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Relationship between measures of thoracic diameter and cardiopulmonary resuscitation-induced thoracoabdominal injury

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SUMMARY

OBJECTIVE: We investigated the relationship between thoracic diameters and chest compression-related thoracoabdominal injury in patients with non-traumatic out-of-hospital cardiac arrest who had a return of spontaneous circulation after cardiopulmonary resuscitation.

METHODS: A total of 63 consecutive adult non-traumatic out-of-hospital cardiac arrest patients were enrolled in this prospective study. Computed tomography was performed on each patient and the anteroposterior diameter, skin-to-skin anteroposterior diameter, and transverse diameter of the chest were measured. Patients were divided into two groups based on the presence or absence of cardiopulmonary resuscitation-related thoracoabdominal injury. Age, sex, and duration of cardiopulmonary resuscitation, anteroposterior diameter, skin-to-skin anteroposterior diameter, and transverse diameter were compared between the groups. The primary outcome was the relationship between thoracic diameters and cardiopulmonary resuscitation-induced thoracoabdominal injuries.

RESULTS: Thoracoabdominal injuries were detected in 46% (n=29) of the patients and consisted of rib fractures in 22 (34.9%) patients, pulmonary contusion in 7 (11.1%), and sternal fracture in 3 (4.8%) patients. There were no significant differences in cardiopulmonary resuscitation duration between patients with and without thoracoabdominal injuries (p=0.539). Similarly, there were no significant differences in anteroposterior diameter, skin-to-skin anteroposterior diameter, or transverse diameter between patient groups (p=0.978, p=0.730, and p=0.146, respectively) or between patients who died within the first 28 days and those who survived for longer than 28 days (p=0.488, p=0.878, and p=0.853, respectively).

CONCLUSION: The iatrogenic thoracoabdominal injuries caused by cardiopulmonary resuscitation performed according to the cardiopulmonary resuscitation guidelines were independent of thoracic diameters. Therefore, the cardiac compression depth of 5–6 cm recommended by the current cardiopulmonary resuscitation guidelines is reliable for patients with different thoracic diameters.

KEYWORDS: Cardiopulmonary resuscitation. Out-of-hospital cardiac arrest.

INTRODUCTION

Cardiopulmonary resuscitation (CPR) involves a set of basic and advanced vital support procedures conducted to recover spontaneous pulse, respiration, and cardiac function in patients with cardiac arrest (CA)[1]. It is carried out based on the international guidelines, and the 2021 CPR Guidelines of the European Resuscitation Council (ERC) and 2020 American Heart Association (AHA) Guidelines for CPR and Emergency Cardiovascular Care emphasize that the depth of chest compression should be 5–6 cm[2-4]. However, chest diameter varies between countries, and there is some debate whether chest compression depth should be adjusted for thoracic diameter in patients undergoing CPR[5,6]. A reasonable hypothesis is that CPR-related injuries may be more common in patients with smaller thoracic diameters.

We investigated the relationships between measures of thoracic diameter and chest compression-related thoracoabdominal injury in patients with non-traumatic out-of-hospital cardiac arrest (OHCA) who had a return of spontaneous circulation (ROSC) after CPR according to the recommendations of the current AHA and ERC guidelines for CPR.

METHODS

Study Design

This prospective, single-centre, observational study was conducted in accordance with the 1989 Declaration of Helsinki and was approved by the Institutional Review Board of Institutional Review Board of Haseki Research and Training Hospital, Istanbul, Turkey (approval no. 03-2021). From March 2021 through September 2021, 63 consecutive adult patients (aged 20–95 years) who were brought by Emergency Medical Services (EMS) ambulance to our tertiary care hospital due to non-traumatic OHCA were enrolled.

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Patients were provided Advanced Cardiac Life Support by the code blue team upon presenting to the hospital, according to the current 2021 ERC and 2020 AHA Guidelines for CPR[2-4]. After the initiation of vital function monitoring, written informed consent was obtained from the authorized representative of each patient for participation in the study. The primary outcome was the relationship between thoracic diameters and CPR-induced thoracoabdominal injuries. Therefore, thoracoabdominal computed tomography (CT) was performed to detect CPR-related thoracoabdominal injury.

The CT scans in axial view with a slice thickness of 4 mm (Ingenuity Elite 128 Slice Philips CT Scan Machine; BMEC Imaging Pvt. Ltd., Chennai, Tamil Nadu, India) were analysed by a senior radiology physician. Thoracic diameter, including anteroposterior diameter (APD), skin-to-skin anteroposterior diameter (SSAPD), and transverse diameter (TD) values, was measured at the midpoint of the lower half of the sternum on axial view images. APD was measured from the anterior side of the vertebral corpus to the posterior side of the sternum. SSAPD was measured as the anteroposterior distance from the skin on the anterior chest wall to the skin on the back in transverse sections on the midsagittal line. TD was measured from the inner surface of the rib to the inner surface of the counter rib (Figure 1).

Data Collection

All cases meeting the eligibility criteria during the study period were included to reduce selection bias. Accordingly, we enrolled a total of 87 patients who were admitted to the emergency department (ED) due to non-traumatic OHCA. Patients with a history of cardiothoracic surgery (N=8), placement of a central venous catheter in the subclavian and/or internal jugular veins (N=11), and patients resuscitated with an automatic chest compression device (N=5) were excluded from the study to clearly detect iatrogenic injuries associated with CPR. Therefore, possible pneumothorax and other complications related to these procedures were excluded. Finally, we included 63 patients who were brought to ED due to non-traumatic OHCA.

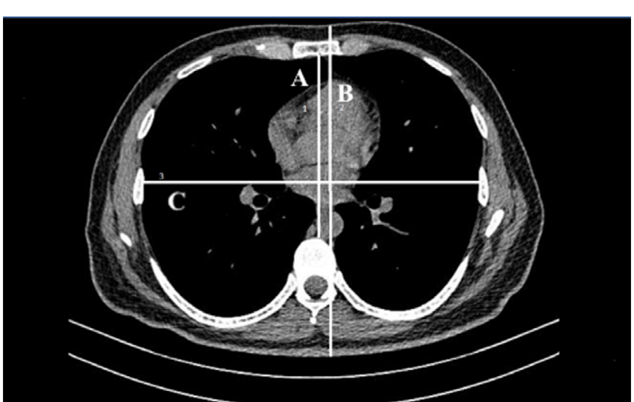

Figure 1. A diagram of the thorax showing each of the thoracic diameter measurements. (A) Anteroposterior diameter (APD). (B) Skin-to-skin anteroposterior diameter (SSAPD). (C) Transverse diameter (TD).

We assessed patients' demographic information (age and sex), arrest rhythm on admission, comorbidities (hypertension [HT], diabetes mellitus [DM], chronic renal failure [CRF], chronic heart failure [CHF], chronic obstructive pulmonary disease [COPD], and coronary artery disease [CAD]), thoracic diameters (including APD, SSAPD, and TD values), duration of CPR, and clinical outcome (death within the first 28 days and survival for longer than 28 days). Patients were divided into two groups based on whether they did or did not have CPR-related thoracoabdominal injury. In addition, APD, SSAPD, and TD were compared between two subgroups stratified as patients who died within the first 28 days and patients who survived for longer than 28 days.

Data analysis

The required sample size was calculated by power analysis prior to data collection based on information from previous studies[5,7]. It was estimated that at least 63 participants would be required with a power of 95% and an alpha error of 5%. All analyses were conducted using SPSS (version 15.0 for Windows; IBM Corp., Armonk, NY, USA). Numerical data (i.e., APD, SSAPD, TD values and duration of CPR) are expressed as the mean (standard deviation [SD]), minimum, maximum, median, and interquartile range (IQR) values; categorical variables (sex and age) are presented as number (N) and percentages (%). Intragroup (patients with vs. without CPR-related thoracoabdominal injury) and subgroup (patients who died within the first 28 days vs. those who survived longer than 28 days) comparisons were conducted using Pearson's chi-square test for normally distributed data and the Mann-Whitney U test for non-normally distributed data. In all analyses, $p<0.05$ was taken to indicate statistical significance.

RESULTS

The study population consisted of 41 male (65.1%) and 22 female (34.9%) patients, with a mean age of 63.8±16.20 (median=64) years. The mean duration of CPR was 19.00±14.30 (median=15) min. The heart rhythms associated with OHCA were asystole in 47 (74.6%) patients, pulseless electrical activity in 5 (7.9%), ventricular fibrillation in 10 (15.9%), and pulseless ventricular tachycardia in 1 (1.6%) patient. Of the patients with ROSC, 48 (76.2%) died within 28 days and 15 (23.8%) survived for longer than 28 days after ROSC. The determined CA causes were acute coronary syndrome in 12 (19%) patients, stroke in 5 (7.9%), COPD in 3 (4.8%), CHF in 4 (6.4%), and malignancy in 6 (9.5%) patients. In 33 (52.4%) patients, the CA cause was not determined.

Of the whole patient population, 87.3% (55) had one or more comorbidities: HT (39.7%, 25), DM (31.7%, 20), CAD (30.2%, 19), CHF (15.9%, 10), COPD (22.2%, 14), and CRF (9.5%, 6).

The mean chest APD, SSAPD, and TD values of the patients with ROSC were 126.40±18.80, 234.30±26.90, and 245.70±20.10 mm, respectively.

The rate of thoracoabdominal injury associated with CPR was 46% (29): chest wall injury in 25 (39.7%) patients, lung parenchymal injury in 8 (12.7%), and abdominal injury in 3 (4.8%) patients. The most common thoracoabdominal injuries were rib fractures in 22 (34.9%) patients, followed by pulmonary contusion in 7 (11.1%), sternal fracture in 3 (4.8%), costochondral separation in 3 (4.8%), pneumothorax in 2 (3.2%), pneumomediastinum in 2 (3.2%), liver pericapsular haematoma in 2 (3.2%), and pneumoperitoneum in 1 (1.6%) patient.

There were no significant differences in median age between patients with and without CPR-related thoracoabdominal injury (p=0.424). Similarly, there were no significant differences in sex distribution (p=0.550) or in CPR duration between the patient groups (p=0.539). In addition, there were no significant differences in APD, SSAPD, or TD values between these two groups (p=0.146) (Table 1).

There was no significant difference in median age or sex distribution between the patients with ROSC who died within the first 28 days and those who survived for longer than 28 days (p=0.488 and p=0.636, respectively). In addition, there was no significant difference between these two groups in terms of frequency of thoracoabdominal injury (p=0.955). However, the median duration of CPR was shorter in patients who survived for longer than 28 days (p=0.006). Finally, there were no significant differences in thoracic diameters between these two groups (p=0.488, p=0.878, and p=0.853, respectively) (Table 2).

DISCUSSION

This study investigated the relationships between measures of thoracic diameter and chest compression-related thoracoabdominal injury in patients with non-traumatic OHCA who had a return of ROSC after CPR in accordance with the recommendations of the current AHA and ERC guidelines for CPR.

It is important to resuscitate patients in accordance with the most current resuscitation guidelines, which are constantly updated and require theoretical and practical training[2-4,8]. The 2020 AHA and 2021 ERC guidelines limit the depth of each compression in CPR to 5–6 cm[2,4]. However, recent studies suggested that CPR may be associated with severe thoracoabdominal injuries[9-11]. Thoracic injuries due to chest compressions cause significant mortality and morbidity[6,7,12]. Previous studies have indicated that CPR-related injuries are more common in older and female patients[13]. In a study including 223

Table 1. Comparison of age, sex, cardiopulmonary resuscitation duration, and thoracic diameters including anteroposterior diameter, skin-to-skin anteroposterior diameter and transverse diameter values in patients with and without cardiopulmonary resuscitation-related thoracoabdominal injury.

Characteristic	Thoracoabdominal injury		p*
	Presence	Absence	
	Median (IQR 25–75)	Median (IQR 25–75)	
Age (year)	63.50 (52–75.25)	65 (58–78)	0.424
CPR duration (min)	15 (8.75–20)	15 (10–30)	0.539
Thoracic diameter (mm)			
APD	126 (111.50–143.75)	127 (118–137)	0.978
SSAPD	235 (212.00–258.50)	238 (213.5–247)	0.730
TD	247 (224.75–255.50)	252 (233.50–264.50)	0.146
Characteristic	n (%)	n (%)	
Sex			
Male	21 (61.8)	20 (69.0)	0.550
Female	13 (38.2)	9 (31.0)	

CPR: Cardiopulmonary resuscitation; APD: anteroposterior diameter; SSAPD: skin-to-skin anteroposterior diameter; TD: transverse diameter. Data are expressed as number (n); percentage (%); median, and interquartile range (IQR). *Intragroup comparisons (patients with vs. without Cardiopulmonary resuscitation-related thoracoabdominal injury) were conducted by Pearson's χ^2 test or Mann-Whitney U test, as appropriate.

Table 2. Comparison of age, sex, cardiopulmonary resuscitation duration, thoracoabdominal injuries, and measures of thoracic diameter, including anteroposterior diameter, skin-to-skin anteroposterior diameter and transverse diameter, between patients who died within the first 28 days and those who survived for longer than 28 days.

Characteristic	Clinical outcome		p*
	Died within 28 days	Survived >28 days	
	Median (IQR 25–75)	Median (IQR 25–75)	
Age (year)	63.5 (55–79)	65 (53–68)	0.488
CPR duration (min)	20 (10–30)	10 (5–15)	0.006
Thoracic diameter (mm)			
APD	127 (116.25–140.50)	124 (103–139)	0.488
SSAPD	238.50 (210–254.25)	236 (217–247)	0.878
TD	249.50 (229.75–261)	247 (225–261)	0.853
Characteristic	**n (%)**	**n (%)**	
Sex			
Male	32 (66.7)	9 (60.0)	0.636
Female	16 (33.3)	6 (40.0)	
Thoracoabdominal injury	22 (45.8)	7 (46.7)	0.955

CPR: Cardiopulmonary resuscitation; APD: anteroposterior diameter; SSAPD: skin-to-skin anteroposterior diameter; TD: transverse diameter. Data are expressed as number (n), percentage (%), median, and interquartile range (IQR). *Subgroup comparisons (patients who died within the first 28 days vs. those who survived for longer than 28 days; patients with vs. without CPR-related thoracoabdominal injury) were conducted by Pearson's χ^2 test or Mann-Whitney U test, as appropriate.

patients, Kashiwagi et al.[13] reported no correlation between CPR-related injury and demographic data, such as age or sex. Similar to Kashiwagi et al.[13], we observed no significant differences in age or sex distribution between groups with and without CPR-related thoracoabdominal injury.

In a study regarding CPR-related injuries, Oya et al.[5] reported a significantly smaller mean APD of the chest in patients with than without pneumothorax and rib fractures. They reported an average chest SSAPD of 253 mm in men and 235 mm in women of European descent and 175 mm in patients of both sexes of Japanese descent. As the SSAPD for individuals of Japanese descent is smaller by more than 50 mm compared to those of European descent, the current international guidelines may allow fatal adverse events associated with CPR. The mean SSAPD value in our study population was similar to individuals of European descent. However, there were no significant differences in median chest APD, SSAPD, or TD between patients with and without CPR-related thoracoabdominal injury. Furthermore, there were no significant differences in median chest APD, SSAPD, or TD between patients who died within the first 28 days and those who survived for longer than 28 days. Conversely, in a study with 246 non-traumatic in-hospital CA patients who received CPR, Hokenek et al.[14] reported that lower thoracic diameters were associated with an increased prevalence of CPR-related thoracic injury.

The most commonly detected CPR-related injuries are chest wall injuries and pulmonary contusions[6,9]. Rib fractures are the most common CPR-related chest wall injuries[9,15]. The rate of iatrogenic chest trauma was reported to be significantly higher in patients following CPR performed per the 2010 AHA compared to the 2005 AHA[5,7]. In a study of 82 OHCA patients, Choi et al.[7] reported that the most common iatrogenic injuries after CPR were skeletal chest wall injuries followed by lung contusions. Krischer et al.[12] reported lung parenchymal injuries at a rate of 13% in an autopsy series among patients with non-traumatic CA. Similarly, the most common iatrogenic complications after CPR in non-traumatic OHCA patients in the present study were chest wall injuries and rib fractures, and 12.7% of patients had lung parenchymal injuries.

Abdominal organ injuries associated with CPR are less common than thoracic wall and lung parenchymal injuries[16]. Spoormans et al.[17] reported gastric perforation after CPR in a series of 67 cases, which they associated with conditions such as misplacement of the hand applying CPR and esophageal intubation. In addition, liver injury was detected at rates of 0.6–3% in their studies, which was attributed to trauma to the left lobe of the liver by the xiphoid process of the sternum. In addition, sporadic cases of pneumoperitoneum related to CPR have been reported as a rare complication of gastric rupture[9,18,19].

Consistent with the literature[16-18], our cases showed an abdominal injury rate of 4.8%, including liver pericapsular haematoma and pneumoperitoneum in 2 and 1 of 29 patients with thoracoabdominal injury associated with CPR.

This study had some limitations; the most important of which were the small sample size, single-centre design, and lack of measurement of chest compression depth using an accelerometer. In addition, we did not evaluate the possible association between body mass index and CPR-related thoracoabdominal injury. Finally, since our study evaluated OHCA cases who underwent CPR, we could not obtain thorax CT images of the patients before CPR. However, we excluded patients with a history of cardiothoracic surgery, placement of a central venous catheter in the subclavian and/or internal jugular veins, and patients resuscitated with an automatic chest compression device to clearly detect iatrogenic injuries associated with CPR. Thus, we assumed that the existing lung pathologies are related to CPR.

CONCLUSIONS

The most commonly detected CPR-related thoracoabdominal injuries were chest wall injuries and pulmonary contusions. The iatrogenic thoracoabdominal injuries associated with CPR performed according to the current guidelines were independent of thoracic diameters. Therefore, a cardiac compression depth of 5–6 cm for CPR is reliable for individuals of different thoracic diameters. In addition, neither CPR-related thoracoabdominal injury nor thoracic diameter is useful for predicting the short-term prognosis of patients with ROSC.

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AUTHORS' CONTRIBUTIONS

TBÜ: Conceptualization, Formal Analysis, Writing – original draft. **OS:** Conceptualization, Data curation, Formal Analysis, Writing – original draft. **AA:** Data curation, Formal Analysis, Writing – original draft. **SC:** Formal Analysis. **ID:** Formal Analysis.

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