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Serious complications from active compression-decompression cardiopulmonary resuscitation

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Abstract Complications arising from techniques of cardiopulmonary resuscitation (CPR) were reviewed by analysing the autopsy protocols of 25 patients who died after standard (Std) CPR and 31 who died after active compression-decompression (ACD) CPR, 15 of them preceded by Std CPR.

The results can be summarised as follows:

After Std CPR (n = 25) rib fractures were detected in 28%, sternal fractures in 16%, and no injuries in 68%.

After ACD-CPR (n = 16) rib fractures occurred in 68%, sternal fractures in 68% and no injuries in 25%.

After ACD-CPR following Std CPR(n = 15) rib fractures were detected in 93%, sternal fractures in 93%, and no patients were without thoracic fracture. In two patients severe cardiac injuries occurred clearly attributable to CPR.

In conclusion cardiopulmonary resuscitation by the ACD-technique caused rib and sternal fractures more often than Std CPR and has a higher risk for iatrogenic cardiac and possible fatal injury.

Key words Cardiopulmonary resuscitation · Active compression-decompression · Complications · Sternal fracture

Introduction

Active compression-decompression (ACD) was developed as a new technique of cardiopulmonary resuscitation (CPR) following a case of successful CPR by applying a drain suction pump to the patient's chest (Lurie et al. 1990). It has been suggested that active decompression improves the hemodynamics (Shultz et al. 1994), thereby increasing the overall survival rate (Wik et al. 1995). The ACD device (Ambu Cardio Pump) consists of a modified silicone rubber suction cup 6.5 cm in height and 13.5 cm in diameter (Fig. 1). A plastic ring is integrated accommodating a circular red rubber cushion pad 6 cm in diameter. The device weighs 700 g and is operated by means of a handle containing a force gauge. The suction cup of the device is applied to the thorax and turned slightly to ensure proper attachment. The rate of compressions and the place of application on the lower third of the sternum correspond to international guidelines (American Heart Association 1992; European Resuscitation Council 1992). During compression a force of 300–500 N should be applied corresponding to a depth of compression of 38–51 mm. During decompression a negative force of 100–150 N should be produced (Ambu Cardio Pump Instruction Manual).

Materials and methods

The autopsy reports of all patients who died between January and October 1995 after receiving only ACD-CPR (n = 16) or ACD-CPR following Std CPR (n = 15) were reviewed. The ACD-CPR study group consisted of 31 patients with complete records on the duration and type of resuscitation provided by the emergency physician. Of these 14 were examined in a prospective study, and for 17 patients autopsy protocols were studied retrospectively. The resuscitation injuries sustained by the patients and examined prospectively were fully documented and in some cases with photographs. In addition the autopsy protocols of 25 patients who received only Std CPR for 15–120 min were analysed.

Results

ACD-CPR (Table 1)

Of the 31 patients in our ACD-CPR study group, 8 were female and 23 male (age range 19–86 years; mean 59.8

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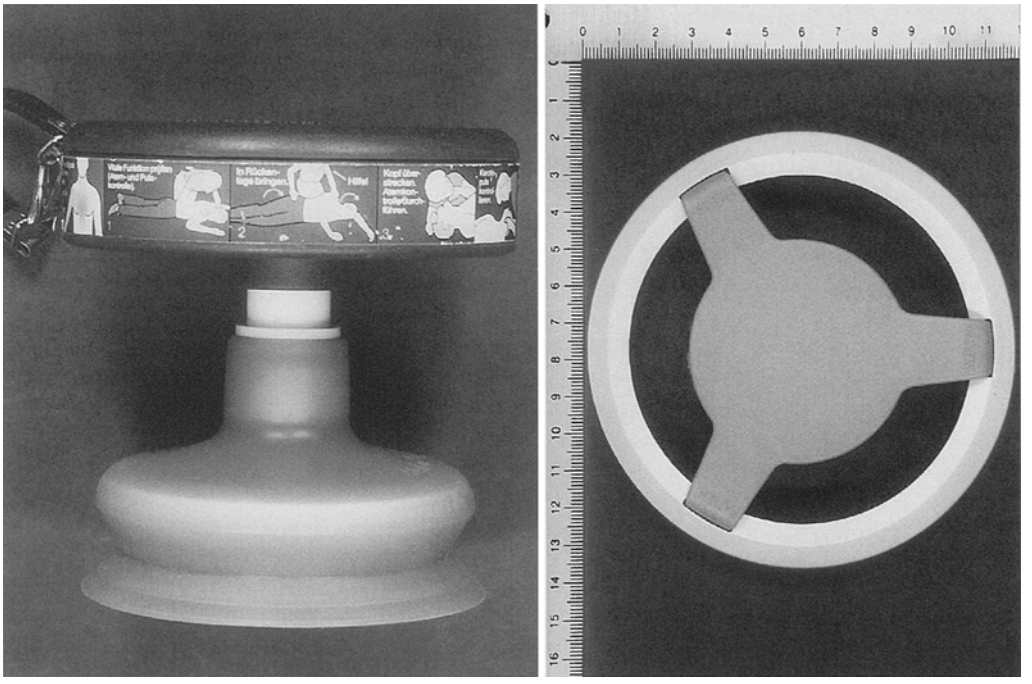

Fig. 1 ACD device (Ambu Cardio Pump); modified silicone rubber suction cup 6.5 cm in height and 13.5 cm in diameter (*left*); integrated plastic ring that accommodates a circular red rubber cushion pad 6 cm in diameter (*right*)

Table 1 Patients who died after receiving ACD-CPR. m = male; f = female; Std CPR = duration of standard resuscitation in minutes; ACD = duration of ACD-CPR in minutes; ribs, sternum = number of fractures; comm = comminuted fracture; – = no bony lesions; 16 patients receiving only ACD-CPR (*upper part*); 15 patients receiving Std CPR followed by ACD-CPR (*lower part*)

Age	Sex	St-CPR	ACD	Cause of death	Ribs	Sternum
Patients receiving only ACD-CPR						
19	m	0	5	Drug abuse	–	–
20	m	0	10	Drug abuse	–	–
39	m	0	45	Myocardial infarction	7	1
45	m	0	90	Myocardial infarction	8	1
46	m	0	10	Aortic aneurysm	–	–
54	m	0	70	Aortic aneurysm	5	1
65	m	0	15	Myocardial infarction	–	–
70	m	0	11	Myocardial infarction	9	1
71	f	0	10	Sepsis	–	1
74	m	0	35	Myocardial infarction	6	1
74	f	0	?	Pulmonary embolism	6	1
77	f	0	50	Myocardial infarction	9	1
78	m	0	?	Myocardial infarction	5	1
81	m	0	40	Myocardial infarction	8	–
83	m	0	30	Myocardial infarction	2	1
86	m	0	20	Pulmonary embolism	6	1
Patients receiving Std CPR followed by ACD-CPR						
33	f	40	60	Myocardial infarction	10	2
40	m	40	60	Myocardial infarction	4	1
40	f	5	60	Pneumonia	1	1
47	m	5	40	Myocardial infarction	2	1
55	m	15	15	Myocardial infarction	5	–
57	m	2	40	Myocardial infarction	19	1
60	m	3	30	Myocardial infarction	6	1
65*	m	15	45	Myocardial infarction	10	comm
65	m	15	120	Myocardial infarction	14	comm
68	f	5	30	Myocardial infarction	9	1
73	f	40	15	Cerebral bleeding	8	1
77	m	5	25	Myocardial infarction	12	comm
81**	m	5	10	Aspiration of blood	12	comm
81	m	1	20	Myocardial infarction	–	comm
83	f	1	20	Myocardial infarction	9	1

* case 1, ** case 2

years) and 21 died due to primary cardiac arrest. Two patients suffered from inflammatory primary diseases, two from pulmonary embolism, two from spontaneous rupture of an aortic aneurysm, and two died from drug abuse. Aspiration of blood following pulmonary contusions was diagnosed in one patient, another patient died from massive cerebral bleeding.

Only 4 of the 31 patients investigated showed no injuries caused by resuscitation. There was evidence of CPR-induced rib fractures in 25 patients. Fractures of the sternum were also detected in 25 cases. In 23 patients rib fractures were found together with sternal fractures. Two patients showed isolated rib fractures and two had isolated sternal fractures. The majority of the sternal fractures were transverse fractures localised between the attachments of the third and fourth ribs. One patient had a comminuted sternal fracture between the attachments of the fourth and fifth ribs. Two patients had transverse fractures localised between the attachments of the second and third ribs; one had a double fracture with the second component located between the attachments of the fifth and sixth ribs. Generally, the bone fragments were projected inwards but evaluation of this aspect was impossible in some cases due to a comminuted fracture pattern.

ACD-CPR only

In this group 16 patients had received only ACD-CPR for 5–120 min. In two cases the duration of resuscitation was insufficiently documented; both of these patients had received only ACD-CPR. Of these patients 11 showed sternal fractures (68%), 11 had rib fractures and 10 had combined rib and sternal fractures (62%).

ACD-CPR preceded by Std CPR

In this group 15 patients had initially received Std CPR for 1–40 min, followed by ACD-CPR. Of these patients 14 had sternal fractures (93%) and 14 showed rib fractures. Each patient showed at least one CPR-induced thoracic fracture.

In two patients (cases 1 and 2) who had received ACD-CPR following Std CPR, cardiac injury at the level of the sternal fracture was observed as a complication associated with the sternal fractures.

Case histories

Case 1

A 65-year-old man collapsed suddenly and died from myocardial infarction.

Resuscitation: 15 min of Std CPR; 45 min of ACD-CPR.

Resuscitation injuries: serial fractures of ribs I – V on both sides in the medioclavicular line; bilateral cartilage fractures of the lower ribs; comminuted sternal fracture between the attachments of the fourth and fifth ribs (Fig. 2); transversal laceration of the anterior pericardium above the right ventricle; superficial contusions of the right posterior ventricular wall; rupture of the visceral pleura in the area of the right hilus of the lung; hemothorax right.

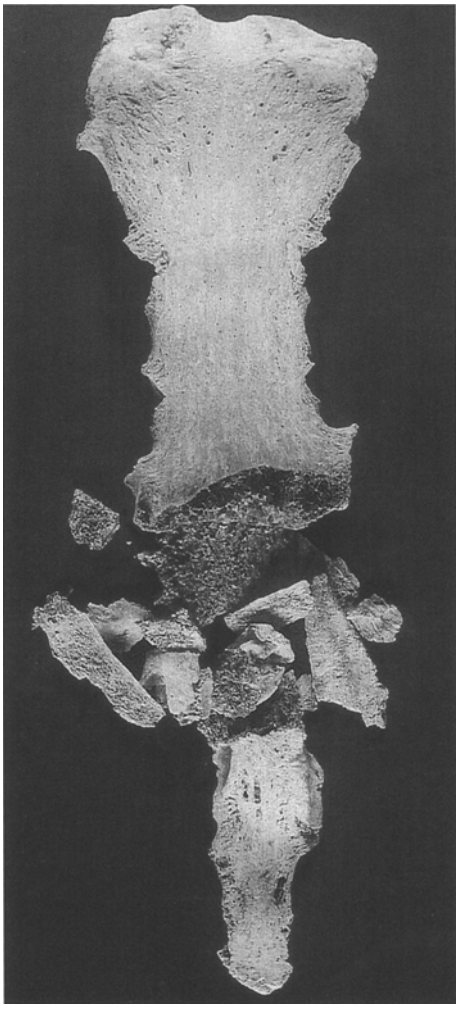

Fig. 2 Case 1. A 65-year-old man died after a sudden collapse from myocardial infarction; 15 min of Std CPR, 45 min of ACD-CPR; comminuted sternal fracture between the attachments of the fourth and fifth ribs

Case 2

An 81-year-old man fell off a ladder from a height of 2 m while doing a repair job. The cause of death was intrapulmonary blood aspiration following paravertebral contusions of the lung.

Resuscitation: 5 min of Std CPR; 10 min of ACD-CPR.

Resuscitation injuries: serial fractures of right ribs II–VIII and of left ribs III–VII at the level of the anterior axillary line; comminuted transverse fracture of the sternum between the attachments of the third and fourth ribs; 3-cm-long laceration of the posterior wall of the left cardiac auricle with a gaping opening into the pericardium; corresponding disruption of the right coronary artery; several corresponding endocardial lacerations up to 3 cm in length in the left atrium without penetration of the entire wall (Fig. 3); three transverse ca. 2-cm-long lacerations in the intima of the thoracic aorta at the level of the atria.

Fig. 3 Case 2. An 81-year-old man died from intrapulmonary blood aspiration following paravertebral contusions of the lung; 5 min of Std CPR, 10 min of ACD-CPR; 3-cm-long laceration of the posterior wall of the left cardiac auricle with a gaping opening into the pericardium; several corresponding endocardial lacerations up to 3 cm in length in the left atrium without penetration of the entire wall

Std CPR (Table 2)

The 25 patients in the Std CPR study group (4 female, 21 male, 16–84 years, mean 54 years) had received Std CPR for 15–120 min. The causes of death were comparable to the ACD-CPR group. CPR-induced rib fractures were detected in seven cases (28%), fractures of the sternum in four cases (16%). A combination of rib fractures and fractures of the sternum occurred in three cases (12%). No injuries of internal organs were observed.

A comparison of the frequencies of rib fractures and sternal fractures between the methods of resuscitation (Std CPR, ACD-CPR, Std CPR followed by ACD-CPR) is given in Fig. 4.

Table 2 Patients who died after receiving Std CPR only. m = male; f = female; Std CPR = duration of standard resuscitation in minutes; ribs, sternum = number of fractures; – = no bony lesions

Age	Sex	St-CPR	Caause of death	Ribs	Sternum
16	m	60	Myocarditis	–	–
24	m	45	Aortic aneurysm	–	–
28	m	60	Myocardial infarction	–	–
37	m	60	Myocardial infarction	–	–
40	m	30	Myocardial infarction	–	–
44	m	45	Myocardial infarction	–	–
45	m	60	Myocardial infarction	7	1
47	m	90	Myocardial infarction	–	–
51	m	30	Reflex shock	–	–
52	m	120	Myocardial infarction	–	–
53	m	30	Myocardial infarction	–	1
54	m	30	Pulmonary embolism	–	–
56	m	100	Myocardial infarction	–	–
58	m	60	Myocardial infarction	11	1
59	m	30	Myocardial infarction	8	–
61	m	30	Myocardial infarction	–	–
62	m	30	Myocardial infarction	–	–
65	f	15	Aortic aneurysm	–	–
67	m	90	Myocardial infarction	8	1
67	m	30	Myocardial infarction	–	–
74	m	30	Myocardial infarction	6	–
75	f	30	Myocardial infarction	–	–
79	m	30	Myocardial infarction	3	–
83	f	15	Pulmonary embolism	–	–
84	f	30	Myocardial infarction	7	–

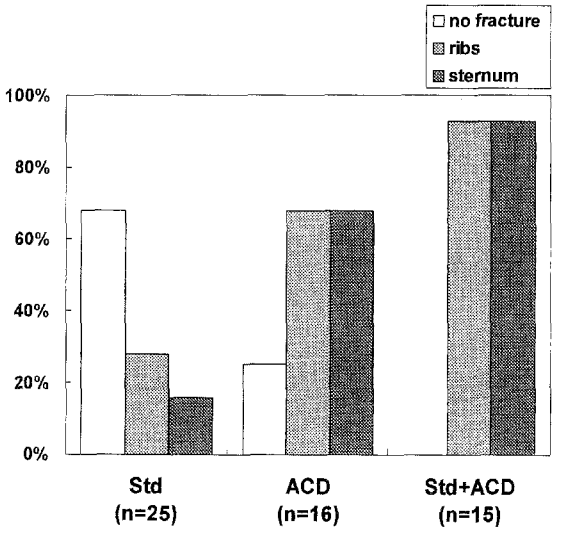

Fig. 4 Frequencies of iatrogenic rib and sternal fractures caused by Std CPR, ACD-CPR and ACD-CPR in combination with Std CPR

Discussion

In addition to bleeding of the skin and subcutaneous fatty tissue, rib fractures are among the most frequent injuries following resuscitation (Atcheson and Fred 1975; Bynum et al. 1963; Clark 1962; Cohn and Sayer 1963; Henriksen

1967; Lignitz and Mattig 1989; Moe 1967; Saternus 1981; Saukko 1980; Schroeder and Stevens 1993; Silberberg and Rachmaninoff 1964). After Std CPR with closed-chest massage, rib fractures occurred in 19% (Powner et al. 1984) – 80% (Bodily and Fischer 1979) of patients. In our Std CPR study group rib fractures occurred in 28%. In older patients especially, displacement of the rib fragments can lead to pulmonary trauma and pneumothorax or hemopneumothorax (Agdal and Jorgensen 1973; Clark 1962; Cohn and Sayer 1963; Cowan 1966; Moe 1967; Paaske et al. 1968). Sternal fractures are also well-known complications produced by Std CPR (Bynum et al. 1963; Clark 1962; Cohn and Sayer 1963; Lignitz and Mattig 1989; Moe 1967) and are reported to occur in 0% (Frey et al. 1964) – 47% (Bodily and Fischer 1979) of cases. We observed sternal fractures in 16% of the patients receiving Std CPR. Cardiac trauma caused by resuscitation is rarely mentioned in the literature and is usually attributed to rib or sternal fragments piercing the heart (Agdal and Jorgensen 1973; Bodily and Fischer 1979; Fosse and Lindberg 1996; Noffsinger et al. 1991).

Reports on complications associated with ACD-CPR are limited to skin abrasions and a few instances of rib fractures and pneumothorax. The incidence of these complications is reported to be 5% at most (Callaham unpublished results 1993; Cohen et al. 1993; Lurie et al. 1994; Schwab et al. 1995; Tucker et al. 1994). No fractures of the sternum or trauma to viscera were described in the literature available to us.

In the present ACD-CPR study group complications were detected in 87% of patients. Rib and sternal fractures occurred in 80% of patients who had undergone ACD-CPR. In two patients potentially life-threatening cardiac injuries produced by CPR were observed. In case 1, no traumatic changes other than those caused by resuscitation were found. In case 2, the possibility of direct trauma to the heart had to be considered. The primary impact site resulting from the patient's fall from a ladder was localised to the back at the level of the thoracic vertebrae III–IV, and no bony lesions were found in this area. Therefore the bony injuries to the chest and the injuries to the left cardiac auricle, atrial endocardium and aorta were clearly attributable to CPR. Histologically, these rescuscitation-induced injuries showed no signs of a vital reaction. The resuscitation injuries to the heart and aorta detected in cases 1 and 2 did not have any legal consequences because death had occurred with certainty before CPR was initiated. While common injuries caused by resuscitation (especially rib fractures) are not usually dangerous to life (Lignitz and Mattig 1989), sternal fractures with fragments projected inwards bear a high risk for lesions to heart and lungs. In the present study the incidence of sternal fractures was at least 4 times higher in patients receiving ACD-CPR compared with Std CPR. The discrepancies between the data reported in the literature and the results of our study are difficult to resolve. We can assume that resuscitation was performed with the Ambu Cardio Pump in all cases. Possible reasons for the discrepancies may be differences in the type of examinations performed, autopsy incidence and modifications made to the ACD device. Fractures of the ribs and sternum can remain undetected if x-ray examination alone is used. This seems a plausible explanation for the discrepancies, especially in view of the fact that in the majority of the sternal fractures, the sternal fragments were projected inwards without displacement of the fracture ends. On the other hand, comminuted sternal fractures are unlikely to be overlooked in radiography. A complete picture of all resuscitation-induced injuries can be obtained only by meticulous preparation during an autopsy.

The red rubber cushion pad mounted in the plastic ring and integrated in the silicone rubber suction cup of the Ambu Cardio Pump was designed to prevent skin abrasions caused by the ACD device. These cushion pads were delivered to Austria in November 1994 as a free of charge upgrade (Kohnke OB, personal communication 1995). Probably this cushion pad was not integrated in the device in previous studies. Its significance in causing bony injuries is currently being investigated in experimental and biomechanical studies.

The clinical study on ACD-CPR was halted in October 1995 on account of the results presented here.

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