Chest Injuries Associated With Manual Chest Compressions in Adult Patients Who Have Suffered Out-of-Hospital Cardiac Arrest: A Retrospective Study

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SUMMARY

The aim of this retrospective observational study was to determine the incidence of chest injuries associated with manual chest compressions during cardiopulmonary resuscitation and the factors influencing their occurrence. Clinical and autopsy data were analyzed through a retrospective review of 71 autopsy reports of adult patients (58 men and 13 women) who did not survive out-of-hospital cardiac arrest. The study included cases from four municipalities in the Obalno-kraška region (Ankaran, Koper, Piran and Izola) of Slovenia, during the period from January 1, 2016 to December 31, 2020. The results showed that 42 patients (59.2%) sustained rib cage fractures following unsuccessful cardiopulmonary resuscitation. Most fractures were located between the second and sixth ribs, with the third, fourth and fifth ribs being the most frequently affected. Sternal fractures were identified in 43.6% of cases. Rib cage injuries increased with age ($\rho = 0.299$, $P = 0.013$) and were more prevalent in cardiac arrests due to drowning ($P = 0.012$) and those occurring in public places ($P = 0.006$). However, given the relatively small sample size, further research is required to confirm the factors influencing the occurrence of chest injuries.

KEYWORDS

Cardiopulmonary resuscitation; *Thoracic injuries*; *Rib fractures*; *Heart arrest*

Introduction

Efficient chest compressions remain the fundamental element for successful cardiopulmonary resuscitation (CPR). Global guidelines stress the critical importance of optimal factors in performing manual chest compressions. These include accurate hand placement, proper positioning of the rescuer towards the victim, and a suitable depth and frequency of compression and decompression actions[1,2]. External chest compressions are recognized as an invasive procedure that carries the risk of causing chest-related injuries. In 2010, changes were made to the European Resuscitation Council guidelines regarding the frequency and depth of compressions that contrast with the 2005 guidelines[3], but remain relevant today[1]. These changes have the potential to escalate the incidence of chest injuries. While changes in chest compression procedures may result in complex scenarios, research in this domain is sparse and findings across studies are inconsistent[4]. Several studies indicate an upsurge in the incidence of chest trauma and thoracic organ injuries following the introduction of the revised guidelines[5–7]. Conversely, Kashiwagi et al.[8] and Yamaguchi et al.[9] report no significant increase in the incidence of complications following the introduction of the updated 2010 guidelines.

Several risk factors that contribute to CPR-related injuries have been identified, including advanced age, sex, prolonged CPR duration and the occurrence of out-of-hospital cardiac arrests (OHCAs)[4,5,7,10–12]. While these studies include a wide range of patient cohorts, emergency medical services (EMS) and hospital protocols, covering both in-hospital cardiac arrest (IHCA) and OHCA cases, there is considerable variation in patient characteristics and circumstances surrounding the event. Research specifically addressing CPR-related injuries associated with OHCAs and their correlation with patient and event characteristics remains vague[13].

Current resuscitation guidelines do not clearly distinguish which chest injuries associated with CPR are unavoidable consequences of life-saving chest compressions and which may be potentially preventable. A clearer understanding of the type, frequency and determinants of CPR-related chest injuries is therefore essential for improving resuscitation quality, patient safety and post-resuscitation care. The aim of the present retrospective observational study was to analyze the incidence, anatomical distribution and characteristics of chest injuries associated with manual chest compressions in adult patients who experienced OHCA, as well as to identify patient- and event-related factors associated with their occurrence.

Methods

Study design and population

The research design was based on a retrospective observational study. The study included 71 adult patients (58 men and 13 women) who experienced OHCA, underwent attempted resuscitation and did not survive, with a post-mortem examination performed. Only deceased patients were included because the study data were derived exclusively from autopsy reports, which were accessible to the researchers through the regional forensic pathology database. OHCA patients who achieved return of spontaneous circulation (ROSC) and were admitted to hospital were not included, as the researchers did not obtain institutional approval to access hospital clinical or radiological documentation, particularly imaging studies required for a reliable assessment of chest injuries. This represents an inherent limitation and potential selection bias of the present study. To avoid any misinterpretation of the primary cause of chest injuries, all patients classified as trauma-related cardiac arrest were excluded. All included patients received manual chest compressions; no mechanical CPR devices were used.

Setting and EMS organization

The study was conducted in the Obalno-kraška region of Slovenia, encompassing four municipalities (Ankaran, Koper, Izola and Piran). Prehospital emergency medical care in this region is coordinated by the Prehospital Emergency Unit Obala, which operates one advanced life support resuscitation team dedicated to life-threatening emergencies. The resuscitation team consists of one emergency medicine specialist physician and two graduate paramedics/nurses. The unit serves a geographical area of approximately 340 km^2, with a resident population of 89,817 inhabitants, according to the Statistical Office of the Republic of Slovenia (SURS, 2019). During the summer months, the population increases substantially due to the influx of tourists.

Bystander involvement and dispatcher-assisted CPR

In cases of suspected cardiac arrest, emergency calls are received by a medical dispatcher. The dispatcher activates the EMS team and instructs the caller to begin chest compressions. However, due to limited dispatcher availability and simultaneous emergency calls, continuous dispatcher-assisted CPR guidance is not systematically provided until EMS arrival, and callers typically do not receive complete instructions on basic life support procedures. Formal, systematic CPR training for lay bystanders is not universally implemented, so the quality and duration of bystander-initiated chest compressions cannot be reliably assessed. Consequently, the potential contribution of bystander CPR to chest injuries cannot be excluded and represents an additional uncontrolled confounding factor.

Data sources and variables

Data were collected from autopsy reports and prehospital medical documentation available in the electronic information system of the regional general hospital. During the study period (January 1, 2016 to December 31, 2020), 34 to 46 OHCA cases were recorded annually in the region. Demographic variables included age and sex. Clinical and epidemiological variables included CPR duration, presumed cause of cardiac arrest, initial cardiac rhythm, the location of the cardiac arrest, and the number and anatomical distribution of chest injuries identified during autopsy. An anonymized Excel database was created, excluding personal identifiers (name, surname, date of birth). Data access was restricted to the research team via password-protected accounts. The dataset was subsequently exported to SPSS for statistical analysis.

The study was approved by the Medical Ethics Committee of the Republic of Slovenia (April 8, 2020; No. 0120-27/2020/5).

Statistical analysis

Data analysis was performed using the Statistical Package for Social Sciences (SPSS Inc.™, Chicago, Illinois), version 26.0. Descriptive univariate statistics (frequencies, percentages, means, standard deviations) were used to characterize the study population. Normality was assessed using normal probability plots and the Kolmogorov–Smirnov test. As the data did not follow a normal distribution, nonparametric statistical tests were applied, including the Kruskal–Wallis H test, Mann–Whitney U test, Spearman's rank correlation coefficient and Fisher's exact test. Statistical significance was defined at $P < 0.05$.

Results

Between 2016 and 2020, a total of 388 EMS calls with the chief complaint of 'not breathing' were recorded in the study region. In 199 cases (52.0%), cardiac arrest was not confirmed and resuscitation was therefore not indicated. Cardiac arrest was confirmed in 189 patients (48.0%), in whom resuscitation was initiated. The return of spontaneous circulation was achieved in 66 patients (34.9%), while resuscitation was unsuccessful in 123 cases (65.1%). Among the patients who did not survive out-of-hospital cardiopulmonary resuscitation, an autopsy was performed in 94 cases. After excluding autopsy reports in which the primary cause of death was traumatic injury and cases with incomplete documentation, a comprehensive review was conducted on 71 autopsy reports. Of the autopsied patients included in the final analysis, 81.7% (n = 58) were male and 18.3% (n = 13) were female. The mean age of the patients included in the study was 64.87 ± 13.77 years, with the youngest patient being 24 years old and the oldest 89 years old. General epidemiological characteristics of the study population, reported using Utstein-style terminology, are presented in Table 1.

Upon reviewing the autopsy reports, it was determined that the majority of autopsied patients had suffered primary cardiac arrest (73.2%), while drowning (12.7%) and other non-cardiac causes including pulmonary thromboembolism (9.9%) were identified as the most common causes of secondary cardiac arrest. The specific causes of cardiac arrest in the patients included in the analysis are detailed in Table 2.

Notably, rib cage fractures were confirmed in 42 of the deceased (59.2%) patients. Specifically, 62.5% (35 out of 58) of the male victims exhibited singular or multiple fractures within the thoracic region, culminating in a total of 294 fractures. Conversely, 53.8% (7 out of 13) of the female victims manifested chest injuries, resulting in a total of 90 fractures. Collectively, the post-mortem cohort presented with a total of 384 rib cage fractures. The frequency and spatial distribution profile of these rib cage fractures are graphically delineated

Table 1. Epidemiological characteristics of the study population according to Utstein-style reporting

Measure	n (%)
Total number of cases	71
Average EMS response time	11.08 min
Mean CPR duration	29.04 min
Mean age in years (SD)	64.87 (13.77)
Sex	
Male	58 (81.7)
Female	13 (18.3)
Location of collapse	
Home	39 (54.9)
Public place	28 (39.4)
Workplace	2 (2.8)
Ambulance / healthcare facility	2 (2.8)
Collapse witnesses	
Bystanders	56 (78.9)
EMS	6 (8.4)
Unwitnessed	9 (12.7)
Bystander response	
No bystander CPR	25 (38.5)
Bystander CPR performed incorrectly	12 (18.5)
Bystander CPR performed correctly	28 (43.1)
First rhythm	
Ventricular fibrillation	13 (18.3)
Pulseless electrical activity	7 (9.9)
Asystole	51 (71.8)

TABLE 2. Cause of cardiac arrest in autopsy patients

Category	Cause	No. of cases
Cardiac causes	Heart failure, acute coronary syndrome	33
	Hypertrophy and dilation of the heart	12
	Rhythm disorder	2
	Sudden cardiac death	3
	Heart tamponade	1
	Aortic dissection	1
Drowning	Drowning	9
Respiratory diseases	Pneumonia	1
	Asphyxia	2
Other non-cardiac causes	Pulmonary thromboembolism	5
	Overdose	1
	Lightning strike	1

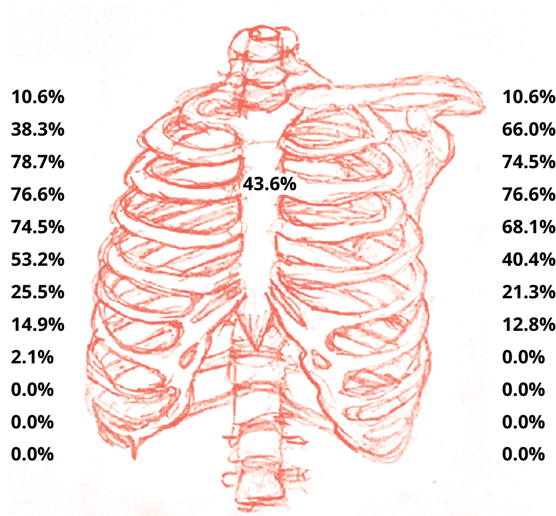

FIG. 1. Distribution of rib cage fractures caused by external cardiac massage

in Figure 1. Among the 71 autopsied patients, most rib fractures were observed between the second and sixth rib, with the third, fourth and fifth ribs being the most frequently fractured. A sternum fracture was identified in 31 victims (43.6% of the autopsies).

In contrast, soft tissue injuries following CPR were rare. Rib fractures with lung hematoma were observed in seven patients (9.8%); all of these patients had multiple bilateral rib fractures. Furthermore, right-sided hemothorax was identified in two patients, while one victim suffered a pericardium rupture following a rib fracture resulting from manual chest compressions. No fatal hemorrhages directly attributable to rib or sternal fractures were observed. As the analysis focused on thoracic injuries associated with manual chest compressions, abdominal injuries were not systematically evaluated.

The descriptive statistics of the sample population's demographic and epidemiological characteristics in relation to the number of rib cage injuries associated with manual chest compressions are presented in Table 3.

Table 3. Demographic and epidemiological characteristics of the sample population related to the number of rib cage injuries associated with manual chest compressions — descriptive statistics

Variable (n = 71)		Number of rib cage injuries	
		M (SD)	*P* value
Sex	Male	4.84 (5.21)	0.745
	Female	6.00 (6.11)	
Initial hearth rhythm	Shockable	3.09 (4.50)	0.264
	Non-shockable	5.43 (5.47)	
Cause of cardiac arrest	Cardiac causes	4.30 (4.94)	0.012*
	Drowning	10.67 (4.87)	
	Respiratory diseases	1.33 (2.31)	
	Other non-cardiac causes	4.86 (5.87)	
Location of cardiac arrest occurrence	Home	3.74 (4.94)	0.006*
	Workplace	0.50 (0.71)	
	Public place	7.63 (5.26)	
	Ambulance/healthcare facility	0.00 (0.00)	
Age	/	/	0.013* (ρ = 0.299)
Length of CPR	/	/	0.359 (ρ = 0.112)

CPR = cardiopulmonary resuscitation, ρ = Spearman's correlation coefficient,
* indicates a statistically significant difference at the $P < 0.05$ level.

The results analysis revealed a positive correlation between age and the number of rib cage injuries. Moreover, injuries were more prevalent when the cause of cardiac arrest was drowning and when the cardiac arrest occurred in public places ($P < 0.05$). Although the analysis revealed no statistical differences in the number of rib cage fractures based on sex, initial cardiac rhythm and duration of CPR, it was observed that women tended to sustain a higher number of rib cage fractures per patient and a higher incidence of non-shockable initial cardiac rhythm. With respect to the duration of CPR, an additional analysis revealed that longer CPR duration inadvertently lead to a higher number of cases with rib cage injuries. Specifically, in 4.2% of cases, rib cage injuries occurred during resuscitation efforts lasting up to 15 minutes, while this percentage rose to 35.2% when CPR continued between 16 and 30 minutes, and further increased to 59.2% when the duration of CPR exceeded 31 minutes. The shortest recorded resuscitation time was 4 minutes while the longest was 69 minutes.

To further investigate whether epidemiological factors could account for the higher number of CPR-related injuries observed in drowning-related arrests occurring in public places, an exploratory subgroup analysis was conducted among cardiac arrests in public locations. No significant

differences were found between drowning-related and non-drowning cases regarding bystander presence (7/9 vs 17/19; $P = 0.574$), the performance of the basic life support by bystanders (7/9 vs 11/17; $P = 0.667$), the presence of any chest injury (9/9 vs 14/18; $P = 0.268$), or duration of resuscitation ($P = 0.362$). However, drowning-related arrests were associated with a significantly higher number of chest injuries compared with other public place arrests (mean rank 18.28 vs 11.86; $P = 0.047$).

Discussion

The study examined the incidence of chest injury occurrence in non-surviving OHCA patients associated with manual chest compressions. The most frequent injuries observed were multiple rib and sternum fractures. Conversely, severe trauma to the thoracic viscera was rare. In the studied patient population, older age, underlying cardiac causes and cardiac arrest occurring in a public place were independently associated with CPR-related injuries. The incidence of chest injuries increased when the duration of out-of-hospital CPR exceeded 15 minutes; however, this association was not statistically significant.

CPR can potentially lead to iatrogenic injuries due to the force and depth of chest compressions, the placement of the rescuer's hands, the direction of chest compressions, and the establishment and maintenance of an open airway. The reported incidence of resuscitation-related injuries varies widely between studies. In a systematic review and pooled analysis of CPR-associated cardiovascular and thoracic injuries, Miller et al.[2] report an overall incidence of 31% of rib fractures and 15% of sternum fractures. Previous studies have reported varying incidences of CPR-related injuries following OHCA. The incidence of rib fractures ranges from 13% to 97%, and the incidence of sternum fractures ranges from 1% to 79%[2,5,10]. Recent autopsy studies have reported a high incidence of chest injuries, indicating that up to 85% of cases involve rib fractures and up to 79% involve sternum fractures[5,14]. Our study also reported a high percentage of sternum fractures. Rib cage fractures were observed in 59.2% of the autopsied patients. A total of 294 thoracic fractures were identified, with sternal fractures present in 43.6% of all cases. Rib cage fractures are the most common injuries resulting from manual chest compressions. It is estimated that rib fractures are sustained by about one-third of patients and sternal fractures by about one-fifth of patients[10]. Furthermore, a study on CPR-related injuries following non-traumatic OHCA found that individuals who died during CPR sustained significantly more CPR-related injuries compared to survivors[7]. Kralj et al.[5] highlight two consequences of rib cage injuries. Firstly, the extensive occurrence of rib and sternum fractures generally impairs respiration, making it shallow and painful, predisposing the patient to bronchopneumonia and general pain-associated impairment. Secondly, these fractures may be associated with vascular or organ damage, potentially leading to significant thoracic cavity bleeding. Vascular damage is highly prevalent and necessitates the optimization of pain management[15], while organ damage is fortunately rare, but warrants caution when performing CPR.

Severe soft tissue and organ injuries, such as liver and spleen lacerations, hemothorax, pneumothorax etc., occur at a significantly lower incidence, typically ranging from 0% to 5%[2,10,16,17], which was also confirmed by our study. However, the relationship between severe soft tissue and organ injuries and CPR mortality is not well-established[7]. The definition of such injuries is complex, and the lethal potential of an injury cannot be predicted based solely on anatomical description. Other factors, such as specific medical procedures and the presence of other causes of death, may influence the outcome[18]. Even less serious injuries can lead

to death in certain medical contexts, for example when patients are undergoing anticoagulation or antiplatelet treatment[19], or when complications arise from therapy, such as mechanical ventilation[7]. Therefore, further research is needed to better understand this relationship and improve patient outcomes.

In this study, an association between CPR-related injuries and older age, the cause of cardiac arrest and the location of cardiac arrest occurrence was discovered. Older age is considered a strong risk factor[8,11,13,20], and some studies have reported the female sex as a risk factor[3,21], while others have found no difference between sexes[20], or have reported the male sex as a risk factor[6,13]. The divergence in these findings could potentially be elucidated by an increased prevalence of osteoporosis in the female and elderly demographic, alongside sex-based disparities in tissue rigidity progression and degenerative skeletal transformations[13]. Although our study did not demonstrate differences in the number of rib cage fractures between sexes, females had a higher average number of chest fractures per patient.

To the best of our knowledge, this study is the first to report a higher number of rib cage fractures among drowning victims and in cardiac arrests occurring in public places. An exploratory subgroup analysis limited to cardiac arrests in public places showed that, despite similar bystander involvement and resuscitation duration, drowning-related arrests were associated with a higher number of chest injuries. However, this finding should be interpreted with caution due to the small sample size and the complete overlap between drowning events and public place cardiac arrests. Our findings suggest that these fractures may be associated with more aggressive resuscitation attempts and less favorable conditions for resuscitation in these cases. The significance of our findings is twofold. Firstly, they suggest that a higher number of rib cage fractures in drowning patients may be due to more vigorous chest compressions during resuscitation attempts. This could be due to the perception that more aggressive treatment is necessary in order to achieve positive outcomes. Secondly, the conditions for resuscitation in public places may be less favorable compared with controlled environments such as hospitals. The presence of bystanders and the added stress of performing resuscitation in public may contribute to rescuers being more aggressive and performing chest compressions more forcefully[13]. Overall, our study highlighted the need for further research and consideration of the potential risks and benefits of more aggressive resuscitation techniques, particularly in cases of drowning. It also emphasized the importance of providing adequate training and support for rescuers in public settings to ensure effective and safe resuscitation efforts.

Our study found no association between the number of rib cage fractures and the duration of resuscitation attempts. This aligns with the reports of Rudinska et al.[14] and Setala et al[13]. However, other studies have suggested that CPR duration is a risk factor for injuries[8,11]. Our results are in line with the findings of Takayama et al.[12], who stressed that the likelihood of chest injuries rises when the duration of out-of-hospital resuscitation exceeds 15 minutes. However, this relationship did not reach statistical significance in either study. It is possible that other factors, such as compression depth, play a more significant role in determining the risk of injury during CPR[4–6]. It is therefore crucial to monitor compression depth and make the necessary adjustments to minimize the risk of injury.

In interpreting the results of our study, several limitations should be taken into account. Most importantly, the study was retrospective in design and focused exclusively on individuals who did not survive an OHCA. The exclusion of OHCA survivors was due to the lack of institutional approval to access in-hospital clinical and radiological documentation, which may limit the generalizability of our findings. Moreover, the study was limited to cases

from only four municipalities served by a single EMS. The scope of the study was also restricted to the observation of variables such as age, sex, cardiac etiology and initial shockable rhythm. It is important to note that numerous other variables that could influence the outcome, including bystander resuscitation, were not included in our analysis. Lastly, the sample size might not have been sufficient to identify all potential factors contributing to CPR-related injuries.

Conclusions

Rib cage fractures are commonly observed injuries that occur as a result of manual chest compressions in individuals experiencing OHCA. Older age, incidents of drowning and cardiac arrests occurring in public places were independently associated with CPR-related injuries, while severe thoracic visceral trauma was not identified as a common occurrence. Our findings highlight the critical need for optimizing the performance of external chest compressions. Further extension of the study is necessary to validate the factors contributing to the occurrence of chest injuries associated with CPR.

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CONFLICTS OF INTEREST No conflict of interest has been declared by the authors.

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INFORMED CONSENT Due to the retrospective nature of the study and the inclusion of deceased patients only, the requirement for informed consent was waived by the Medical Ethics Committee of the Republic of Slovenia.

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SAŽETAK

Ozljede prsnog koša povezane s ručnim kompresijama prsnog koša kod odraslih bolesnika koji su doživjeli izvanbolnički srčani zastoj: retrospektivna studija

Igor Karnjuš, Robert Hajdinjak i Aljaž Božič

Cilj ove retrospektivne promatračke studije bio je utvrditi učestalost ozljeda prsnog koša povezanih s ručnim kompresijama prsnog koša tijekom kardiopulmonalne reanimacije i čimbenike koji utječu na njihovo nastajanje. Klinički i obdukcijski podaci analizirani su retrospektivnim pregledom 71 obdukcijskog nalaza odraslih pacijenata (58 muškaraca i 13 žena) koji nisu preživjeli izvanbolnički srčani zastoj. U studiju su uključeni slučajevi iz četiri općine Obalno-kraške regije (Ankaran, Kopar, Piran i Izola) u Sloveniji u razdoblju od 1. siječnja 2016. do 31. prosinca 2020. godine. Rezultati su pokazali da su 42 bolesnika (59,2 %) zadobila prijelome prsnog koša nakon neuspješne kardiopulmonalne reanimacije. Većina prijeloma bila je smještena između drugog i šestog rebra, pri čemu su treće, četvrto i peto rebro bili najčešće zahvaćeni. Prijelomi prsne kosti zabilježeni su u 43,6 % slučajeva. Učestalost ozljeda prsnog koša povećavala se s dobi (ρ = 0,299; *P* = 0,013) te je bila veća kod srčanih zastoja uzrokovanih utapanjem (*P* = 0,012) i onih koji su se dogodili na javnim mjestima (*P* = 0,006). Međutim, zbog malog uzorka studiju je potrebno proširiti kako bi se potvrdili čimbenici koji utječu na pojavu ozljeda prsnog koša.

KLJUČNE RIJEČI

Kardiopulmonalna reanimacija; Ozljede prsnog koša; Prijelomi rebara; Srčani zastoj