
Toxic	2 (15)	5 (19)	7(18)
Unknown	0 (0.0)	1 (4)	1(3)
Duration of CPR (min)			
0–10	4 (31)	13 (50)	17 (44)
10–20	3 (23)	7 (27)	10 (26)
>20	5 (38)	6 (23)	11 (28)
Unknown	1 (8)	0 (0.0)	1 (3)
Outcome			
Survived	5 (38)	13 (50)	18 (46)
Deceased	8 (62)	13 (50)	21 (54)

IQR interquartile range, *BMI* body mass index, *ACO* anticoagulants, *SCA* sudden cardiac arrest, *CNS* central nervous system, *CPR* cardiopulmonary resuscitation

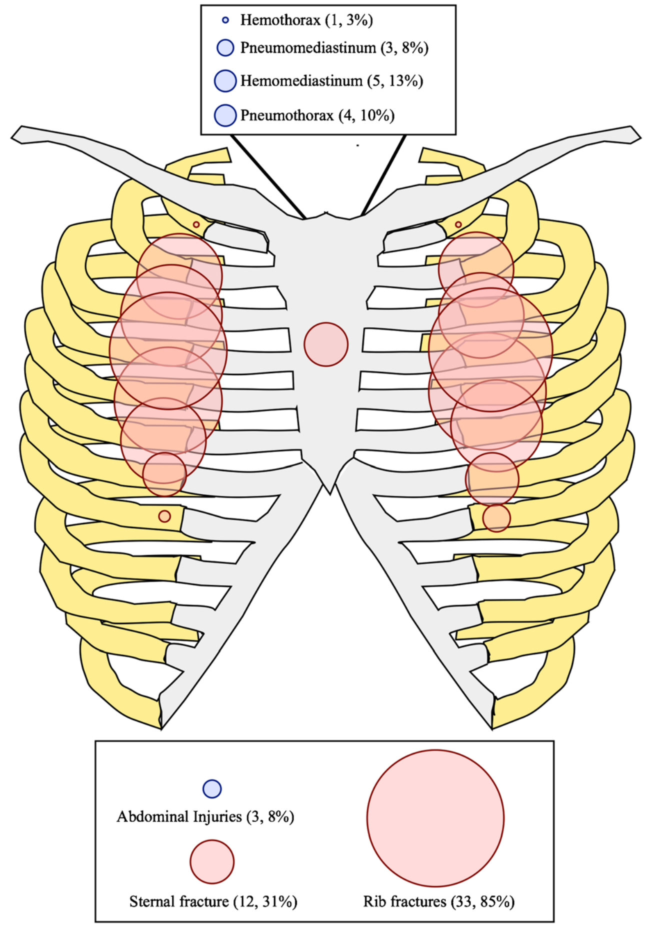

Fig. 1. Schematic demonstrating cardio pulmonary resuscitation (CPR)-related injury distribution

of SCA may account for some of the variability in CPR injury incidence.

A factor not addressed in prior studies is rib fracture type, which may contribute to the variability in reported rib fracture incidence. We found rib fractures in 84.6% of patients, which is at the upper end of the previously reported ranges. The majority of these fractures (74%) were incomplete and identified by focal increased rib angulation without discrete fracture line (Fig. 2). This can be a subtle radiologic finding and may not be reported as a fracture. Indeed, numerous fractures were only identified on a single plane of the multiplanar reconstructions (MPR). Use of curved planar reformats may be helpful with reported improved rib fracture detection sensitivity and reduced read time compared to MPR [12]. Although the clinical significance of these incomplete fractures has yet to be determined, traumatic rib fractures in general are independent risk factors for morbidity and mortality, particularly in the elderly [13], or when there are three or more [14].

When evaluating the number of rib fractures per patient, there were two general groups, those with no fractures and those with multiple. Of those with rib fractures only 15% (5/33) had one to five fractures while 76% (25/33) had eight or more fractures. Given this frequency of numerous fractures and the possible subtle radiologic findings, if a rib fracture is identified, there should be a high index of suspicion for multiple additional fractures. Similar to prior studies [8, 15], we found that patients with multiple rib fractures were significantly older.

Beyond rib and sternal fractures, multiple CPR related injuries have been described [2]. As expected based on proximity to the chest compressions, injuries most frequently arise in the chest and upper abdomen. We found a similar rate of thoracic injuries as previously described. The most common thoracic injuries are those associated with rib and sternal fractures including mediastinal haematoma (10.2–20.7%) and pneumothorax (2.5–12.2%) [16, 17]. We identified liver

Table 2 Comparison of age for total rib fractures and presence of segmental fractures

	Mean age (years)	SD	p-value
Total rib fractures			
Less than 7 (n=14)	46.57	14.16	0.046
7 or more (n=25)	56.16	12.92	
Segmental rib fractures			
Yes (n=6)	67.50	9.46	0.003
No (n=33)	50.03	13.04	

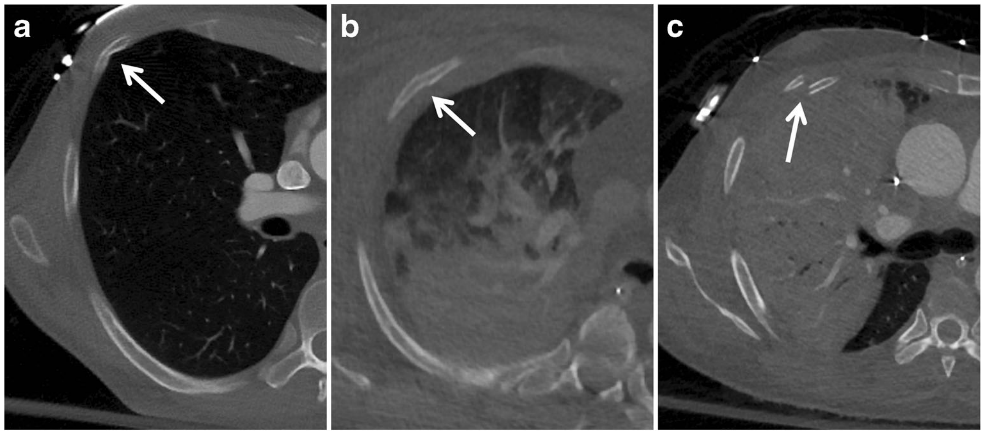

Fig. 2. Spectrum of rib fracture types. Axial contrast-enhanced CT from three different patients shows incomplete rib fracture (**a**, arrow), complete non-displaced fracture (**b**, arrow), and displaced fracture (**c**, arrow)

injuries in 3 patients (7.7%), which is higher than the reported incidence at autopsy of 0.6% [18] - 2.1% [19]. Other abdominal visceral injuries rarely occur with the spleen and stomach the next most commonly injured [19]. Most studies utilising CT have focused on thoracic injuries [3, 8–10, 16, 20] and were either performed without intravenous contrast or were limited to the thorax. However, Koga et al. [17] found secondary signs of abdominal injury, including haemoperitoneum in 14% of patients following CPR using post-mortem CT. Thus CPR related abdominal injuries on CT could be more common than previously described at autopsy. Larger studies utilising whole body contrast enhanced CT are required to better delineate the incidence of abdominal injuries.

All patients in our study underwent manual compression and bystander assisted CPR. No use of automated mechanical chest compression devices was recorded. Published data regarding CPR-related injuries after using mechanical chest compression devices shows that traumatic injuries are more common with use of these devices [21, 22], including abdominal injuries [17]. A recently published meta-analysis does not support that routine mechanical CPR improves survival or neurologic outcome [23]. A potential advantage of mechanical CPR is that WBCT can be acquired with minimal interruption to continued resuscitation [24].

No cardiovascular injuries were identified in our study. The most common cardiac injuries related to CPR include pericardial injury, haemopericardium, myocardial contusion, and conduction system injuries [16]. With the exception of haemopericadium, these injuries may not be identifiable on CT. Also our inclusion criteria of ROSC selects out most patients with severe cardiovascular injuries as the injuries may preclude spontaneous circulation. It is, however, important to be aware of these injuries, as they would require immediate intervention. Indeed successful repair of CPR-related ventricular rupture has been described [25]. Cardiac rupture occurs in up to 0.6% [16] of patients and although usually associated with prior ischemia/infarct, may arise without underlying wall weakness [25]. Traumatic vascular injuries including laceration, transection, pseudoaneurysm, and occlusion occur in the vessels immediately adjacent to the chest compressions. Coronary artery injury or His bundle haemorrhage has been found in up to 44% [26] of patients at autopsy. The aorta and internal mammary arteries are less commonly injured.

Bedside focused ultrasound to assess pericardial and peritoneal fluid plays a valuable role in screening trauma patients. Similarly, it may play a role in patients who underwent CPR to detect potential life-threating injuries like haemopericardium [16]. Benefits of ultrasound are well known: it is widely available, can be used at the bedside, avoids ionising radiation and is less expensive than CT. The use in the setting of CPR should be further explored.

Out of hospital CPR with ROSC carries a poor prognosis with only 10.8% [1] of patients surviving to discharge. Although we found a higher survival of 46%, the sample size is too small to determine any significance. The purpose of the

Table 3 Rib fracture distribution

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
Right, total	1	19	23	30	28	23	12	5	1	0	0	0
Right, segmental	0	0	3	3	3	2	2	2	0	0	0	0
Left, total	1	22	26	30	26	22	8	2	0	0	0	0
Left, segmental	0	1	3	3	3	1	0	0	0	0	0	0
Both sides, total	2	41	49	60	54	45	20	7	1	0	0	0
Both sides, segmental	0	1	6	6	6	3	2	2	0	0	0	0

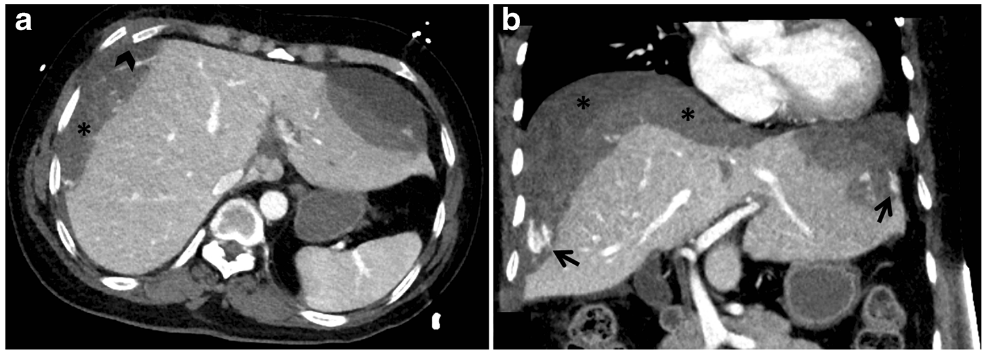

Fig. 3. 50-year old male underwent 10-20 minutes of CPR for sudden cardiac arrest (SCA) with return of spontaneous circulation (ROSC). Axial (**a**) and Coronal (**b**) contrast-enhanced CT demonstrates hepatic subcapsular haematoma (asterisk) with multiple foci of active extravasation (arrows) and adjacent displaced rib fracture (arrowhead). Patient survived to discharge

SCA imaging protocol is to identify the SCA aetiology and direct early intervention. Whether this has been successful will be evaluated after larger patient enrolment. An unanticipated role of the imaging protocol has been to identify a variety of CPR related injuries. The effect of the injuries on outcome is not (yet) known and thus the role of routine imaging for CPR related injuries remains unclear. Only a small fraction of the identifiable injuries necessitate emergent intervention. However, with as many as 84.6% suffering rib fractures, the potential clinical impact should be considered. Indeed each additional rib fracture in the elderly increases the mortality risk by 19% and the risk of pneumonia by 27% [13]. Also, as up to 76% of those with rib fractures had eight or more, there may be a role for surgical intervention. Early rib plating for severe rib fracture patterns, such as flail chest, has demonstrated improved morbidity including reduced time on ventilation, days in ICU and rate of pneumonia [27]. Further studies are required to delineate the impact of CPR-related injuries on outcomes and possible early intervention. However, radiologists should be aware of the spectrum of CPR-related injuries, as well as their known and potential clinical impact.

Table 4 Injury summary

	Female (*n*=13)	Male (*n*=26)	Total (*n*=39)
No injuries	2 (15)	4 (15)	6 (15)
Rib fractures	11 (85)	22 (85)	33 (85)
All mean (IQR; range)	8.1 (3; 1–13)	8.7 (2; 2–13)	8.5 (2; 1–13)
Sternal fractures	1 (8)	11 (42)	12 (31)
Pneumothorax	2 (15)	2 (8)	4 (10)
Haemothorax	0 (0.0)	1 (4)	1 (3)
Mediastinal haemorrhage	1 (8)	4 (15)	5 (13)
Pneumomediastinum	2 (15)	1 (4)	3 (8)
Haemopericardium	0 (0.0)	0 (0.0)	0 (0.0)
Cardiac injuries	0 (0.0)	0 (0.0)	0 (0.0)
Great vessel injuries	0 (0.0)	0 (0.0)	0 (0.0)
Abdominal injuries	1 (8)	2 (8)	3 (8)

IQR interquartile range

Conclusion

CPR-related injuries on WBCT after ROSC are common, with serial rib fractures detected most commonly. An unexpectedly high rate of abdominal injuries was detected on SCA-WBCT. As more institutions adopt SCA imaging protocols, radiologists should be aware of the spectrum of CPR related injuries.

Acknowledgements Scientific paper was presented at ECR 2017 (17-P-1685-ECR).

Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Ken F. Linnau, MD, MS.

Conflict of interest The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Funding This study was partially supported by the Institute of Translational Health Science (ITHS) (grant UL1 RR025014 from NCRR/NIH).

Statistics and biometry No complex statistical methods were necessary for this paper.

Informed consent Written informed consent was waived by the Institutional Review Board.

Ethical approval Institutional Review Board approval was obtained.

Methodology
• retrospective
• observational
• performed at one institution.

References

1. Kleinman ME, Brennan EE, Goldberger ZD, et al. Part 5: Adult Basic Life Support and Cardiopulmonary Resuscitation Quality: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. In: Vol 132. American Heart Association, Inc.; 2015:S414-S435

2. Olds K, Byard RW, Langlois NEI (2015) Injuries associated with resuscitation - an overview. J Forensic Leg Med 33:39–43
3. Kashiwagi Y, Sasakawa T, Tampo A et al (2015) Computed tomography findings of complications resulting from cardiopulmonary resuscitation. Resuscitation 88:86–91
4. Boland LL, Satterlee PA, Hokanson JS, Strauss CE, Yost D (2015) Chest compression injuries detected via routine post-arrest care in patients who survive to admission after out-of-hospital cardiac arrest. Prehosp Emerg Care 19:23–30
5. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG (2009) Research electronic data capture (REDCap)–a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform 42:377–381
6. Moore EE, Shackford SR, Pachter HL et al (1989) Organ injury scaling: spleen, liver, and kidney. J Trauma 29:1664–1666
7. Hoke RS, Chamberlain D (2004) Skeletal chest injuries secondary to cardiopulmonary resuscitation. Resuscitation 63:327–338
8. Kim MJ, Park YS, Kim SW et al (2013) Chest injury following cardiopulmonary resuscitation: a prospective computed tomography evaluation. Resuscitation 84:361–364
9. Kim EY, Yang HJ, Sung YM et al (2011) Multidetector CT findings of skeletal chest injuries secondary to cardiopulmonary resuscitation. Resuscitation 82:1285–1288
10. Hellevuo H, Sainio M, Nevalainen R et al (2013) Deeper chest compression - more complications for cardiac arrest patients? Resuscitation 84:760–765
11. Nichol G, Thomas E, Callaway CW et al (2008) Regional variation in out-of-hospital cardiac arrest incidence and outcome. JAMA 300: 1423–1431
12. Ringl H, Lazar M, Töpker M et al (2015) The ribs unfolded - a CT visualization algorithm for fast detection of rib fractures: effect on sensitivity and specificity in trauma patients. Eur Radiol 25:1865–1874
13. Bulger EM, Arneson MA, Mock CN, Jurkovich GJ (2000) Rib fractures in the elderly. J Trauma 48:1040–1046. discussion1046–7.
14. Sirmali M, Türüt H, Topçu S et al (2003) A comprehensive analysis of traumatic rib fractures: morbidity, mortality and management. Eur J Cardiothorac Surg 24:133–138
15. Kralj E, Podbregar M, Kejžar N, Balažic J (2015) Frequency and number of resuscitation related rib and sternum fractures are higher than generally considered. Resuscitation 93:136–141
16. Miller AC, Rosati SF, Suffredini AF, Schrump DS (2014) A systematic review and pooled analysis of CPR-associated cardiovascular and thoracic injuries. Resuscitation 85:724–731
17. Koga Y, Fujita M, Yagi T et al (2015) Effects of mechanical chest compression device with a load-distributing band on post-resuscitation injuries identified by post-mortem computed tomography. Resuscitation 96:226–231
18. Meron G, Kurkciyan I, Sterz F et al (2007) Cardiopulmonary resuscitation-associated major liver injury. Resuscitation 75:445–453
19. Krischer JP, Fine EG, Davis JH, Nagel EL (1987) Complications of cardiac resuscitation. Chest 92:287–291
20. Cho SH, Kim EY, Choi SJ et al (2013) Multidetector CT and radiographic findings of lung injuries secondary to cardiopulmonary resuscitation. Injury 44:1204–1207
21. Lardi C, Egger C, Larribau R, Niquille M, Mangin P, Fracasso T (2015) Traumatic injuries after mechanical cardiopulmonary resuscitation (LUCAS2): a forensic autopsy study. Int J Legal Med 129: 1035–1042
22. Smekal D, Lindgren E, Sandler H, Johansson J, Rubertsson S (2014) CPR-related injuries after manual or mechanical chest compressions with the LUCAS™ device: a multicentre study of victims after unsuccessful resuscitation. Resuscitation 85:1708–1712
23. Bonnes JL, Brouwer MA, Navarese EP et al (2016) Manual cardiopulmonary resuscitation versus CPR including a mechanical chest compression device in out-of-hospital cardiac arrest: a comprehensive meta-analysis from randomized and observational studies. Ann Emerg Med 67:349–360.e3
24. Wirth S, Körner M, Treitl M et al (2009) Computed tomography during cardiopulmonary resuscitation using automated chest compression devices–an initial study. Eur Radiol 19:1857–1866
25. Fosse E, Lindberg H (1996) Left ventricular rupture following external chest compression. Acta Anaesthesiol Scand 40:502–504
26. Frink R, Rose J (1997) Cardiopulmonary resuscitation and direct cardiac injury: evidence of fractured coronary arteries and HIS bundle hemorrhage. J Invasive Cardiol 9:578–585
27. Cataneo AJM, Cataneo DC, de Oliveira FH, Arruda KA, Dib El R, de Oliveira Carvalho PE (1996) In: Cataneo AJM (ed) Surgical versus nonsurgical interventions for flail chest. John Wiley & Sons, Ltd, Chichester, pp 1–39. https://doi.org/10.1002/14651858.CD009919.pub2