

Selected Bibliography Summaries

June 2016

Prehospital Studies

Studies with Control Groups

Rubertsson S, Lindgren E, Smekal D, et al. Per-protocol and pre-defined population analysis of the LINC study. *Resuscitation*. 2015;96:92-99.

This study performed two pre-defined sub-group analyses within the large randomized controlled European LINC trial to evaluate if the results supported the previously reported intention to treat (ITT) analysis; the rationale being to see if results were consistent when excluding possible protocol violations and factors with estimated dismal influence on both treatment interventions tested in the randomized ITT groups (n = 2589). These sub-groups were predefined in an effort to reduce bias and the negative effects of subgroup analyses decided upon after the completion of the study. The pre-protocol group (n = 2370) excluded patients that violated the inclusion/exclusion criteria or did not get the actual treatment to which they were randomized. The pre-defined group (n = 1133) excluded patients in which the time from dispatch to arrival at the scene exceeded 12 minutes, non-witnessed cardiac arrests and in cases where the LUCAS device was not immediately brought to the scene. Patient 4-hour survival was 23.8% in the mechanical-CPR group versus 23.5% in the manual-CPR group in the per-protocol population and 31% versus 33.9% in the pre-defined group. There was no difference in any of the second outcome variables analyzed. 6 month survival with CPC score 1 (best neurological outcome) was 8.3% in the mechanical CPR group vs. 6.8% in the manual CPR group (p = 0.19) in the per protocol population, and 12.2% vs. 10.3% (p = 0.35) in the predefined population, respectively. In summary, the results from these pre-defined sub-group analyses were consistent with the previously published ITT analysis.

Tranberg T, Lassen J, Kaltoft A, et al. Quality of cardiopulmonary resuscitation in out-of-hospital cardiac arrest before and after introduction of a mechanical chest compression device, LUCAS-2; a prospective, observational study. *Scand J Trauma Resusc Emerg Med*. 2015;23:37.

This Danish study analyzed CPR quality metrics in 155 of 696 OHCA patients who were treated with manual compressions followed by LUCAS compressions treated between April 2011 to February 2013. CPR quality was evaluated using transthoracic impedance measurements collected by the LIFEPAK 12 defibrillator. Median total CPR duration was 21 min. In the cases with both manual and LUCAS CPR, the episode with the LUCAS compressions was significantly longer than the time with manual CPR (13 mins vs. 5 mins; p < 0.001), reflecting the LUCAS device being used in selected prolonged resuscitation attempts. The no-flow fraction was significantly lower during LUCAS CPR than during manual CPR (16% vs. 35%; p < 0.001). No differences were found in pre- and post-shock no-flow time throughout manual and LUCAS CPR. Contrary to manual CPR, the average compression rate with the LUCAS device was in conformity with the current Guidelines (102/min vs. 124/min, p < 0.001). The authors reported an overall 9% survival of the patients treated with the combination of the LUCAS device and manual CPR, which included six patients where PCI was performed during ongoing LUCAS CPR, and two patients who were taken into the hospital during ongoing LUCAS CPR and treated with cardiopulmonary support. The latter two were reported alive at 30 days follow up with minimal neurological sequelae. In summary, chest compressions provided by the LUCAS device improved CPR quality by significantly reducing the no-flow fraction and by improving the quality of chest compression compared with manual CPR during OHCA resuscitation.

Levy M, Yost D, Walker R, et al. A quality improvement initiative to optimize use of a mechanical chest compression device within a high-performance CPR approach to out-of-hospital cardiac arrest. *Resuscitation*. 2015;92:32-37.

This U.S. report describes a quality improvement initiative undertaken by the Anchorage Fire Department to reduce LUCAS device application time in OHCA patients and to optimize the overall CPR process. Updated high-performance CPR training was rolled out which included: lectures, online tests, mock drills and in-person debriefing and review of downloaded CPR data from defibrillator/monitors after each event. A protocol change was instituted to require completion of two full cycles of manual CPR before transition to mechanical CPR to ensure those patients with the potential for early ROSC received 4 min of minimally interrupted manual chest compressions before device

application. A new LUCAS application method took advantage of existing protocol-specified CPR interruptions, to allow for placement of the device's back plate under the patient, and feeding the device's support legs through the arms of the provider performing manual compressions without interfering with the continuity of manual compressions. Crews were instructed to immediately resume manual compressions upon experiencing any device difficulties. CODE-STAT™ CPR quality data from the year before (2012), during and after the initiative (2013) were evaluated. Compared to OHCA cases from 2012 (n = 61), median duration of the pause prior to first mechanical compression for cases from 2013 (n = 71) decreased from 21 to 7 sec (p < 0.001), while median chest compression fraction increased from 0.90 to 0.95 (p < 0.001). Median duration of the longest pause decreased from 25 to 13 sec (p < 0.001), while the proportion of cases where the longest pause was for mechanical CPR application decreased from 74% to 31% (p < 0.001). In summary, significant increases in compression fraction and significant decreases in duration of the longest pause strongly suggest a large improvement in LUCAS device application efficiency when implementing an overall high-performance CPR process.

Esibov A, Banville I, Chapman F, et al. Mechanical chest compressions improved aspects of CPR in the LINC trial. *Resuscitation*. 2015;91:116-121.

This analysis compared chest compression fraction (CCF) and perishock pauses in a subset of patients (N: 206) enrolled in two of the six sites of the European multicenter randomized controlled LINC trial comparing the LUCAS device vs. manual CPR in OHCA. Using electronic downloads of continuous ECG and impedance data from LIFEPAK 12 monitor defibrillators, the authors analyzed CCF over the first 10 min of recorded data as well as perishock pauses for shocks. The LUCAS device was applied and started within 5 min of the beginning of recorded signals in 89% of the LUCAS cases. Median CCF was 0.79 in the manual treatment group and 0.84 in the LUCAS treatment group (p < 0.001). Beginning with the minute following the LUCAS device deployment, the median CCF over the next 10 min was 0.91 in the LUCAS group. The median perishock pause was 10 sec for manual CPR and 0 sec when using the LUCAS device (p < 0.001). During LUCAS use, 70.9% of shocks were delivered without pausing compressions. In conclusion, good chest compression fractions were achieved in both groups, indicating high-quality CPR in both groups. Furthermore, patients treated with the LUCAS protocol had a significantly higher CCF, and shorter perishock pauses, compared to patients treated with conventional CPR.

Kamrud J, Boland L, Frazee C, et al. Use of transthoracic impedance data to evaluate intra-arrest chest compression quality before and after placement of a mechanical chest compression system. *Prehosp Emerg Care*. 2015;19(1):Abstract 131.

This U.S. retrospective analysis was conducted in all OHCA patients treated with the LUCAS device by a single ambulance service in Minnesota in 2013. Transthoracic impedance (TTI) data from 269 events obtained from CODESTAT data review software were used to compare chest compression quality metrics between the manual vs mechanical compression phases. The mean (range) duration of the manual phases was 3:37 min. and 23:39 min. for the mechanical phases. Mean compression fraction was significantly higher during mechanical versus manual compressions (89% vs 75%; p<0.0001). Compression rate was also better aligned with the recommended 100 compressions/min during mechanical compressions, with mean compression rates of 102/min and 121/min (p<0.0001) in the mechanical and manual phases, respectively. On average, the first mechanical compression was delivered 4 min 15 sec after the start of TTI recording, with a median device application pause of 26 sec. In summary, these data demonstrate the use of a mechanical chest compression device can improve compression fraction and increase compliance with compression rate guidelines. Based on these findings, this system will emphasize earlier device placement with minimal pauses for application.

Perkins G, Lall R, Quinn T, et al. Mechanical versus manual chest compression for out-of-hospital cardiac arrest (PARAMEDIC): a pragmatic, cluster randomised controlled trial. *Lancet*. 2015;385(9972):947-955.

This large cluster randomized prehospital UK study examined whether the "pragmatic" introduction of the LUCAS 2 device into front-line emergency response vehicles would improve OHCA survival compared to conventional manual CPR. The study was conducted from April 15, 2010 to June 10, 2013 at four UK ambulance services. Clusters consisted of ambulance service vehicles, which were randomly assigned (1:2) to use the LUCAS device or to perform manual compressions, meaning every third vehicle carried a LUCAS device. Patients received manual (N: 2819) or LUCAS CPR (N: 1652) according to the first trial vehicle to arrive on scene. In the LUCAS group, 60% of patients actually received mechanical chest compression, the rest got manual CPR. The primary endpoint, thirty-day survival, was similar between the LUCAS treatment group (6%) and in the manual CPR group (7%) (adjusted odds ratio 0.86, 95% CI 0.64–1.15). No serious adverse events were noted in any of the groups. In the LUCAS group three patients had chest bruising, two had chest lacerations, and two had blood in mouth. Fifteen device incidents occurred during operational use. In summary, there was no evidence of improvement in 30-day survival with LUCAS 2 device compared with manual compressions, but it was noted that actual use of the LUCAS device in the LUCAS group was low.

Villadiego Sanchez J, Borja Padilla J, del Valle Fernandez P, et al. Comparison of survival in cardiorespiratory arrest patients receiving conventional manual or external mechanical chest compression. *Resuscitation*. 2014;85S:S48. APO74.

This Spanish prospective observational cohort study from 2012 compared survival rates in 169 OHCA patients receiving manual CPR (N: 108) or LUCAS CPR (N: 61). Survival to hospital arrival was achieved in 29.5% of the LUCAS group vs. 24.1% of the manual CPR group (no significant differences). Survival to hospital discharge was achieved in 13.3% of the LUCAS group vs. 14.8% of the Manual CPR group (no significant differences). In summary, prehospital use of the LUCAS device did not result in statistically significant survival to hospital arrival or discharge in patients treated with automatic or manual CPR.

Rubertsson S, Lindgren E, Smekal D, et al. Mechanical chest compressions and simultaneous defibrillation vs conventional cardiopulmonary resuscitation in out-of-hospital cardiac arrest. The LINC randomized trial. *JAMA*. 2013;311(1):53-61.

This European large randomized control multicenter LINC trial hypothesized that a 3 minute algorithm of mechanical chest compressions delivered by the LUCAS device with defibrillation during ongoing chest compressions would improve 4-hour survival in patients as compared to guideline-based manual CPR in OHCA. From Jan. 2008 to Aug. 2012, 2,589 patients were randomized to either LUCAS CPR (N:1300) or manual CPR (N:1289) at six sites in Europe. Surviving patients were evaluated for neurological outcome using a CPC score 1-2 as good outcome. Survival at 4 hours was 23.6% with LUCAS CPR and 23.7% with manual CPR ($p > .99$). Survival with good neurological outcome was 7.5% vs 6.4% at intensive care unit discharge, 8.3% vs 7.8%, at hospital discharge, 8.1% vs 7.3%, at 1 month, and in 8.5% vs 7.6% at 6 months with LUCAS CPR and Manual CPR, respectively, and without statistical significance. The proportion of survivors with CPC 1-2 in the LUCAS and manual CPR groups was 99% vs. 94% respectively at 6 months. The numbers of serious adverse events and device-related adverse events were low, the LUCAS device showed a high reliability of 99.4% during the four years the study was conducted. After randomization, 3.5% of the patients randomized to mechanical CPR did not fit the device; 2.3% were too big and 1.2% too small, suggesting the device can be expected to fit about 95% of cardiac arrest patients. In conclusion, there was no significant difference in 4-hour survival between patients treated with the LUCAS device and the 3 minute algorithm or those treated with guideline-adherent manual CPR. The vast majority of survivors in both groups had good neurological outcomes by 6 months.

Satterlee P, Boland L, Johnson P, et al. Implementation of a mechanical chest compression device as standard equipment in a large metropolitan ambulance service. *J Emerg Med*. 2013;45(4):562-569.

This U.S. retrospective OHCA case series describes the results after implementing the LUCAS device for routine use across a large ambulance service during the initial 2 years of use (during 2008-2010). 38 devices were deployed in a 70-vehicle, 400-provider ambulance service within 3 months in Minnesota. The LUCAS device was used in 85% (498 of the 572 cases where LUCAS usage data were available). Primary reasons for not using the LUCAS device were; short resuscitation times due to early ROSC or early declaration of death (8%), patient too large for the device (2.3%), patient too small for the device (0.9%). Overall ROSC rates were 35% of LUCAS-treated arrests and 41% of non-device-treated, respectively ($p = 0.31$). When removing short resuscitation attempts of less than 5 min, ROSC rates were 26% among LUCAS-treated arrests and 24% among non-device treated arrests, respectively ($p = 0.78$). User feedback was positive with 9.1 out of max 10 for perceived device efficacy and 8.9 for overall ease of operation. In conclusion, the LUCAS device fit most patients and was well received by prehospital providers. Resuscitation of limited duration due to early death or early ROSC frequently precluded device use, and this has important implications for evaluating the association between device use and ROSC in observational settings.

Axelsson C, Herrera M, Fredriksson M, et al. Implementation of mechanical chest compression in out-of-hospital cardiac arrest in an emergency medical service system. *Am J Emerg Med*. 2013;31(8):1196-1200.

This is a Swedish retrospective analysis of the survival of consecutive OHCA patients before (period 1, N: 1,218 patients) and after implementing the LUCAS device (period 2, N: 1,183 patients) in the EMS organization. In period 2, survival improved significantly over period 1; patients admitted to hospital alive increased from 25.4% to 31.9% ($p < 0.0001$), survival at 1 month increased from 7.1% to 10.7% ($p = 0.002$). Bystander CPR, crew-witnessed cases and post-resuscitation care increased, whereas the rates of VF declined and the response times as well as the delay to defibrillation increased. The LUCAS device was used in 60% of OHCA, manual CPR alone in 40%. Survival rates of patients who were actually treated with the LUCAS device were significantly lower than those who received only manual CPR during period 2; admission to hospital 28.6% vs. 36.1% ($p = 0.008$), survival to 1 month 5.6% vs. 17.6% ($p < 0.0001$). There were significant differences between the groups that likely influenced the difference in outcomes. Patients treated with the LUCAS device appeared to be a higher risk group with a lower chance of survival; there were significantly fewer crew-witnessed cardiac arrests treated with LUCAS vs manual CPR (13% vs. 22%) (data indicated crew-witnessed arrests had three times higher chance of survival), and the LUCAS patients were significantly more likely to have got adrenalin (95% vs. 53%) (data indicated patients who got adrenalin had a significantly lower chance to survive and generally had a longer time to defibrillation compared to those who only got manual CPR). The main reason for not having mechanical compression was probably early ROSC as the treatment protocol called for the LUCAS device to be applied first after manual CPR and defibrillator. In summary, due to many changes in care over the time periods, the authors could not conclude the LUCAS device was the contributor to the significantly increased survival. The LUCAS device did provide benefits to the staff's working environment and it appeared to be used in more difficult patients with a lower chance of survival.

Maule Y. The aid of mechanical CPR; better compressions, but more importantly – more compressions... (translated from French language; Assistance Cardiaque Externe; Masser mieux, mais surtout masser plus...). *Urgence Pratique*. 2011;106:47-48.

This is a Belgian retrospective study that compared compression ratios (the amount of time compressions were being delivered compared to the total CPR time) of the LUCAS chest compression system to that of manual compression. CODE-STAT™ 7.0 Data Review software was used to analyze the data. Two cohorts, consisting of 200 recordings each of non-traumatic CPR, were randomly created. Total duration of CPR was 41 minutes, 20 seconds (± 5 min., 15 sec.). The average compression ratio for cases using the LUCAS device was 93% ($\pm 4\%$). The compression ratio for cases using manual compressions was 69% ($\pm 6\%$). The author concludes that based on these ratios, mechanical chest compression devices, regardless of the type, allows for optimization of compression times during CPR.

Carmona Jiménez F, Padró P, García A, et al. Cerebral flow improvement during CPR with LUCAS, measured by Doppler *Resuscitation*. 2011; 82S1: 30. AP090. (This study is also published in a longer version, in Spanish language with English abstract, in *Emergencias* 2012;24:47-49.)

This is a Spanish prospective study which compared the middle cerebral artery flow (measured by Doppler at 5-6 cm) during manual chest compressions and then during LUCAS 2 chest compressions in six prehospital cardiac arrest patients. In three patients no data could be recorded due to early ROSC or no flow due to subarachnoid hemorrhage. In three patients the median flow during manual chest compressions was 31.6 ± 8.32 cm/s which increased to 50.6 ± 17.12 cm/s during LUCAS compressions. The authors mention that normal flow for a healthy person is 60-80 cm/s. The authors concluded that the LUCAS device seems to improve cerebral flow compared to manual CPR.

Saussy J, Elder J, Flores C, et al. Optimization of cardiopulmonary resuscitation with an impedance threshold device, automated compression cardiopulmonary resuscitation and post-resuscitation in-the-field hypothermia improved short-term outcomes following cardiac arrest. *Circulation*. 2010;122:A256. (Poster on file at Physio-Control.)

This a retrospective prehospital study from New Orleans EMS system comparing the results after implementing the LUCAS device 1(V2), the impedance threshold device (ITD) and post-ROSC in-field hypothermia (N: 180) in December 2009 to end of September 2010, with historical data (N: 374). Stable ROSC increased to 36% (38/106) compared to 21% (78/374) ($p < 0.002$). 69% (58/84) of the patients in which EtCO₂ was measured had an increased EtCO₂ value, and in 36% (30/84) this increase was over 10mm. EtCO₂ is a surrogate for circulation. There were no major adverse events. The authors concluded that the implementation of the devices was feasible, safe and resulted in a 71% increase of stable ROSC.

Axelsson C, Karlsson T, Axelsson Å, et al. Mechanical active compression-decompression cardiopulmonary resuscitation (ACD-CPR) versus manual CPR according to pressure of end tidal carbon dioxide (PETCO₂) during CPR in out-of-hospital cardiac arrest (OHCA). *Resuscitation*. 2009;80(10):1099-1103.

This prospective, cluster randomized Swedish study of 126 prehospital cardiac arrest patients showed that the LUCAS device 1(V1) (N:64) created significantly higher PETCO₂ values compared to manual CPR (N:62) with an average value of 3.26 vs. 2.69 kPa, $p = 0.04$. There were no differences in survival, probably due to the fact that the study inclusion was late, about 20 minutes after the cardiac arrest occurred, and the patients constituted a high risk group with a very low overall survival. PETCO₂ is a practical, non-invasive method that correlates well with circulation, such as pulmonary blood flow and cardiac output, and is known to be an almost immediate indicator for return of spontaneous circulation. PETCO₂ has also been used as an indicator for rescuer fatigue.

Olasveengen T, Wik L, Steen P. Quality of cardiopulmonary resuscitation before and during transport in out-of-hospital cardiac arrest. *Resuscitation*. 2008;76:185-190.

This is a Norwegian retrospective, observational study of CPR hands-off ratio on scene compared to during transport while treating prehospital cardiac arrest patients who received manual CPR (N: 36) or who got LUCAS 1(V1) CPR (N:7). With manual CPR the hands-off ratio increased from 0.19 ± 0.09 on-scene to 0.27 ± 0.15 ($p = 0.002$) during transport. Quality was significantly better with mechanical rather than manual CPR with no difference in hands-off ratio on scene (0.10 ± 0.06) vs. during transport (0.08 ± 0.06) ($p = 0.248$). The hands-off ratio over the entire episode of approx. 33 to 40 minutes was 0.22 ± 0.09 with manual CPR and 0.09 ± 0.06 with LUCAS CPR.

Maule Y. Mechanical external chest compression: a new adjuvant technology in cardiopulmonary resuscitation. (Translated from French language :L'assistance cardiaque externe: nouvelle approche dans la RCP.) *Urgences & Accueil*. 2007;29:4-7.

This publication describes the implementation and early results of LUCAS 1(V1) CPR at the Brugmann University Hospital in Belgium. 150 consecutive out-of-hospital cardiac arrest patients receiving LUCAS CPR (N: 123) or manual CPR (N: 27) were analyzed and compared to historical data on manual CPR (N: 140). The ROSC data with LUCAS (57.7%) was more than double as high compared to both the contemporary manual group (25.9%) as well as the historical manual group (22.2%). LUCAS CPR improved the physiological values of the patients; e.g. systolic blood pressure could be measured during LUCAS CPR which is hardly ever possible during manual CPR, SaO₂ readings were around 95%, patients showed signs of life again (moving, etc.) while they were still in VF or had a heart rhythm that produced no blood flow. In addition, the LUCAS device created an option to transport patients with effective CPR and freed up resources to focus other lifesaving tasks.

Axelsson C, Nestin J, Svensson L, et al. Clinical consequences of the introduction of mechanical chest compression in the EMS system for treatment of out-of-hospital cardiac arrest – a pilot study. *Resuscitation*. 2006;71:47-55.

This was the first cluster-controlled pilot study (N: 328) on LUCAS 1(V1) CPR vs. manual CPR in the out-of-hospital setting in Sweden. The LUCAS device was placed in the second tier and applied very late in the resuscitation process (18 minutes after collapse). The results on ROSC (both groups: 51%), hospitalized alive (38% in LUCAS and 37% in manual group n.s.) and discharged alive (8% vs. 10% n.s.) were the same in both groups. The majority of the survivors had CPC score 1 or 2 in both groups with no significant difference between the groups. During training, the LUCAS device was applied with CPR hands-off time of less than 20 seconds. The device proved to be impact resistant and dependable. Resuscitation efforts were facilitated by freeing the hands of the rescuer from chest compression. For the same reasons, safety increased during transport in a moving ambulance. The LUCAS device fit on >98% of the patients.

Patient Series

Beesems S, Hardig B, Nilsson A, et al. Force and depth of mechanical chest compressions and their relation to chest height and gender in an out-of-hospital setting. *Resuscitation*. 2015;91:67-72.

This analysis reviews chest wall dimensions and mechanics data stored in the LUCAS 2 device during chest compressions on 95 Dutch OHCA patients. Cases were included only if the suction cup was placed correctly, there was no realigned during the first 5 min of chest compressions, and if no other anomaly in device use was noted. All patients received manual CPR prior to the application of the device. The mean chest height was 232 mm for males and 209 mm for females ($P < 0.001$). The LUCAS device was found to deliver the compression depth according to its specifications (53 mm depth in patients with chest height >185 mm). The mean force required to achieve the compression depth of 53 mm ranged between 219 and 568 Newton with a mean of 410 Newton. No correlation was found between chest height and force required to reach 53 mm depth, nor gender and force. In summary, there was a large variation of the required force to achieve a compression depth of 53 mm in individual patients.

Pietsch U, Lischke V, Pietsch C. Benefit of mechanical chest compression devices in mountain HEMS: lessons learned from 1 year of experience and evaluation. *Air Med J*. 2014;33(6):299-301.

This Swiss study used and evaluated 2 mechanical chest compression devices in the alpine helicopter emergency services (HEMS). Seven rescues with ongoing CPR (3 with the LUCAS device; 4 with the AutoPulse® device) were performed in remote alpine terrain. These devices functioned properly and were easily applied even in difficult mountainous terrain. A previous study regarding helicopter rescue already proved the use of the LUCAS device lead to increased CPR quality and reduced hands-off time compared with manual chest compressions (Putzer, 2013). In summary, CPR under special circumstances like deep hypothermia, in which a prolonged CPR is essential, the use of the LUCAS or AutoPulse device was easy even in difficult alpine terrain which requires special rescue missions like winch or multi evacuation and rescue system evacuation.

Boyce L, Vliet Vlieland T, Bosch J, et al. High survival rate of 43% in out-of-hospital cardiac arrest patients in an optimised chain of survival. *Neth Heart J*. 2015;23(1):20-25.

This Dutch study describes short term and 1 year survival after OHCA in a system using LUCAS chest compression system. 242 consecutive OHCA patients were admitted to the emergency department between April 2011 and December 2012. Follow-up took place in July 2014. 76% of the patients had a cardiac origin, and 52 % had a shockable rhythm. In 74 % of patients, the cardiac arrest was witnessed, 76 % received bystander CPR and in 39 % an automatic external defibrillator (AED) was used. Of the 168 hospitalized patients, 144 underwent therapeutic procedures. A total of 105 patients survived until hospital discharge. Younger age, cardiac arrest in public area, witnessed cardiac arrest, cardiac origin with a shockable rhythm, the use of an AED, shorter time until return of spontaneous circulation, Glasgow Coma Scale (GCS) ≥ 13 during transport and longer length of hospital stay were associated with survival. Seventy two (69 %) survivors were alive at 1 year after the cardiac arrest. In summary, a survival rate of 43% after hospital admission of OHCA is achievable. Witnessed cardiac arrest, cardiac cause of arrest, initial cardiac rhythm and GCS ≥ 13 were associated with higher survival.

Walker R, Esibov A, Chapman F. Impact of shock timing during mechanical CPR on defibrillation efficacy. *Circulation*. 2014;130. Abstract 152.

This is a retrospective analysis of electronic defibrillator recordings from the Amsterdam Resuscitation Study (ARREST), a Dutch prospective out-of-hospital cardiac arrest registry, to investigate if shock efficacy (defined as absence of VF at five sec after the shock) varied if delivered during a pause of chest compressions vs during ongoing mechanical chest compressions, and, in the latter case, if the shock efficacy varied during the chest compression cycle. 153 cases using the LUCAS device and having at least one shock delivered after LUCAS device initiations were included. After LUCAS compressions were started, 509 shocks at 360 J occurred; VF termination outcome could be determined for 460 of these. There was no statistical difference in VF termination efficacy if the first eligible shock was delivered during a pause in mechanical compressions compared to if it was delivered during ongoing compressions (87% VF termination during a pause, and 85% during ongoing LUCAS compressions; $p=0.74$). For all eligible shocks, VF termination efficacy was 83.9% and 79.1% ($p = 0.20$) in the pause group vs ongoing compression group, respectively. For shocks delivered during mechanical chest compressions, there were no statistically significant differences in VF termination rate if the shock was delivered during four different stages of chest compression duty cycle, starting with piston upstroke phase : 89%, 80%, 69%, 80% ($p = 0.12$). For shocks during a pause, VF termination rate did not differ for pre-shock pauses ≤ 5 sec (82.4%) vs. >5 sec (84.8%; $p = 0.63$). In summary, shocks can be delivered during ongoing LUCAS compressions without reducing defibrillation efficacy. The exact shock timing during the LUCAS device compression cycle did not significantly alter shock efficacy. VF termination rate was not affected by pre-shock pause duration during LUCAS compressions.

Escott M, Traynor K, Jenks S, et al. A case series: hemodynamics of LUCAS device plus an ITD in cardiac arrest. *Prehosp Emerg Care.* 2014;18(1):156. AP144.

This is a U.S (suburban Houston TX) retrospective chart review of an EMS service that routinely uses the LUCAS device together with the impedance threshold device (ITD) in cardiac arrest. The goal was to determine if there was adequate perfusion, oxygenation, and ventilation in a case series of OHCA patients. Inclusion criteria included: PEA or asystole cardiac arrest with no ROSC recorded, ITD + LUCAS compressions, hemodynamic parameters (BP, SPO₂, ETCO₂, and ECG). For the 13 patients in cardiac arrest without ROSC, the parameters were mean arterial pressure: median 83 mmHg, mean of 86 mmHg (SD 31), ETCO₂: median 28 mmHg, mean of 31 mmHg (SD 17), SpO₂: median 85%, mean 82% (SD 16). This data set demonstrates near-normal parameters of perfusion, oxygenation, and ventilation in cardiac arrest patients with an initial rhythm of asystole or PEA, however, none of these patients obtained ROSC. In summary, despite optimization of cardiac arrest perfusion management with excellent hemodynamic parameters, resuscitation was not successful. Further studies in this area are needed.

Frattini B, Jost D, Lanoe V, et al. How to minimize “hands-off times” during mechanical chest compression device installation. *Resuscitation.* 2014;85S:S87. AP.

This French observational prospective open study measured the hands-off-times related to the installation of the LUCAS device, depending on whether it was applied in one step or using a two-step approach, in OHCA patients treated by advanced life support team. In 128 eligible patients the hands-off time, using thoracic impedance signals recorded by the CODE-STAT 9.0 data software, could be measured in 77 cases (44 cases using a one-step LUCAS application; 33 cases using a two-step LUCAS application). The total hands-off time at the application of the LUCAS device was similar between the two methods (20-30 sec). The two-step approach allowed for an on average 12 second period of manual chest compressions between the two interruptions. In summary, the authors suggest installing the LUCAS device in two stages with a minimum of 30 chest compressions between the two application steps to ensure satisfactory coronary and cerebral perfusion.

Fagnoul D, Taccone F, Belhaj A, et al. Extracorporeal life support associated with hypothermia and normoxemia in refractory cardiac arrest. *Resuscitation.* 2013;84:1519-1524.

This is a Belgian retrospective, observational study of in- and out-of-hospital patients (N = 24) with refractory cardiac arrest treated with early ECMO. Twenty two of 24 patients received compressions with the LUCAS device prior to initiation of ECMO. The time from collapse to ECMO was on average 58 min and shorter in survivors than in non-survivors (41 min vs. 60 min, p = 0.059). Overall six patients (25%) survived with good neurological outcome at day 28. Four patients with irreversible brain damage had organ function suitable for donation. In summary, ECMO provided satisfactory survival rates with good neurologic recovery in refractory CA for both in- and out-of-hospital patients and allowed organ donation in a significant proportion of the EMCO non-survivors. It was noted that the LUCAS device had advantages over manual CPR, facilitating more rapid transportation to the hospital as well as ECMO insertion.

Belohlavek J, Skalicka H, Smid O, et al. Implementation of hyperinvasive approach to out-of hospital cardiac management: results from presimulation and simulation phases of the “Prague OHCA Study”. *Resuscitation.* 2013;84S:S68. AP150.

This Czech prospective, randomized study combining prehospital intra-arrest hypothermia, mechanical chest compression, intra-hospital ECLS and early, aggressive clinical diagnosis and treatment encountered logistic barriers that necessitated a presimulation and simulation phase. Sixty seven patients were enrolled (57-presimulation and 10-simulation protocol) from January to February 2012. Thirty-seven patients were admitted after ROSC in prehospital setting while 30 patients were admitted with ongoing mechanical CPR. Acute coronary syndrome was the cause of arrest in 42% of patients; STEMI 36%, overall cardiac origin of OHCA was identified in 61% of patients. Average time until ROSC was 40 min, (median 31 min). Fifty-four percent of patients survived to discharge. CPC scores of 1-2 during hospitalization occurred in 75% of survivors. Survival with good neurological outcomes in patients admitted with ongoing CPR was 33%. In conclusion, a combined, “hyperinvasive” approach to refractory OHCA is a viable option with challenging preliminary results.

lordache D, Dinga V, Grasu C. CPR of OHCA in Bucharest Romania: a comparative study of different crew types. *Resuscitation.* 2012;83:e49. AP067.

This Romanian study compared the resuscitation results of 445 OHCA when three different crew combinations provided resuscitation; PA crew (BLS), B crew (nurse-care mobile unit) and C-crew (mobile intensive care unit lead by a physician). One ambulance had a LUCAS device. Maximum time between collapse and starting resuscitation was 20 min. Overall, ROSC was achieved in 38 patients. PA+C crews treated 80 patients of which 3 patients achieved ROSC (3.75%). B+C crews treated 161 patients of which 12 patients achieved ROSC (7.45%). C crews treated 204 patients of which 23 patients achieved ROSC (11.2%). C crew used the LUCAS device on 11 patients of which 7 patients achieved ROSC (63.63%). In summary, the results obtained were higher when qualified personnel performed resuscitation. The highest percentage of ROSC was obtained when using the LUCAS device in these OHCA.

Yost D, Phillips R, Gonzales L, et al. Assessment of CPR interruptions from transthoracic impedance during use of the LUCAS mechanical chest compression system. *Resuscitation*. 2012;83(8):961-965.

This is a retrospective U.S. prehospital analysis of CPR interruption time when applying and using LUCAS 1(V2) by looking at transthoracic impedance data transcripts from 32 prehospital cardiac arrest patients. The analysis showed it was possible to apply the LUCAS device with interruptions of less than 20 seconds in ~16% of the cases, whereas 25% had an interruption time of over 1 minute. The median interruption time was 32.5 seconds (Interquartile Range IQR 25-61 sec). The perceived interruption time by the rescuer correlated poorly to the real (pauses were often double as long as perceived). The compression fraction during mechanical CPR was 0.88. The authors conclude that training on application technique is key to keep the interruption time at a minimum and that impedance data can provide objective feedback on use of mechanical CPR devices.

Van Gerven E, Keirens A, Muysoms W, et al. Combination of a mechanical active compression-decompression cardiopulmonary resuscitation mechanism (LUCAS 1 and the Boussignac tube) during CPR in out-of-hospital cardiac arrest. *Resuscitation*. 2011;81(S1):S31 AP094.

This is a prehospital observational patient series (N: 58) investigating the combination of LUCAS 1(V1) and the Boussignac tube as ventilation method. ROSC was achieved in 24 (41.4%) patients and 9 survived (15.5%). The authors conclude that the combination increased success rates compared to general statistics for Europe and U.S. (survival rates of 10.7% and 8.4% respectively) and that the fully hands-free CPR was accepted by great enthusiasm by the users.

Yost D, Gonzales L, Lick C, et al. Abstract 38: North American LUCAS Evaluation: prehospital use of a mechanical chest compression system. *Circulation*. 2010;122:A38. (Poster on file at Physio-Control.)

This is a prehospital patient series (N: 332) evaluating the feasibility of 66 LUCAS 1(V2) devices when used in four large U.S. EMS systems; Austin (TX), St Paul (MN), Anchorage (AK) and Contra Costa (CA). The device fit 95% of the patients (317/332). It was estimated that the pause in CPR for LUCAS application was less than 20 seconds in 71% of the cases. On a scale of 1 to 10, providers rated the ease of use of the LUCAS device to an average of 9.0 ± 1.4 and a perceived effectiveness of the LUCAS device to provide quality compressions on a scale of 0 to 10 to an average of 9.3 ± 1.4 .

Steen S, Sjöberg T, Olsson P, et al. Treatment of out-of-hospital cardiac arrest with LUCAS, a new device for automatic mechanical compressions and active decompression resuscitation. *Resuscitation*. 2005;67:25-30.

These are the first 100 consecutive prehospital patients receiving LUCAS 1(V1) CPR in Lund, Sweden. The guidelines from year 2000 were followed, i.e. defibrillate before CPR. The 1-month survival was best in the group of witnessed VF patients; 25%, whereas the survival of non-witnessed cardiac arrest patients was zero. This publication reports on safety aspects of using the LUCAS device in ambulances. The LUCAS device did not move on a manikin in a crash test at 30 km/h. The authors recommend that mechanical compressions should be mandatory during transport out of safety reasons.

In-Hospital Studies

Studies with Control Group

Verstraete S, De Knock J, Müller N, et al. Does the use of LUCAS influence survival for in-hospital cardiac arrest patients? ERC congress 2008. (Poster 240 on file at Physio-Control.)

This is a Belgian retrospective analysis of 73 consecutive in-hospital cardiac arrest patients who got random allocation to either LUCAS 1(V1) CPR (N:18) or manual CPR (N:34). 22 patients were excluded from the analysis due to ROSC within 4 minutes (N:16), insufficient data records (N: 4) or too obese to fit the LUCAS device (N:2). There was no significant difference in ROSC (56% vs. 44%) or hospital discharge (17% vs. 14%) between LUCAS CPR and manual CPR. All patients had a good neurological outcome. There were no major complications reported with the use of the LUCAS device, and the authors note that the device spares a useful pair of hands during the advanced life-support efforts.

Patient Series

Cloïn J, van Berkomp P, Venema A, et al. In-hospital implementation of the LUCAS-2: Early, one-time right, is essential. *Resuscitation*. 2012;83(S1)e120-121. AP252 (Poster on file at Physio-Control).

This is a Dutch retrospective study (N:50 patients) measuring how long time it took for nurses to apply LUCAS 2, by using defibrillator monitoring data, supervisor observations and hospital records. The LUCAS device was used in 80% of the resuscitations, and applied after median 13 sec (5-20 sec) of BLS interruption, as early as possible. A two stop deployment was used; back plate first, upper part secondly. The LUCAS device required 10 ±25 sec. total interruption of compressions in the real time set up. The most frequently and serious delaying application factors were: not fully attaching the claw locks to the back plate; needing to reposition the device; clothing getting stuck in the claw locks; and not powering on the device in advance. The authors relate these factors to infrequent use and time since training, and conclude that the LUCAS device can be applied early, within 10-25 sec. if having a trained personnel and looking out for confounding factors.

Bonnemeier H, Simonis G, Olivecrona G, et al. Continuous mechanical chest compression during in-hospital cardiopulmonary resuscitation of patients with pulseless electrical activity. *Resuscitation*. 2011;82:155-9.

This is an analysis of 28 in-hospital patients that went into PEA due to pulmonary embolism (N: 14), cardiogenic shock/AMI (N:9), severe hyperkalemia (N:2), sustained arrhythmias/electrical storms (N:3). During on average 37.5 minutes (from 10 to 180) of LUCAS 1(V1) compressions the underlying cause were diagnosed and treated with help of CT or PCI or medication. A total of 14 patients (50%) survived of which 13 had no significant neurological deficit. The authors discussed that in six patients that had pulmonary emboli but contraindications to thrombolysis, it was possible that the LUCAS compressions alone were responsible for the thrombus fragmentation. The authors noted that the device bought time and allowed for interventional procedures and treatments. They concluded the device was feasible, safe and might improve outcomes.

Catheterization Laboratory & PCI Patient Series

Wagner H, Hardig B, Rundgren M, et al. Mechanical chest compressions in the coronary catheterization laboratory to facilitate coronary intervention and survival in patients requiring prolonged resuscitation efforts. *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine*. 2016;24(1):4.

This Swedish study aimed at re-evaluating survival to hospital discharge and assessed long-term outcome in patients who received chest compressions (CC) during simultaneous PCI. Patients presenting to the cath lab with spontaneous circulation, suffering CA and requiring prolonged mechanical CC during cath lab procedures between 2009 and 2013 were included. For comparison, patients receiving prolonged manual CC in the cath lab in the pre-mechanical CC era were evaluated. Six-month and one-year survival with a mechanical CC treatment strategy from 2004 to 2013 was also evaluated. Thirty-two patients were included between 2009 and 2013 (24 ST-elevation myocardial infarction (STEMI), 4 non-STEMI, 2 planned PCI, 1 angiogram and 1 intra-aortic counter pulsation balloon pump insertion). Twenty were in cardiogenic shock prior to inclusion. Twenty-five were successfully treated with PCI. Median mechanical CC duration for the total cohort (n = 32) was 34 min (range 5–90), for patients with circulation discharged from the cath-lab (n = 15) it was 15 min (range 5–90), and for the patients discharged alive from hospital (n = 8) it was 10 min (range 5–52). Twenty-five percent (8/32) survived with good neurological outcome at hospital discharge. This survival rate was compared to the period in the pre-mechanical CC era, where only 10% (1/10) survived to hospital discharge with good neurological outcome. Eighty-seven percent of the patients in the mechanical CC cohort had their coronary or cardiac intervention performed during mechanical CC with an 80 % success rate. This shows that the use of mechanical CC during an intervention does not seem to impair the interventional result substantially. In summary, in patients in which normal advanced resuscitation efforts had failed, and who were treated with the LUCAS device during a simultaneous PCI, 25% survived with good neurological outcome to hospital discharge. The majority (87%) of these survivors was alive at 1-year follow up.

Retzer E, Friant J, Beiser D, et al. Utilization of a mechanical compression device increases return of spontaneous circulation in patients with cardiac arrest in the cardiac catheterization laboratory. Abstract presented at The Society for Cardiovascular Angiography and Intervention (SCAI) Congress, May 2015, San Diego. Abstract #146.

This is a U.S. retrospective analysis of all patients in whom resuscitation was attempted in the cath lab at University of Chicago between May 2011 and November 2014. Chest compressions were performed on 16 patients for cardiac arrest (11 manual and 5 mechanical). 100% of patients receiving mechanical compressions achieved ROSC in comparison to only 36% of those receiving manual compressions. This improved rate of ROSC was achieved in the setting of great patient comorbidities (increased BMI and diabetes). In summary, resuscitation performed in the cath lab with a mechanical chest compression device increases the rate of ROSC achieved without the expense of increased adverse patient outcomes and allows consistent compressions within a small space and reduces rescuer exposure to radiation.

Balevski I, Markota A, Purg D, et al. Intra-arrest percutaneous coronary intervention: a case series. *Wiener klinische Wochenschrift*. 2015;1-4.

This Slovenian retrospective analysis presents experience with emergency coronary angiography performed during on-going mechanical CPR in a eight patients, six witnessed OHCA (75%) and 2 witnessed IHCA patients (25%). Revascularization under continuous CPR was achieved in all 8 patients. Mean total duration of CPR was 90.5 ± 33.3 min. Mechanical CPR (2 patients using LUCAS, 6 patients using AutoPulse) was initiated in the emergency room and not in the prehospital setting. IABP was only inserted when ROSC was achieved in catheterisation laboratory. Sustained ROSC was achieved in 2 patients (25 %). Both patients had poor neurological outcome (CPC 4), and both died within 3 months. In summary, the prolonged duration of CPR, lack of prehospital mechanical cardiopulmonary resuscitation devices and lack of extracorporeal life support devices were the most likely reasons contributing to poor survival.

Koyalakonda S, Nair S, Patel B, et al. Cardiac arrest in the catheter laboratory: feasibility and outcomes of mechanical chest compression device. *Catheterization and Cardiovascular Intervention*. 2014;83,(S1):S1–S247. A-061.

This UK retrospective study assesses the feasibility and outcomes of using the LUCAS device in patients who had cardiac arrest in the cath lab of a large tertiary cardiac center. A total of 4654 PCIs including 1401 primary PCIs were performed from January 2012 to August 2013. The LUCAS device was used in 17 patients who had cardiac arrest in the cath lab during that time. Cardiac arrest prior to arrival in the cath lab occurred in 12% of patients (n = 2). Cardiogenic shock on initial presentation occurred in 35% of patients (n = 6). Cardiac arrest rhythm prior to the deployment of the device was PEA in 71% (n = 12) and VT/VF in 29% (n = 5) of patients. The average duration of LUCAS device use was about 40 min. In all patients, the planned procedure was carried out and 4 patients required emergency surgical intervention. ROSC was restored in 41% (n = 7) of patients. Survival to hospital discharge was 12% (n = 2) without any residual neurological deficit. In summary, these data demonstrate the LUCAS device can be successfully used in the cath lab setting for a prolonged period of time, allowing for the operator to continue with the PCI.

Kalra A, Maharaj V, Johannsen R, et al. Catheterization laboratory activation during mechanical cardiopulmonary resuscitation: When should we say "No?". *Catheterization and Cardiovascular Interventions*. 2014;83(1):58-64.

This U.S. editorial discusses the strengths and pitfalls of mechanical CPR, current evidence behind activation of the cath lab with ongoing mechanical chest compressions, and shares experience from 2 institutions with patients brought to the cath lab in cardiac arrest. Six patients transferred to the cath lab for PCI without ROSC while on the LUCAS device died. Two patients were transitioned to mechanical circulatory support via ECMO following completion of coronary angiography performed with LUCAS compressions ongoing. Mean time of LUCAS device use was 88.6 min. The most common initial non-perfusing rhythm was VF (n = 5). The most common culprit vessel was left anterior descending coronary artery (n = 3; 66%) with the left main coronary artery being occluded in the other two cases; coronary angiography could not be completed in one patient. In contrast, 67% (4/6) of patients brought to these cath labs with spontaneous circulation who then suffered cardiac arrest while in the cath lab survived (the LUCAS device was used some time before or while in cath lab). In summary, currently available data do not support routine activation of the cath lab for patients without ROSC, even if mechanical CPR is being performed. For patients with cardiac arrest in the cath lab, however, it seems reasonable to institute mechanical CPR when this is available. Alternatively, other means of cardiac support, such as early transition of patients to ECMO or assist devices, to allow intra-arrest PCI could be mobilized for selected patients.

Wagner H, Rundgren M, Hardig B, et al. (2013) A structured approach for treatment of prolonged cardiac arrest cases in the coronary catheterization laboratory using mechanical chest compressions. *Int J Cardiovasc Res*. 2013;2:4.

This Swedish article describes a logistic approach for prolonged resuscitation efforts in the cath lab using the LUCAS device during simultaneous PCI. Physiological measurements and logistics in 10 patients experiencing prolonged cardiac arrest in the cath lab were identified and analyzed. Critical areas included: Familiarity with the working environment in the cath-lab, team work among the multiple staff involved, recognizing the cause of arrest, and the opportunity for continuous monitoring of vital physiological parameters during the resuscitation effort. A structured approach was developed: In patients not obtaining ROSC following a few min of ALS according to guidelines, activate LUCAS compressions while performing PCI and optimize physiological parameters (arterial blood pressure $\geq 70/40$ mmHg, $\text{ETCO}_2 \geq 15$ mmHg/2.0 kPa, pulse oximetry $>80\%$, thrombolysis in myocardial infarction-3 flow in open vessels and cerebral oximetry $\sim 45\%$). In shock-resistant VF, maintain circulation with the LUCAS device until restoration of coronary flow prior to further defibrillation attempts. Consider therapeutic hypothermia. In summary, implementing a structured resuscitation approach during prolonged resuscitation efforts in the cath lab, might improve team work and physiological parameters, which may result in a more calm and success-oriented setting.

Mooney M, Hildebrandt D, Feldman D, et al. Level 1 shock team—early experience in ECMO use as a rescue device in cardiac arrest from STEMI in the cardiac catheterization laboratory. *JACC*. 2013;(61);10:E17.

This is a U.S. retrospective cath lab review of STEMI patients experienced a cardiac arrest during PCI and who remained hemodynamically unstable despite mechanical CPR (LUCAS), IABP and inotropes, and therefore were placed on ECMO. Five patients (median age 64) presented during a 14-month period. LUCAS CPR was used as a bridge to ECMO. The time from arrest to ECMO was on average 52 minutes (16-133 minutes). ECMO was continued for a median time of four days (three to five days). Therapeutic hypothermia was provided in four out of the five patients. Prior to ECMO, ejection fractions of less than 10% were noted in four patients, and one patient had no cardiac output present. Four out of five patients (80%) survived to hospital discharge with a good neurological outcome (CPC score 1-2). The ejection fraction at hospital discharge was 45% (25-65%). The authors conclude that ECMO can be a lifesaving technique for refractory PEA occurring in the cath lab and that the LUCAS device was a valuable adjunct. Together with cooling, excellent neurological outcomes were seen and there was a striking recovery of left ventricular function.

Wagner H, Madsen Hardig B, Rundgren M, et al. Cerebral oximetry during prolonged cardiac arrest and percutaneous coronary intervention. *ICU Director*. 2013;4(1):22-32.

This is a Swedish study measuring cerebral oxygenation as well as other physiologic parameters during LUCAS 2 or LUCAS 1(V1) chest compressions in five prolonged resuscitation cases during PCI in the cath lab (median 45 min, 12-90 min). The use of the LUCAS device produced numerically higher cerebral oxygenation values compared to previously published values on manual chest compressions (SctO_2 values of 44-55% with LUCAS vs. earlier studies showing 30-40% with manual. Normal values are 65-70%). Median systolic arterial blood pressure during LUCAS CPR was 88 mmHg, mean arterial perfusion pressure was 58 mmHg, coronary perfusion pressure was 19 mmHg, SPo_2 was 81% and ETCO_2 2.5kPa/18.8 torr. Three of the five patients had cardiac arrest due to STEMI and were unstable upon arrival to the cath lab. One had cardiac arrest caused by a cardiac tamponade post PCI procedure, and one elective NSTEMI patient crashed during PCI procedure. Four patients had technically successful PCI during cardiac arrest. Two achieved ROSC, however, none survived to hospital discharge. The authors noted that the LUCAS device had to be repositioned cranially in two patients to produce acceptable physiological values. The authors discuss that cerebral oximetry is feasible during LUCAS CPR and might be an complementary tool to indicate CPR quality and serve as a guide for decision of further treatment like ECMO or IABP.

Azadi N, Niemann J, Thomas J. Coronary imaging and intervention during cardiovascular collapse: Use of the LUCAS mechanical CPR device in the cardiac catheterization laboratory. *Invasive Cardiol.* 2012;24:79-83.

This is a U.S. case series describing the use of LUCAS 2 in the cath lab. Four patients experienced sudden cardiac arrest in the setting of acute ST-elevation myocardial infarction (STEMI) and one patient during elective (non-acute, planned) PCI. In all cases it was possible to do the emergency PCI during LUCAS compressions, however only one patient survived. The survivor, who received 15 defibrillation shocks, was discharged home without any neurological sequelae. The authors discuss that critically ill patients will likely comprise a larger portion of catheterization laboratory patients in the future and mechanical CPR may prove itself to be an efficient, effective, and practical back up tool. The publication provides angiographic images with the LUCAS device and a discussion of the benefits and feasibility of coronary angiography and PCI during LUCAS compressions.

Wagner H, Hardig B, Harnek J, et al. Monitoring possibilities of resuscitation efforts during cath lab resuscitation. *Resuscitation.* 2010;81:S50. (Poster on file at Physio-Control.)

This is a single case report where hemodynamic measurements, ETCO₂ and SpO₂ saturation were recorded continuously during the whole cardiac arrest event. The LUCAS device 1(V2) maintained circulation during 52 minutes of resuscitation and PCI as well as 10 minutes after ROSC was achieved. It showed how injection of epinephrine influenced flow and oxygen saturation. It confirmed that the LUCAS device could produce and maintain circulation for up to at least one hour with good neurologic outcome. The LUCAS device produced significantly higher systolic and mean arterial pressure and significantly lower diastolic arterial pressure compared to manual chest compressions.

Wagner H, Madsen Hardig B, Harnek J, et al. Abstract 91: Aspects on resuscitation in the coronary interventional catheter laboratory. *Circulation.* 2010;122:A91. (Poster on file at Physio-Control.)

This is an analysis of vital physiological parameters during resuscitation efforts collected by a cath lab monitoring system during manual and LUCAS 1(V2) chest compressions in 10 cardiac arrest patients. The patients were mainly acute STEMI patients and required lengthy resuscitation of an average of 45 ±23 minutes. The LUCAS device created higher systolic and mean arterial blood pressures (103 ±33 and 46 ±17) vs. manual CPR (48 ±10 and 32 ±6 mmHg). CPP fluctuated widely over the resuscitation time, and increased at infusion of adrenalin. However, adrenalin decreased EtCO₂ and SpO₂. 9/10 patients had a successful PCI, 50% survived between 0.5 and 13 days and 20% were discharged with good neurological outcome. The authors concluded that mechanical chest compressions could maintain circulation for extended periods of time during cardiac arrest in the cath lab.

Larsen A, Hjörnevik Å, Bonarjee V, et al. Coronary blood flow and perfusion pressure during coronary angiography in patients with ongoing mechanical chest compression: a report on 6 cases. *Resuscitation.* 2010;81:493-497.

This publication investigates the relationship between coronary perfusion pressure and TIMI flow (flow visualized by coronary angiography) in six Norwegian patients who received LUCAS 1(V1) CPR and had a simultaneous coronary angiography. The duration of resuscitation was 30 to 150 minutes. In 4 out of 6 patients there was a satisfactory coronary artery perfusion pressure (measured invasively) and TIMI grade 3 flow (normal) on coronary angiography. Two of the six patients survived the first 24 h. Two patients did not have a satisfactory perfusion pressure and adequate flow rate was not seen. This case series showed that the LUCAS device was capable of producing a coronary perfusion pressure above 15 mmHg at least in some patients, which was associated with TIMI 3 flow as demonstrated with coronary angiography. In the discussion part the importance of correct positioning of the LUCAS device in the middle of the chest to ensure flow is highlighted.

Wagner H, Terkelsen, C, Friberg H, et al. Cardiac arrest in the catheterization laboratory: a 5-year experience of using mechanical chest compressions to facilitate PCI during prolonged resuscitation efforts. *Resuscitation.* 2010;81(4): 383-387.

This is a Swedish retrospective study of the use of LUCAS 1 (V1 and V2) over five years, in mainly STEMI patients who arrived to the cath lab alive but required lengthy resuscitation with LUCAS CPR during continued coronary angiography/intervention. 33 STEMI patients (out of a total 3,058) required LUCAS CPR, indicating an incidence of prolonged cath lab resuscitations of 10.8 per 1000 STEMI procedures. An additional 10 patients (7 NSTEMI, 2 elective and 1 patient with tamponade) required LUCAS CPR, resulting in a total of 43 patients during the five years. Of these 43 patients, 12 patients were discharged alive from the hospital, 11 with good neurological outcome (CPC 1). The one who did not have a good outcome died in a referral hospital due to anoxic brain injury; this was one of the earliest patients for whom the LUCAS device was applied very late. Survival rate in this high-risk group of patients was ~25%. The mean treatment time was 28.15 minutes (1-90 minutes), and for the survivors the mean treatment time was 16.5 minutes (1-50 minutes). In the majority of cases the culprit artery was the LAD or Left Main coronary artery. 65% of the patients had PEA as the initial rhythm. The LUCAS device was compatible for use with most fluoroscopy projection angles except the straight anterior posterior angle. Fortunately, the available views are almost always the preferred angiographic views during PCIs even without the LUCAS device. These authors concluded it is unlikely that few if any of these patients would have survived without the use of the LUCAS device.

Larsen A, Hjernevik A, Ellingsen C, et al. 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.

Norwegian out-of-hospital and in-hospital cardiac arrest patients (N: 13) were transported to and treated in the cath lab with ongoing LUCAS compressions. The mean LUCAS 1(V1) compression time was long: 105 ±60 minutes (range 45–240 minutes). Angiography and eventually PCI was possible in all cases during ongoing LUCAS chest compressions. There were no practical problems with regard to LUCAS application or ventilation. The mean systolic and diastolic blood pressure obtained by the LUCAS device was 81±23 and 34±21 mmHg, respectively. Three patients survived the procedure, but no one was discharged alive. Autopsies were performed in 11 patients and showed no life-threatening or unexpected injuries despite the long resuscitation attempt. Manual CPR would have been almost impossible and could not have been extended for a prolonged period. The LUCAS device was considered well-suited for use in the cath lab and ensured an adequate systemic blood pressure in most patients without life-threatening injuries.

Grogaard H, Wik L, Eriksen M, et al. Continuous mechanical chest compressions during cardiac arrest to facilitate restoration of coronary circulation with percutaneous coronary intervention. *J Am Coll Cardiol*. 2007;50:1093-1094.

These Norwegian authors report on two cardiac arrest patients receiving LUCAS 1(V1) CPR during PCI. Moreover, the applicability of performing PCI during uninterrupted LUCAS chest compressions in a methodological pig study (N: 5) is evaluated. It was concluded that the LUCAS device enabled adequate hemodynamics as well as angiography and PCI in both humans and pigs. The coronary arteries were visualized despite the fact that the LUCAS device occupies the space above the middle of the chest allowing only for oblique angiographic projections. The first case describes a prehospital patient with a therapy-resistant cardiac arrest that arrived in the emergency department with ongoing LUCAS compressions. Due to a delay in the decision to transport the patient to the cath lab, the patient was sent to surgery for revascularization after 110 minutes of cardiac arrest. Circulation was maintained by the LUCAS device only, and 6 hours after the cardiac arrest, LUCAS was discontinued and the patient died. The second case was a patient who had received a successful PCI. Immediately afterwards she developed PEA. After ten minutes of manual CPR, VF and failed defibrillation attempts, LUCAS compressions were initiated. A control angiogram showed reduced coronary flow, which was followed by PCI and increased medication. After 70 minutes of LUCAS compressions and a successful revascularisation, stable ROSC was achieved. This patient recovered neurologically intact and today has a 100% working capacity. The authors concluded that LUCAS CPR may be an alternative approach for at least two circumstances: Cardiac arrest occurring during the PCI procedure and other cardiac arrests with suspected MI, if the patient can be brought to the cath lab in a short time with uninterrupted mechanical chest compressions.

Case Reports

Zhang Z-P, Su X, Liu C-W, et al. Continuous mechanical chest compression-assisted percutaneous coronary intervention in a patient with cardiac arrest complicating acute myocardial infarction. *Chinese Med J.* 2015;128(6):846-848.

This Chinese report describes a 47 year-old male who presented with an AMI complicated by cardiac arrest undergoing successful PCI using the LUCAS device. VF occurred during transfer to the cath lab. CPR and defibrillation were performed, but incessant VT/VF occurred. ECMO could not be performed at first due to lack of proper personnel. The LUCAS device was used to maintain blood pressure about 104/50 mmHg. With the LUCAS device running, PCI of the LAD and a stent was deployed and an intraaortic balloon pump (IABP) was inserted in a total of 13 min. PCI was successful, but the patient did not regain ROSC. ECMO was inserted and then the LUCAS device was stopped. The patient converted to sinus rhythm and ROSC was achieved. ECMO was removed on the 4th day and IABP weaned off on the 7th day after admission. Although cardiac function recovered very well, the patient had incurred hypoxic brain injury and died. In summary, the outcome was poor in this case, but it illustrates the use of the LUCAS device made it possible perform uninterrupted PCI during ongoing cardiac arrest, especially under the condition of EMCO could not be applied immediately.

Darocha T, Kosinski S, Moskwa M, et al. The role of hypothermia coordinator: a case of hypothermic cardiac arrest treated with ECMO. *High Alt Biol Med.* 2015;00(00):1-4.

This Polish case report describes a rescue of a patient with severe hypothermia who was found in the mountains. The hypothermia coordinator started the procedure for these types of patients with the option of extracorporeal warming and secured access to a LUCAS 2 device. The patient suffered VF in the ambulance and the LUCAS device was applied. After reaching the hospital, warming was started with ECMO. The total duration of circulatory arrest was 150 min. The patient regained ROSC, was extubated, and left the ICU 5 days later with good neurological status. Echocardiogram showed the patient had normal left ventricular ejection fraction (EF-65%). After 6 months, neurological examination did not show any functional impairment. In summary, good coordination, planning, predicting possible problems, and acting in accordance with the agreed procedures, made it possible to shorten the time of reaching the destination hospital while the LUCAS device allowed for perfusion of vital organs especially the brain until definitive treatment could be implemented.

Stechovsky C, Hajek P, Cipro S, et al. Mechanical chest compressions in prolonged cardiac arrest due to ST elevation myocardial infarction can cause myocardial contusion. *Int J Cardiol.* 2015;182:50-51.

This Czech report describes a 60 year-old man with STEMI who developed VF, then PEA during transport to the hospital. The LUCAS 2 device provided compressions. Coronary angiography showed total LAD occlusion and PCI was performed with ongoing LUCAS compressions. Intraaortic balloon pump was inserted. Needle to first balloon inflation was 10 min and the whole procedure took 20 min. Mean arterial blood pressure with ongoing LUCAS compressions was 20-50 mmHg. After reperfusion the heart generated sufficient contractions and LUCAS CPR was discontinued. ROSC was achieved after 90 minutes of cardiac arrest. The patient died of cardiogenic shock 11 hours later. Autopsy showed transmural infarction of the anterior septum and anterior-lateral walls of the left ventricle but also massive subepicardial hemorrhage under the inferior part of the sternum over which the suction cup of the LUCAS device had been placed. Histological samples of the myocardium outside the infarct itself and from the right ventricle showed marked interstitial edema and hemorrhages with preserve viability of myocytes. In summary, in this case, prolonged compressions with the LUCAS device can cause myocardial contusions.

Langwieser N, Sinnecker D, Rischpler C, et al. Treatment of acute left main occlusion by early revascularization combined with extracorporeal circulation achieves substantial myocardial salvage as assessed by simultaneous positron emission tomography/magnetic resonance imaging. *Resuscitation.* 2014.85;10:e171-e173.

This German case report describes a 31 year-old male who collapsed in the physician's office and had CPR started immediately. The patient was transported to the cath lab with ongoing CPR using the LUCAS 2 device. ROSC was confirmed 100 min after onset of resuscitation. Cardiac catheterization showed severe impairment of the global left ventricular function due to thrombotic occlusion of the proximal left main trunk that was re-cannulation by stenting with support of an intraaortic balloon pump (IABP). Due to profound cardiogenic shock, IABP was replaced by ECMO to stabilize the hemodynamic situation and to allow recovery of the stunned myocardium as well as therapeutic hypothermia for 24 hours. The patient improved and was weaned from ECMO after 5 hours. He was transferred to the ward on day 6 with no signs of neurological impairment. In conclusion, treatment of acute left main occlusion by early revascularization combined with prolonged CPR with LUCAS device and ECMO achieved substantial myocardial salvage.

Forti A, Zilio G, Zanatta P, et al. Full recovery after prolonged cardiac arrest and resuscitation with mechanical chest compression device during helicopter transportation and percutaneous coronary intervention. *J Emerg Med.* 2014.47;6:632-634.

This Italian case used the LUCAS device while transporting a 53-year-old man in cardiac arrest by helicopter emergency medical services (HEMS) to the cath lab facility for a PCI. The patient received bystander CPR prior to arrival of the first emergency unit. He had persistent VF despite multiple defibrillations and standard ACLS care. After the LUCAS device was started, the skin color of the face turned from a dark gray to middle red-gray. SpO₂ was 89%, with 100% FIO₂. After a 10 min transport by helicopter, the patient underwent PCI. He received 2 stents during PCI and an intraaortic balloon was inserted. ROSC was achieved 115 min after cardiac arrest and 90 min of LUCAS compressions. One hour after intensive care unit admission, the patient developed a large left pectoral hematoma. A CAT scan revealed bleeding from a left intercostal artery which was immediately treated with arterial embolization. He initially suffered a deficit in short-term memory and 30 days after the event was transferred to a rehabilitation facility. Sixty days after the event, the patient could walk without help and did not show any neurological or renal impairment. In summary, the LUCAS device permitted safe and effective CPR during helicopter transportation and during PCI. The bleeding complication cannot be certainly ascribed to the LUCAS device, as it has been reported also with manual chest compressions, but regardless, it is considered only a minor complication.

Putzer G, Mair B, Hangler H, et al. Emergency extracorporeal life support after prolonged out-of-hospital cardiac arrest. *J Cardiothoracic and Vascular Anesthesia.* 2014.28;4:1024-1026.

This Austrian case reports describes a 43-year old male who received 107 min of CPR and survived with good neurological outcomes. The previously healthy man collapsed in cardiac arrest while skiing and received immediate bystander CPR. Ski patrol Advanced Life Support (ALS) arrived after 5 min and shortly after that a physician-staffed helicopter equipped with a mechanical chest compressor arrived and the LUCAS device was applied. VF persisted and after 35 min of treatment on the scene, the patient was transported in the helicopter with ongoing LUCAS compressions and arrived, still in VF, at the hospital 28 min later. The patient was monitored for cerebral oxygenation (NIRS). NIRS values varied from 27% to 54% (with peaks during periods of transient ROSC, lows during short interruptions of mechanical chest compressions, and marked increases at restart of mechanical compressions). After 31 min in the emergency room the patient was transferred with ongoing LUCAS compressions to the operating room for initiation of ECMO. Mean arterial pressure during LUCAS compressions and continuous vasopressor support was 45 mmHg, ETCO₂ ranged between 14 - 20mmHg. After a total of 107 min of CPR, ROSC was achieved before ECMO was initiated. NIRS increased to ~70% and ETCO₂ to 45mmHg. After 9 days, ECMO was weaned off. He was discharged home with good neurological function (CPC score 1) on day 30. In summary, the LUCAS device guaranteed uninterrupted high-quality chest compressions and more than half of the CPR efforts were performed under particularly difficult circumstances at the scene and during helicopter transport. Further, extensive monitoring of CPR quality, early induction of moderate hypothermia, and early institution of ECMO may have been additional key factors for survival with favorable neurologic outcome in this OHCA patient.

Giraud R, Siegenthaler N, Schussler O, et al. The LUCAS 2 chest compression device is not always efficient: an echographic confirmation. *Ann Emerg Med.* 2015.65;1:23-26.

This Swiss report describes a 41 year-old male with STEMI in cardiac arrest. The patient was immediately resuscitated by manual chest compressions; CPR was continued with the LUCAS 2 device. The patient experienced a 15-minute period of "low-flow" without "no-flow" episode and was a candidate for ECMO. During the ECMO implantation, it was noted that while performing transesophageal echocardiography, mechanical chest compressions were ineffective. After the ECMO implantation, myocardial damage in the right-sided heart cavities was observed. The report illustrates the likelihood that the LUCAS device has limitations that might contribute to inadequate CPR. In summary, rescuers should consider the efficacy of their chest compression through a continuous hemodynamic monitoring during CPR.

Fidler R, Hirsch J, Stechert M, et al. Three modes of cardiac compressions in a single patient: a comparison of usual manual compressions, automated compressions, and open cardiac massage. *Resuscitation.* 2014.85;5:e75-e76.

This U.S. report describes a 65 year-old diabetic man with hemodialysis-dependent end-stage renal disease who underwent a 3-vessel CABG. His post-op course was uncomplicated, and underwent dialysis the morning of post-op day 2. Later, the patient was sitting without distress before slumping over in his chair. The radial arterial line blood pressures dropped from 100/55 mmHg to 50/38 mmHg, and manual chest compressions were started. Pulseless bradycardia quickly degraded to asystole. Manual chest compressions appeared excellent generating average arterial pressures of 65/10 mmHg. After 8 min. of manual chest compressions, the LUCAS 2 device was started, resulting in average blood pressures of 100/60 mmHg. After 10 min of LUCAS compressions, the cardiac surgery team arrived, performed sternotomy and open cardiac massage generating arterial pressures averaging 70/15 mmHg. After continued aggressive treatment, ROSC was achieved with a systolic pressure of 190 mmHg. The patient re-arrested shortly thereafter and resuscitation was ultimately deemed unsuccessful and halted after a total of 90 min. In summary, this case demonstrated compressions using the LUCAS device could provide superior arterial blood pressure when directly compared to manual closed chest compressions and open cardiac massage from experienced providers. There was no evidence of trauma from using LUCAS device in this patient with recent sternotomy.

Michalski T, Gottardi R, Dünser M. Extensive soft tissue trauma due to prolonged cardiopulmonary resuscitation using an automated chest compression (ACC) device. *Emerg Med J.* 2014;31:431.

This Swiss report describes a middle-aged patient with chronic depression found floating face-down in a mountain river. She was seen the last approximately 20 min before she had most likely ingested an unknown amount of benzodiazepines in a suicidal intention. At rescue, she was comatose but had a bradycardic palpable pulse. During helicopter transport, she developed VF. Due to adverse weather conditions, the patient could not be taken directly to the university hospital for extracorporeal rewarming but had to be admitted to a secondary care hospital where CPR was continued using an automated chest compression (ACC) device. When ground transport was possible, the patient was transferred to the university hospital where cardiopulmonary bypass was prepared. By this time CPR had been going on for 5 h and 20 min. At admission, ECG rhythm showed asystole and potassium levels had risen to 10.5 mmol/L, indicating severe hypoxic cell damage with minimum chances of survival. At this point resuscitation was stopped. Although the ACC device had been repositioned several times during resuscitation, it caused extensive skin and subcutaneous tissue trauma. In summary, extremely long periods of CPR with an ACC device may be associated with trauma to the skin and subcutaneous tissue.

Platenkamp M, Otterspoor L. Complications of mechanical chest compression devices. *Neth Heart J.* 2014;22:404-407.

This Dutch case report describes a 77 year-old woman who was found on the street where she appeared to be unconscious, suffering from head injury and had no detectable pulse. Chest compressions were initiated by bystanders until the ambulance arrived. PEA was observed and the LUCAS device was applied to deliver chest compressions. She was difficult to intubate. Patient regained ROSC and was transported to the hospital where she was noted to have a swollen and firm abdomen. Chest X-ray revealed massive subdiaphragmatic free air. Emergent laparotomy was performed; a few holes in the stomach indicated blowout injury. There was no injury to the liver, spleen, or intestines. She had multiple post-op complications for several days and finally died. The combination of difficult ventilation causing gastric air insufflations and the vigorous LUCAS device compressions most probably led to the injury described. In summary, risk of complications from CPR (manual and mechanical) never outweighs the benefit of potential ROSC. Any patient who regains ROSC should be monitored carefully for CPR-related injuries.

Pietsch U, Lischke V, Pietsch C, et al. Mechanical chest compressions in an avalanche victim with cardiac arrest: an option for extreme mountain rescue operations. *Wilderness & Environmental Medicine.* 2014.25;2:190-193.

This Swiss case report describes a successfully performed resuscitation of an avalanche victim. Because of the remote location and the absence of mobile phone reception, the helicopter emergency medical service (HEMS) crew arrived on scene about 60 min after the avalanche. The LUCAS 2 device was applied in approximately 45 sec to ensure continuous chest compressions during the technically difficult rescue from the steep incline and the transport into the hovering helicopter. On admission to the hospital, the patient was in asystole, with dilated, nonresponsive pupils and an esophageal temperature of 24 C. After establishing cardiopulmonary bypass, the patient was successfully warmed and ROSC was obtained. Unfortunately, brain death in the patient was confirmed and he died. In summary, this case report shows mechanical compression devices can contribute to a significant increase in adequately performed CPR. The LUCAS device was easy to apply and could minimize hands-off time compared with the experience of previous similar cases in which manual CPR was performed.

Veien K, Terkelsen C, Ilkjær L. Kombinationen af hjertestop og cerebral infarkt behandlet med ekstrakorporal cirkulation (English title: A combination of cardiac arrest and cerebral haemorrhage treated with extracorporeal membrane oxygenation). *Ugeskr Læger.* 2014;176: V10120607:72-7.

This Danish case report describes a 46-year-old, healthy woman with sudden hemiplegia and nausea resulting in OHCA during transport to the hospital in which the LUCAS 2 device was used for compressions. A CAT scan ruled out cerebral hemorrhage, and an ECG showed inferior myocardial infarction. During emergent PCI the patient had another cardiac arrest. Despite revascularization she was very unstable and received 20 shocks for VF. In the cath lab, the patient was connected to ECMO with ongoing compressions from the LUCAS 2 device. After two months of hospitalization, the patient was able to walk and had minor cognitive impairment. In summary, this very unstable patient underwent PCI and ECMO with ongoing compressions provided by the LUCAS device. This may not have been possible with only manual compressions.

Libungan B, Dworeck C, Omerovic E. Successful percutaneous coronary intervention during cardiac arrest with use of an automated chest compression device: a case report. *Therapeutics and Clinical Risk Management.* 2014;10:255-257.

This Swedish case report describes a 50 year-old man with STEMI who was transported directly to the cath lab where he developed refractory VT/VF. The LUCAS device was applied and intraarterial systolic pressures rose to 110 mmHg. An external transvenous pacemaker was inserted during LUCAS compressions, but VF persisted. During 40 min of mechanical compressions, an occluded right coronary artery was identified and treated with a stent. Sinus rhythm was restored and the LUCAS device was discontinued. Intraaortic balloon pump (IABP) was inserted, and therapeutic hypothermia initiated. On day 2 the patient was without any neurological disability, no clinical suspicion of rib or sternal fractures and no unusual extent of musculoskeletal chest pain. He was discharged home and at follow up a few months later the patient was asymptomatic with good neurological outcome (CPC 1). The LUCAS device made it possible for staff to concentrate on other treatment elements rather than solely on performing CPR and permitted acceptable coronary imaging without risking high radiation exposure to the cath lab staff. In conclusion, electrical storm in this case was managed with full neurological and cardiac recovery by giving efficient CPR using the LUCAS device and treating the underlying pathology, namely, acute coronary occlusion. Treatment with ECMO was a considered possibility but was abandoned due to good hemodynamic response with help of the LUCAS device and IABP.

Psaltis P, Meredith I, Ahmar W. Survival with good neurological outcome in a patient with prolonged ischemic cardiac arrest - utility of automated chest compression systems in the cardiac catheterization laboratory. *Catheterization and Cardiovascular Interventions*. 2014;84(6):987-991.

This Australian case report describes a 41 year-old woman with OHCA caused by acute STEMI who was admitted directly to the cath lab for PCI within 75 min of initial onset of chest pain. She re-fibrillated on the cath lab table. Manual CPR was started immediately but she remained in VF despite aggressive ALS treatment, including 12 shocks. The LUCAS 2 device was applied while the team proceeded with the PCI and stented an occluded LAD. The patient was defibrillated a further three times before finally reverting to stable sinus rhythm with ROSC. In total this patient survived after 52 mins of manual CPR and then mechanical CPR during simultaneous PCI. Transthoracic echocardiography showed severe left ventricular dysfunction (ejection fraction 25–30%), while ECG showed near complete resolution of ST-segment elevation. The patient received therapeutic hypothermia in ICU and was discharged home in a week (EF = 65%). She was doing well 4 months later. The current case has prompted cath lab staff to prepare the LUCAS 2 device before positioning high risk patients on the table, such as those who have already required resuscitative measures prior to their arrival. In summary, the LUCAS device was fundamental in allowing the provision of sustained and effective chest compressions during PCI, without compromising the safety of the staff or prohibitively obstructing the angiographic imaging field.

Zimmermann S, Rohde D, Marwan M, et al. Complete recovery after out-of-hospital cardiac arrest with prolonged (59 min) mechanical cardiopulmonary resuscitation, mild therapeutic hypothermia and complex percutaneous coronary intervention for ST-elevation myocardial infarction. *Heart & Lung*. 2014;43(1):62-65.

This German case report describes a 68 year-old man with OHCA due to a STEMI. He received bystander CPR by 2 nurses, and was unsuccessfully treated by ALS providers before he was transported to hospital with ongoing CPR using the LUCAS device. He was without ROSC for 59 mins. He finally achieved ROSC and was taken to the cath lab where he underwent PCI and received 3 stents and was treated with therapeutic hypothermia for 24 hours. He was eventually transferred to a neurological rehab facility for 3 weeks and then went home. Three months later he was completely recovered without neurological deficits. In summary, even a patient with prolonged resuscitation has a chance at survival with good neurological outcome when there is effective chain of survival in action. In geographic areas with long transportation distances, the use of the mechanical chest compression seems to be warranted to avoid a reduction in the quality of CPR due to decreasing performance of EMS personnel.

Ali A, Hothi S, Cox D. Coronary intervention on a moving target: a case report and procedural considerations. *J Invasive Cardiol*. 2013;25(8):E178-E179.

This UK reports a case of OHCA in a 60 year-old man due to STEMI who was transferred to the hospital with ongoing manual CPR due to intractable VF. At hospital arrival compressions were switched to the LUCAS device. The mechanical compressions were so effective that despite VF, the patient could open his eyes and squeeze hands on command. He was sedated, intubated, and taken to the cath lab. Arterial pressure was 64/26 mm Hg in VF with ongoing LUCAS compressions. Although arterial access was difficult due to device-induced motion and weak arterial pulses, PCI succeeded in stenting the LAD. IABP was inserted, and the patient received therapeutic hypothermia for 24 hours. He was discharged home without neurological deficit with an EF of 45% despite 79 mins without ROSC. In summary, this may be the first published case of successful use of the LUCAS device for treating OHCA with ongoing VF and successful PCI rather than cardiac arrest occurring in the cath lab.

Park C, Roffi M, Bendjelid K, et al. Percutaneous noncoronary interventions during continuous mechanical chest compression with the LUCAS-2 device. *Am J Emerg Med*. 2013;31(2):456.e1-456.e3.

This Swiss report describes 2 patients with cardiac arrest where the use of the LUCAS device occurred during non-coronary interventions. Patient 1: an 84-year-old man who had hip surgery was found in cardiac arrest (PEA). After several min of standard CPR, ROSC was achieved but patient remained hemodynamically unstable. Emergent echo confirmed a massive pulmonary embolism. While the patient underwent pulmonary angiography he suffered another arrest. Compressions with the LUCAS device were started while the rheolytic thrombectomy system was readied. Mechanical pulmonary thrombectomy was performed rapidly without interruption of CPR. The patient regained ROSC but died 2 days later from multi-organ failure. Patient 2: a 75-year-old male with severe aortic stenosis was transferred to the cath lab for a rescue PCI after failed fibrinolysis for an extensive STEMI. He developed PEA and CPR was started with the LUCAS device while the PCI was completed. The patient was LUCAS-dependent so an urgent aortic balloon valvuloplasty was successfully performed with ongoing mechanical compressions. Despite all these successfully attempted interventions, the patient died after 56 min of CPR. In summary, this is the first reported cases suggesting the application of the LUCAS-2 device in the cath lab may be also expanded to patients undergoing non-coronary interventions.

Jensen P, Andersen C, Nissen H. Transcatheter aortic valve implantation in a patient with circulatory collapse, using the LUCAS® chest compression system. *Catheter Cardiovasc Interv.* 2013;81(6):1084-1086.

This Danish report describes a case of Transcatheter Aortic Valve Implantation (TAVI) using the LUCAS device in an elderly high risk patient with severe aortic stenosis and heart failure. This patient developed severe aortic regurgitation following predilatation of the native aortic valve and automated cardiopulmonary resuscitation (A-CPR) was initiated. The procedure was performed under ongoing A-CPR for a total of 28 min. The patient was transferred to the intensive care unit and to a step down unit the following day. At follow-up 30 days later, she showed no signs of neurologic or cardiac damage. In summary, this case report shows it is possible to perform the TAVI procedure under ongoing A-CPR and that A-CPR, judged by invasive blood pressures, was capable of maintaining a satisfactory perfusion pressure even with a damaged aortic valve.

Tranberg T, Vagner N, Christensen A, et al. Acute pulmonary embolism and cardiac arrest treated with thrombolysis and an automatic chest compression device. [Article in Danish]. *Ugeskr Laeger.* 2013;175(36):2043-2044.

(No English translation available.)

Trivedi K, Borovnik-Lesjak V, Raúl J, et al. LUCAS 2 device, compression depth, and the 2010 cardiopulmonary resuscitation guidelines. *Am J Emerg Med.* 2013;31(7):1154.e1-1154.e2.

This U.S. report describes 2 cases in which the LUCAS device failed to generate physiological surrogates of blood flow (i.e., end-tidal carbon dioxide tension and aortic blood pressure) at levels indicative of effective chest compressions. Case 1: A 65-year-old male experienced cardiac arrest after developing septic shock. CPR was initiated with a LUCAS 2 device measuring depth with an accelerometer attached to a ZOLL defibrillator (NOTE: According to the LUCAS instructions for use, nothing is to be placed under the pressure pad). The resulting PETCO₂ (7 mmHg) and aortic systolic pressure (87 mmHg) generated were considered suboptimal. Compressions were switched to manual technique enabling delivery of deeper compressions which resulted in higher PETCO₂ (12 mmHg) and higher aortic systolic pressure (124 mmHg). Despite vigorous resuscitation efforts lasting 33 min, cardiac activity could not be restored. Case 2: A 19-year-old male without significant past medical history collapsed while exercising. CPR was started by bystanders and continued by paramedics without ROSC. Patient was transferred to the emergency department with ongoing manual chest compressions. The patient arrived approximately 25 min after the onset of cardiac arrest. CPR in the emergency department was continued using a LUCAS 2 device. While on the LUCAS 2 device, PETCO₂ was undetectable, prompting removal of the ETT and insertion of a new tube suspecting misplacement at some point. The new ETT again failed to yield detectable PETCO₂ despite visualization of passage through the vocal cords. The effort was switched to manual resulting in deeper compressions with detectable PETCO₂ (8 mmHg). Despite vigorous resuscitation efforts that lasted 63 min, cardiac activity could not be restored. In summary, the authors suggest the manufacturer of the LUCAS 2 device consider incorporating capability for increasing compression depth by the trained and knowledgeable rescuer and encourage rescuers to use physiological measurements to guide resuscitation.

Protasiewicz M, Szymkiewicz P, Sciborski K, et al. Cardiac arrest during percutaneous coronary intervention in a patient 'resistant' to clopidogrel - successful 50-minute mechanical chest compression. *Postep Kardiol Inter.* 2013;9(4):394-396.

This Polish case report describes a 72 year-old woman undergoing PCI complicated by cardiac arrest (PEA) due to a coronary thrombus that developed with prolonged manipulations. Manual compressions were started then the LUCAS device was applied. The whole PCI lasted over 50 min during which the ongoing LUCAS device was continuously used. After the procedure she regained ROSC and was transferred to ICU the patient with a blood pressure of 160/80 mm Hg and heart rate 110/min. She was later discharged with slightly improved ejection fraction and no neurological deficits. In summary, the management of cardiac arrest during PCI presents a substantial challenge and effective CPR with continuous chest compressions is the primary method of circulatory support. The LUCAS device can accomplish this.

Tambe S, Rasmussen V, Modrau I. Continuous mechanical chest compression using the LUCAS-2 device as a bridge to emergency aortic valve surgery. *J Cardiothoracic and Vascular Anesthesia.* 2012;26(5):e50-e52.

This Danish case report describes a 44 year-old woman diagnosed with infective endocarditis who was transported to a tertiary-level hospital for further treatment. On arrival she developed cardiac arrest (asystole). Manual CPR was started immediately. After 10 min of ACLS treatment, the LUCAS 2 device was applied. She obtained ROSC with sinus rhythm within 4 min. The decision was made to replace her aortic valve. She was transferred to the operating room with ongoing LUCAS compressions. Extracorporeal circulation (ECC) was initiated and the LUCAS device was stopped. Although she had a complicated post-operative course, she eventually had a full recovery and was discharged. In summary, compressions with the LUCAS device allowed transport in the hospital for further procedures until ECC was established. She likely would never have made it to the operating room without the assistance of mechanical compressions.

Dembeck A, Sonntag J, Liechti B, Becker M. Reanimation in alpinem Gelände – der etwas andere Einsatz (Resuscitation in the alpine terrain – a slightly different ambulance mission - Article in German language and abstract in English). *Notfall Rettungsmed.* 2012;15:51-57.

This is a Swiss alpine case report on a 70 yr. old man who had acute chest pain and dyspnea while walking in the alps at a 2000 m altitude. The thick mist made it impossible for the rescue helicopter to fly, and a rescue team had to walk and search for the patient, in snowy ground, and wet, cold weather. After more than 2 hours, the rescue team found the man alive but cold and exhausted. After 40 minutes of transporting the patient in the steep alpine terrain, partly using ropeway, the man went into cardiac arrest. A defibrillator and the LUCAS 2 device was brought and applied to the patient. After 30 minutes of resuscitation with LUCAS 2 and seven defibrillations, the patient achieved ROSC. The transportation of the patient down the alps continued two more hours until the rescue ambulance was reached and the patient could be taken to the hospital. The now hypothermic patient had a successful PCI of the occluded coronary arteries that had caused the arrest. The patient was discharged without any neurological deficits after 11 days and is now hiking in the alps again. This case report contains many interesting photos of the challenging resuscitation and is the first publication on the LUCAS device use in the alpine environment.

Chenaitia H, Fournier M, Brun J, et al. Association of mechanical chest compression and prehospital thrombolysis. *Am J Emerg Med.* 2011 Jun 22. [Epub ahead of print.]

This is a prehospital case report on a 54-yr. old woman who had chest pain and dyspnea and went into PEA during prehospital physical examination by the mobile ICU team. Massive pulmonary embolism was suspected and prehospital thrombolysis was initiated during mechanical chest compressions with the LUCAS 2 device*. After 75 minutes of effective chest compressions the patient achieved ROSC. The patient regained consciousness the next day at the ICU, and three weeks later she was sent home in good neurological condition (CPC score 1). The authors discuss that prolonged CPR may lead to mechanical fragmentation of the pulmonary emboli, which enhances the effect of the thrombolysis.

* The LUCAS 2 device is not mentioned in publication, but was confirmed by Dr. Chenaitia.

Rudolph S, Barnung S. Case Report: Survival after drowning with cardiac arrest and mild hypothermia. *ISRN Cardiology.* 2011; ID 895625.

This is a Danish case report on a 45 year-old patient who had a cardiac arrest after winter-swimming in icy water and got lost and trapped under the ice. After 20 minutes he was brought up and in asystole. He had 70 minutes of manual CPR on the scene and during transportation, followed by 40 minutes of LUCAS 2 CPR in the hospital, and then the initiation of ECLS (extracorporeal life-support). After 80 minutes on ECLS he regained a spontaneous pulse. The patient was kept in hypothermia and rewarmed after 24 hours. He woke up at day 21 with only smaller deficits and has continued to make progress. The authors discuss the difficulties in judging when a submersion and hypothermic patient is futile based on temperature, and that every link in the chain of survival is key for outcomes.

Gottignies P, Devriendt J, Ngoc E, et al. Thrombolysis associated with LUCAS (Lund University Cardiopulmonary Assist System) as treatment of valve thrombosis resulting in cardiac arrest. *Am J Emerg Med.* 2011; 29:476.e3-5.

This is a Belgian case report on a 57-year-old patient who arrived in the ED in respiratory distress due to a prosthetic mitral valve thrombosis, which proceeded to a cardiac arrest. Rescue thrombolysis during ongoing LUCAS 1(V1) CPR was initiated and improvement seen after 15 minutes. Patient was discharged from hospital on day 13. The authors speculated that the combination of LUCAS CPR with thrombolysis could have hastened the valve mobility and reduced the arrest time.

Kyrval H, Ahmad K. Automatic mechanical chest compression during helicopter transportation. (Article in Danish, Abstract in English.) *Ugeskr Laeger.* 2010;172:3190-3191.

This is a Danish case of a drowned, hypothermic trauma patient. After falling from a 25 meter high bridge into 2°C water, she was rescued lifeless 17 minutes later. Advanced life support was initiated. During transport by a rescue helicopter, chest compressions were effectively provided by the LUCAS device 1(V1). Upon arrival to a trauma centre approx. 60 minutes later, extracorporeal circulation was set up during LUCAS CPR and the patient was rewarmed during 9.5 hours. She was eventually discharged to her home with minor loss of cerebral function. The authors commented that the LUCAS device provided effective compressions during helicopter transport, something that is difficult to achieve manually.

Greisen J, Golbækdal K, Mathiassen O, et al. Prolonged mechanical cardiopulmonary resuscitation. (Article in Danish and abstract in English.) *Ugeskr Laeger.* 2010;172:3191-3192.

This is a case-report from Denmark on a male patient who was admitted after 55 minutes of out-of-hospital manual CPR which was followed by 45 minutes of in-hospital CPR with the LUCAS 2 device. The patient had an angiography during LUCAS CPR, showing no signs of coronary artery disease. During LUCAS CPR the systolic blood pressure was measured to 100 mmHg, and the patient woke up during ongoing CPR and had to be sedated. Cardiac arrest was found to be due to severe electrolyte disorders with plasma potassium: 2.0 mmol/L and ionized calcium: 0.87 mmol/L. The electrolyte balances were corrected during pacing and anti-arrhythmic therapies. The patient was later discharged without neurological deficits. The authors commented that the LUCAS device increased vital signs, freed up resources and allowed for other lifesaving procedures like catheter insertion without compromising on CPR quality, and that angiography/plasty was accomplished despite CPR and cardiac arrest. They concluded that adequate mechanical massage during CPR may improve survival.

Prause G, Archan S, Gemes G, et al. Tight control of effectiveness of cardiac massage with invasive blood pressure monitoring during cardiopulmonary resuscitation. *Am J Emerg Med.* 2010;746.e5-6.

This is a case report from Graz, Austria, where a 69-year-old prehospital refractory VF patient successfully was saved with manual CPR on the scene and during helicopter transportation, and then LUCAS 1 (V1) device during a lifesaving PCI procedure. The effectiveness of manual CPR was monitored with invasive blood pressure measurement by an arterial line and motivated the rescuers to continue. At 60 minutes, the patient was still in VF and showing signs of life and the decision was taken to fly him to the hospital to do a PCI. During 28 minutes of coronary intervention with help of LUCAS CPR, the right artery was successfully treated and ROSC achieved; in total 1 hour and 57 minutes after the cardiovascular collapse. The patient was discharged 2 weeks later without any neurological deficit. The authors conclude that this case illustrates the chance of survival for a patient with out-of-hospital cardiac arrest and prolonged CPR and that the "no transport during CPR" paradigm may need to be revised.

Lassnig E, Maurer E, Nömeier R, et al. Osborn waves and incessant ventricular fibrillation during therapeutic hypothermia. *Resuscitation.* 2010;81:500-501.

This is a case report from Austria on a 33-year-old ROSC patient who goes into incessant VF during therapeutic hypothermia in the hospital. The LUCAS device (model unknown, probably LUCAS 1 (V1)), is used for 60 minutes and the patient is saved without any neurological deficits. The authors discussed a potential linkage between the Brugada syndrome and a risk for incessant arrhythmia during mild hypothermia.

Matevossian E, Doll D, Säckl J, et al. Prolonged closed cardiac massage using LUCAS device in out-of-hospital cardiac arrest with prolonged transport time. *Open Access Emerg Med.* 2009;1:1-4. www.Dovepress.com

This German case report describes a 44-year-old patient who – approximately 15 min after the onset of clinical death due to VF– received CPR; initially manual followed by LUCAS 1(V1) compressions. After 90 min of CPR and seven defibrillations ROSC was achieved. After a 16-day period of hospital convalescence followed by rehabilitation, the patient was able to return home with no evidence of health impairment. The authors conclude that the LUCAS device contributed to a favorable outcome in the context of prolonged out-of-hospital cardiopulmonary resuscitation.

Riemann U, Münz S, Maier J, et al. P06: Life-threatening accidental hypothermia in a 55 year old patient (translated from German language: Lebensbedrohliche akzidentelle Hypothermie bei einer 55jährigen Patientin). *Intensivmedizin und Notfallmedizin.* 2009; 46:261-262.

This is a German case report of a 55-year-old patient who was found in the snow with accidental hypothermia and refractory VF. After transportation into the hospital, LUCAS CPR was started. Lab tests showed among others an alcohol level of 2.8 promille (0.28%), and the patient had a temperature of 20.1°C. A triple rewarming therapy was initiated. After 3 hrs and 15 min of resuscitation with LUCAS CPR, the patient had reached 23.6°C and was successfully defibrillated and a stable ROSC was achieved. Within 11 hours after arrival to the hospital the patient was warmed up to 33 °C and was kept in this therapeutic hypothermia for 24 hours. After 22 days the patient was discharged from the hospital back home without any neurological deficits. The authors concluded that "Nobody is dead unless warm and dead!" and that also prolonged resuscitations can lead to full patient recovery.

Weise M, Lützner J, Heineck J. P14: Thrombolysis therapy at fulminant pulmonary embolism and a high risk of bleeding – what therapy makes sense? (translated from German language: Lysetherapie bei fulminanter Lungenembolie und hohem Blutungsrisiko – sinnvolle Therapieentscheidung?) *Intensivmedizin und Notfallmedizin.* 2009;46: 264:P14.

This is a German case report on an 83-year-old patient with cardiac arrest due to fulminant pulmonary embolism after a hip surgery. Thrombolysis is given, and due to shock, the patient is resuscitated using the LUCAS device for 45 minutes. After thrombolytic therapy a hemorrhagic shock occurred, but with help of fibrinogen preparations the patient is stabilized and survives and is discharged from hospital. The authors concluded that fulminant pulmonary embolism in combination with a considerably increased risk of bleeding is a medical challenge. Besides the operational/interventional thrombectomy, the only alternative in principle is the thrombolytic therapy.

Friberg H, Rundgren M. Submersion, accidental hypothermia and cardiac arrest, mechanical chest compressions as a bridge to final treatment: a case report. *Scand J Trauma, Resusc Emerg Med.* 2009;17:7.

This is a case report of an accident in Sweden where three young men were trapped in their car under water at the bottom of a canal and brought up after 21 minutes but in cardiac arrest. The only survivor got early and uninterrupted LUCAS 1(V1) chest compressions, which might have made the difference as a bridge to final treatment in the hospital. The authors concluded that a mechanical chest compression device facilitated chest compressions during transportation and may be beneficial as a bridge to final treatment in the hospital.

Hödl R, Maier R, Stoschitzky, et al. A case of complicated transcatheter aortic valve implantation (TAVI). *Journal für Kardiologie*. 2009;16:189. Abstract 167. (Austrian Journal of Cardiology: available at www.kup.at/kup/pdf/7899.pdf)

This is an Austrian cath lab case report of a 82-year-old patient who was treated for a severe aortic valve stenosis with balloon valvuloplasty. When the balloon was deflated the patient developed hemodynamic shock. Manual CPR was started, followed by application of LUCAS 1(V1). The coronary arteries were open, but aortic root angiogram revealed severe aortic valve regurgitation as a functional cause of the cardiac arrest. An aortic valve prosthesis was inserted during ongoing CPR. After 20 minutes of cardiac arrest and a successful insertion of the new valve, the patient obtained ROSC. The patient was discharged from ICU after five days with excellent valve prosthesis function and recovered completely without any sequelae. The authors concluded that severe complications may occur during TAVIs and therefore a mechanical chest compression device should be available to improve both quality of chest compressions and patients' clinical outcome.

Schäfer K, Flemming K. Resuscitation with LUCAS – a case report. (Translated from German language Reanimationsbehandlung mittels LUCAS – ein Fallbericht.) *Clin Res Cardiol*. 2007;96(Suppl 1)P961.

This is a case reported from Dresden, Germany. The cardiac arrest patient was found in the hospital stairways. The patient was defibrillated but stable ROSC was not achieved due to refractory VF. The ECG revealed ST-elevation and the patient was transported with ongoing LUCAS compressions to the cath lab. The right coronary artery was stented during LUCAS 1(V1) CPR, the coronary blood flow restored and ROSC achieved. Despite 60 minutes of LUCAS CPR and several parameters indicating a poor prognosis, the patient was fully recovered with very good neurological status and left the hospital after two weeks. The authors concluded that LUCAS CPR enabled a fast intervention of an occluded coronary artery and allowed for a shortening of the door-to-balloon time.

Agostoni P, Cornelis K, Vermeersch P. Successful percutaneous treatment of an intraprocedural left main stent thrombosis with the support of an automatic mechanical chest compression device. *Int J Cardiol*. 2008;124:e19-e21.

This case study describes a PCI procedure on a patient who suddenly goes into cardiac arrest on the cath lab table in Belgium. The patient was initially successfully stented with a drug-eluting stent in one of the large coronary arteries (LAD). However, after five minutes the patient suddenly experienced hemodynamic collapse. Manual CPR was provided and a control angiogram showed a total occlusion of the stented artery. LUCAS 1(V1) CPR was initiated and the blood pressure rose to 90/40 mmHg while more medication was given and the patient was intubated. During ongoing LUCAS CPR, during which the patient had episodes of VF, PEA and asystole, the coronary artery flow was restored by ballooning and stenting. A temporary pacemaker and an intra-aortic balloon pump were placed, and the patient hemodynamically stabilized and moved to the intensive care unit. After progressive improvement she was discharged back to the referral hospital in stable conditions.

The authors discussed the urgent need for CPR is difficult to handle in the cath lab due to the C-arm around the patient and the height of the table. Furthermore PCI can be done during efficient manual CPR due to hindrance and high radiation exposure for the personnel performing CPR. This case shows that a PCI procedure can be carried out successfully during ongoing LUCAS compressions, which provides an efficient circulatory pulsatile support (as shown by the pressure curves recorded for both manual and LUCAS CPR in this case) without the need for additional staff involved in basic life support.

Vatsgar T, Ingebrigtsen O, Fjosea L, et al. Cardiac arrest and resuscitation with an automatic mechanical chest compression device (LUCAS) due to anaphylaxis of a woman receiving caesarean section because of pre-eclampsia. *Resuscitation*. 2006;68:155-159.

This case report from Norway is the first to describe the use of LUCAS 1(V1) during resuscitation from cardiac arrest (PEA) caused by anaphylactic shock. A 30-year-old woman received a caesarean section of her 24 week baby because of pre-eclampsia. During the procedure and due to pre-operation medication she fell into an anaphylactic shock. Manual CPR and then LUCAS CPR was provided for a total of 50 minutes as a bridge to ROSC. The patient and baby survived without any complications or sequelae at one month follow up. During manual chest compressions, it was impossible to measure any intra-arterial blood pressure. When LUCAS chest compressions were started, a pressure of 115/75 mmHg was measured in the femoral artery. The authors discussed that by replacing manual CPR with the LUCAS device, elements of fatigue and hands-off intervals were eliminated and a more consistent blood flow could be provided to the heart and brain. CPR in anaphylactic cases may have to be continued for a long time. Mechanical CPR can provide organ perfusion until more sophisticated support is available. Victims of anaphylaxis with circulatory arrest should be seen as potentially resuscitable with a prospect of full recovery if prolonged manual and mechanical CPR, epinephrine and infusion of isotonic solutions are delivered.

Wik L, Kiil S. Use of an automatic chest compression device (LUCAS) as a bridge to establishing cardiopulmonary bypass for a patient with hypothermic cardiac arrest. *Resuscitation*. 2005;66:391-394.

In Norway, a man was found frozen to the ground. Manual CPR was given during transport to the hospital. At the hospital, the patient had an isoelectric ECG and received 1.5 h of LUCAS 1(V1) chest compressions until cardiopulmonary bypass was established. Rapid re-warming followed during which VF was converted to a pulse-generating cardiac rhythm. The patient survived with good physical and mental recovery. Mechanical chest compression may be indicated in both hypothermia and intoxication-related cardiac arrest. Cardiopulmonary bypass may be the best method for rapid re-warming and preservation of circulation, but it is not available in all hospitals.

Safety Trials

Studies with Control Group

Baumeister R, Held U, Thali M, et al. Forensic imaging findings by post-mortem computed tomography after manual versus mechanical chest compression. *J Forensic Radiology and Imaging*. 2015;3(3):167-173.

This Swiss retrospective study included 44 cases that had CPR before death. One group (n = 20) had manual CPR and the other group (n = 24) had compressions using the LUCAS device. All bodies underwent post mortem computed tomography. The main traumatic findings associated with CPR were reported, and a statistical evaluation was performed. Rib fractures were the most frequent injury in both groups. A mean of 10.4 rib fractures/case was observed in the LUCAS device group, and 10.4 fractures/case was observed in the manual group (p = 0.999). Subcutaneous pre-sternal hematomas were described in 63% (15/24) patients in the LUCAS device group and 30% (6/20) in the manual group. The frequency of sternal fractures was similar in both groups. A few trauma injuries to internal organs (i.e., retrosternal, perihepatic, and retroperitoneal hematomas and lung contusion) were recorded in both groups. In summary, the LUCAS 2 device has a greater association with subcutaneous pre-sternal hematomas than standard CPR. There is no further significant difference in the incidence of injuries between mechanical and manual chest compression.

Lardi C, Egger C, Larribau R, et al. Traumatic injuries after mechanical cardiopulmonary resuscitation (LUCAS 2): a forensic autopsy study. *Intl J Legal Med*. 2015;129(5):1035-1042.

This Swiss retrospective study analyzed consecutive autopsy reports in two patient groups undergoing medicolegal autopsies from 2011 to 2013 after unsuccessful CPR, focusing on traumatic injuries. The study group was comprised of 26 LUCAS cases, while 32 cases were included in the manual control group. The duration of CPR performed by the LUCAS 2 device was longer than manual CPR 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 69% (18/26) of patients in the LUCAS 2 group and 19% (6/32) of the control group. A mean of 6.6 rib fractures/case was observed in the LUCAS 2 group vs. 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. Typical round concentric skin lesions were observed in LUCAS device cases. In summary, LUCAS 2 device is associated with more rib fractures than standard CPR. No life-threatening injuries were reported. Petechiae were common findings.

Kralj E, Podbregar M, Kejžar N, et al. Frequency and number of resuscitation related rib and sternum fractures are higher than generally considered. *Resuscitation*. 2015;93:136-141.

This Slovenian study analyzed CPR-related skeletal chest injuries (SCI) in 2148 patients who had autopsies from 2004–2013, specifically looking at age and gender as differentiators. Chest compressions caused injuries in 86% of males and 91% of females; sternum fractures occurred in 59% of males and 79% of females, rib fractures in 77% of males and 85% of females and sternocostal separations in 33% of males and 12% of females. The average number of all SCI per person was the same in males and females (10.95 vs. 10.96). No adverse effects of the use of the LUCAS device (N: 134) were found. In summary, the percentage of patients injured and the number of SCI increased with age. Changes in resuscitation guidelines (increased compression rate and depth) were also identified as a factor contributing to the incidence and number of SCI.

Koster R, Beenen L, van der Boom E, et al. Safety and possible damage from mechanical chest compression during resuscitation. *Abstracts/AHA/RESS 2014*. Abstract 12.

This Dutch publication reports on the results of two simultaneous randomized controlled trials investigating possible serious or life-threatening damage caused by mechanical chest compression devices; AutoPulse compressions (N: 116) vs. manual control (N: 132) and LUCAS compressions (N:122) vs. manual control (N: 131). The control groups consisted of manual chest compressions with corrective depth and rate feedback from a sternal transducer. Hypothesis: Mechanical chest compressions compared to manual control do not increase serious or life threatening visceral resuscitation related damage by >10%. Patients < 18 years old with in-hospital or out-of-hospital cardiac arrest arriving with manual CPR at the emergency department were included; trauma patients <18 years old were excluded. Postmortem CT and/or autopsy were done in 116 of the cases in the AutoPulse study and in 121 of the patients in the LUCAS study. Clinical outcome was assessed in 109 patients in the AutoPulse study and 107 patients of the LUCAS study. Outcome analysis was possible in 453 of 501 (90.4%) of included patients. Mean compression depth of manual CPR was 47 mm as measured by the sternal accelerometer. Serious or life-threatening visceral resuscitation-related damage was seen in 12/104 AutoPulse patients (11.5%) and 8/121 study controls (6.6%) and in 8/108 LUCAS patients (7.4%) and 9/120 L study controls (7.5%). Serious rib and sternal damage was observed in 47 AutoPulse patients (45%) and 51 controls (42%) and in 43 LUCAS patients (40%) and 50 controls (42%). In summary, the LUCAS device did not cause significantly more serious or life threatening visceral damage than manual chest compressions. For the AutoPulse device, the non-inferiority hypothesis was not accepted and significantly more serious or life-threatening visceral damage than manual chest compressions could not be excluded.

Smekal D, Lindgren E, Sandler H, et al. CPR-related injuries after manual or mechanical chest compressions with the LUCAS device: a multicentre study of victims after unsuccessful resuscitation. *Resuscitation*. 2014;85(12):1708-1712.

This Swedish autopsy study evaluated injuries after mechanical and manual CPR. Non-survivors from OHCA (n = 222), treated according to the randomized LINC trial protocol (139 LUCAS compressions, 83 manual CPR), were included. At least one rib fracture was found in 78.8% of the patients treated with the LUCAS device vs 64.6% (p = 0.02) of the manually treated, however, in these patients, the median number of rib fractures were similar (6 with the LUCAS device, 7 with manual CPR). There were no difference in sternal fractures; 58.3% with the LUCAS device and 54.2% with manual CPR (0 = 0.56). A thorough analysis of the different injuries by a forensic expert suggested that no CPR-related injury was considered to be the cause of death or life-threatening. Some findings (large tamponades due to myocardial infarcts or aortic dissections, liver injuries) were considered to be part of the primary cause of death and not caused by CPR. None of the cardiac injuries was found in the right side of the heart and there was no cardiac injury with penetration throughout both the pericardium and myocardium. In summary, in patients with unsuccessful CPR OHCA, rib fractures were more frequent after LUCAS compressions but there was no difference in the incidence of sternal fractures. No CPR injury was deemed fatal by the pathologist.

Fontanals J, Carretero M, Arguis M, et al. Lung injury secondary to resuscitation using mechanical external chest compression devices (LUCAS vs AUTOPULSE). Histopathology study: 13AP2-4. *European J Anaesthesiology*. 2010;27(47):191.

This Spanish experimental animal study compared two chest compression (LUCAS and AutoPulse) devices to assess differences in the lung injury produced. Twenty-four pigs were randomized into two groups (LUCAS and AutoPulse). VF was induced. After 5 min of cardiac arrest without treatment, CPR was started. ECG, IAP (carotid artery), Swan-Ganz catheter (CVP, PAPm, CPP, CO, CI, SVR, PVR) and the CPP were measured during the resuscitation period (before VF and after 5, 15, 30 and 45 min of resuscitation) in the supine position. After the resuscitation time (45 min), a lung biopsy was obtained and histological study was performed. The hemodynamic data showed no statistical difference in MAP comparing both methods. The CO media along time was = 0.636 mmHg in the LUCAS group, and 0.399 mmHg in the AutoPulse group. There was statistical significant difference (p<0.05) in the cardiac output generated being higher using the LUCAS device versus AutoPulse device. The findings observed in all samples studied were a heterogeneous interstitial infiltrate and vascular congestion that is similarly found in ventilator associated lung injury. There were no differences between the two devices. In two samples interstitial emphysema similar to barotrauma injury in young people (both in AutoPulse group) was seen. In one sample, bone marrow embolism was found, probably secondary to sternal fractures (LUCAS group). In summary, the two chest compression devices generate comparable MAP. The LUCAS device generated higher cardiac output than AutoPulse device. No differences in lung injury were observed.

Menzies D, Barton D, Nolan N. Does the LUCAS device increase injury during CPR? *Resuscitation*. 2010; 81S:S20,AS076. Abstract.

This Irish study compared postmortem findings on patients receiving manual CPR in combination with LUCAS 1(V1) CPR (N: 40) at the Emergency Department in one hospital with the findings from patients receiving manual CPR alone (N:39) in the Emergency Department in another hospital. Rib fractures were present in 13/40 (32.5%) patients in the LUCAS group and 19/39 (48.7%) in the manual group (p = 0.142). Sternal fractures were present in 9/40 (22.5%) patients in the LUCAS group and 16/39 (41%) in the manual group (p = 0.144). The mean number of rib fractures was 1.84 in the LUCAS group and 3.21 in the manual group (p = 0.096). The authors concluded that they could not identify a significant variation in trauma with the use of the LUCAS device compared to manual CPR. This author presented interim data from the same study at the ERC congress in 2008. Menzies D, Barton D, Darcy C, Nolan N. Does the LUCAS device increase trauma during CPR? *Resuscitation*. 2008;77S:S13, AS-034.

Truhlar A, Hejna P, Zabka L, et al. Injuries caused by the AutoPulse® and the LUCAS II resuscitation systems compared to manual chest compressions. *Resuscitation*. 2010;81S:S62, AP110.

This Czech prospective study compared injuries caused by the AutoPulse (ZOLL), LUCAS 2 and manual CPR in both survivors and non-survivors of out-of-hospital cardiac arrest (OHCA). The survivors underwent physical examination and a thoracic X-ray, non-survivors were autopsied. CPR was attempted in thirty patients: A-CPR 8, L-CPR 11, and M-CPR 11. Injuries were observed in 7/8 (87.5%) in A-CPR, 8/11 (72.7%) in L-CPR, and 3/11 (27.3%) in M-CPR group (P = 0.02). Sternal fractures were present in 3/8, 4/11, and 1/11 (P = 0.33), multiple rib fractures (≥3) in 4/8, 6/11, and 2/11 (P = 0.25), and mediastinal haematomas in 5/8, 2/11, and 0/11 patients (P = 0.003). Pericardial effusions (2 pts.) and adventitial aortic haematomas (4 pts.) were observed in A-CPR group only (P = 0.06 and 0.002). There were 1/8 (12.5%), 1/11 (9.1%), and 4/11 (36.4%) patients discharged from hospital [CPC 1-2] (P = 0.33). Preliminary results of this study are limited by its size and prior BLS (90.0%) whose complications are difficult to separate from device associated injuries.

Smekal D, Johansson J, Huzevka T, et al. 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.

This is a Swedish prospective, controlled autopsy study on 85 patients not surviving cardiac arrest. The majority of patients were prehospital cardiac arrest patients randomized to either LUCAS 1(V1) CPR (N: 38) or manual CPR (N: 47). All patients got a few minutes of manual CPR before randomization. Autopsy showed no injuries at all in 42.1% of the patients in the LUCAS group and 55.3% in the manual CPR group (n.s., p = 0.28). The incidence and type of injuries from CPR were not significantly different between the two groups and none of the CPR-related injuries were considered to be life-threatening. Multiple rib fractures (more than three) were present in 17/38 (44.7%) of the patients in the LUCAS group and 13/47 (27.7%) in the manual group (n.s., p = 0.12). Sternal fractures were present in 29.0% in the LUCAS group compared to 21.3% in the manual group (n.s., p = 0.46). The authors concluded that LUCAS seemed to be associated with the same incidence and variety of injuries as manual CPR.

Patient Series

Boland L, Satterlee P, Hokanson J, et al. Chest compression injuries detected via routine post-arrest care in patients who survive to admission after out-of-hospital cardiac arrest. *Prehosp Emerg Care*. 2015;19(1):23-30.

This U.S. retrospective, observational study of consecutive OHCA patients (N:235), admitted alive to the emergency room between January 2009 and May 2012, characterized compression injuries detected via routine post-arrest care (117 survived to discharge; 118 died during hospitalization). In 44% (104/235) of the cases the LUCAS device was used in conjunction with manual CPR. Injuries were identified in 31 patients (13%), the most common being rib fracture (9%) and intrathoracic hemorrhage (3%). Among survivors, the mean length of stay was not statistically significantly different between those with injuries (13.5 days) and those without (10.8 days; $p = 0.23$). Crude injury prevalence was higher in those who died prior to discharge, had received compressions for >10 min and underwent computer tomography (CT) imaging, but did not differ by bystander compressions or use of mechanical compression. After multivariable adjustment, only compression time > 10 min and CT imaging during hospitalization were positively associated with detected injury. In summary, in patients who survived OHCA to admission, documented compression injury was associated with longer duration of compressions and use of CT post-arrest. Compression-induced injuries detected via routine post-arrest care are likely to be largely insignificant in terms of length of recovery.

Kůdela M, Grossova I, Strejc P. Traumatic changes of intrathoracic organs due to external mechanical cardiopulmonary resuscitation. Case reports. [Article in Czech]. *Soud Lek*. 2013;58(3):42-44.

This Czech report describes 4 autopsy cases where the LUCAS ($n = 3$) and AutoPulse ($n = 1$) devices were used prior to death. Traumatic changes commonly described in various studies (skin abrasions on the chest, multiple rib fractures, fracture of the sternum and hematoma in the mediastinum or pericardium) were found in all cases. Abdominal organ injuries in connection with mechanical compressions were not present. In addition to these usual traumatic injuries of intrathoracic organs, contusions of the heart and contusions and laceration of the lungs were observed. Rupture of the right common carotid artery intima was found in one case associated with prolonged AutoPulse compressions. In one LUCAS device case presenting as sudden cardiac arrest, contusion of the myocardium due to the device was found though the cause of death was massive thrombotic embolism to pulmonary arteries. In summary, injuries in all cases were similar in the relatively prolonged resuscitation with mechanic compression devices.

Mateos Rodríguez A, Navalpotro Pascual J, Peinado Vallejo F, et al. Lung injuries secondary to mechanical chest compressions. *Resuscitation*. 2012;83(10):e203.

This is a Spanish study investigating lung injuries secondary to mechanical chest compressions (both LUCAS and AutoPulse is used in this organization) in 33 patients who were potential organ donors. Chest X-ray and bronchoscopy were used as method. The average mechanical CPR time was 136 min \pm 16 min. The few injuries that were found and are described in the article were considered mild in all cases and not life-threatening if ROSC would have occurred. All lungs except three lungs with bronchial aspiration were considered to be possible to use for transplantation purposes. The authors concluded that mechanical chest compression devices can be used safely without concern about the feasibility of the donor organ.

Oberladstaetter D, Braun P, Freund M, et al. Autopsy is more sensitive than computed tomography in detection of LUCAS-CPR related non-dislocated chest fractures. *Resuscitation*. 2012;83:e89-e90.

This is an Austrian prospective, blinded study comparing computer tomography (CT) and autopsy findings with the purpose to determine the frequency of thorax injuries after one minute of LUCAS 1(V1) CPR on 13 fresh, female corpses for whom autopsy was planned. Exclusion: trauma, surgery, CPR or lack of consent. One minute of LUCAS CPR was given on each corpse. Autopsy showed that 9/13 had sternum fractures and 10/13 had rib fractures. All fractures were classified as minor and non-dislocated. No lesions of the inner organs could be detected. None of the lesions were visible in a CT scan. The authors compare the results with previous studies on the manual ACD CardioPump®, and speculate that the LUCAS device caused less injuries due to a better positioning and a refined active decompression technique. The authors concluded that one minute of LUCAS CPR caused only minor lesions and non-dislocated fractures on sternum and ribs in fresh, female cadavers. They also concluded that autopsy was more sensitive to detect chest fractures compared to CT.

Englund E, Silfverstolpe J, Halvarsson B. Injuries after cardiopulmonary resuscitation: A comparison between LUCAS mechanical CPR and standard CPR. *Resuscitation*. 2008;77S: S13, AS-036. Abstract.

This is an analysis of injuries found at autopsy of 200 LUCAS 1(V1) non-survivors and on 21 manual CPR non-survivors in Lund, Sweden. Sternal fractures were found in 65% of the LUCAS cases and in 28% of the manual CPR cases. Rib fractures were found in 92.5% of the LUCAS cases and 52% of the CPR cases. Hemothorax and liver capsule rifts were also seen in the LUCAS group. In non-survivors of cardiac arrest injuries found at autopsy were more common following LUCAS CPR when compared to standard CPR.

Bonnemeier H, Gerling I, Barantke M, et al. Necropsy findings of non-survivors of CPR after mechanical and conventional chest compression. ERC congress 2008. (Poster 470 on file at Physio-Control.)

This is a German autopsy study on 64 consecutive non-survivors of cardiac arrest, of which 57 received manual CPR and 7 received manual as well as LUCAS 1(V1) CPR (from 15 minutes up to 80 minutes). 85% of the patients had rib fractures, 19% had sternum fractures, 44% had minor tissue injuries and 23% had insignificant hematomas (<50ml). There were no life-threatening CPR-related injuries. There was a trend to less injury following LUCAS CPR: 43% (3 pts.) had rib fractures, no sternal fractures were found, 29% (2 pts.) had tissue injuries and 29% (2 pts.) had hematomas. The authors concluded that mechanical compressions did not cause more serious complications than manual CPR. They also concluded that the LUCAS device was safe, feasible and when correctly used and applied, it may assist in significantly improving the care and outcome of cardiac arrest patients.

Organ Donation Studies

Trials with Control Group

Mateos A, Navalpotro J, Andres A, et al. Mechanical CPR devices in donors after cardiac death. *Resuscitation*. 2014;85:S88. Abstract AP171.

This Spanish study compared long-term outcomes of transplanted organs from 200 donors who were treated with mechanical vs. manual compressions during attempted resuscitation. Age, gender, arrival times to scene and hospital arrival times are similar in both groups. In the manual group the average number of kidneys was 1.51 (SD 0.83) kidney donor while the mechanical group was 1.20 (SD 0.93) resulting in a statistically significant difference (95% 0.3–0.1 t = 0.04). Creatinine values at one year in the right kidney were higher in the manual group (2.01 vs. 1.79). Creatinine values at one year in the left kidney were lower in the manual group (1.77 vs. 1.93). Forty-one livers were transplanted with a one-year survival of 29 recipients (70%) of which 20 donors had mechanical compression. Fourteen lung donors received mechanical compressions in 16 (88%) of recipients that survived 18 years. In summary, mechanical compression devices seems to lower the kidney function after transplant but the evaluation of these and other long term transplants is similar to donors who had manual compression.

Palma P, Ruiz A, Carmona F, et al. How LUCAS® device affects kidney transplant rate in a “donors after circulatory death” program. *Resuscitation*. 2013;84:S73. AP160.

This Spanish prospective analytic study looked at variables associated with potential kidney donors in a “donor after circulatory death program” (DACDP) from January 2002 to December 2011.

Studied variables were: donors’ age, sex, body mass index (BMI) and presence of cardio-circulatory risk factors (CCRF), total out-of-hospital CPR time (OHCP), kidney transplantation and use of the LUCAS device. Sixty percent (97/160) potential donors met the study criteria. Mean age was 47.8 years, male gender was 91.8% (89), mean BMI was 27.1 kg/m², and mean OHCP was 60.3 min. CCRF was seen in 48.5% of all patients. The LUCAS device was used in 52.6% (51) of patients. A total of 74% (144/194) of kidneys were transplanted. The LUCAS device was associated with a 13 % increase of the transplant rate (p = 0.039). Lower mean age and BMI were also associated with an increase of the transplant rate (p = 0.004 and 0.001). No other significant statistical association was observed but a trend in lower OHCP mean (p = 0.145). After adjusting LUCAS effect by donors’ age and BMI, OHCP and their first order interactions in a logistic regression model, the use of the LUCAS device increases the transplantation odds by 1.9. In summary, the use of the LUCAS device increases the number of transplanted kidneys when used in a DACDP.

Mateos-Rodriguez A, Navalpotro-Pascual J, Andres-Belmonte A. Donor after cardiac death kidney graft under mechanical cardiac compression evolution. *Resuscitation*. 2013;84(9):e117.

This Spanish study assessed medium-term renal function of 50 kidney grafts obtained from non-heart beating donors (NHBD) who had mechanical chest compression devices (MMC) used vs. those who didn’t. The mean age was significantly younger in the non-MCC group (35 yrs. vs 49 yrs.; p = 0.04). MMC device was not used in 20 patients; 15 patients were treated by with the LUCAS device and 12 with the AutoPulse device (data from the remaining 3 patients were not available). The average time from call to arrival onto the scene was 13 min 35 sec in the non-MCC group and 11 min 19 sec in the MCC group. No significant difference was found in the time of arrival at hospital between the groups (76 min 34 sec for non-MCC group and 83 min 20 sec for MMC). The creatinine level was slightly higher at 6 months (1.30 mg/dl vs. 1.97 mg/dl) and 12 months (1.34 mg/dl vs. 1.88 mg/dl) in the MCC group, but no significant difference between both groups was found. In summary, many variables play a role in the NHBD, but the use of MCC devices does not produce significant changes in renal function and, therefore, kidney grafts are perfectly valid for organ preservation in this procedure.

Mateos-Rodriguez A, Navalpotro-Mateos-Rodriguez A, Navalpotro-Pascual J, et al. Research Paper: Out-hospital donors after cardiac death in Madrid, Spain: A 5-year review. *Australasian Emerg Nurs J*. 2012;15:164-169.

This is a Spanish retrospective, descriptive study of 214 out-of-hospital cardiac arrest patients that failed to respond to resuscitation and were considered or included the organ donation program. Mechanical chest compression devices, both LUCAS and the AutoPulse (ZOLL), were introduced during the time period and used for transportation during compressions of the organ donors in 85 cases (39% of the total group). The number of organs per donor was found significantly lower in the mechanical chest compression group compared to the manual group (2.1 organs or tissues per donor vs. 2.5 organs in the non-compressor group). The authors discuss that there are several other factors that could explain this result, and that the devices improve the chest compression quality and provision during the code.

Carmona F, Ruiz A, Palma P, et al. Use of the LUCAS mechanical chest compression device in an asystolic organ donation program: effect on kidney perfusion and organ procurement and transplantation rate. *Emergencias*. 2012;24:366-371.

This is a retrospective and prospective comparative study from January 2006 to January 2010 on LUCAS 1(V1) (N: 91) vs. manual chest compressions (N: 112) during transportation of potential organ donors (N total: 203) after cardiac death in Barcelona, Spain. 37.4% (34/91) in the LUCAS group and 33.0% (37/112) in the manual group became real donors. The use of the LUCAS device was associated with a significant decrease in rejected kidneys due to poor perfusion (32.9% decrease, 95% CI, 3.8% to 56.6%) (P = .026). Despite a significantly longer average prehospital CPR time in the LUCAS group compared to manual group, there was a trend of increased number of organs procured and transplanted in the LUCAS group. The authors concluded that the LUCAS device was at least as effective as manual CPR.

Mateos-Rodriguez A, Pardillos-Ferrer L, Navalpotro-Pascual J, et al. Short communication: Kidney transplant function using organs from non-heart-beating donors maintained by mechanical chest compressions. *Resuscitation*. 2010;81:904-907.

This Spanish retrospective, observational study investigated if mechanical CPR in non-heart beating donors would give a lower failure rate of transplanted kidneys in recipients of organs, compared to manual CPR. Both AutoPulse and LUCAS 1(V1) were used in the mechanical group. No significant difference could be found. Note: three patients achieved successful ROSC in the mechanical chest compression group after initiation of the non-heart beating donor protocol, one of whom had good neurological recovery.

Experimental Data

In addition to these experimental studies evaluating different aspects of the efficacy and safety of the LUCAS device, there is a wide range of experimental study publications where the LUCAS device has been used to provide standardized chest compressions while evaluating and comparing other resuscitation therapies. These studies are not included in this overview.

Casado M, Fontanals J, Arguis M, et al. Reanimacion con cardiocompresores: comparacion de los efectos hemodinamicos entre LUCAS y AutoPulse en un modelo porcino. (English title: Resuscitation with the LUCAS and AutoPulse automated chest compression devices: comparison of hemodynamic variables in a porcine model.) *Emergencias*. 2014;26(6):459-463.

This Spanish experimental study aimed to compare the LUCAS and AutoPulse devices. Hemodynamic variables and end-tidal carbon dioxide (ETCO₂) were recorded in 24 pigs during a period of resuscitation in supine position. Results: Significantly higher cardiac output and ETCO₂ (P < .001) were found in the LUCAS group on follow-up. The analysis showed no significant differences in mean arterial pressure (P = .121) or coronary perfusion pressure (P = .690) between groups. In summary LUCAS and AutoPulse devices were both effective in generating and maintaining adequate cardiac output and coronary perfusion pressure. The present study suggests that the LUCAS device may be superior to the AutoPulse device when comparing cardiac output and ETCO₂ values generated during cardiopulmonary resuscitation; however, no differences in coronary perfusion pressure were found.

Debaty G, Segal N, Matsuura T, et al. Hemodynamic improvement of a LUCAS 2 automated device by addition of an impedance threshold device in a pig model of cardiac arrest. *Resuscitation*. 2014;85(12):1704-1707.

This U.S. animal study of 10 pigs tested the hypothesis that the addition of an Impedance Threshold Device (ITD) on LUCAS CPR would enhance cerebral and coronary perfusion pressures. After 4 min of untreated ventricular fibrillation, 4 min of LUCAS CPR + an active ITD or LUCAS CPR + a sham ITD was initiated and followed by another 4 min of the alternative method of CPR. Decompression phase airway pressure was significantly lower with LUCAS + active ITD versus LUCAS + sham ITD (-5.3 vs. -0.5; p < 0.001). LUCAS + active ITD treatment resulted in significantly improved hemodynamics versus LUCAS + sham ITD: ETCO₂, 35 vs. 29 mmHg (p = 0.015); systolic BP, 99 vs. 93 mmHg (p = 0.050); diastolic BP, 24 vs. 19 mmHg (p = 0.006); coronary perfusion pressure, 29 vs. 26 mmHg (p = 0.004) and cerebral perfusion pressure, 24 vs. 21 mmHg (p = 0.028). In summary, in pigs undergoing LUCAS CPR the addition of the active ITD significantly reduced intrathoracic pressure and increased vital organ perfusion pressures.

Reynolds J, Salcido D, Sundermann M, et al. Extracorporeal life support during cardiac arrest resuscitation in a porcine model of ventricular fibrillation. *J Extra-corporeal Technology*. 2013;45(1):33-39.

This U.S. experimental study explored ischemia duration, CPR duration, and physiologic variables in 8 pigs to predict which animals would obtain ROSC after a period of VF with ECMO. After 8 (n = 4) or 15 min (n = 4) of VF, animals received 30, 40, 50, or 60 min of CPR and then drugs after 5 min of CPR. After conventional resuscitation, animals were reperfused with ECMO. ECMO flow rate was 3 L/min ≤ 2 hours and then 1.5 L/min ≤ 2 hours before weaning. Animals were defibrillated (150 J biphasic) ≥ 15 min ECMO. All 8-min VF animals were successfully resuscitated and had ROSC. Mean arterial pressure (MAP) was higher at the beginning (27.0 vs. 15.0 mmHg; p = .03) and end (31.3 vs. 11.5 mmHg; p = .03) of CPR in animals successfully resuscitated. Coronary perfusion pressure was higher at the beginning of CPR (11.9 vs. 3.3; p = .01) and the end of CPR (18.5 vs. .9; p = .03) among animals with ROSC. Amplitude spectrum area (AMSA) was superior at the end of CPR (-2.0 vs. -5.0; p = .04) in animals successfully resuscitated. In summary, in a porcine OHCA model, MAP and coronary perfusion pressure at the beginning and end of CPR were higher in animals successfully resuscitated. AMSA was superior at the end of CPR in animals successfully resuscitated.

Wagner H, Madsen Hardig B, Steen S, et al. Evaluation of coronary blood flow velocity during cardiac arrest with circulation maintained through mechanical chest compressions in a porcine model. *BMC Cardiovasc Disord*. 2011;11:73.

This experimental study from Sweden studied the correlation between peak coronary flow velocity (APV) as measured by Doppler, and the coronary perfusion pressure (CPP) during LUCAS 2 chest compressions. 11 pigs got VF induced during one minute and then 20 minutes of LUCAS chest compressions before first defibrillation. No epinephrine was administered before the first defibrillation. 9/11 pigs achieved ROSC. There was a significant correlation between CPP and APV during LUCAS compressions. APV was equal or higher with LUCAS compressions compared to baseline (normal flow) before VF was induced in the pigs. CPP was maintained at greater than 20 mmHg during LUCAS compressions. The authors concluded the LUCAS device can sustain and reestablish coronary blood flow in non-diseased coronary arteries during cardiac arrest. They also noted that this is in line with the more subjective visual coronary artery flow (TIMI III) that has previously been documented for the LUCAS device during extensive periods of resuscitations in humans.

Menegazzi J, Salcido D, Housler G, et al. Feasibility of initiating extracorporeal life support during mechanical chest compression CPR: A porcine pilot study. *Resuscitation*. 2012;83:130-133.

This study from Pittsburgh, PA, evaluates the feasibility of installing a portable cardio-pulmonary bypass (CPB) circuit during LUCAS 1(V2) compressions in five pigs. After 8 minutes of VF, the LUCAS device was started and five minutes later the installation of the CPB was initiated. After a total of 17-30 minutes of LUCAS CPR, the CPB was successfully installed in all five animals and took over circulation support and continued until ECG indicated a shockable rhythm. First rescue shocks were given at 22, 32, 35, 44, and 65 minutes respectively. It was necessary to briefly discontinue chest compressions only during the most delicate part of inserting the catheters into the vessels. Only the 65-minute animal did not attain ROSC. The authors conclude that mechanical chest compression may be a suitable therapeutic bridge to the installation of CPB and does not interfere with CPB catheter placement.

Xhantos T, Pantazopoulos I, Roumelioti H, et al. A comparison of autopsy detected injuries in a porcine model of cardiac arrest treated with either manual or mechanical chest compressions. *Eur J Emerg Med*. 2011;18:108-110.

This is a Greek retrospective, experimental autopsy study that compared complications after ~16 min CPR with manual technique vs. LUCAS 1(V1), in pigs (N: 53). There were significantly fewer injuries in the LUCAS group compared to the manual group ($p = 0.004$). The manual CPR was performed by qualified rescuers alternating every 2 min and according to guidelines. The authors conclude that the LUCAS device minimized the resuscitation-related trauma compared to manual CPR in this swine study.

Liao Q, Sjöberg T, Paskevicius A, et al. Manual versus mechanical cardiopulmonary resuscitation. An experimental study in pigs. *BMC Cardiovasc Disord*. 2010;10:53. (open access: www.biomedcentral.com/1471-2261/10/53).

This Swedish experimental study on 16 pigs evaluated the LUCAS 1(V2) (N:8) compared to manual CPR (N:8) according to guidelines 2005 provided by 16 trained paramedics, who took turns every two minutes and had a metronome to help keep an accurate rate. After 5 minutes of induced VF, CPR was provided during 20 minutes, then defibrillation was given. LUCAS CPR resulted in improved hemodynamics and ROSC vs. manual CPR (CPP 20 mmHg vs. 5 mmHg ($P < 0.01$), EtCO₂ 3.4 kPa (25.5 mmHg) vs. 2.2 kPa (16.5 mmHg), ROSC 8/8 vs. 3/8 pigs) There were also less rib fractures with LUCAS vs. manual CPR. The authors concluded that the LUCAS device was significantly more efficient and gave less injury than manual CPR in this porcine model.

Fontanals J, Carretero M, Arguis M, et al. Lung injury secondary to resuscitation using mechanical external chest compression devices (LUCAS vs. AutoPulse). Histopathology study: 13AP2-4. *Eur J of Anaesthesiol*. 2010;47:191. (open access; http://journals.lww.com/ejanaesthesiology/Fulltext/2010/06121/Lung_injury_secondary_to_resuscitation_using.611.aspx)

This Spanish experimental study on 24 pigs compared the LUCAS 1(V1) and AutoPulse (ZOLL) chest compression systems with regards to cardiac output (CO) and lung injury. There were no statistical difference in MAP comparing both methods, but there was statistical significant difference ($p < 0.05$) in the CO generated being higher using LUCAS versus AutoPulse (0.636 ± 0.061 mmHg vs. 0.399 ± 0.038 mmHg). They did not find any differences between the two different chest compression devices with regards to lung injury.

Carretero M, Fontanals J, Agusti M, et al. Monitoring in resuscitation: Comparison of cardiac output measurement between pulmonary artery catheter and NICO. *Resuscitation*. 2010;81:404-409.

This Spanish experimental study on 24 pigs evaluated the accuracy of the non-invasive NICO® Cardiopulmonary Management System to assess the cardiac output, compared to invasive thermodilution. Even if not designed to compare LUCAS 1(V1) and AutoPulse, it utilized both methods for CPR to ensure that the different mechanisms of compression did not interfere with the measurement of cardiac output. The cardiac output figures were consistently higher for the LUCAS device.

Response by Halperin H, Paradis N, noted that a porcine-specific model of AutoPulse has to be used to appropriately evaluate load-distributing band (LDB) CPR in animals, and therefore the data in this study should not be misinterpreted to reflect the hemodynamics of AutoPulse in humans. Resuscitation. 2010 Sep;81(9):1216

Matsuura T, McKnite S, Metzger A, et al. An impedance threshold compression-decompression combined with an automated active compression decompression CPR device (LUCAS) improves the chances for survival in pigs in cardiac arrest. *Circulation*. 2008;118:S1449-S1450.

This study made in Minneapolis, MN, U.S., evaluates the efficacy and safety of an active vs. a non-active (sham) impedance threshold device (ITD) (ResQPod, Adv. Circulatory Systems Inc.) on pigs who all received LUCAS 1(V1) CPR. There were no differences in hemodynamic values with or without the active ITD. The endotracheal pressure was significantly higher with the active ITD (active ITD = -2.0 ± 0.5 vs. sham ITD = -0.2 ± 0.5 , $P < 0.01$) than the non-active ITD. ROSC was achieved with fewer shocks in the active ITD group. These positive findings and lack of any adverse outcomes as shown in autopsy support the safety and efficacy of combining ITD with the LUCAS device.

Walcott P, Melnick S, Banville I, et al. Pauses for defibrillation not necessary during mechanical chest compressions during prehospital cardiac arrest. *Circulation*. 2007;116:II386. Abstract 1811.

This study made in Birmingham, AL, U.S., on pigs (N: 6) showed that randomly timed shocks delivered during ongoing compressions had a similar defibrillation threshold as shocks during a 3-5 s pause. The defibrillation threshold varied with shock timing with respect to the different LUCAS 1(V1) compression phases. The authors concluded that shocks can be delivered during ongoing LUCAS compressions without compromising efficacy, removing the need for potentially detrimental pauses in compressions.

Ristagno G, Tang W, Wang H, et al. Comparison between mechanical active chest compression/decompression and standard mechanical chest compression. *Circulation*. 2007;116:II929-II930. Abstract 31.

This study from Weil Institute in California, U.S., on (39 kg) pigs (N: 10) compared LUCAS 1(V1) with Thumper (Michigan Instruments, U.S.) after 5 min VF followed by 5 min of CPR. The LUCAS device created significantly higher blood flow compared to Thumper, a higher negative intrathoracic pressure in the decompression phase, a higher coronary perfusion pressure (31 mmHg vs. 19 mmHg), a higher EtCO₂ (28.6 mmHg vs. 22.5 mmHg) as well as an increased carotid artery blood flow (84.3 mL/min vs. 70 mL/min). Thumper caused significantly more broken ribs.

Rubertsson S, Karlsten R. Increased cortical cerebral blood flow with LUCAS, a new device for mechanical chest compressions compared to standard external compressions during experimental cardiopulmonary resuscitation. *Resuscitation*. 2005;65:357-363.

In this Swedish study, the LUCAS device 1(V1) was evaluated against a standardised manual CPR device in pigs (N: 14) with the aim to measure and compare the cerebral flow. The standardised manual CPR device was set regarding depth (5 cm) and frequency (100/min) similarly to LUCAS, but had no suction cup (i.e. no assisted recoil) and a less controlled duty-cycle. LUCAS created a significantly higher cortical cerebral flow (65% of the baseline/normal value) vs. the standard manual CPR (40% of the baseline/normal value). Flow of over 50% of baseline/normal flow could result in return of consciousness and awareness during CPR. End-tidal CO₂ values were significantly higher during LUCAS compressions. End-tidal CO₂ values are known to correlate well to cardiac output during CPR.

Steen S, Liao Q, Pierre L, Paskevicius A, et al. The critical importance of minimal delay between chest compressions and subsequent defibrillations: a haemodynamic explanation. *Resuscitation*. 2003;58:249-258.

This Swedish study examined the pathophysiology of fibrillating hearts in pigs (N: 18). During the first 3 min of VF the arterial blood was transported to the venous circulation, with the consequence that the left ventricle emptied and the right ventricle became greatly distended. After about 5 minutes, the blood pressures on the arterial and venous side reached equilibrium, resulting in zero coronary perfusion pressure and no carotid flow. It took 10 s of LUCAS 1(V1) compressions to regain acceptable flow in the carotid artery, however, it took one minute to bring back a negative CPP to zero, and a further half minute to bring it up to adequate levels (greater than or equal to 15 mmHg). Adequate heart massage before and during defibrillation greatly improved the likelihood of return of spontaneous circulation.

Steen S, Liao Q, Pierre L, et al. Evaluation of LUCAS, a new device for automatic mechanical chest compression and active decompression for cardiopulmonary resuscitation. *Resuscitation*. 2002;55:289-299.

This Swedish first publication on LUCAS 1(V1) evaluated LUCAS CPR vs. manual CPR in four different pig models (total N:100). The LUCAS device provided significantly better circulation to the brain and heart and more ROSC compared to manual CPR; increased coronary perfusion pressure (CPP; 17 mmHg vs. 10 mmHg), higher cardiac output (0.9 l/min vs. 0.5 l/min) higher carotid artery blood flow (58 ml/min vs. 32 ml/min) and more ROSC (83% vs. 0%). LUCAS square-shaped compressions created a higher pressure and flow than the peak-shaped manual ones in an artificial thorax model. The publication contains a pilot study of the first 20 human LUCAS cases, highlighting a lifesaving case. The authors concluded that the LUCAS device was easy to use and apply and appreciated by staff for freeing resources and facilitating rescue. The device fit on stretchers, worked well within ambulances, and defibrillation was possible during ongoing compressions.

Manikin Studies

Rehatschek G, Muench M, Schenk I, et al. Mechanical LUCAS resuscitation is effective, reduces physical workload and improves mental performance of helicopter emergency teams. *Minerva Anesthesiologica*. 2015; Advance online publication. Online ISSN 1827-1596.

In this German study 12 EMS teams performed manual or LUCAS CPR in random order on a manikin during simulated helicopter flights. Various components of CPR were measured. EMS member heart rate was monitored as a surrogate of physical workload. Cognitive performance was evaluated shortly after each flight by a questionnaire and a memory test about medical and extraneous items presented to the teams during the flights. Overall times of chest compressions were similar. LUCAS-CPR compression rate was lower than manual CPR (101.7/min vs 113.3/min) and compressions were deeper (3.9 cm vs 3.7 cm) $P < 0.01$, respectively. Heart rates of the EMS staff were increased after manual as compared to mechanical CPR (100.1 vs. 80.4, $P < 0.01$). Results of the questionnaire (93.6% vs. 87% correct answers, $P < 0.01$) and memory test (22.4 % vs. 11.3 %, $P < 0.02$) were significantly better after LUCAS resuscitation. Dosing of drugs, application intervals and rate of correct handling of drugs and defibrillation were not different between LUCAS and manual CPR. In summary, LUCAS CPR improved the efficacy of chest compressions, was physically less demanding and provided enhanced cognitive performance of the EMS team when compared to manual CPR during simulated helicopter flights.

Gittinger S, Grand J, Nichol G, et al. Impact of an automated chest compression device on team communication during simulated cardiac arrest resuscitations - a pilot study. Abstract 15955. Presented at ReSuscitation Science Symposium (ReSS), November 8, 2015.

This U.S. study assessed the impact of the LUCAS device on team communication and adherence to ACLS algorithms during a simulated CA resuscitation. Resuscitation teams ($n = 12$) were randomly assigned to manual compressions (control) or LUCAS (intervention) during a simulated CA consisting of Phase 1, pre-arrest (Baseline), and Phase 2, ventricular fibrillation phase (Arrest). Phase 1 metrics included total team communication statements and 10 patient care actions. Phase 2 communication was measured as number of statements related to (a) CPR coordination, (b) compression performance, and (c) diagnosis. Phase 2 patient care metrics included (a) adherence to ACLS algorithm and (b) quality of compressions. In Phase 1 there was no difference in either communication or patient care outcomes. In Phase 2, teams in the intervention group ($n = 6$) made more frequent statements focused on diagnosis ($p = 0.01$) and fewer directed toward CPR coordination ($p = 0.1$) and compression performance ($p = 0.02$). Teams using the the LUCAS device had a 22.8% decrease in delivery of poor quality chest compressions ($p = 0.08$) and fewer deviations in medication administration ($p = 0.02$) as compared to in the control group ($n = 6$). In summary, use of an automated compression device was associated with an increase in team communication focused on diagnosis and improved adherence to ACLS algorithms. While not all outcomes reached statistical significance, the large effect sizes demonstrate practical significance.

Gassler H, Kummerle S, Ventzke M, et al. Mechanical chest compression: an alternative in helicopter emergency medical services? *Internal and Emergency Medicine*. 2015;10(6):715-720.

This German study compared manual chest compression with the LUCAS 2, AutoPulse and animax mono devices in a rescue-helicopter-based scenario comprised of the installation of each device, transport and loading phases, as well as a 10-min phase inside the helicopter (type BK 117). Practicability and compression quality were measured. All mechanical devices could be used readily in a BK 117 helicopter. The LUCAS device group was the only one that fulfilled all recommendations of the ERC (frequency 102 min, compression depth 54 mm, hands-off time 2.5 %). Performing adequate manual chest compression was barely possible (fraction of correct compressions 21 %). In all four groups, the total hands-off time was < 10 %. In summary, performing manual compressions during rescue-helicopter transport is barely possible, and only of poor quality. If rescuers are experienced, mechanical compression devices could be good alternatives in this situation. The LUCAS 2 device complied with all recommendations of ERC guidelines, and all three tested devices worked consistently during the entire scenario.

Szarpak L, Karczewska K, Evrin T, et al. Comparison of intubation through the McGrath MAC, GlideScope, AirTraq, and Miller Laryngoscope by paramedics during child CPR: a randomized crossover manikin trial. *Am J Emerg Med*. 2015;33(7):946-950.

This Polish study compared success rate and time to intubation of 4 video laryngoscopes in pediatric manikin-simulated CPR using 102 paramedics who had no prior video laryngoscopy experience. After a standardized 45 minute audiovisual lecture, the paramedics participated in a practical demonstration using the PediaSIM CPR manikin designed to be an accurate representation of a 6-year-old child. CPR was performed using LUCAS 2 mechanical compression device. Afterward, paramedics were instructed to perform ETI using 4 intubation devices (McGRATH MAC, GlideScope, AirTraq, and Miller Laryngoscope Blade [Miller]) in a randomized sequence. The mean time to intubation was 30.7, 28.6, 24.1, and 39.3 sec, respectively; and the success rate was 100% vs 100% vs 100% vs 77.5%, respectively. In summary, child endotracheal intubation performed by paramedics during uninterrupted chest compression often has a low success rate. In contrast, the McGRATH, GlideScope, and AirTraq devices are fast, safe and easy to use. This manikin study suggests inexperienced medical staff might benefit from using video laryngoscopy devices for child emergency airway management.

Winkler B, Hartig F, DuCanto J, et al. Helicopter-based in-water resuscitation with chest compressions: a pilot study. *Emerg Med J.* 2015;32:7 553-558.

This German study evaluated a novel helicopter-based ALS rescue concept with in-water ventilation and chest compressions. CPR and vascular access were performed in a self-inflating Heliboat platform in an indoor wave pool using the Fastrach intubating laryngeal mask, the Oxylator resuscitator, the LUCAS device and EZ-IO intraosseous power drill. Time requirement and physical exertion on a Visual Analogue Scale (VAS) were compared between a procedure without waves and with moderate swell. Measurement of the elapsed time of the various stages of the procedure did not reveal significant differences between calm water and swell: Ventilation was initiated after 02:48 vs. 03:02 and chest compression after 04:20 vs. 04:18 min; the intraosseous cannulization was completed after 05:59 vs. 06:30 min after a simulated jump off the helicopter. The attachment of the LUCAS device to the manikin and the intraosseous cannulization was rated significantly more demanding on the VAS during swell conditions. In summary, CPR appears to be possible when performed in a rescue platform with special equipment. This novel strategy appears to enable the rescuers to initiate CPR in an appropriate length of time and with an acceptable amount of physical exertion for the divers.

Barcala-Furelos R, Abelairas-Gomez C, Romo-Perez V, et al. Influence of automatic compression device and water rescue equipment in quality lifesaving and cardiopulmonary. *Resuscitation. Hong Kong J Emerg Med.* 2014;21(5):291-299.

This Spanish study analyzed how rescue equipment and automatic compression devices influenced CPR after a water rescue on the beach, using a group of 65 lifeguards (51 men and 14 women). The lifeguards carried out a 5 minute CPR pretest then, were randomly divided into two groups. Both groups performed a water rescue, and immediately afterwards 5 min of CPR. One group did not have any additional rescue material, while the other used flippers and a rescue tube to swim and performed CPR using the LUCAS device. Use of the LUCAS device improved the number of correct chest compressions during CPR after a water rescue (manual: 283; LUCAS: 352; $p = 0.042$). There was no significant difference in the correct breathing ($p = 0.758$). During water rescue, lifeguards equipped with flippers and rescue tube were faster (227 s) than lifeguards without additional equipment (271 s, $p = 0.003$). In summary, the use of flippers and rescue tube improved the rescue time. CPR quality when the lifeguard was exerted worsened significantly, but the use of LUCAS device improved the quality of chest compressions. This was not the case with the ventilations, these being of poor quality in both groups.

Palacios-Aguilar J, Bores-Cerezal A, Navarro-Paton R. The automatic compression devices: An alternative to improve the quality of chest compressions. *Resuscitation.* 2013;84S:S26. AP046.

This Spanish study analyzed use of an automatic compression device on the quality of chest compressions after a water rescue using 20 lifeguards. Two tests were performed: the first test consisted of 5 min of CPR (rested), and then the participants were divided into two groups. In the second test, one group performed a water rescue (50m running – 75m swimming – 75m dragging manikin) and 5 min of manual CPR and the other group did CPR with the LUCAS device. CPR data were recorded with the Laerdal ResusciAnnie Manikin. There were differences in the percentage of correct chest compressions. Lifeguards achieved 71.1% of correct compressions in rested conditions. After water rescue, the percentage decreased to 62.4% ($p < 0.001$) but, increased with the use of the LUCAS device to 91.3% ($p < 0.001$). In summary, fatigue caused by water rescue decreases the quality of chest compressions. In this study, the use of the LUCAS device improved the quality of chest compressions.

Caruana E, Gauss T, Josseaume J, et al. Hands-up to set up two different mechanical chest compression devices. *Ann Emerg Med.* 2013;62(4):S143. Abstract 397.

This French study compared the time necessary to setup and start the AutoPulse and LUCAS devices using EMTs trained in the use of these devices. The test sequence consisted of manual CPR, interruption of CPR, application of the device on the manikin and startup of the device. This sequence was timed from the interruption of CPR to the first mechanical CPR (“hands-up” time). For both devices, a batch of 3 EMTs performed the sequence 4 times, resulting in 12 measures. Hands-up time was 19[13-26] sec for application of the AutoPulse device and 12[12-14] for the LUCAS device ($p = 0.03$). In summary, the results of the present evaluation showed the setup of the LUCAS takes less time than the AutoPulse device and with a tighter IQR appears more predictable. In the absence of data on efficacy, this experimental study suggests that the use of the LUCAS device is associated with a fewer interruptions of CP during CPR.

Ventzke M, Gassler H, Lampl L, et al. Cardio pump reloaded: in-hospital resuscitation during transport. *Internal and Emergency Medicine.* 2013;8(7):621-626.

This German study compared the Animax Mono (AM), AutoPulse (AP) and LUCAS 2 (L2) devices with manual chest compression using a manikin during transport from a fifth floor ward to the cardiac catheterization laboratory in the basement. Chest compressions were interrupted for 10.7 sec to set up the AM, 15.3 sec for the L2 and 23.5 sec for the AP. The use of a mechanical device reduced transport times from 144.5 sec when manual compressions were underway, to 126.8, 111.1 and 98.5 sec with AM, L2 and AP, respectively ($p = 0.05$). Transfer to the laboratory gurney required little or no interruption in compressions with L2 (0.8 s) and AP (no interruption), compared with 10.3 sec with AP and 3.3 sec for manual compressions. Manual compression frequency was 124 min, compared with 100.4 min for AM, 99.9 min for L2 and 79.7 min for AP. Compression depth did not change during transport in any group. Devices maintain the same compression depth, but fell short of current guidelines, as did manual compressions. Some interruptions occurred while the devices were set up. In summary mechanical compression devices are suitable for use during transport, but are not clearly superior to manual compressions.

Abelairas-Gomez C, Barcala-Furelos R, Garcia-Soidan J, et al. The use of automatic compression device on the cardiopulmonary resuscitation by lifeguards. *European Journal of Human Movement*. 2012;29:17-28.

This Spanish study analyzed how auxiliary rescue material and the mechanical compression devices influence CPR using a group of 78 lifeguards (50 men and 28 women). An initial test was performed which consisted in the execution of 5 min of CPR. The sample was divided in two groups. Each group performed a second test; water rescue and subsequent 5 min of CPR. One group performed the rescue without material and manual CPR. The other one, the water rescue with flippers and rescue tube and the CPR the LUCAS device. The use of the LUCAS device improved the amount of correct compressions ($p < 0.001$). There was no significant difference in the correct breathing ($p = 0.56$). During the water rescue men were faster when compared to women ($p < 0.001$). When the rescuers are equipped with flippers and a rescue tube, gender is not as significant ($p = 0.26$). In summary, rescue materials are a key to reduce the time to water rescue, and the LUCAS device to improve CPR quality.

Figgis D, Carlin B, O'Donnell C, et al. Paramedic perceptions of mechanical chest compression devices for use in adult out-of-hospital cardiac arrest. *Resuscitation*. 2012;83:e78. AP143.

This Irish study investigated paramedic perceptions of mechanical chest compression (m-CPR) devices for use in the prehospital environment. The ZOLL AutoPulse[®], Michigan Instruments' Model 1008 Life-Stat[®] and Physio-Control LUCAS 2 devices were evaluated. Following standardized video instruction on device assembly and application, personnel initiated m-CPR on a manikin simulating OHCA. Assembly time was recorded and a questionnaire was administered to ascertain paramedic opinions on the overall experience with each device. Of the 25 participants 40% had no prior experience with m-CPR devices. Mean device assembly times were: 77 sec with LUCAS 2, AutoPulse 82 sec and Life-Stat 168 s. LUCAS 2 was rated highest on user comfort, portability, ease of assembly and ease of positioning. However, 36% of subjects required assistance with set-up of the LUCAS 2 than the Life-Stat (24%) and AutoPulse (20%). Sixty-eight percent of participants felt the AutoPulse would cause the least emotional distress to family members witnessing the resuscitation. Overall, 68% ranked their first preference for the LUCAS 2 in comparison to 20% for the AutoPulse and 12% for the Life-Stat. In summary, the LUCAS 2 was the m-CPR device preferred by these personnel for use in the prehospital setting. Although there is insufficient evidence for improved outcomes with m-CPR in OHCA patients, use of m-CPR is becoming more widespread, therefore the opinion of the paramedics who will ultimately be using these devices in the field is an important consideration.

Putzer G, Braun P, Zimmerman A, et al. LUCAS compared to manual cardiopulmonary resuscitation is more effective during helicopter rescue—a prospective, randomized, cross-over manikin study. *Am J of Emerg Med*. 2013;31(2): 384-389.

This Austrian prospective, randomized, crossover study compared the LUCAS device and manual chest compressions in a simulated CPR scenario during helicopter rescue. ALS certified paramedics ($n = 25$) were enrolled and given 30 mins of training on both LUCAS and manual CPR. Every candidate then performed the same scenario twice, once with the LUCAS device and once using manual CPR. The primary outcome measure was the percentage of correct chest compressions relative to total chest compressions. When compared to manual chest compressions, the LUCAS device compressions were correct more frequently (99% vs 59% $P < .001$) and had correct depth (99% vs 79%, $P < .001$), pressure point (100% vs 79%, $P < .001$) and pressure release (100% vs 97%, $P = .001$) more often. Hands-off time was shorter with the LUCAS device than in the manual group (46 vs 130 seconds, $P = .001$). Time until first defibrillation was longer in the LUCAS group (112 vs 49 seconds, $P < .001$). In summary, compressions using the LUCAS device compared to manual chest compressions increased CPR quality and reduced hands-off time, but prolonged the time interval to the first defibrillation during this simulated cardiac arrest scenario in helicopter rescue.

Rodriguez Venegas J, Carmona Jimenez F, Nieto Cenxual A, et al. Effect of a mechanical chest compression (LUCAS[®]) over hands off and good quality chest compression time. *Resuscitation*. 2012;83:e24–e123. AP141.

This Spanish study analyzed whether the use of a mechanical chest compressor improved the "hands off" and high quality of chest compressions time during resuscitation. ALS teams composed of a doctor, nurse and emergency technician ($N = 12$) of the Barcelona city EMS performed an 8-min persistent VF mannequin simulation resuscitation scenario, first with the LUCAS device and then without it. The simulations were video recorded and the objective times were timed later. The "hands off" mean time was 86 sec during manual resuscitation compared to 82 sec during LUCAS resuscitation ($p = 0.683$). Good quality chest compressions mean time was 131 sec during manual resuscitation compared to 362 sec ($SD = 62$ sec) using LUCAS resuscitation ($p < 0.001$). In summary, the use of the LUCAS device did not improve the "hands off" time over manual resuscitation. However, the LUCAS device significantly improved chest compressions quality time over manual resuscitation. Good quality chest compression time during manual resuscitation conducted by experienced rescuers was poor.

Fox J, Fiechter R, Gerstl P, et al. Mechanical versus manual chest compression CPR underground ambulance transport conditions. *Acute Cardiac Care*. 2013;15(1):1–6.

This Swiss manikin study simulated an eight-minute cardiac resuscitation scenario during ambulance transport. Teams consisting of two rescuers experienced in manual CPR and the use of the LUCAS device were compared. Mean manual compression rate was within the recommended range (103/min), mean compression depth was closely below the recommended compression depth of > 5 cm (49.7 mm). Only 67% of all manual compressions were classified as correct (defined as sternal compression depth > 5 cm). In contrast, the LUCAS

device showed a constant and reliable CPR performance (99.96% correctly applied chest compressions within the device programmed parameters, $P = 0.0162$) with almost no variance between the different sequences. In summary, the LUCAS device represents a reliable alternative to manual CPR in a moving ambulance vehicle during emergency evacuation. Furthermore, it requires less human resources and is safer for the EMS personnel.

Gassler H, Ventzke M, Lampl L, et al. Transport with ongoing resuscitation: a comparison between manual and mechanical compression. *Emerg Med J.* 2013;30(7):589-92.

This German manikin study compared manual chest compressions (CC) with compressions using the LUCAS (L), AutoPulse (AP) and animax mono (AM) devices during transport. Measurements were obtained in a standard ambulance vehicle during transport on a predefined track. Transport duration differed strongly, mainly in the manual group, because the speed had to be reduced in the turns to avoid injuries to the paramedics. Mean CC rate in the manual group (117/min) and in the AM group (115/min) were significantly higher than in the L group (100/min, $p = 0.02$) and the AP group (80/min, $p < 0.01$). The compression depth was 44 mm in the manual group, 38 mm in the L group, and 51 mm in the AM group. A reason for the difference in the L group is the small diameter of the Ambu M MegaCode System in comparison with human patients. AP uses semicircular compressions of the chest and not ventral pressure. The quality of manual CC decreased considerably during braking or change maneuvers during driving while the mechanical devices continued to work constantly. In summary, mechanical compression devices may be a good alternative to manual compression during patient transport because they increase the safety of the rescuer and patient.

Blomberg H, Gedeberg R, Berglund L, Karlsten R, Johansson J. Poor chest compression quality with mechanical compressions in simulated cardiopulmonary resuscitation: a randomized, cross-over manikin study. *Resuscitation.* 2011;82:1332-1337.

This is a Swedish study measuring the time to first defibrillation and the no flow time prior to the first defibrillation comparing manual chest compressions with LUCAS 2 chest compressions in a manikin set up. 21 prehospital teams, consisting of 2 rescuers in each, and who had used the LUCAS device in their routine practice, were randomized to two identical 10 minute long CPR scenarios with or without the aid of LUCAS. The study showed there were no differences between LUCAS vs. manual CPR in time to first defibrillation (182 s vs. 178 s, $p = 0.56$) or hands-off time before the first defibrillation (79 s vs. 73 s, $p = 0.04$) – showing that the LUCAS device could be applied quickly without causing detrimental interruptions to chest compressions. There was also no difference in the hands-off fraction during the whole scenario (30% vs. 33%). The authors noted, however, that only 58% of the LUCAS compressions were meeting guidelines depth (defined as >38 mm according to G2005) whereas the manual CPR met guidelines depth in 88% of the compressions. The LUCAS compressions were found shallow (median 3.8 cm) compared to manual compressions (median 4.7 cm). The authors suggest the poor depth results from the LUCAS device were due to the users' failure to recognize and correct a malposition of the device and that this might counteract a potential benefit of mechanical chest compressions.

*Response by Physio-Control/Jolife AB emphasized that the depth measurements by the manikin used in this study were flawed, and that the depth measurement error was more pronounced in the LUCAS group due to the curved LUCAS back plate causing a gap to the manikin's flat back and making the manikin flex downwards during each LUCAS compression. Nilsson A, Chapman FW, *Resuscitation.* 2012;Apr;83(4):e97.*

Münch M, Rehatscheck G, Strohm M, et al. Resuscitation in Rescue Helicopter (RTH) – the feasibility and efficacy of a mechanical CPR device in an RTH simulator. (Translated from German language.) *Intenziv und Notfallmedizin.* 2010;4:295.

This is a German study on the quality of manual vs. mechanical CPR during a simulated 20 minutes long flight in a rescue helicopter with a resuscitation event. 13 teams with 2 people in each were randomized to a defined 14 min long resuscitation scenario with or without the LUCAS 2 device. The compression pauses was less with LUCAS (120 ± 60 sec) compared to manual (176 ± 80 sec). The authors conclude that the use of the LUCAS 2 device was possible in an EC 135 helicopter and its use resulted in guidelines compliant compressions measured as depth, frequency, pauses, share of effective compressions, compared to conventional manual chest compressions.

Wyss C, Fox J, Franzeck F, et al. Mechanical versus manual chest compression during CPR in a cardiac catheterisation setting. *Cardiovascular Medicine.* 2010;13:92-96. (<http://www.cardiovascular-medicine.ch/pdf/2010/2010-03/2010-03-005.PDF>)

This is a Swiss study on the quality of ten minutes of chest compressions provided manually by a three experienced resuscitators (rotating every minute) compared to compressions provided by LUCAS 1(V2) and by LUCAS 2. The test was done on a manikin in a cath lab set up. The quality was significantly higher with the two LUCAS devices compared to manual CPR. 98% of the LUCAS compressions had a correct depth versus 70% of the manual compressions ($p < 0.01$). Of the manual compressions 8% were too deep and 21% too shallow. The hands-off time due to application of the LUCAS device was on average 10 seconds (9-11 seconds) whereas the hands-off time due to change of rescuers was on average 9 seconds (8-12 seconds). The frequency was similar in all groups but showed lower variation with LUCAS (99-102/min) vs. manual CPR (88-121/min).

Review Articles And Miscellaneous Articles

Olaussen A, Shepherd M, Nehme Z, et al. Return of consciousness during ongoing cardiopulmonary resuscitation: a systematic review. *Resuscitation*. 2015;86:44-48.

This Australian systematic review identified cases where CPR-induced consciousness is mentioned in the literature and explored its management options. The search yielded 1997 unique records, of which 50 abstracts were reviewed. Nine reports, describing 10 patients, were relevant. Six of the patients had CPR performed by mechanical devices; three of these patients were sedated. Four patients arrested in the out-of-hospital setting and six arrested in hospital. There were four survivors. Varying levels of consciousness were described in all reports, including purposeful arm movements, verbal communication and resuscitation interference. Management strategies directed at consciousness were offered to six patients and included both physical and chemical restraints. In summary, CPR-induced consciousness was infrequently reported in the medical literature, and varied in management. Given the increasing use of mechanical CPR, guidelines to identify and manage consciousness during CPR are required.

Ong M, Anantharaman V. Out-of-hospital cardiac arrest: manual or mechanical CPR? *The Lancet*. 2015;385(9972):920-922.

This commentary from Singapore offers views on the PARAMEDIC Trial and the complexities of large-scale resuscitation trials. One of the comments made by the authors is that the absence of quality implementation measures in the PARAMEDIC study, such as data on delays in application of the device or CPR interruptions, makes it difficult to refute the hypothesis that the outcomes noted are possibly more an effect of the quality of implementation rather than the therapy in question. The authors discuss that EMS services should aim to provide the best quality of CPR possible and that safety concerns for unrestrained crew using manual CPR in a moving ambulance are real. Mechanical CPR allows crews to be safely belted up and is a logical choice from the safety perspective.

Ong M, Shin S, Sung S, et al. Recommendations on ambulance cardiopulmonary resuscitation in basic life support systems. *Prehosp Emerg Care*. 2013;(4):491-500.

In many Asian countries with BLS systems, patients experiencing OHCA are routinely transported in ambulances in which CPR is performed. This report makes recommendations on best practices for CPR during ambulance transport in BLS systems. Several critical issues for the safe performance and high-quality of CPR during ambulance transport were agreed upon. The main recommendations are as follows: (1) the EMS crew should stay and treat for more than 3–4 cycles of CPR at the scene; (2) advanced airways should be established prior to transport; (3) online medical control for termination of resuscitation should be considered; (4) seat belts for improving provider safety should be implemented; and (5) mechanical CPR can be considered as an alternative to manual CPR. In summary, consensus suggests the usefulness of mechanical CPR in patients during ambulance transport. These devices can also be used as a second-tier method when high-quality manual CPR is provided initially by a first responder. Mechanical devices can constitute a useful alternative to manual CPR, in terms of safety for the ambulance crew.

Brugger H, Durrer B, Elsensohn F, et al. Resuscitation of avalanche victims: evidence-based guidelines of the international commission for mountain emergency medicine (ICAR MEDCOM). *Resuscitation*. 2013;84(5):539-546.

Recommendations for transport and treatment decisions of hypothermic patients including avalanche victims have been recently developed by the International Commission for Mountain Emergency Medicine (ICAR MEDCOM). Although there are many topics, two recommendations are regarding CPR and transportation. CPR: In severely hypothermic patients respirations and pulse may be indistinct. Recommendations: Check carefully for vital signs and ECG activity for up to 1 min (Class IIIb, LOE C). Initiate CPR if signs of life are absent at standard BLS rates (Class IIa, LOE B). Patients with cardiac instability or in cardiac arrest (with a patent airway) should be transported with uninterrupted CPR to an ECMO/CPB rewarming centre. If resuscitation is successful or termination of CPR criteria is not met victims should be transported to the nearest hospital, preferably one with intensive care services (Class IIa, LOE C). Mechanical chest compression devices and therapeutic hypothermia may be considered for prolonged transports (Class IIIb, LOE B). In summary, hypothermic patients who are in cardiac arrest should be transported with uninterrupted CPR...the LUCAS device can provide uninterrupted compressions.

Rubertsson S, Silfverstolpe J, Rehn L, et al. The Study Protocol for the LINC (LUCAS in Cardiac Arrest) Study: a study comparing conventional adult out-of-hospital cardiopulmonary resuscitation with a concept with mechanical chest compressions and simultaneous defibrillation. *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine*. 2013;21:5.

This article describes the design and protocol of the randomized, controlled, multicentre LINC study. The LINC study is designed to include 2,500 prehospital cardiac arrest patients and to compare a manual CPR algorithm according to 2005 guidelines to the LINC algorithm (using the LUCAS device, defibrillation during ongoing compressions as well as providing the first shock without any prior analysis of initial cardiac rhythm). The primary outcome is 4-hour survival, and secondary endpoints include 6-month survival, neurological outcome and a safety analysis.

Dissertations

Beesems S. Doctoral thesis: Quality and outcome of cardiopulmonary resuscitation. Amsterdam University, Amsterdam, the Netherlands, 2015. <http://hdl.handle.net/11245/1.484928>

Wagner H. Doctoral thesis: Clinical and experimental insights into the use of mechanical chest compressions during prolonged resuscitation in the coronary catheterization laboratory. Lund University, Lund, Sweden, 2015. <http://www.lunduniversity.lu.se/lup/publication/5323084>

Blomberg H. Doctoral thesis: Influence of The education and Training of Prehospital Medical Crews on Measures of Performance and Patient Outcomes. Uppsala Univerisity, Uppsala, Sweden, 2013. <http://uu.diva-portal.org/smash/record.jsf?pid=diva2%3A601321&dswid=-9295>

Smekal D. Doctoral thesis: Safety with Mechanical Chest Compressions in CPR - Clinical studies with the LUCAS™ device Uppsala Univerisity, Uppsala, Sweden, 2013. <http://uu.diva-portal.org/smash/record.jsf?searchId=1&pid=diva2:63936>

Liao Q. Doctoral thesis: Safety with Mechanical Chest Compressions in CPR - Clinical studies with the LUCAS™ device Lund University, Lund, Sweden, 2011. <http://www.lu.se/lup/publication/1883004>

Axelsson C. Doctoral thesis. Safety with Mechanical Chest Compressions in CPR - Clinical studies with the LUCAS™ device. Göteborgs Universitet, Göteborg, Sweden, 2010. <http://gupea.ub.gu.se/handle/2077/23078>

Jaschkowitz T. Doctoral thesis: Kontrastmittelgestützte Notfall-Computertomographie unter Reanimationsbedingungen mit. Medizinischen Fakultät der Ludwig-Maximilians-Universität zu München, Germany, 2008. https://edoc.ub.unimuenchen.de/9415/1/Jaschkowitz_Thomas_H.pdf.

There are different generations (i.e., versions) of the LUCAS Chest Compression System. The first generation was driven by compressed air, whereas the later generations are driven by battery. Although all LUCAS versions are similar in most respects and deliver chest compressions according to the AHA and ERC guidelines, they differ somewhat in mechanical design and usability. The differences need to be considered when extrapolating clinical and animal data from the different versions.

This document aims at providing an at-a-glance overview of research presented on the LUCAS Chest Compression System. The studies have been selected and summarized by Physio-Control, and although summarized with the best of intentions and believed to be correct, please always read the referenced publication for original and comprehensive information.

Abbreviations

ALS—Advanced Life Support

AMI—acute myocardial infarction

BLS—Basic Life Support

CA—cardiac arrest

CPB—cardiopulmonary bypass

CPC—cerebral performance scale

CPR—cardiopulmonary resuscitation

ECLS—extraorporeal life support

ECMO—extracorporeal membrane oxygenator

EMS—emergency medical services

GCS—Glasgow coma score

IABP—intra-aortic balloon pump

IHCA—in-hospital cardiac arrest

LAD—left anterior descending coronary artery

LMA—left main coronary artery

MAP—mean arterial pressure

OHCA—out-of-hospital cardiac arrest

PCI—percutaneous cardiac intervention

PEA—pulseless electrical activity

RCA—right coronary artery

ROSC—return of spontaneous circulation

STEMI—ST segment elevation myocardial infarction

VF—ventricular fibrillation

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