A comparison of autopsy detected injuries in a porcine model of cardiac arrest treated with either manual or mechanical chest compressions

Theodoros Xanthos[a], Ioannis Pantazopoulos[e], Hara Roumelioti[d], Pavlos Lelovas[a], Nicoletta Iacovidou[f], Ismene Dontas[b], Theano Demestiha[a] and Hara Spiliopoulou[c]

The objective of this study was to evaluate and compare the complications of cardiopulmonary resuscitation after manual or mechanical chest compressions in a swine model of ventricular fibrillation. In this retrospective study, 106 swine were treated with either manual ($n=53$) or mechanical chest compressions with the LUCAS device ($n=53$). All swine cadavers underwent necropsy. The animals with no autopsy findings were significantly fewer in the LUCAS group ($P=0.004$). Sternal fractures were identified in 18 animals in the manual and only two in the LUCAS group ($P=0.003$). Rib fractures were present in 16 animals in the manual and only four in the LUCAS group ($P=0.001$). Nine animals in the manual, and two in the LUCAS group had liver hematomas ($P=0.026\%$). In the manual group, eight animals were detected with spleen hematomas whereas no such injury was identified in the LUCAS group ($P=0.003$). LUCAS devise minimized the resuscitation-related trauma compared with manual chest compressions in a swine model of cardiac arrest.
***European Journal of Emergency Medicine* 18:108–110**

European Journal of Emergency Medicine 2011, **18**:108–110

Keywords: hematomas, LUCAS, manual cardiopulmonary resuscitation, rib fractures, sternal fractures

Departments of [a]Anatomy, [b]Experimental Surgery and Surgical Research, [c]Forensic Medicine and Toxicology, University of Athens, Medical School, [d]University of Athens, Medical School, [e]12th Department of Respiratory Medicine, Sotiria General Hospital and [f]Neonatal Division, 2nd Department of Obstetrics and Gynecology, University Medical School, Athens, Greece

Correspondence to Theodoros Xanthos, PhD, Department of Anatomy, University of Athens, Medical School, 75 Mikras Asias Street, 11527, Athens, Greece
Tel/fax: +302107462305; e-mail: theodorosxanthos@yahoo.com

Received 4 March 2010 **Accepted** 20 July 2010

Introduction

Cardiopulmonary resuscitation (CPR) is physically invasive for the victim and techniques used during CPR carry the risks for possible complications [1]. LUCAS is a new gas-driven CPR-device providing automatic chest compressions. It provides the same quality for all patients, independent of transport conditions, rescuer fatigue, or variability in the experience level of the caregiver. However, LUCAS is not a complication-free device.

The aim of this study was to evaluate and compare the complications of CPR after manual or mechanical chest compressions using the LUCAS device, in a porcine model of ventricular fibrillation (VF).

Methods

This investigation is a retrospective consecutive-case series study, from data available from cardiac arrest experiments performed from February 2006 to November 2009 in our Department. All the animals included were resuscitated (chest compressions, mechanical ventilation and defibrillation) according to the European Resuscitation Council 2005 guidelines [2]. In all experiments, the systolic/diastolic aortic pressures and systolic/diastolic right atrial pressures were monitored continuously and coronary perfusion was calculated as described earlier [3]. VF was induced in all animals through an ordinary cadmium battery [3]. Animals were earlier used as VF models for experimental and teaching purposes; therefore further approval from the Veterinary Services of the Prefecture of Athens was not required.

In this study, we included 106 male Landrace–LargeWhite swine, aged 10–15 weeks and with an average weight of 19 ± 2 kg which were treated with either manual (manual group, $n = 53$) or mechanical chest compressions (LUCAS group, $n = 53$).

Manual chest compressions were performed by the same qualified Basic Life Support instructors/directors, alternating every 2 min, whereas mechanical chest compressions were performed with LUCAS. The device was tied on the surgical table to ensure stability. Compression depth was measured manually with a transparent ruler to ensure that the depth is the same, independently of the mode of chest compressions. The duration of the resuscitation efforts was recorded in every experiment using a digital stopwatch.

All swine cadavers underwent necropsy immediately after their original experiment. After the removal of the thoracic and abdominal viscera, the pleura were stripped and the internal surface of the ribs was examined for

0969-9546 © 2011 Wolters Kluwer Health | Lippincott Williams & Wilkins DOI: 10.1097/MEJ.0b013e32833e79cf

fractures. As a fracture, we considered the break in the continuity of the bone seen macroscopically, with hemorrhagic infiltration in the surrounding tissues.

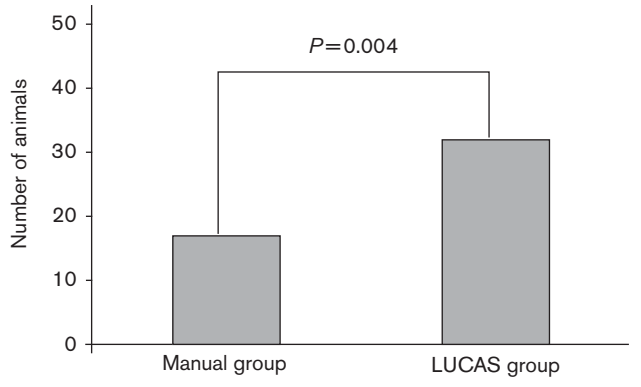
Data from each autopsy was recorded through a standardized study protocol for external and internal injuries. The protocol included recording of sternal or rib fractures, hemorrhage in the mediastinum, pericardium, or pleural space, pneumothorax, heart and thoracic aorta injuries and finally injuries to the liver and/or spleen. All autopsies on study animals were performed by the same veterinarian, blinded to the mode of chest compressions. The veterinarian was supervised by a medical examiner also blinded to the mode of chest compressions.

The rate of complications between the two groups was assessed with χ^2 or Fisher's exact test, when the expected cell count was less than 5. All reported P values were two-tailed with P value less than 0.05 considered to be significant. All analyses were performed using SPSS 15 (SPSS Inc., Chicago, Illinois, USA).

Results

Duration of resuscitation efforts in both the groups did not differ significantly (manual group: 16.2 ± 4.5 min; LUCAS group: 15.8 ± 6.4 min; P = NS). During CPR, diastolic pressure and coronary perfusion pressures did not differ significantly between the manual (42.8 ± 1.6 and 23.5 ± 2.9, respectively) and the LUCAS group (40.6 ± 3.9 and 22.8 ± 3.8, respectively). Figure 1 illustrates the number of animals with no autopsy findings in each group. Autopsy injuries for either group are shown in Table 1. In both of the groups left hemithorax was more frequently affected than the right ($P < 0.05$). Moreover, 75% (12/16) of the animals in the manual group had multiple rib fractures, defined as fractures in two or more adjacent ribs. All fractures were located at ribs 2–7. Ten (86.6%) of these cases had more than six ribs broken. On the other hand, one out of two animals (2/4, 50%) in the LUCAS group had multiple rib fractures that occurred at ribs 3–6. None of these cases had more than three ribs broken.

Fig. 1



Number of animals with no autopsy findings for each group.

Table 1 Injuries detected by autopsy

Injuries	Manual group	LUCAS group	P value
Rib fractures	16 (30.2%)	4 (7.5%)	0.001
Average number of fractures	6.0 ± 2.3	1.8 ± 1.0	0.03
Sternal fractures	18 (33.7%)	2 (3.8%)	0.003
Middle third of the sternum	50%	100%	
Lower third of the sternum	50%	0%	
Liver hematomas	9 (17%)	2 (3.8%)	0.026
Spleen hematomas	8 (15.1%)	0 (0%)	0.003
Tracheal laceration	1 (1.9%)	0 (0%)	NS
Myocardial hemorrhage	2 (3.8%)	1 (1.9%)	NS
Pneumothorax	1 (1.9%)	0 (0%)	NS

NS, not significant.

Discussion

Recently, there has been a call for intensive research on the effectiveness of LUCAS and its possible side-effects, before it is introduced routinely into clinical practice [4]. After the completion of CPR, fractures of the ribs and especially of the sternum may remain undetected on conventional X-ray examination as sternal fracture fragments are projected inwards without displacement of the fracture ends [1,4].

Few reports in the literature highlight the adverse effects of both manual and mechanical CPR. In a recent study [5], manual CPR was performed not only in the manual group, but also in the LUCAS group for an average time of 2.9 ± 2.1 min before the initiation of LUCAS-CPR. Mean maximal compression force is always higher at the beginning of manual CPR [5] and as most fractures occur at the very beginning of CPR efforts [6], this study may have overestimated injuries in the LUCAS group. Furthermore, older patients and especially women carry a higher risk for rib fractures and previous chest trauma or surgery may alter the chest resistance before CPR application. In an attempt to control all these potentially interacting variables, this study was performed on uninjured porcine chests. It is known that human and porcine chest behave in a relatively similar manner during CPR [7].

Sternal fractures were more frequent after manual CPR in this study. They are considered to be more dangerous than uncomplicated rib fractures, as sternum fragments tilt inwards and can cause serious organ injuries. The reported incidence of thoracic injury results in the literature varies from 1.3–43% for sternal and 12.9–96.6% for rib fractures after manual CPR [6]. Our results are in excellent agreement with these reports.

An interesting observation was that 18.9% of the animals treated with manual CPR had more than six ribs fractured. None of the animals treated with LUCAS-CPR presented so many fractures. Multiple fractures of

neighboring ribs on both sides of the thoracic cage may produce a flail chest. A flail chest can critically disable the thoracic pump mechanism.

Liver and spleen hematomas showed a significantly higher incidence in animals treated with manual CPR. Many investigators suggest that liver injury can be attributed to the incorrect placement of hands performing chest compressions, over the xiphoid bone and the close anatomical relation between the liver and the xiphoid bone [8].

Coronary perfusion pressure is a determinant for successful resuscitation and is related to compression depth and compression force [9]. The LUCAS device has sustained adequate systolic and diastolic pressures in the catheterization laboratory with minimum life-threatening injuries [10]. However when chest injuries occur, they may be a price worth paying to achieve optimal efficacy of chest compressions.

Limitations

The sample size is relatively small and the study is retrospective. Furthermore, the animals included in this study were relatively young. Moreover, differences in chest viscosity during chest compressions should be kept in mind when extrapolating these results to humans. Furthermore, the LUCAS device was placed before VF induction, and it does not thus reflect real human cardiac arrest management, where some time of manual chest compressions is vital before the LUCAS placement.

Conclusion

Complications, especially rib and sternal fractures, may occur even with properly performed CPR. Our study showed that use of LUCAS device minimized these complications in this swine model of cardiac arrest and resuscitation. However, to ensure validity, these findings need to be reproduced in a larger prospective study.

Acknowledgement

There is no source of funding and the authors of this manuscript have no conflict of interest to declare.

References

1 Lederer W, Mair D, Rabl W, Baubin M. Frequency of rib and sternum fractures associated with out-of-hospital cardiopulmonary resuscitation is underestimated by conventional chest X-ray. *Resuscitation* 2004; **60**:157–162.
2 Nolan JP, Deakin CD, Soar J, Böttiger BW, Smith G. European Resuscitation Council guidelines for resuscitation 2005. Section 4. Adult advanced life support. *Resuscitation* 2005; **67**:S39–S86.
3 Xanthos T, Iacovidou N, Pantazopoulos I, Vlachos I, Bassiakou E, Stroumpoulis K, *et al.* Ischaemia-modified albumin predicts the outcome of cardiopulmonary resuscitation: an experimental study. *Resuscitation* 2010; **81**:591–595.
4 Baubin M, Rabl W, Pfeiffer KP, Benzer A, Gilly H. Chest injuries after active compression-decompression cardiopulmonary resuscitation (ACD-CPR) in cadavers. *Resuscitation* 1999; **43**:9–15.
5 Smekal D, Johansson J, Huzevka T, Rubertsson S. No difference in autopsy detected injuries in cardiac arrest patients treated with manual chest compressions compared with mechanical compressions with the LUCAS device-a pilot study. *Resuscitation* 2009; **80**:1104–1107.
6 Baubin M, Sumann G, Rabl W, Eibl G, Wenzel V, Mair P. Increased frequency of thorax injuries with ACD-CPR. *Resuscitation* 1999; **41**:33–38.
7 Neurauter A, Nysaether J, Kramer-Johansen J, Eilevstjønn J, Paal P, Myklebust H, *et al.* Comparison of mechanical characteristics of the human and porcine chest during cardiopulmonary resuscitation. *Resuscitation* 2009; **80**:463–469.
8 Meron G, Kurkciyan I, Sterz F, Susani M, Domanovits H, Tobler K, *et al.* Cardiopulmonary resuscitation-associated major liver injury. *Resuscitation* 2007; **75**:445–453.
9 Bellamy RF, DeGuzman LR, Pedersen DC. Coronary blood flow during cardiopulmonary resuscitation in swine. *Circulation* 1984; **69**:174–180.
10 Larsen AI, Hjørnevik AS, Ellingsen CL, Nilsen DW. Cardiac arrest with continuous mechanical chest compression during percutaneous coronary intervention. A report on the use of the LUCAS device. *Resuscitation* 2007; **75**:454–459.