Treatment of out-of-hospital cardiac arrest with LUCAS, a new device for automatic mechanical compression and active decompression resuscitation

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Abstract

Lund University Cardiopulmonary Assist System (LUCAS) is a new gas-driven CPR device providing automatic chest compression and active decompression. In an experimental model on pigs, LUCAS-CPR produced significantly better circulation during ventricular fibrillation (VF) than manual CPR [8]. When used on 20 patients with in-hospital cardiac arrest, LUCAS was easy to handle, light (6.5 kg) and quick to apply (10–20 s). In one patient with witnessed asystole where manual CPR failed, LUCAS-CPR achieved return of spontaneous circulation (ROSC) and one year later the patient was living at home, fully neurologically intact [8].

1. Introduction

It has been estimated that 375,000 people in Europe [1] and 275,000 in the USA [2] are victims of sudden cardiac arrest each year. The great majority occur out of hospital and the 1-year survival rate remains extremely poor – less than 5% [1–3]. Recent insights into the physiology of cardiac arrest indicate that the role of adequate chest compressions needs to be upgraded in the guidelines for treatment of out-of-hospital cardiac arrest if better results are to be hoped for [4–7].

Lund University Cardiopulmonary Assist System (LUCAS) is a new gas-driven CPR device providing automatic chest compression and active decompression. In an experimental model on pigs, LUCAS-CPR produced significantly better circulation during ventricular fibrillation (VF) than manual CPR [8]. When used on 20 patients with in-hospital cardiac arrest, LUCAS was easy to handle, light (6.5 kg) and quick to apply (10–20 s). In one patient with witnessed asystole where manual CPR failed, LUCAS-CPR achieved return of spontaneous circulation (ROSC) and one year later the patient was living at home, fully neurologically intact [8]. In March 2002, three emergency cars were equipped with LUCAS in two cities in southern Sweden. The first cardiac arrest patient was treated with LUCAS on
20 March 2002, and this and the next 99 consecutive patients treated with LUCAS were followed up for up to 1 month after ROSC. Added information is given for recently treated patients with LUCAS illustrating important possibilities for a dramatic improvement in the treatment of cardiac arrest.

2. Material and methods

LUCAS was introduced into pre-hospital care in Lund and Malmö in southern Sweden during the spring of 2002, with permission from the Ethics Committee of the Medical Faculty of Lund University. Together the pre-hospital ambulance services in the two cities have an admission area of 921 km² with 440,000 inhabitants.

LUCAS can be driven by oxygen or air. It produces 100 compressions/decompressions per minute. The maximum depth of each compression is 5 cm and the maximum compression and decompression forces are 500 and 410 N, respectively. With a 6.5 l gas bottle (300 kPa) LUCAS can be run for about 30 min. A detailed description of the device and how it may be used have been given elsewhere [4,8,9].

Special tests were done to study the oxygen concentration and the noise level created by LUCAS in two different types of ambulances (Volvo 90 and Mercedes). During these measurements we also simulated treatment with a Boussignac tracheal tube [9] or a CPAP-mask consuming 20 l/min of oxygen up to 100% oxygen, and good linearity in the sensor was released within the ambulance during the measurements. Oxygen concentrations were measured in the middle of the ambulance by an Oxygen Monitor no. 5590 (Hudson Respiratory Care Incorporated, Temecula, CA, USA). Before each measurement, the sensor was calibrated with air and mixtures of oxygen up to 100% oxygen, and good linearity in the sensor was shown. The frequency and level of noise were measured in the middle of the ambulance by CEL 383 equipment with an octave band filter (Casella CEL Ltd., Kemptown, Bedford, UK). The inbuilt calibrating function was checked, measurements were performed in both dB(A) and dB(L) modes, and an octave band analysis was performed.

A crash test was performed by a company with the appropriate authorization. LUCAS was applied to a manikin fixed to a stretcher with a 4-point fixation belt on an ambulance with a flow of 80 l/min oxygen was released within the ambulance during the measurements. Oxygen concentrations were measured in the middle of the ambulance by an Oxygen Monitor no. 5590 (Hudson Respiratory Care Incorporated, Temecula, CA, USA). Before each measurement, the sensor was calibrated with air and mixtures of oxygen up to 100% oxygen, and good linearity in the sensor was shown. The frequency and level of noise were measured in the middle of the ambulance by CEL 383 equipment with an octave band filter (Casella CEL Ltd., Kemptown, Bedford, UK). The inbuilt calibrating function was checked, measurements were performed in both dB(A) and dB(L) modes, and an octave band analysis was performed.

A crash test was performed by a company with the appropriate authorization. LUCAS was applied to a manikin fixed to a stretcher with a 4-point fixation belt on an ambulance model run against a wall at a speed of 30 km/h which is comparable to a force of 10 G.

When LUCAS was introduced into the ambulances, a report form was constructed and ambulance staff required to complete it after each use of LUCAS. The results of this study are based on data from these forms, pre-hospital data records, and hospital records for the first month of follow-up of patients with ROSC.

The guidelines for treatment of cardiac arrest of the Swedish Association for Cardiology were followed. When the ambulance personnel arrived at the scene, an ECG was taken, and if VF was diagnosed, up to three defibrillation attempts were made before manual CPR was started. LUCAS-CPR could not be started before the second ambulance tier arrived with the device. LUCAS was introduced as an aid for the staff to provide chest compressions within the existing guidelines. Eighty-eight of the patients were intubated at the scene of the cardiac arrest, and twelve were ventilated with a face mask over a pharynx tube. Ventilation was given with an Ambu self inflating bag with a flow of 15 l/min of oxygen into the Ambu bag reservoir. Adrenaline (epinephrine) was given (1–7 mg in total) to 93 patients and atropine to 7 patients. Of those who achieved ROSC (31 patients), 9 were cooled to 33 ºC on arrival at hospital. Cooling was initiated with cold Ringer solution i.v. (30 ml/kg) and a cooling mattress was used to maintain 33 ºC for 24 h, after which the body temperature was gradually increased to normothermia over the next 8 h.

3. Results

LUCAS was used on patient’s with all types and causes of cardiac arrest. There were 75 men with a mean age of 64 (range 22–94) years and 25 women with a mean age of 70 (25–89) years. The initial ECG showed VF in 42% of the patients and asystole/PEA in 58%. Fifty-seven of the cardiac arrests took place in the home and 43 in other places. The ROSC-rate and 30-day survival are reported in Fig. 1, and logistics are summarised in Fig. 2.

3.1. Return of spontaneous circulation

Thirty-one per cent of the patients achieved a stable ROSC and were admitted to the intensive care unit. Of the 43 patients with a witnessed cardiac arrest treated with LUCAS within 15 min of the ambulance staff being called, 20 (47%) achieved stable ROSC.

One of the unwitnessed cases was a 71-year-old man found collapsed in an office. After the call to the emergency number, bystander CPR was started. The first tier arrived after 7 min and the staff found an unconscious and cyanotic man without a pulse. Manual chest compressions were started and the airway was secured by tracheal intubation. The initial ECG showed VF and several defibrillations were attempted without success. Seven minutes after the arrival of the first tier, the second tier arrived with LUCAS, which was applied to the patient immediately. Defibrillation was performed during ongoing LUCAS-CPR and the patient regained sinus rhythm and a measurable blood pressure within the normal range. The patient was then loaded into the ambulance. During transport to the hospital the patient developed pulseless electrical activity (PEA) and LUCAS-CPR was restarted. The patient was taken to the catheter laboratory with ongoing LUCAS-CPR. Coronary angiography showed three-vessel disease with occlusion of the left coronary artery (LAD). After PCI, ROSC was obtained and the patient was trans-
ferred to the intensive care unit. The patient had a stable circulation but never regained consciousness and died after 15 days because of severe brain damage.

3.2. 30-day survival

Only patients with a witnessed cardiac arrest treated with LUCAS within 15 min of the ambulance alarm survived for 30 days, in all 7 of the 43 patients (16%) (Fig. 1). Six of these patients had ventricular fibrillation and one had pulseless electrical activity according to the initial ECG. All seven had good cerebral performance at 30 days. Of these seven patients, five had been cooled to 33 °C for 24 h after to the hospital.

One of these patients illustrates that LUCAS-treatment should not be interrupted too soon. This was an 81-year-old woman who had undergone coronary bypass surgery in 1996. She collapsed in a concert hall in 2002. The ambulance staff arrived after 7 min and the ECG showed ventricular fibrillation. One defibrillation attempt caused asystole.

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**Fig. 1. Flow chart showing the results of the study.**

**Fig. 2. Times of interest given as mean ± S.D.; median (range); number of observations.**
from the back plate. LUCAS device moved with the manikin and did not detach being fastened to the stretcher with a 4-point safety belt. The 30 km/h, the manikin moved forward for up to 40 cm despite when the siren was on it was 89 dB(L). 88 dB(L), on the highway it was 70–71 dB(A) and 88 dB(L), was moving in the city the level of noise was 67 dB(A) and produced a noise level of 83–88 dB(A), the same level of when the ambulance engine was running but the vehicle standing still, LUCAS produced a noise level of 83–88 dB(A), the same level of dB(L), and a peak value of 111 dB. The highest frequencies were in the octave band at 1000 Hz. When the ambulance was moving in the city the level of noise was 67 dB(A) and 88 dB(L), on the highway it was 70–71 dB(A) and 88 dB(L), and when the siren was on it was 89 dB(L).

3.3. The chain of logistics

As seen in Fig. 2, the alarm system did not function optimally. In one case there was a period of 12 min between the alarm being raised and the time it reached the ambulance staff, and in another case it was 35 min before the second tier (with LUCAS) was alerted. Since many of the ambulance staff had very little experience with the LUCAS device in the beginning, they hesitated before using it. As seen in Fig. 2, it took a mean of 6 min before LUCAS-CPR was started, and in one case 25 min.

3.4. Oxygen concentration within the ambulance during LUCAS-CPR

The oxygen concentration in the ambulance during LUCAS-CPR (601 oxygen/minute) plus CPAP treatment (201 oxygen/minute) was dependent on the speed of the ambulance and the ventilation settings. When the vehicle was standing still with all ventilation openings closed, the oxygen concentration increased to about 35% after 15 min, but when the vehicle was moving and the ventilation fan working at the highest speed, the oxygen concentration never exceeded 22%.

3.5. Noise levels within the ambulance during LUCAS-CPR

The noise measurements showed that when the vehicle engine was running but the vehicle standing still, LUCAS produced a noise level of 83–88 dB(A), the same level of dB(L), and a peak value of 111 dB. The highest frequencies were in the octave band at 1000 Hz. When the ambulance was moving in the city the level of noise was 67 dB(A) and 88 dB(L), on the highway it was 70–71 dB(A) and 88 dB(L), and when the siren was on it was 89 dB(L).

3.6. Crash test

When the ambulance crashed against a wall at a speed of 30 km/h, the manikin moved forward for up to 40 cm despite being fastened to the stretcher with a 4-point safety belt. The LUCAS device moved with the manikin and did not detach from the back plate.

4. Discussion

To establish an adequate circulation to the brain as quickly as possible after cardiac arrest is of prime importance for survival with good neurological outcome. Of the cases reported here, only patients with a witnessed cardiac arrest treated with LUCAS-CPR within 15 min of the ambulance staff being called survived for 30 days. Stable ROSC was obtained in 31% of the patients, but only 7% survived 30 days; the other patients never regained consciousness and all died within 18 days. The patients with witnessed cardiac arrest caused by ventricular fibrillation and treated with LUCAS-CPR within 15 min had a 25% 30-day survival rate with good neurological outcome.

Among the 29% of the patients with a non-witnessed cardiac arrest, none survived 30 days. In many of the witnessed cases, the time that passed from collapse of the patient to the time the alarm reached the SOS centre is unknown, but in other studies done in Sweden this interval has been estimated to range from 2 to 5 min (3). The time needed for the SOS centre to alert the ambulance staff can, and should be, less than 1 min. Thus, if more than 20 min elapse after a collapse due to cardiac arrest in normothermia, and if no bystander CPR is given, the chance of survival seems to be very poor. This is in accordance with other studies done in Sweden (3).

As an example, bystander CPR was started immediately in a patient with a witnessed cardiac arrest and continued for 22 min before an ambulance equipped with LUCAS arrived at the scene, the patient was intubated and defibrillation was attempted during on-going LUCAS-CPR. The patient achieved ROSC after a few minutes of LUCAS-CPR and was transported to the hospital with the LUCAS device in position but switched off. Just before the ambulance arrived at the hospital, the patient awoke and extubated himself. Emergency coronary angiography showed three-vessel disease. The patient had an acute bypass operation with a normal post-operative course. This case illustrates the critical importance of good bystander CPR. The dispatcher should give instructions to start forceful chest compressions immediately. New insights into the physiology of cardiac arrest (4,5) indicate that chest compressions should be considered to be the prime and most essential element of the early treatment of cardiac arrest out-of-hospital, and the defibrillation should be done with a minimum delay between chest compressions and subsequent defibrillation. In one of the cases referred to in the Results section, successful defibrillation was not obtained during manual CPR, but during on-going LUCAS-CPR. The reason for this is that the coronary perfusion pressure falls within seconds of interrupting the chest compressions and to defibrillate a fibrillating heart in these conditions is less effective (4).

Another recent case illustrates what can be done when mechanical circulation keeps the brain alive until the heart function is restored. A 61-year-old man had a cardiac arrest in his home witnessed by his wife. He received no bystander CPR, but the wife immediately alerted the SOS centre and
LUCAS-CPR was started within 10 min of the time of the alert being received. No ROSC was obtained at the scene. The patient was transported to the hospital with on-going LUCAS-CPR. Still no stable ROSC was achieved, and cold lactated Ringer solution (30 ml/kg) was given intravenously and a decision to do coronary angiography was taken. The patient arrived at the catheter laboratory 1 h after the cardiac arrest. Angiography showed occlusion of the left main coronary artery and no movement of the left ventricle was seen. Percutaneous coronary intervention (PCI) was done successfully between manual chest compressions and the patient recovered fully [10]. Three months later he underwent a coronary bypass operation for stenosis of the left main coronary artery and no movement of the left ventricle was seen. Percutaneous coronary intervention (PCI) was done successfully between manual chest compressions and the patient recovered fully [10].

It is impossible to do adequate manual chest compressions for more than a few minutes [11]. In a moving ambulance it is impossible to ensure an adequate circulation by manual chest compressions and furthermore, any attempt to do so entails a risk to the ambulance staff [12]. Thus, during transport of a patient with cardiac arrest, mechanical chest compressions should be mandatory, foremost for safety reasons. Besides giving adequate circulation to the brain until PCI or coronary artery surgery allows ROSC, a further advantage of mechanical CPR is that defibrillation can be given during ongoing CPR [4] which can not be done, for safety reasons, during manual CPR.

To conclude, establishment of an adequate circulation to the brain as quickly as possible after cardiac arrest is mandatory for a good outcome. In this report, patients with a witnessed cardiac arrest receiving LUCAS-CPR within 15 min had a 30-day survival of 25% in cases of VF and 5% in cases of asystole, but if more than 15 min passed, and in all unwitnessed cases, none survived 30 days.

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References


