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Clinical paper

CPR-related injuries after manual or mechanical chest compressions with the LUCAS™ device: A multicentre study of victims after unsuccessful resuscitation☆

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ABSTRACT

Aim: The reported incidence of injuries due to cardiopulmonary resuscitation using manual chest compressions (manual CPR) varies greatly. Our aim was to elucidate the incidence of CPR-related injuries by manual chest compressions compared to mechanical chest compressions with the LUCAS device (mechanical CPR) in non-survivors after out-of-hospital cardiac arrest.
Methods: In this prospective multicentre trial, including 222 patients (83 manual CPR/139 mechanical CPR), autopsies were conducted after unsuccessful CPR and the results were evaluated according to a specified protocol.
Results: Among the patients included, 75.9% in the manual CPR group and 91.4% in the mechanical CPR group ($p = 0.002$) displayed CPR-related injuries. Sternal fractures were present in 54.2% of the patients in the manual CPR group and in 58.3% in the mechanical CPR group ($p = 0.56$). Of the patients in the manual CPR group, there were 64.6% with at least one rib fracture versus 78.8% in the mechanical CPR group ($p = 0.02$). The median number of rib fractures among patients with rib fractures was 7 in the manual CPR group and 6 in the mechanical CPR group. No CPR-related injury was considered to be the cause of death.
Conclusion: In patients with unsuccessful CPR after out-of-hospital cardiac arrest, rib fractures were more frequent after mechanical CPR but there was no difference in the incidence of sternal fractures. No injury was deemed fatal by the pathologist.

1. Introduction

Cardiopulmonary resuscitation (CPR) is a desperate, potentially life-saving measure to regain spontaneous circulation. Subsequent reports about injuries due to CPR have not changed the way it has been performed.[1–5] The use of mechanical devices in CPR has been linked to a higher incidence of injuries compared to standard CPR with manual chest compressions (manual CPR).[6–8] The LUCAS™ device, which delivered mechanical chest compressions (mechanical CPR), was introduced in 2002. Indications of injuries associated with the device's use revealed the need for further studies looking into its safety.[9,10] Preliminary data from two as yet unpublished studies had diverging results and a pilot study revealed no difference in incidence of injuries between the two methods of chest compressions in CPR.[11–13] Therefore, we conducted a multicentre autopsy trial and hypothesised that there would be no difference in CPR-related injuries by manual chest compressions compared to mechanical chest compressions with the LUCAS™ device in patients after unsuccessful resuscitation from out-of-hospital cardiac arrest.

2. Materials and methods

This prospective multicentre study, with fixed dates from January 15, 2008 to August 31, 2012, was reviewed and approved by the human ethics committee in Uppsala, Sweden. This committee waived the need for informed consent.

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2.1. Study design

The study was conducted in conjunction with the LINC study.[14] The non-surviving population was eligible for inclusion in this trial. The admitting physician sought the relatives' views to determine whether there would be an autopsy or not, except where a forensic autopsy was required.

Accordingly, all patients within our study population were also included in the LINC study.

In the LINC study, patients with unexpected, out-of-hospital cardiac arrest were eligible for inclusion. Exclusion criteria were traumatic cardiac arrest including hanging, age believed to be less than 18 years (no upper limit), known pregnancy, defibrillated before LUCAS™ was brought to the scene, or patient's body size not fitting the LUCAS™ device. Closed letter randomisation was conducted on site directly after the recognition of a cardiac arrest and during the randomisation process manual chest compressions were conducted on all patients. Patients were randomised to either standard CPR according to the 2005 ERC guidelines or to mechanical CPR with the LUCAS™ device including defibrillation during ongoing CPR. In the 2005 guidelines it was stated that the depth of chest compression was to be 4–5 cm. In the LINC trial there were 746 patients in total included in Uppsala, Gävle and Västerås, and all these patients were assessed for eligibility for the autopsy trial. A total of 55 patients survived to hospital discharge and were accordingly excluded.

Autopsies were performed in 222 cases. Of these, 139 patients had been treated with mechanical CPR and 83 with manual CPR. The autopsy rate in this study was 32.1%, which is higher than the Swedish national autopsy rate of about 10%.

Pathology departments in the three sites and one centre for forensic medicine (in Uppsala) were responsible for the autopsies. These sites had Emergency Medical Services (EMS) that fulfilled the specific requirements including experience of pre-hospital studies and/or of the use of the LUCAS™ device, and all but one pathology department had prior experience of the autopsy protocol from a previous pilot study.[13] Pathologists in each of the centres recorded autopsy data using this standardised study protocol for external and internal injuries. The protocol consisted of questions about different injuries and the possible relationship of the injury to CPR (yes/no/not possible to answer). Forty different pathologists/forensic experts were involved in the autopsies in this study. In almost 22% of the cases, at least two pathologists/forensic experts collaborated with the autopsies. Protocols from patients with major injuries were reviewed by a forensic expert to evaluate aetiology and severity.

Demographic and baseline data are presented in Table 1.

2.2. The properties of the LUCAS™ device

Two models of LUCAS were used during the study. Initially, from January, 2008 to early 2010, it was the LUCAS™ 1 Chest Compression System which was a pneumatic gas-driven device. From early 2010, this was replaced by the LUCAS™ 2 Chest Compression System which is electrically powered. During the study, both devices provided chest compressions according to 2005 guidelines, with mechanical chest compressions at a constant rate of 100/min and to a fixed depth of 4–5 cm by a piston that has a 50% duty cycle, with the added feature of a suction cup that could assist the chest back to a neutral position.

2.3. Statistical analysis

Data were analysed with IBM SPSS statistics version 22 for Apple MacIntosh. All injuries not considered to be related to CPR were retracted before the analysis but all injuries deemed by the pathologists to be connected to CPR, or where it was impossible to tell if the injury was related to CPR or not, were included in the analyses. Groups were compared using the chi-square test or Fisher's exact test for categorical variables and the Wilcoxon rank sum test for continuous variables. The total number of injuries, rib and sternal fractures were presented with the odds ratio estimate and 95% Wald confidence limits. The Hodges–Lehmann approach was used to estimate the median shift parameter between groups for continuous variables. Mean values were presented with SD and median values with interquartile range. A two-sided $p < 0.05$ was considered statistically significant.

Table 1
Demographic and baseline data of autopsy population.

	Manual CPR, $N = 83$	Mechanical CPR, $N = 139$	p value
Age (years)[a]	66.3 (22–90)	67.7 (21–100)	0.541
Sex (female)[b]	28 (34%)	42 (30%)	0.585
CPR time[c]	34.7 (16.0)	35.0 (17.3)	0.904
Osteoporosis	18 (24.7%)[d]	28 (27.5%)[e]	0.679
Bystander CPR	51 (61.4%)	77 (55.4%)	0.377

[a] Mean (range).
[b] Number of patients (%).
[c] Mean (SD).
[d] 10/83 patients treated with manual CPR with missing data concerning osteoporosis.
[e] 37/139 patients treated with Mechanical CPR with missing data concerning osteoporosis.

3. Results

Of the 222 patients included, 83 patients (37.4%) had been treated with manual CPR only and 139 patients (62.6%) with mechanical CPR including manual CPR prior to mechanical CPR. There was no difference in age, gender or duration of CPR by EMS personnel between the two groups and there was no correlation between the two latter parameters and the incidence of rib or sternal fractures.

In the patients receiving mechanical CPR, the average duration of initial manual chest compressions by EMS personnel was 3.4 min (*SD* 3.2 min) with a range from 0 to 16 min before mechanical chest compression was started. Bystander CPR was performed in 61.4% of the patients receiving manual CPR and in 55.4% of the patients receiving mechanical CPR.

In the group of patients treated with manual CPR, 75.9% had at least one injury and the corresponding number among those treated with mechanical CPR was 91.4% ($p = 0.002$, OR 3.4, CI 1.55–7.31). Manual CPR resulted in rib fractures in 64.6% of the cases and in 57.3% there were multiple rib fractures. Mechanical CPR resulted in rib fractures in 78.8% ($p = 0.02$, OR 2.0, CI 1.11–3.75) of the patients and in 65.0% ($p = 0.26$, OR 1.4, CI 0.79–2.42) there were multiple rib fractures.

Sternal fractures were found in 54.2% of the patients with manual CPR and 58.3% of the patients with mechanical CPR ($p = 0.56$, OR 1.18, CI 0.68–2.04). The sternal fractures were considered to have protruding edges in 5.9% of the patients with manual CPR and 4.5% of the patients receiving mechanical CPR ($p = 0.71$, OR 0.76, CI 0.16–3.55). In 13.7% of the patients receiving manual CPR and 11.4% of those receiving mechanical CPR there were multiple sternal fractures (>1 fracture) ($p = 0.68$, OR 0.81, CI 0.29–2.27).

The population with at least one injury was older than the uninjured population, with a mean age of 69.1, *SD* 15.5, versus 55.8, *SD* 20.0 ($p = 0.001$).

The population with rib fractures had a median number of 7 (IQR 3–10) rib fractures in the manual CPR group and 6 (IQR 4–10) rib fractures in the mechanical CPR group (Hodge–Lehmann location shift 1.00, CI 0.00–2.00, $p = 0.197$).