Traumatic injuries after mechanical cardiopulmonary resuscitation (LUCASTM2): a forensic autopsy study

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Abstract

Aim The aim of our study was to compare traumatic injuries observed after cardiopulmonary resuscitation (CPR) by means of standard (manual) or assisted (mechanical) chest compression by Lund University Cardiopulmonary Assist System, 2nd generation (LUCASTM2) device.

Methods A retrospective study was conducted including cases from 2011 to 2013, analysing consecutive autopsy reports in two groups of patients who underwent medicolegal autopsy after unsuccessful CPR. We focused on traumatic injuries from dermal to internal trauma, collecting data according to a standardised protocol.

Results The study group was comprised of 26 cases, while 32 cases were included in the control group. Cardiopulmonary resuscitation performed by LUCASTM2 was longer than manual CPR performed in control cases (study group: mean duration 51.5 min; controls 29.4 min; $p=0.004$). Anterior chest lesions (from bruises to abrasions) were described in 18/26 patients in the LUCASTM2 group and in 6/32 of the control group. A mean of 6.6 rib fractures per case was observed in the LUCASTM2 group, but this was only 3.1 in the control

group ($p=0.007$). Rib fractures were less frequently observed in younger patients. The frequency of sternal fractures was similar in both groups. A few trauma injuries to internal organs (mainly cardiac, pulmonary and hepatic bruises), and some petechiae (study 46 %; control 41 %; $p=0.79$) were recorded in both groups.

Conclusion LUCASTM2-CPR is associated with more rib fractures than standard CPR. Typical round concentric skin lesions were observed in cases of mechanical reanimation. No life-threatening injuries were reported. Petechiae were common findings.

Keywords Cardiopulmonary resuscitation (CPR) · Mechanical chest compression · LUCASTM2 · Traumatic injuries · Post-mortem · Forensic pathology · Autopsy

Introduction

Cardiopulmonary resuscitation (CPR) is well known and has been recognised for more than 50 years as a treatment in cases of cardiac arrest [1, 2]. Latest advances in this field have brought to the development of different assisted devices [3–6] that have shown some efficiency [7] and intended to improve outcome and chances of survival. The Lund University Cardiopulmonary Assist System, 2nd generation (LUCASTM2) device is a fully pneumatic automatic device, equipped with a drag for compression and a suction cup for active decompression (Fig. 1), which needs to be properly placed on the central breast region. The drag piece and suction disc are maintained on top of a plastic ring that surrounds the body for fixation. LUCASTM2 is particularly useful when CPR must be performed during advanced resuscitation

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Fig. 1 Inferior view of the LUCAS™2 drag and suction device

techniques and reduces CPR interruptions during transportation [8, 9].

From the early development of manual CPR, the authors have investigated injuries related to the procedure. Frequent chest wall trauma with rib and sternal fractures were identified and described in autopsy studies. Himmelhoch et al. observed rib fractures in 47 % of the cases and pulmonary fat embolism in 42 % of cases in a series of 52 autopsies after CPR [10]. The highest number of fractured ribs observed in this study was 8, and no major visceral trauma was observed. In their review, Buschmann et al. [11] reported a wide range of rib and sternal fractures associated with CPR (13–97 % and 1–43 %, respectively). Visceral injuries were rarely observed (0.6–2.1 % liver injury and 1.0 % aortic rupture). After the introduction of automatic CPR devices, the question was raised as to whether these instruments were more or less traumatic than manual CPR. Many different active compression-decompression (ACD) devices were investigated [12–15]. Pinto et al. [12] observed that standard CPR induced more rib fractures than ACD-CPR performed with AutoPulse®, with the exception of posterior fractures. On the contrary, Baubin et al. [13] observed an increased frequency of thoracic injuries following CardioPump® CPR. No difference was observed by Smekal et al. [15] when comparing traumatic injuries after LUCAS™ versus manual CPR. Those results show great variation and permit no reproducibility. This observation can be partly attributable to many methodological differences that do not allow the results to be compared to one another.

Specific post-mortem investigations are needed to establish the frequency of major trauma to vital organs such as the ascending aorta or liver, to better evaluate the risk of life-threatening injuries in case of survival [16, 17].

In the Canton of Geneva, a 283 km² region in western part of Switzerland (approximately 600,000 inhabitants), emergency services have been using LUCAS™2 since November 2011. They acquired this system in the context of implementation of an extracorporeal membrane oxygenation (ECMO) program for acute cardiac failure and a non-heart-beating donor (NHBD) program [18, 19].

The aim of this study was to describe and compare the traumatic injuries observed at autopsy after manual and mechanical CPR, with emphasis placed on forensic considerations.

Materials and methods

Patients and study area

In a retrospective and descriptive study, the autopsy records of all consecutive cases performed at the University centre of legal medicine in Geneva were reviewed from January 2011 to January 2013. Inclusion criteria were patients deceased after cardiac arrest with CPR attempt by means of LUCAS™2 (study group) or by manual cardiopulmonary resuscitation (control group). In every case, medicolegal investigations

were ordered by the local public prosecutor. Exclusion criteria were the presence of trauma, pregnancy, age under 18 and extra CPR manoeuvres performed after a first successful resuscitation phase (after second cardiac arrest at hospital for example).

The standard response to out of hospital cardiac arrest (OHCA) in Geneva is provided by a unique emergency dispatch centre ordering emergency ambulances with advanced life support equipment and skills and a mobile emergency care unit staffed with a physician and a paramedic. Except for mechanical thoracic compressions by LUCASTM2, CPR is performed according to American Heart Association guidelines [20]. Resuscitation analysis and quality control are based on Utstein style data collection [21].

In addition to evident violent deaths, the emergency physician is used to inform the public prosecutor of all unexpected deaths. All medicolegal investigations in Geneva are performed at the same centre according to European forensic standards [22].

Data collection

The following information was collected for every case:

- General data (sex, age, cause and manner of death, duration of CPR, post-mortem interval, previous thoracic surgery, presence of osteoporosis)
- Information from external examination of the body (body mass index, presence and localisation of petechiae, presence and localisation of cutaneous lesions, presence of subcutaneous emphysema)
- Data from internal examination (thickness of thoracic fat, number and localisation of sternum fractures, number and localisation of rib fractures, presence of fractures of the thoracic vertebrae, presence of blood in the pleural, pericardial or abdominal cavity, lesions of internal organs, osteoporosis)

For internal organs, we reported every traumatic injury described. Internal petechiae (at epicardium and subpleural space, for example) were not considered traumatic injuries. Microscopic examination of the heart, lungs, liver and brain was available in every report. The protocol was approved by the local Ethic Committee. For this type of study, formal consent was not required.

Statistical analysis

For comparison of the groups, significances were calculated for categorical data by Fisher's exact test and for continuous variables by Student's *t* test. Mean values were presented with standard deviation (SD). A *p* value of <0.05 was considered significant.

Results

The study group was comprised of 26 cases (9 women, 17 men, 18 natural deaths, 8 violent deaths (not traumatic, namely acute and not natural); mean age 52.3 years, minimum 20 years, maximum 85 years, SD 20.2). The control group was composed of 32 individuals (11 women, 21 men, 17 natural deaths, 16 violent deaths, mean age 52 years, min. 21 years, max. 86 years, SD 16.9). Demographic and general data are depicted in Table 1. The causes of death are detailed in Fig. 2. Study results are summarised in Table 2.

In the control group, CPR was performed at Geneva University Hospitals (*n*=2), by the French local emergency service (*n*=1), by the Swiss Air-Rescue team (*n*=1) or by Geneva's mobile emergency care unit (*n*=22), as were all reanimation manoeuvres performed in the study group (*n*=26).

The mean post-mortem interval (time between death/discovery and autopsy) was less than 37 h in both groups. Global CPR time was longer in the LUCASTM2 group (study

Table 1 Demographic and general data of patient in study groups

	Control <i>n</i> =32 (%)	LUCAS TM 2 <i>n</i> =26 (%)	LUCAS TM 2 (CPR time≤60 min) <i>n</i> =20 (%)	<i>p</i> value
Sex (M/F)	21/11 (65.6/34.4)	17/9 (65/35)	14/6 (70/30)	NS*/NS*
Age (years)	52	52.3	54.1	NS*/NS*
Age M/F (years)	49.9/56.1	47.9/60.8	46.3/67.3	NS*/NS*
BMI (kg/m ²)	24.3	25.3	24.3	NS*/NS*
Total CPR time (min)	29.4	51.5	34	0.004/NS*
Time since death (hour)	35.1	37	41.1	NS*/NS*

Mean values or number of patients

*Non-significant

Fig. 2 Cause of death in study population. *Miscellaneous* includes: natural of unknown origin, anaphylactic choc, sepsis, asphyxia

group: mean duration 51.5 min, min. 14, max. 166, SD 36.6; controls: mean 29.4 min, min. 3, max. 60, SD 14.9; $p=0.004$). Every patient included in the study group was first resuscitated by manual chest compression (by witnesses or paramedical team), before the arrival of LUCAS™2-equipped emergency medical staff. The mean duration of this first part of the reanimation procedure was 9.3 min (SD 5.6).

The presence of thoracic skin lesions (bruises, abrasions) was more frequently observed in cases resuscitated by the LUCAS™2 (73 %) equipment than in controls (22 %) ($p<0.001$). In the study group, all of the superficial thoracic lesions were round-shaped, with a specific pattern corresponding to the part of the device placed on chest (Figs. 1 and 3).

Very few patients showed only posterior chest lesions, located at the scapular region, in both groups (3 in LUCAS™2 and 1 in control). The thickness of the subcutaneous fat was similar (study: mean 1.4 cm (SD 0.8); control: 1.5 (SD 1.2)).

The occurrence of sternum and rib fractures was common in both groups (LUCAS™2 35 and 81 %; control 22 and 63 %, respectively; these differences were not statistically significant, $p=0.38$ and $p=0.07$). The observed sternal fractures were isolated and localised at the central part of the body. In the study group, the number of rib fractures was significantly higher than in the controls (total of 171 in LUCAS™2: mean 6.6, min. 0, max. 18 per case, SD 5.7; total of 100 in control: mean 3.1, min. 0, max 11, SD 3.4; $p=0.007$). After the

Table 2 Injuries detected by autopsy

Injuries	Control group (32)	LUCAS™2 group (26)	LUCAS™2 (CPR time≤60 min) (20)	<i>p</i> value
No injury	9	5	4	NS*/NS*
Chest cutaneous anterior lesions	6	18	13	<0.001/0.001
Chest cutaneous posterior lesions	1	3	2	NS*/NS*
Sternal fractures	7	9	7	NS*/NS*
Rib fractures	100	171	128	NS*/NS*
Average number of rib fractures	3.1	6.6	6.4	0.007/0.017
Maximal number of rib fractures	11	18	18	NS*/NS*
Posterior localisation of rib fractures	0	3	3	NS*/NS*
Associated trauma injury to viscera	8	5	2	NS*/NS*
Great vessel hematoma (ascending aorta)	0	2	1	NS*/NS*
Heart injury (subepi-/subendocardial hematoma)	2	1	1	NS*/NS*
Pulmonary contusion	5	1	0	NS*/NS*
Liver injury (subcapsular/ parenchymal hematoma)	1	1	0	NS*/NS*
Right renal hilary hematoma	1	1	1	NS*/NS*

*Non-significant

Fig. 3 Typical round-shaped cutaneous lesions as seen on anterior chest wall after LUCASTM2 CPR (**a** bruises, **b** post-mortal abrasions, **c** detail of post-mortal abrasion)

exclusion of cases with a total CPR time of more than 60 min (maximal CPR time in control group was 60 min), a subgroup of 20 patients was identified who had been reanimated with LUCASTM2 with a mean CPR time of 34 min (SD 12.7). In this subgroup, the number of rib fractures was 128 (mean 6.4 per case, min 0, max. 18, SD 6.0; $p=0.017$). More data concerning this subgroup are shown in Tables 1 and 2. Rib fractures were less frequently observed in younger patients (5 cases without rib fracture in study group, mean age 25 years, SD 5.0; 12 cases in control, mean age 45, SD 21.8) and more common in older patients, especially in LUCASTM2 group (6 cases with >10 rib fractures, mean age 73 years, SD 8.4; only one in control, 49 years). Female gender was associated with a higher frequency of rib fractures in the LUCASTM2 group, with a mean fracture number of 9.7 per case, min. 5, max 18, SD 4.5 (mean of 4.9 for men, min. 0, max. 17, SD 5.7). In the control group, the mean rib fracture number was 2.8 (min. 0, max. 10, SD 3.9) for women and 3.3 (min. 0, max. 11, SD 3.1) for men. Women were older than men in both groups (female population: mean age 61 years in LUCASTM2 group (SD 18.4) and 56 years (SD 22.1) in control; men: mean age 48 years (SD 19.7) and 50 years (SD 12.9), respectively).

In the vast majority of cases, rib fractures were localised in the anterior region; in only 2 patients in the LUCASTM2 group were posterior rib fractures observed at the 1st, 2nd and 11th level. A few traumatic injuries of internal organs (mainly cardiac, pulmonary and hepatic bruises) were observed in both groups (5/26 cases in the study group, 8/32 in control). They are described in Table 2. No life-threatening injuries were identified. Isolated conjunctival and periocular petechiae were reported in both groups, without any statistical difference (46 % study group, 41 % controls; $p=0.79$).

After LUCASTM2 CPR, one case of unilateral rupture of a breast implant was noticed. The breast silicone implants were located above the pectoral muscles. On the right side, at the medial region of the implant, autopsy revealed a localised rupture of the prosthesis, with gel-like fluid exteriorisation,

without any vital reaction (no haemorrhage, no sign of scar or inflammatory process).

Discussion

The two groups showed similar age and sex distribution. The numbers of cases with rib fractures reported in the present study (81 % in LUCASTM and 63 % in control group) are within the range of previously published studies regarding CPR-related trauma [11, 23]. Baubin et al. [13] observed an increased frequency of thorax injury with mechanical CPR. With the Ambu CardioPump®, they described particularly more sternal and rib fractures. On the contrary, Pinto et al. [12] observed more traumatic injuries after manual CPR. They reviewed 87 autopsy records involving manual-only CPR and 88 cases involving the combination of manual and AutoPulse® CPR. Global reanimation times of both groups were not given. Differences in methodological procedures could explain the disparity of those results.

For the aim of this study, every patient who suffered from any trauma concurrent to the onset of death was excluded. As shown in Fig. 2, the causes of death were mostly related to heart or pulmonary failure and acute intoxication. However, cases of hanging, asphyxia or drowning deaths, although violent, were not excluded.

A few studies have already focused on LUCASTM-CPR-related injuries. Smekal et al. [15] observed no difference in autopsy-detected injuries after LUCASTM CPR compared with manual CPR. In a prospective pilot study, 85 patients were autopsied according to a special protocol in two centres. All traumatised patients were excluded from the study. CPR time was not significantly different in the two groups (between 23 and 61 min in LUCASTM (mean 42), and between 23 and 49 (mean 36) in the control group). All patients in the LUCASTM group had undergone an average of 3 min of manual chest compressions before the LUCASTM device was set

up by the rescue team. Recently, the same author published new results of a substantial prospective multicentre trial, including 222 autopsies of patients randomised for manual or mechanical CPR (performed by LUCASTM 1 and 2 devices) after OHCA [23]. Post-mortem investigation was completed in four centres, by various pathologists or forensic pathologists (40 experts, 3 pathology departments and 1 forensic medicine centre). The study results showed more rib fractures in the mechanical CPR group (62.6 %) versus the manual one (37.4 %). Early manual CPR time was shorter than in the present study (mean 3.4 min). There was no statistical significance in the number of sternal fractures observed (58.3 % in LUCASTM and 54.2 % in the manual CPR group). Localisation of the fractures, of liver injuries or petechiae, was not reported.

CPR time was significantly different between both groups in the present study. In Geneva, the emergency staff decided from late 2011 to apply the LUCASTM2 device as soon as possible in their CPR protocol. When the medical staff deemed that CPR was futile, after a long period of no flow or in cases of severe associated morbidities, they mostly underwent manual chest compressions only. Resuscitation manoeuvres were then performed for a shorter period of time, probably resulting in the difference in global CPR times observed. Some authors stated that the duration of resuscitation manoeuvres does not influence the type and frequency of related traumatic injuries [10]. Other authors presume that traumatic lesions mostly occur during the first minutes of heart massage [15, 24]. They assume that the energy provided by the rescue team is at its peak at that point, producing most of the injuries after the first chest compressions. Other authors have stated that the number of injuries increases with the duration of CPR [25]. After excluding study cases with a global CPR time of greater than 60 min (to approach the time distribution observed in the control group), a subgroup was created. This showed us that the mean rib fracture number per case was still significantly higher in the LUCASTM subgroup. This tends to support the hypothesis that longer CPR manoeuvres themselves do not directly cause more rib fractures.

Moreover, in all studies involving patients resuscitated by mechanical devices, even in prospective ones, it is difficult to obtain one group of mechanical CPR only to compare with manual CPR. For evident ethical reasons, OHCA patients frequently underwent previous manual chest compressions before devices were applied [12–15, 23]. Resuscitation cannot be delayed for scientific purposes. Porcine model studies [26, 27] do allow the comparison of manual CPR with ACD-CPR only, however. Both authors observed more traumatic injuries associated with manual CPR in their animal model. Based on those considerations, it is possible to hypothesise that human studies tend to overestimate device-related trauma injuries in assisted CPR.

Human cadavers were investigated for CPR-associated lesions. Such studies permitted analysis of the injuries that were directly related to the use of mechanical CPR devices, without any bias due to manual compressions. Baubin et al. [24] worked on cadavers to specifically study CPR-related lesions after the use of an Ambu CardioPump[®] device. In this study, no control group was used to allow further comparison with manual CPR. The influence of CPR duration was not evaluated. Age and female gender were found to be related to higher rates of rib and sternal fractures, respectively. Other authors [28, 29] worked on cadaver models performing chest compressions. Wininger et al. [30] proposed criteria for trauma evaluation of CPR-related studies, including the examination of CPR survivors with chest and sternum radiographs. Investigating survivors was however known to present methodological problems, mostly for the diagnosis of traumatic injuries, and especially when considering the evidence of rib fractures [31]. Indeed, autopsy is still considered the gold standard for post-mortem trauma investigation of the human body [23, 32]. The possible impact of thorax compliance and post-mortem time will have to be considered when evaluating the results of future studies involving cadavers and CPR manoeuvres.

A few petechiae were observed in more than 40 % of our cases. Some authors [33–35] have already reported petechial conjunctival haemorrhages after CPR; however, Maxeiner et al. [36, 37] did not find any correlation between chest compression manoeuvres and eyelid or conjunctival petechiae. Congestion of the venous territory (as seen in right heart failure) and other factors, such as asphyxia and weakness of the capillary wall in older people, seem to explain their appearance more than CPR itself. In addition, we are not able to state that the petechiae reported were absent before CPR manoeuvres were initiated.

In the present study, no major (immediately life-threatening) injury related to CPR was observed. A few cases with internal trauma injuries were described in both groups (without significant difference). Injuries to visceral organs related with CPR manoeuvres are known [25], but life-threatening complications are rare. Concerning hepatic injuries, one case of subcapsular liver haematoma involving both lobes (with limited extension into the parenchyma) was observed after LUCASTM2-CPR, as well as one liver subcapsular haematoma at the left lobe after manual CPR. Fanton et al. [17] reported two fatalities (due to heart infarct and cerebral haemorrhage) with liver ruptures in the right lobe in patients reanimated by manual techniques followed by AutoPulse[®] and LUCASTM CPR consecutively (global CPR time of 110 and 76 min, respectively). Associated massive haemoperitoneum (1.8 l) was reported in one case. Fanton [17] and Englund [16] relied on the importance of autopsy studies for evaluation of injuries related to the application of new mechanical CPR devices.

One haemorrhage in the retroperitoneal space, at the right kidney region, was described in each group; it was not considered life-threatening. To the best of our knowledge, this complication was only previously described in a paediatric population [38]. Survival rate and outcome after LUCAS™ CPR have been analysed by other studies [39–41].

Our observations are limited by medicolegal sampling of patients that does not represent all post-CPR deaths in Geneva. Therefore, some selection bias could not be excluded. Inference to the whole population suffering from OHCA should be considered cautiously.

However, only prospective multivariate future studies, with more cases involved and the analysis of potential confounding factors (such as age, sex, type of cardiac arrest, team motivation and CPR duration) could secure and control the validity and reproducibility of presented results. However, the timing of the appearance of fractures during chest compression manoeuvres could only be properly investigated by future studies of cadavers.

The results presented showed more rib fractures related to LUCAS™2 CPR compared to manual reanimation manoeuvres, especially for women and older people. A few internal organ lesions related to reanimation were observed and considered not to be immediately life-threatening. The possibility of overestimation of mechanical-CPR-associated trauma injuries in human studies has been discussed. Autopsy is still considered the best way to evaluate CPR-related injuries.

In the presence of typical round-shaped lesions on skin of the anterior thoracic region, the use of an ACD-CPR with a piston device, such as the LUCAS™2, during the resuscitation period must be suspected. In those cases, special attention must be focused on searching for and studying associated internal traumatic lesions, such as sternal, rib and visceral injuries.

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Conflict of interest The authors declare that they have no conflict of interest.

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