Original Article

CPR related thoracic injury: a comparison of CPR guidelines between 2005 and 2010

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Aim: The objective of this study was to investigate the incidence and characteristics of thoracic injuries associated with cardiopulmonary resuscitation (CPR) performed under the 2005 and the 2010 guidelines.

Methods: We evaluated patients who had an out-of-hospital cardiac arrest in 2010 (2005 group) and 2012 (2010 group). We analyzed the incidence and characteristics of rib fractures and pneumothoraces received during CPR as determined by medical records and image studies.

Results: Two hundred and ninety-two patients in the 2005 group and 243 in the 2010 group were enrolled. The number of patients with rib fractures was greater in the 2010 group than in the 2005 group (123 [42.1%] versus 167 [68.7%], $P < 0.001$), and the number of pneumothorax patients with rib fractures was also higher (8 [2.7%] versus 21 [8.6%], $P = 0.004$). Of the 21 patients, four had a tension pneumothorax. The anterior–posterior diameter of the chest (APD) was smaller in patients with a pneumothorax and rib fractures than those without the injuries (166.0 mm [standard deviation 22.8] versus 176.2 mm [standard deviation 21.0], $P = 0.04$), and the APD for patients of Japanese descent was smaller than that of patients of European descent by more than 50 mm.

Conclusion: The number of rib fractures and pneumothoraces received during CPR increased significantly under the 2010 guidelines when compared with the 2005 guidelines. As the APD for patients of Japanese descent is smaller than that of patients of European descent, Japanese medical facilities need to be prepared for possible fatal adverse events associated with CPR under the current international guidelines.

Key words: AP diameter of the chest, chest compression, CPR, iatrogenic injury, pneumothorax

INTRODUCTION

CHEST COMPRESSIONS ARE a fundamental part of cardiopulmonary resuscitation (CPR). Peter Safar developed the technique of CPR in the 1960s¹ and we have been using it ever since.

Currently, CPR is carried out based on the 2010 international guidelines.^{2–4} However, there have been discussions about iatrogenic injuries received as a result of chest compressions.⁵ Also, considering the physical differences

between individuals of European descent and those of Japanese descent, it is questionable whether Japan should adopt international CPR techniques.

The objective of this study is to investigate the incidence and characteristics of thoracic injuries associated with CPR performed under the 2005 and the 2010 guidelines.

METHODS

Study design and setting

WE UNDERTOOK THIS study in a single emergency medical center located in Yokohama, Japan. We retrospectively evaluated patients who had an out-of-hospital cardiac arrest in 2010 and 2012. The establishment of the 2010 international guidelines and their subsequent implementation in our region in 2011 are the reasons behind the selection of the 2 years in question. Therefore, patients were treated in accordance with the 2005 guidelines in 2010 (2005 group), whereas the 2010 guidelines were followed when treating patients in 2012 (2010 group). We analyzed

The Japanese version of this paper was published in the June, 2015 issue of the Journal of the Japanese Association for Acute Medicine (JJAAM). The authors have obtained permission for secondary publication of the English version in another journal from the Editor of JJAAM. This paper is based on the translation of the Japanese version with some slight modifications.

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Received 20 Jan, 2016; accepted 5 Apr, 2016; online publication 11 May, 2016

iatrogenic thoracic injuries received during CPR by reviewing medical records, chest X-rays, and post-mortem computed tomography (CT) results.

Outcome measures and image analysis

Accurately evaluating all kinds of injuries received during CPR is difficult,⁶ so this study focused on rib fractures and pneumothoraces. The primary outcome was rib fractures, and the secondary outcome was pneumothorax with rib fractures. In addition, we evaluated tension pneumothoraces, which are defined as pneumothoraces with hemodynamic instability, in general. However, it is impossible to identify a tension pneumothorax in patients with cardiac arrest. Therefore, pneumothoraces with mediastinal displacement were classified as tension pneumothoraces in this study.

At least three attending emergency physicians read the post-mortem CT results and each patient was analyzed with a 64 channel scanner, axial view, 7-mm slice thickness images (Aquilion TSX-101A/HA or Aquilion TSX-101A/Otawara, Japan; both Toshiba Medical Systems).

We also collected potential contributing factors such as patient age and gender, witness testimonies, bystander CPR information, initial electrocardiogram results, epinephrine use, rates of return of spontaneous circulation (ROSC), survival to hospital discharge rates, duration of CPR, and the anterior–posterior diameters of each patient's chest (APD). The APD was measured at the midpoint of the lower half of the sternum in an axial view.⁷

Statistical analysis

Student's *t*-test and the Mann–Whitney *U*-test were used for continuous data, and continuity-corrected χ^2 statistic and Fisher's exact tests were used for ordinal data as appropriate. All statistical analyses were undertaken with EZR (Saitama Medical Center, Jichi Medical University, Shimotsuke, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing, <http://www.jichi.ac.jp/saitama-sct/>). More precisely, it is a modified version of R Commander designed to add statistical functions frequently used in biostatistics. *P*-values <0.05 were considered statistically significant.

Exclusion criteria

Trauma patients, patients who had a central line insertion at the subclavian or internal jugular vein, and pediatric patients under 18 years of age were excluded.

Table 1. Baseline characteristics of patients who had an out-of-hospital cardiac arrest in 2010 or 2012 and underwent cardiopulmonary resuscitation (CPR) according to the 2005 or 2010 guidelines, respectively

Comparator	2005 (n = 292)	2010 (n = 243)	<i>P</i> -value
Age, mean (SD), y	73.3 (16.6)	73.0 (15.7)	0.830
Male sex	165 (54.8%)	140 (57.6%)	0.860
Witness	112 (38.4%)	98 (40.3%)	0.660
Bystander CPR	154 (52.7%)	131 (53.9%)	0.800
Initial ECG			
VF/VT	28 (9.6%)	25 (10.3%)	0.890
PEA	92 (31.5%)	81 (33.3%)	0.710
Asystole	172 (58.9%)	137 (56.4%)	0.600
Epinephrine use	281 (96.2%)	227 (93.4%)	0.170
ROSC	79 (27.1%)	73 (30.0%)	0.500
Survive	6 (2.1%)	10 (4.1%)	0.160
Duration of CPR (SD), min	53.3 (10.1)	49.1 (9.2)	<0.001
APD (SD), mm	174.0 (21.7)	175.4 (21.4)	0.430

APD, anterior–posterior diameter of the chest; ECG, electrocardiogram; PEA, pulseless electrical activity; ROSC, return of spontaneous circulation; SD, standard deviation; Survive, survival to hospital discharge; VF, ventricular fibrillation; VT, ventricular tachycardia.

RESULTS

A TOTAL OF 535 patients were enrolled. Of the 535 patients, 292 patients were in the 2005 group and 243 patients were in the 2010 group. Table 1 summarizes the baseline characteristics of the two groups. The mean age was 73.3 years (standard deviation [SD] 16.6) and 73.0 years (SD 15.7), and the number of male patients was 165 (54.8%) and 140 (57.6%) in the 2005 and the 2010 group, respectively. Return of spontaneous circulation was seen in 79 (27.1%) and 73 (30.0%) patients in the 2005 and the 2010 group, respectively. The mean duration of CPR was 53.3 min (SD 10.1), and 49.1 min (SD 9.2) in the 2005 and the 2010 group, respectively. The mean APD was 174.0 mm (SD 21.7) and 175.4 mm (SD 21.4) in the 2005 and the 2010 group, respectively, which were not statistically different.

A comparison of thoracic injuries in the two groups is shown in Table 2. The number of patients with rib fractures was greater in the 2010 group than in the 2005 group (167 [68.7%] versus 123 [42.1%], *P* < 0.001), and the number of pneumothorax patients with rib fractures also increased (21 [8.6%] versus 8 [2.7%], *P* = 0.004). Of the 21 patients in

Table 2. Comparison of patients with thoracic injuries following cardiopulmonary resuscitation under the 2005 and 2010 guidelines

Comparator	2005 (n = 292), n (%)	2010 (n = 243), n (%)	P-value
Rib Fx	123 (42.1)	167 (68.7)	<0.001
Pneumothorax	9 (3.1)	21 (8.6)	0.005
Pneumothorax with rib Fx	8 (2.7)	21 (8.6)	0.004

Fx, fractures.

Table 3. Comparison of patients with and without rib fractures (Fx) following cardiopulmonary resuscitation (CPR) under 2010 guidelines

Comparator	Rib Fx (n = 167)	No rib Fx (n = 76)	P-value
Age, years, mean (SD)	76.4 (12.6)	65.4 (18.8)	<0.001
Male sex	97 (58.1%)	44 (57.9%)	0.970
Duration of CPR, min (SD)	50.1 (10.2)	47.1 (6.0)	0.020
APD, mm (SD)	174.1 (20.5)	178.0 (23.1)	0.200

APD, anterior-posterior diameter of the chest; SD, standard deviation.

the 2010 group, four patients had a tension pneumothorax, and all of them underwent drainage procedures during CPR.

A comparison of patients with rib fractures and without rib fractures in the 2010 group is shown in Table 3. Elderly patients suffered a high rate of rib fractures (76.4 versus 65.4 years, $P < 0.001$). A comparison of patients with severe injuries (pneumothorax with rib fractures) and without severe injuries (no pneumothorax and no rib fractures) in the 2010 group is shown in Table 4. The mean APD in patients with severe injuries was smaller than in patients without severe injuries (166.0 mm [SD 22.8] versus 176.2 mm [SD 21.0], $P = 0.04$).

There was no case in which an automated chest compression device was used.

DISCUSSION

AFTER INTRODUCING THE technique of CPR, several bodies of research have reported on the incidence of iatrogenic thoracic injuries due to chest compressions.^{5,8–11}

Table 4. Comparison of patients with severe injuries and without severe injuries following cardiopulmonary resuscitation (CPR) under 2010 guidelines

Comparator	Severe (n = 21)	Not severe (n = 222)	P-value
Age, years, mean (SD)	76.6 (8.6)	72.6 (16.1)	0.28
Male sex	13 (61.9%)	127 (57.2%)	0.67
Duration of CPR, min (SD)	46.0 (8.4)	49.4 (9.2)	0.11
APD, min (SD)	166.0 (22.8)	176.2 (21.0)	0.04

APD, anterior-posterior diameter of the chest; Not severe, no pneumothorax and no rib fractures; SD, standard deviation; Severe, pneumothorax with rib fractures.

To the best of our knowledge, this is the first study to investigate the incidence of iatrogenic thoracic injuries received during CPR in Japan, and this is the first report on patients with fatal injuries under the current guidelines.

Although resuscitation guidelines have improved year by year, the number of rib fractures and pneumothoraces in the 2010 group showed a remarkable increase over the 2005 group; however, the proportion of ROSC and patients discharged alive was not different between the two groups. This result should be considered to be a vital point when we review the resuscitation guidelines.

Recent studies have shown that the age of the patients was not related to CPR-associated injuries.^{12,13} In terms of gender, previous studies have suggested that females are more susceptible to CPR-related injuries.^{11,14} However, our research found that, although elderly patients tended to suffer rib fractures, there was no statistical difference between genders. One of the reasons why these differences occurred was that the mean age in our study was older than previous studies.

Regarding the duration of CPR and the number of chest compressions, previous studies have shown that these did not contribute to CPR-associated injuries.^{12–14} Although the duration of CPR was shorter in the 2010 group than in the 2005 group, the incidence of thoracic injuries increased in the 2010 group. However, the number of chest compressions was unclear, so the number might be larger in the 2010 group than in the 2005 group. Chest compressions of at least 100 per minute are recommended in the 2010 guidelines compared with the 2005 guidelines of approximately 100 per minute.

The recommended depth of chest compressions was from 40 to 50 mm in the 2005 guidelines. However, it was changed to chest compressions of at least 50 mm in the 2010

guidelines, although there is little research supporting the change.¹⁵ A recent study reported that the incidence of thoracic injuries as a result of chest compressions has increased, particularly in patients who received chest compressions with depth of more than 60 mm.¹² Another study showed that the mean APD in adults in the UK was 253 mm in males, and 235 mm in females.⁷ In contrast, our results revealed that the mean APD was 174.0 mm in the 2005 group and 175.4 mm in the 2010 group. In addition, the APDs in the severe injury group (patients who had pneumothoraces with rib fractures) were smaller than those of the no severe injury group by 10 mm. Therefore, it may be considered to be inappropriate that a depth of at least 50 mm be recommended without any upper limitation for individuals of Japanese descent who are physically smaller than those of European descent. However, the results showing that the APD depth in the severe injury group was smaller than the other group could be due to thoracic deformities caused by the ribs or sternal injuries.

Generally speaking, the majority of pneumothoraces associated with chest trauma were caused by the physical action of rib fractures.¹⁶ In this study, all 21 patients with pneumothorax in the 2010 group had rib fractures as well. Although the force of the chest compressions might have been the cause of the injuries, excessive force would not have occurred in these cases, as chest compressions were withheld during ventilation when an airway was not maintained, and the lung capacity was small as it was controlled by a tidal volume of 6 mL/kg when an airway was established.^{2–4} Thus, pneumothoraces associated with CPR were probably caused not by the force of chest compressions but by the physical action of rib fractures, as excessive pressure on the lungs would not have occurred during CPR.

One of the reasons why the deeper chest compressions were beneficial was that the actual depth of the chest compressions were not as deep as those recommended in the 2005 guidelines.¹⁷ As ROSC and patients discharged alive could not have occurred with chest compressions of <38 mm,¹⁵ optimal instructions in CPR training will be another key to improving survival rates as well as preventing fatal injuries.¹⁸

However, a certain number of fatal thoracic injuries associated with CPR could occur under the current guidelines. If the patient has multiple rib fractures, the recoil of the thorax will be poor, which will interfere with efficient CPR. In addition, although a pneumothorax itself would only affect oxygenation for the patient during resuscitation, if it was preceded by a tension pneumothorax, it will cause hemodynamic instability and a low rate of ROSC. In the 2010 group, although 17 patients with plain pneumothoraces did not experience drainage, approximately half of them achieved

ROSC. In contrast, all four patients with tension pneumothoraces experienced drainage during CPR, and only two of them reached ROSC. However, if these procedures were not undertaken at an early stage of the resuscitation, these patients could not have achieved ROSC. Therefore, the early diagnosis and treatment of iatrogenic tension pneumothoraces is important, and a physical examination, ultrasound, and chest X-rays are invaluable tools.

Our study had several limitations. First, as we only assessed the patients by reviewing medical records and post-mortem CT scans, the assessment of the injuries might not be accurate. Also, the findings in the CT scans might not be associated with CPR but with the cardiac arrests themselves. Second, we focused on rib fractures and pneumothoraces in this study. However, we used axial 7-mm slice CT scans only and did not use multislice CT scans. Also, we did not carry out any autopsies. Thus, there is a possibility that some injuries went undetected. Furthermore, the depth of chest compressions were not measured by equipment. Therefore, the relationship between the thoracic injuries and the actual depth of chest compressions is unclear. Finally, this was a single center study in a limited region in Japan. Further research would be necessary.

CONCLUSIONS

IN THIS STUDY, the number of iatrogenic injuries during CPR significantly increased in the 2010 group compared with the 2005 group. Elderly persons are susceptible to rib fractures. Also, patients with tension pneumothoraces were observed in the 2010 group. As the APD for patients of Japanese descent is smaller than that of patients of European descent, preparation for possible fatal adverse events associated with CPR is vital under the 2010 international guidelines.

ACKNOWLEDGMENTS

NONE.

CONFLICT OF INTEREST

NONE.

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