MAY | 2018

corpuls.science

ESSAYS, RESEARCH AND INFORMATION



MECHANICAL CPR

SPECIAL EDITION







Dear ladies and gentlemen



Dr. Christian Klimmer, CEO

Mechanical CPR is of course nothing new but it is currently becoming a lot more popular. For years, developers and engineers have been trying to come up with mechanical solutions that can assist rescuers in applying chest compressions to victims of cardiac arrest. Unfortunately, none of these devices proved to be much help or to have a positive effect on patient's survival. The entire perspective on this changed when batteries became available that made devices smaller, lighter and allowed longer usage. Together with a regained focus on chest compressions during CPR, devices to assist with this life saving procedure became more attainable. A hand full of studies then tried to evaluate the effectiveness of these devices over manual compressions. The majority of these studies concluded that there is no difference regarding survival of patients whether the chest was compressed by a machine or a rescuer. Some even pointed out that the performance of well trained professionals was slightly better.



Michael Heller, Director

During this time GS corpuls decided to start its own development aiming for a solution which would overcome the restrictions of previous devices and produce ideal chest compressions. Therefore, we had to intensely study which factors influenced better quality chest compressions. Interestingly, we found a lot of similarities between optimal mechanical chest compressions and high quality manual compressions. One of which is the compression algorithm for example. Whilst healthcare professionals use their upper body weight to compress the chest, mCPR devices should not be too heavy. The upper body weight of the rescuer creates a special squeeze of the heart muscle which can only be created by an mCPR through an increased holding period. The developers of the **corpuls cpr** were able to reproduce this exact behaviour with the electrical motor that powers the device. Other similarities include the automatic adjustment to the patient's chest and the size and shape of the compression disc, which proved to be ideal as it is roughly the same size as a human hand.

Since the latest release of the Resuscitation Guidelines 2015, mCPR devices have become more and more popular. This may be because there is a number of patients who benefit from the use of these devices or need them as bridging therapy whilst being transported to the ambulance and onwards to the receiving qualified hospital where they will undergo further treatment such as PCI and/or ECMO. There is a growing number of cases where patients have benefitted from these advantages and this group of patients will hopefully be joined by a very small but even more important group very soon as the **corpuls cpr** has just been certified to be used on pediatric patients above the age of 8 years.

Thank you very much and enjoy reading the following articles.



Dr. Christian Klimmer
CEO



Michael Heller
Director Medical Research and Application

3 Editorial

5 The history of resuscitation

6 Trial of the mechanical resuscitation aid “corpuls cpr” in a pig model – a feasibility study by Tobias Lutz Neumann

7 corpuls cpr resuscitation device generates superior emulated flows and pressures than LUCAS II in a mechanical thorax model

13 corpuls cpr generates higher mean arterial pressure than LUCAS II in a pig model of cardiac arrest

22 Practical aid for effortless resuscitation? User report “corpuls cpr”

24 The corpuls cpr User Test – Interview

25 Mission investigation with corpuls.web REVIEW

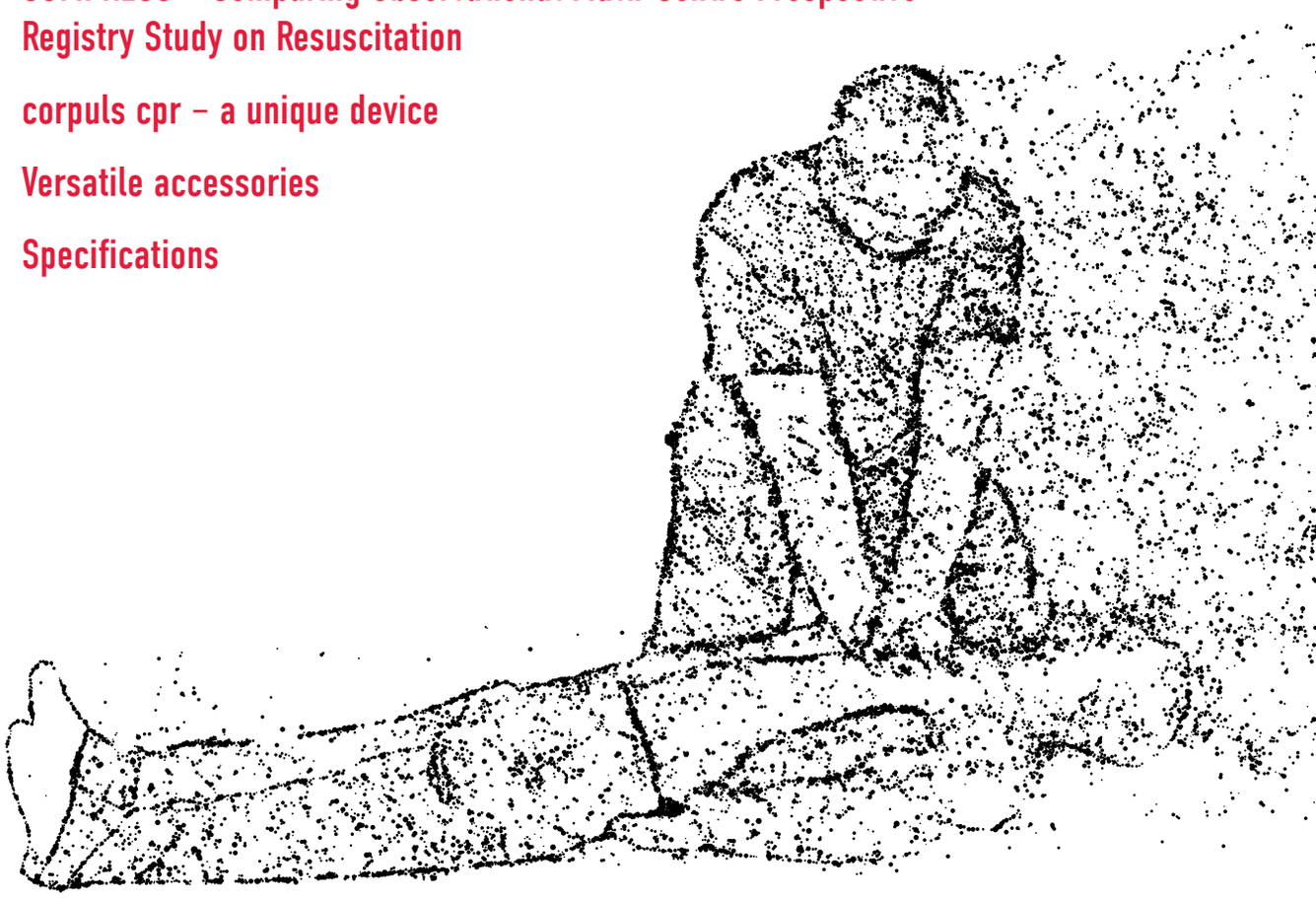
26 High Safety for Patient and Rescuers

27 COMPRESS – Comparing Observational Multi-Centre Prospective Registry Study on Resuscitation

28 corpuls cpr – a unique device

29 Versatile accessories

31 Specifications



The history of resuscitation

The origins of resuscitating unconscious people date back to the time of the Egyptians around 5000 BC and breathing techniques were also mentioned in the Old Testament. The work of Galenus of Pergamon, a Greek doctor working predominantly in Rome, influenced human medicine and its development from late antiquity. Discoveries such as the blood circulation by William Harvey in the 17th century laid the foundations for today's modern medicine.

At first the focus was on the ventilation of the lungs by mouth-to-mouth resuscitation, it was not until the 19th century that a combination of direct or indirect chest compressions was used. Here, the Silvester technique roved to be a ground-breaking milestone, which held up in part until the 20th century.

At the beginning of the 1960s, Peter Safar took decisive steps to demonstrate that the combination of ventilation and chest compressions known today led to significant survival and success rates. This research was flanked by developments such as bag valve makes and corresponding training, which also made it possible for laymen to learn cardiopulmonary resuscitation.

With the establishment of associations such as the American Heart Association, the European Resuscitation Council and the German Resuscitation Register, the accompanying professionalisation of the rescue services and numerous research projects, the focus shifted from respiration to chest compressions. Today, a 30:2 ratio in favour of chest compressions is considered to be the ideal way to ensure adequate blood flow to a lifeless person.

Since the 1960s, the industry has been trying to develop mechanical chest compression devices. Due to the inability to downscale the devices, it did not prevail. Only since the turn of the millennium, when it was finally possible to design manageable and practicable devices, have these devices been used increasingly.

GS Elektromedizinische Geräte G. Stemple GmbH (corpuls) has also been busy developing a chest compression device and introduced it under the name **corpuls cpr** in 2016. Research, experience with the devices currently on the market, current guideline recommendations as well as new ideas and approaches were incorporated into the development of this device.



Abstract of the dissertation

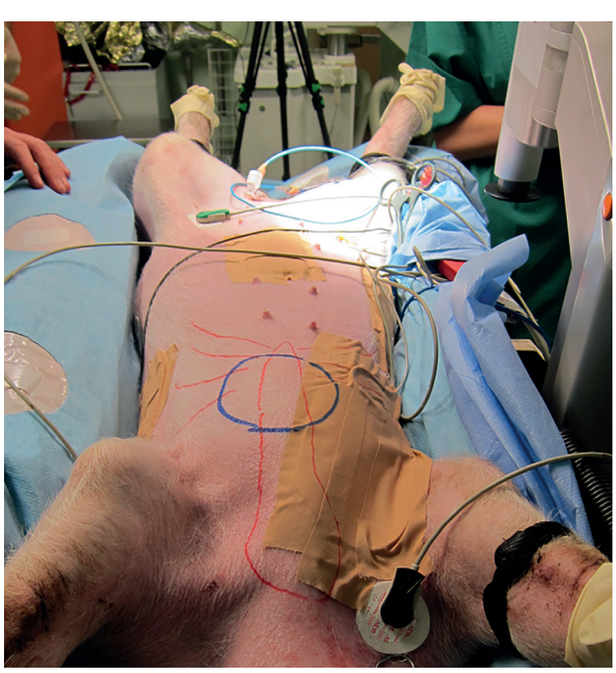
Trial of the mechanical resuscitation aid "corpuls cpr" in a pig model – a feasibility study by Tobias Lutz Neumann

from the Department of Anaesthesiology and Intensive Care Medicine the University of Cologne
Director: University Professor MD Bernd W. Böttiger

For the treatment of cardiac arrest, effective chest compressions are an essential part of life-saving cardiopulmonary resuscitation (CPR). To date, the superiority of mechanical chest compression aids over manual chest compression has not been shown. This feasibility study aimed to investigate how to adapt an established porcine model of CPR to detect differences in quality between manual and mechanical chest compressions. As a mechanical chest compression aid, a prototype of the corpuls cpr was used. Transpulmonary thermodilution with pulse contour analysis and a left ventricular pressure-volume measurement system were used as haemodynamic monitoring.

Materials and methods

Eight pigs were placed under general anaesthesia while receiving circulatory monitoring and ventilation. After taking the baseline measurements, electrical stimulation was induced in all animals and ventilation was discontinued. After 8 minutes of untreated ventricular fibrillation, the animals received guideline compliant resuscitation. Chest compressions were performed in correlation to the allocated randomised groups, the test group used the **corpuls cpr** and the control group preformed manual compressions. After Return of Spontaneous Circulation (ROSC) the animals were stabilized for 60 minutes using a defined algorithm for targeted hemodynamic therapy and myocardial performance was recorded.



Results and discussion

It was possible to produce consistent starting conditions in both groups. Four out of four animals were successfully resuscitated. There was a tendency for shorter resuscita
tion periods in the **corpuls cpr** (n.s.) group. The guideline approved compression frequency was met in all eight animals. After 60 seconds of CPR, the end tidal carbon dioxide partial pressure in the **corpuls cpr** group was significantly higher. Further differences in lung perfusion did not appear during CPR. Also, after ROSC the cardiorespiratory function was comparable between the groups. In both groups, peak lactate and potassium concentration were measured 5 minutes after ROSC with no significant group difference. As a requirement for the use of load-dependent measurements of the myocardial performance, a high degree of therapy standardization was achieved in the post-resuscitation phase. Changes in myocardial function in the post-resuscitation phase were detectable with help by transpulmonary thermodilution in the first half hour after ROSC without any significant difference between the groups.

For future experiments, the following findings were obtained: To show subtle differences in quality between manual and mechanical chest compression, the phases with cardiac arrest and basic life support should last longer. Furthermore, a higher number of cases are necessary that by means of group-sequential design are adapted to economic and animal welfare requirements. As a suitable main target size, in the context of this feasibility study, the resuscitation duration was determined for future trials. In the future, a period without therapeutic measures should allow the inclusion of native data after CPR. The use of echocardiography is considered for future trials as well as the measurement of coronary reserve. Nevertheless, the left ventricular pressure-volume measurement system is still considered indispensable and should be used as early as possible after ROSC to measure systolic and diastolic myocardial performance. Finally, proinflammatory cytokine measurement is recommended for the etiological examination of the intermittent oxygenation disorders.

corpuls cpr resuscitation device generates superior emulated flows and pressures than LUCAS II in a mechanical thorax model

S. Eichhorn[1] · A. Mendoza Garcia[3] · M. Polski[1] · J. Spindler[1] · A. Stroh[5] · M. Heller[4] · R. Lange[1, 2] · M. Krane[1, 2]

1 Department of Cardiovascular Surgery, Division of Experimental Surgery, German Heart Center Munich,
2 Munich Heart Alliance, Lazarettstrasse 36, 80636 Munich, Germany
3 Fakultät für Informatik, Robotics and Embedded Systems, Technische Universität München, Munich, Germany
4 GS Elektromedizinische Geräte G. Stemple GmbH, Kaufering, Germany
5 DZHK (German Center for Cardiovascular Research) – Partner Site Munich Heart Alliance, Munich, Germany

Abstract

The provision of sufficient chest compression is among the most important factors influencing patient survival during cardiopulmonary resuscitation (CPR). One approach to optimize the quality of chest compressions is to use mechanical-resuscitation devices. The aim of this study was to compare a new device for chest compression (**corpuls cpr**) with an established device (LUCAS II). We used a mechanical thorax model consisting of a chest with variable stiffness and an integrated heart chamber which generated blood flow dependent on the compression depth and waveform. The method of blood-flow generation could be changed between direct cardiac-compression mode and thoracic-pump mode. Different chest-stiffness settings and compression modes were tested to generate various bloodflow profiles. Additionally, an endurance test at high stiffness was performed to measure overall performance and compression consistency. Both resuscitation machines were able to compress the model thorax with a frequency of 100/min and a depth of 5 cm, independent of the chosen chest stiffness. Both devices passed the endurance test without difficulty. The **corpuls cpr** device was able to generate about 10–40% more blood flow than the LUCAS II device, depending on the model settings. In most scenarios, the **corpuls cpr** device also generated a higher blood pressure than the LUCAS II. The peak compression forces during CPR were about 30% higher using the **corpuls cpr** device than with the LUCAS II. In this study, the **corpuls cpr** device had improved blood flow and pressure outcomes over the LUCAS II device. Further examination in an animal model is required to prove the findings of this preliminary study.

Introduction

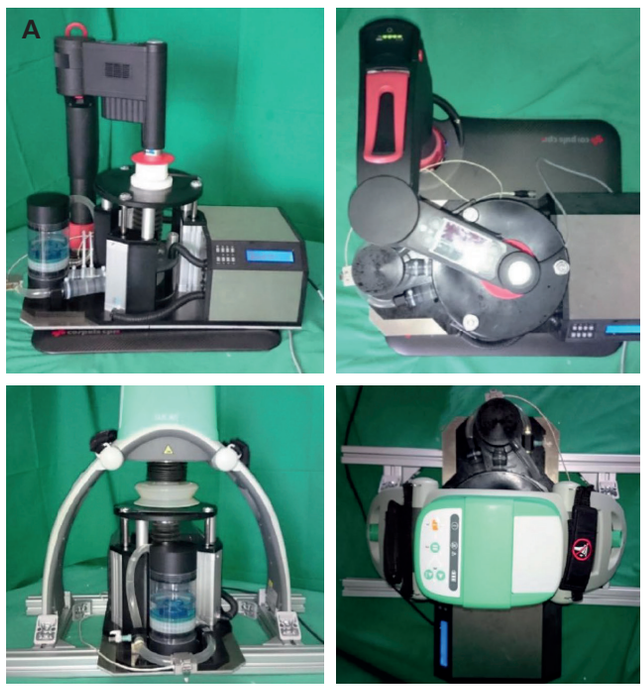
Sudden cardiac arrest is among the most challenging situations in emergency medicine. Sufficient chest compression joins ventilation, early defibrillation and the use of vasopressors and antiarrhythmic drugs as the most important factors influencing patient survival. To alleviate provider exhaustion and reduce the need to perform multiple medical procedures at once, the provision of cardiopulmonary resuscitation (CPR) using a mechanical-resuscitation device has been the aim of ongoing projects since the early 1960s [1]. Animal experiments and computer simulations have compared manual resuscitation with CPR using a chestcompression device [2–6]. Mechanical chest-compression devices are able to generate a higher blood flow than manual chest compression in animal models. Efforts to improve mechanical-resuscitation devices, in particular the duty cycle and compression frequency, have yielded varying results [7–11]. Refining these devices is an ambitious process, dealing with compression velocity, duty cycle, energy consumption and potential patient traumatization. A new apparatus for mechanical chest compression, the **corpuls cpr** device, consists of a board positioned under the patient and an adjustable arm containing an electrically driven piston with a duty cycle of 50%. It is designed to give maximum freedom and flexibility to practitioners during treatment. Devices that use only a single fixed arm face potentially reduced system stability, and compression depth may be not sufficient when treating a patient with significant chest stiffness. The aim of this study was to compare the newly introduced **corpuls cpr** device with an established device (LUCAS II) that is used widely in the field. We used a suitable technical model, focusing on compression depth and the generation of blood flow and blood pressure at different chest-stiffness settings.

Methods

We used a mechanical thorax model with adjustable chest stiffness and an internal mechanism capable of generating blood flow corresponding to compression depth and waveform. The model was able to generate variable chest resistance (5–12 N/mm) which corresponds to measurements taken in human subjects during resuscitation. The model also integrated a single-chamber heart with a vessel circuit to simulate blood flow. The adjustable stiffness was achieved using 3 pneumatic pistons (ADN-32-100- A-P-A-S11; Festo AG, Esslingen, Germany) which used a constant flow of compressed air and a computer-controlled valve (ST4118L0804; Nanotec Electronic GmbH, Feldkirchen, Germany) at the end of the circuit. The model's chest-plate resistance was regulated by adjusting the valve orifice. For more realistic chest recoil, three springs (C = 0.57) were added to the cylinders (0X-DF2091; Febrotec GmbH, Halver, Germany). The model's stiffness profiles were verified using data from a literature

review [12–16]. The model's silicone single-chamber heart (filling volume, 130 mL) was placed in an airtight chamber, connected by a flexible gaiter to the thorax compression plate. The heart's inlet and outlet were equipped with 22-mm artificial heart valves (Tekna; Edwards Lifesciences Corporation, Unterschleissheim, Germany) and connected to a circuit of two silicon tubes ending in a reservoir. According to the thoracic-pump theory, pressure inside the artificial chest increases during the compression phase, generating blood flow. An adjustable stamp, connected to the thorax plate which compressed the heart, was also integrated into the model. Depending on the position of the stamp inside the model's chest chamber, the ratio between the thoracic pump and the direct compression can be changed, altering blood flow inside the model. The stamp position was adjusted as a percentage of the primary height of the single-chamber heart at 5 cm chest compression. The movement of the model's thoracic plate was recorded using a cable potentiometer (SP3-25; Celesco Transducer Products, Towcester, Great Britain). Both the pressure and the flow inside the arterial outlet were measured with a pressure transducer (DPT 9300; Codan GmbH & Co., Forstinning, Germany) and an ultrasonic flow measurement system (T 206; Transsonic Systems Inc., Ithaca, New York City, USA). Additionally, a load cell (KM40 2 kN; ME-Meßsysteme GmbH, Hennigsdorf, Germany) was placed between the resuscitation device and the chest-compression plate to register the forces generated during CPR. All data were recorded using Powerlab V and Labchart V 8.0 (AD Instruments Ltd., Oxford, UK) using a frequency of 1 kHz. Statistical analyses were performed using Statistical Package for the Social Sciences (SPSS), version 22. We employed Student's t-test with the significance level set at <0.05. A detailed schematic of the model is given in Fig. 1. Two different electromechanical driven devices for chest compression were used in the examination. LUCAS II (Jolife AB, Lund, Sweden) and the **corpuls cpr** (GS elektromedizinische Geräte G. Stemple GmbH, Kaufering, Germany) device. Three different stiffness profiles were chosen, representing the lower (6 N/mm, Stiffness I) the mean (8 N/mm, Stiffness II) and the upper value (10 N/mm, Stiffness III) of patients treated with chest compressions. Three different stamp positions (20%, thoracic-pump mode; 50%, mixed thoracic-pump and direct-compression modes; 70%, direct-compression mode) were used when measuring blood-flow generation.

The mechanical thorax model was placed under the resuscitation devices. When using the LUCAS II device, the curved board that is usually positioned under the patient was replaced with a solid metal frame to eliminate movements of the model due to an uneven underground. After ensuring proper contact of the device's patient interface with the model's compression plate, CPR was started in continuous mode for 2 min for each setting. Data was analysed every



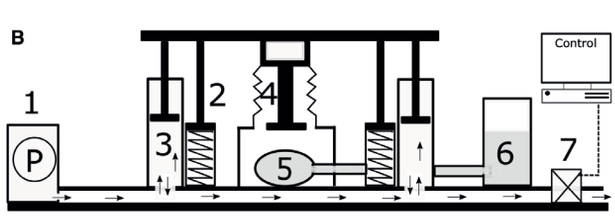


Fig. 1. a Two different chest compression devices interacting with a physical thorax model. Upper pictures **corpuls cpr**; lower pictures LUCAS II (backboard replaced with metal frame for better contact with model). **b** Schematic of the physical patient model: 1 air-compression pump; 2 spring; 3 pneumatic piston; 4 variable gaiter; 5 single-chamber heart; 6 reservoir with bubble trap; 7 computer-controlled valve

30 s for 10 compression cycles. Both devices were run for an endurance test: 30 min at room temperature (20 °C) at Stiffness III to check temperatureand battery management. The interaction of the resuscitation devices with the physical thorax model are shown in **Fig. 1**.

Results

Both mechanical resuscitation devices were able to compress the model chest up to a depth of 5 cm, even with the highest chest stiffness selected. The CPR machines passed the 30-min endurance test without difficulty. Both devices performed compression with a duty cycle of about 50%, but there was a detectable, if small, difference in compression speed, maximum compression timeand decompression time over the whole cycle. The **corpuls cpr** device generated a 20-ms shorter compression phase and a 20-ms shorter decompression phase than the LUCAS II, and a 20-ms longer duration of maximum compression. The difference in the time–displacement curve of the chestcompression plate is illustrated in **Fig. 2**. Independent of chest stiffness and stamp position, the **corpuls cpr** device was able to generate a higher mean blood flow than the LUCAS II device. A considera-

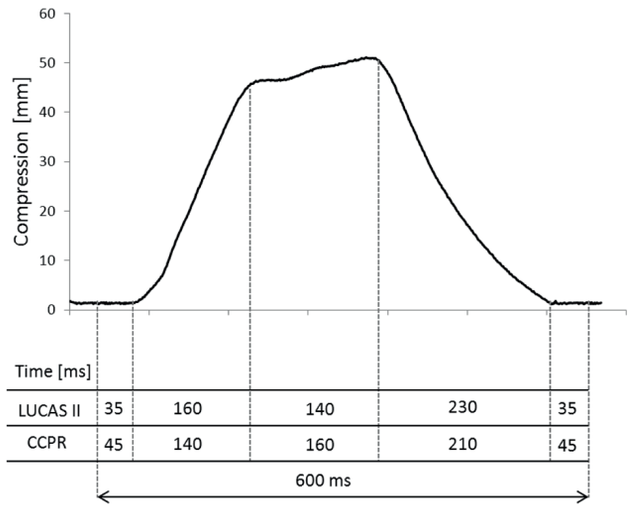


Fig. 2. Model compression and decompression times with different resuscitation devices

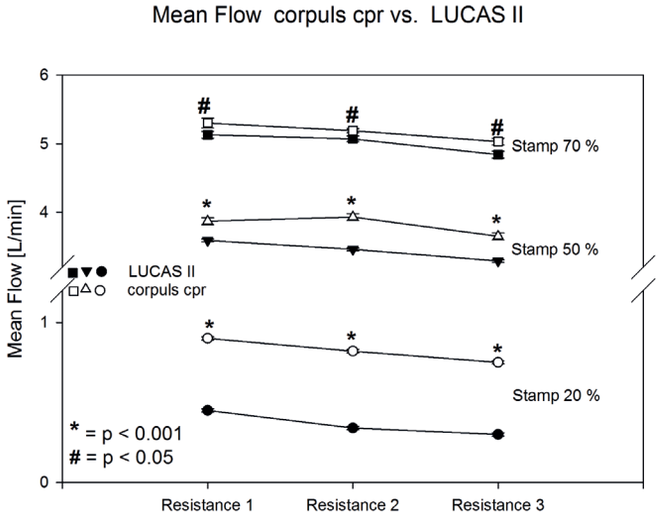


Fig. 3. Mean flow according to chest resistance and stamp position. Using 20 and 50% Stamp position, the **corpuls cpr** shows a significantly higher mean flow than LUCAS II ($p < 0.001$). In 70% stamp position the **corpuls cpr** shows a marginally higher mean flow than LUCAS II ($p < 0.005$)

ble difference in mean blood flow was observed when the stamp was placed at 20%, representing the thoracic-pump mechanism as the main blood-flow generator. In this scenario, the model treated with the **corpuls cpr** device showed up to double the mean flow of the LUCAS II device, regardless of chest stiffness ($p < 0.001$). Increasing the stamp to direct-compression mode led to a decrease in the difference between the generated mean blood flow of the two devices. In 50% thoracic-pump/direct-compression mode, the **corpuls cpr** was still able to generate a mean blood flow that was about 10% higher than the LUCAS II ($p < 0.001$). When the stamp was increased to 70% (direct-compression mode), the difference in the mean flow shortened by approximately 5% ($p < 0.005$). Detailed results are given in **Fig. 3** and **Table 1**. When the model was adjusted to the thoracic-pump mode (20% stamp position), there was no significant difference ($p > 0.05$) in the maximum arterial pressure, regardless of the chosen chest stiffness. The maximum pressure in all scenarios was about 10 mm Hg. Increasing the stamp to the direct-compression mode increased the maximum chamber pressure, and the **corpuls cpr** device was able to generate a significantly higher ($p < 0.001$) maximum blood pressure in all scenarios that used the 50 and 70% stamp positions, independent of chest stiffness. The highest difference in maximum blood pressure was recorded in the 50% stamp position. In this scenario, the **corpuls cpr** device reached approximately a 20% higher peak pressure (~30 mm Hg) than the LUCAS II (~24 mm Hg) at every chest-stiffness value. In the 70% stamp position, the **corpuls cpr** device generated a pressure (~54 mm Hg) about 8–10% higher than that of the LUCAS II (~49 mm Hg), decreasing with rising chest stiffness. Detailed results are provided in **Table 2** and **Fig. 4**. For every chosen model configuration, the **corpuls cpr** device produced a maximum peak compression force approximately 30% higher than that generated by the LUCAS II device ($p < 0.001$). The maximum forces generated by the LUCAS II were between 350 and 560 N, with the **corpuls cpr** device yielding results between 510 and 730 N. These results are presented in **Table 3**.

Discussion

Both chest-compression devices were able to compress the mechanical model to a depth of up to 5 cm, with a frequency of 100 compressions per minute and a duty cycle of about 50%, even when a high chest stiffness was used. From the mechanical point of view, the construction of the LUCAS II system, with 2 fastening points and a compression cylinder in the middle of the system frame, provides high stability with little elastic deflection during chest compression. A major disadvantage of this apparatus is its restricted flexibility in performing additional diagnostic and therapeutic procedures due to the cumbersome setting with an unfavorably high balance point.

The **corpuls cpr** device consists of a single flexible arm that can be adjusted, using lockable pinjoints, to be appropriate to any patient's individual situation. This provides the persons treating the patient a maximum of flexibility compared with a closed-frame system. However, implementing a CPR machine with an open frame has its challenges. The torque, generated by the compression cylinder at the end of an open frame produces higher bending moments than in a closed frame. Therefore, the mechanical components and pinjoints have to be extremely rigid. We expected a higher compliance of the system with high chest stiffness, resulting in reduced compression depth, but this was not the case. In every chosen scenario, the resuscitation device was able to compress the model up to a depth of 5 cm. It seems that a slight bending of the frame occurs when the forces generated by the piston increase, but this is compensated by a longer path of the compression cylinder, regulated by an intelligent-controller algorithm. A slight difference in the movement speed

l/min (%)	Stamp position					
	20%		50%		70%	
	LUCAS II	**corpuls cpr**	LUCAS II	**corpuls cpr**	LUCAS II	**corpuls cpr**
Stiffness I	0.45 ± 0.05	0.9 ± 0.03	3.59 ± 0.05	3.87 ± 0.06	5.13 ± 0.05	5.3 ± 0.07
%Change	50 ± 5.5	100 ± 3.3	93 ± 1.3	100 ± 1.6	97 ± 1	100 ± 1.3
Stiffness II	0.34 ± 0.06	0.82 ± 0.05	3.46 ± 0.06	3.93 ± 0.05	5.07 ± 0.04	5.19 ± 0.03
%Change	41 ± 7	100 ± 6	88 ± 1.5	100 ± 1.3	97 ± 0.8	100 ± 0.6
Stiffness III	0.3 ± 0.05	0.75 ± 0.04	3.29 ± 0.05	3.65 ± 0.05	4.84 ± 0.05	5.03 ± 0.05
%Change	40 ± 6.7	100 ± 5.33	90 ± 1.4	100 ± 1.4	96 ± 1	100 ± 1

Table 1
Mean blood flow [l/min] according to stamp position and model stiffness. Additionally the percental difference (%) of the mean flow is described, setting the flow of the **corpuls cpr** to 100%

mm Hg (%)	Stamp position					
	20%		50%		70%	
	LUCAS II	**corpuls cpr**	LUCAS II	**corpuls cpr**	LUCAS II	**corpuls cpr**
Stiffness I	10.6 ± 0.5	10.6 ± 0.5	25.9 ± 1.7	31.3. ± 1.6	49.2 ± 2.3	59.3 ± 1.7
%Change	100 ± 4.7	100 ± 4.7	82 ± 5.4	100 ± 5.3	83 ± 3.9	100 ± 3
Stiffness II	10.8 ± 0.6	9.95 ± 0.7	23.2 ± 2.1	31.2 ± 2.5	49.3 ± 1.2	53.1 ± 0.4
%Change	108 ± 6	100 ± 7	74.3 ± 6.7	100 ± 8	93 ± 2,3	100 ± 7.5
Stiffness III	9.35 ± 0.2	10.2 ± 0.4	23.4 ± 1.5	30.3 ± 1.7	49.4 ± 1.3	53.3 ± 0.8
%Change	91 ± 2	100 ± 3.9	78 ± 4.9	100 ± 5.6	93 ± 2.4	100 ± 1.5

Table 2
Maximum aortic pressure (mm Hg) according to model stiffness. Additionally the percental difference (%) of the maximum aortic pressure is described, setting the generated pressure of the **corpuls cpr** to 100%

Maximum (N)	Stamp position					
	20%		50%		70%	
	LUCAS II	**corpuls cpr**	LUCAS II	**corpuls cpr**	LUCAS II	**corpuls cpr**
Stiffness I	352 ± 4	510 ± 4	354 ± 2	536 ± 3	382 ± 5	576 ± 3
%Change	69 ± 0.8	100 ± 0.8	66 ± 0.4	100 ± 0.6	66 ± 0.9	100 ± 0.5
Stiffness II	429 ± 5	597 ± 8	427 ± 7	632 ± 4	465 ± 8	635 ± 7
%Change	72 ± 0.8	100 ± 1.3	68 ± 1.1	100 ± 0.63	73 ± 1.3	100 ± 1.1
Stiffness III	502 ± 3	714 ± 8	521 ± 6	720 ± 8	561 ± 7	730 ± 5
%Change	70 ± 0.4	100 ± 1.1	73 ± 0.8	100 ± 1.1	76 ± 1	100 ± 0.7

Table 3
Maximum compression force (N) according to stamp position, and percental difference, the values of the **corpuls cpr** set to 100%

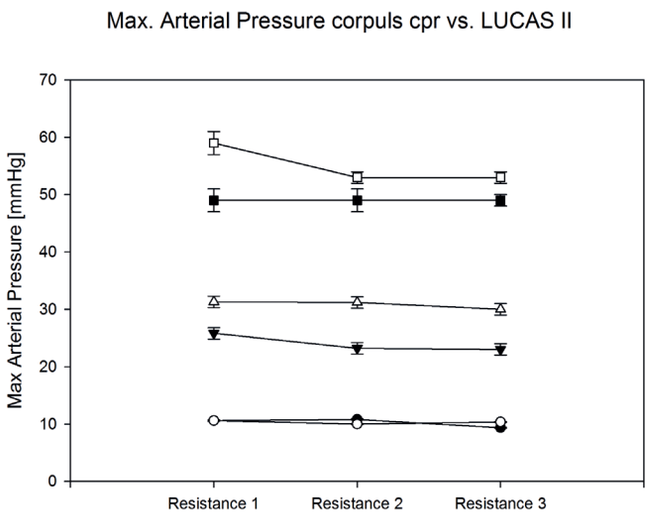


Fig. 4. Maximum arterial pressure according to adjusted stamp position. In 20% position, no significant difference in the maximum arterial pressure, generated by the two different devices could be detected ($p > 0.05$). In 50 and 70% Stamp postion the **corpuls cpr** was able to generate a highly significant superior maximum arterial pressure than the LUCAS II device ($p < 0.001$)

curve of the chest plate of the model due to compression of the machine was detected between the two devices. A more trapezoidal compression waveform with a longer maximum compression time was seen with the **corpuls cpr** device. This slight modification in the compression waveform generated greater blood flow in our model. There is no clear consensus on the cause of perfusion during resuscitation. There are two main theories discussed widely in the literature: direct cardiac compression [17–20] and the intrathoracic pump mechanism [21–24]. Depending on the flow-generating effect, either increasing compression frequency or modifying the compression time or duty cycle might result in higher blood flow. If flow generation is mainly influenced by the thoracic pump, prolonging compression time will increase flow.

If it is predominantly created by direct compression, increasing frequency would thereby increase flow [25]. In our trial, the most prominent difference in flow occurred when the model was tuned to thoracic-pump mode; this is consistent with the measured waveform and findings of several other groups. In an animal study, Kramer-Johansen et al. [26] compared a trapezoidal to a more sinusoidal waveform. The trapezoidal waveform improved the hemodynamics during cardiac arrest, similar to our results. Using a mathematical model developed by our research group, several trapezoidal waveforms at different frequencies result in a peak generated flow at 100 compressions per minute and a prolonged compression of 300 ms [27]. We were able to represent both mechanisms of flow generation, as well as a mixed mechanism, in our study. A combination of both effects seems to be the most probable explanation for blood-flow generation. In both the 50 and 70% stamp positions, the **corpuls cpr** device was able to generate a higher blood pressure and a higher flow than the LUCAS II device, independent of the stiffness setting. This result warrants intensive investigation in further studies using a suitable animal model of cardiac arrest. Generating a trapezoidal waveform requires more energy than generating a sinusoidal waveform, causing the device battery to drain more quickly and the motor to heat up during resuscitation. This needs to be addressed with a larger capacity battery and an intelligent motor temperature-management system. Both devices passed the endurance test without difficulty, so we can conclude that energy- and temperature management are efficient in both devices and that both are capable of generating constant compressions. Because of its longer compression duration at a frequency of 100 compressions/minute, the **corpuls cpr** device compresses the chest faster than the LUCAS II device, causing higher peak forces. In all model settings, we measured a peak force approximately 30% higher than with the LUCAS II device. Whether these higher peak forces potentially increase the risk of patient trauma cannot be answered by this study; additional trials with a suitable cadaver model are warranted.

Conclusion

In examinations using a mechanical thorax model, the **corpuls cpr** device generates superior blood flow and higher blood pressure than the LUCAS II device. These results require verification in further studies using suitable animal models.

Acknowledgements

The examination was also funded by Bayerische Forschungsstiftung, project "automation of an electrical driven resuscitation device, AZ1012-12".

Compliance with ethical standards

Conflict of interest

Michael Heller is employed at GS Elektromedizinische Geräte G. Stemple GmbH.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Literature

1. Harrison-Paul R (2007) Resuscitation great. A history of mechanical devices for providing external chest compressions. Resuscitation 73(3):330–336. doi:10.1016/j. resuscitation.2007.01.002
2. Gassler H, Ventzke MM, Lampl L, Helm M (2012) Transport with ongo ing resuscitation: a comparison between manual and mechanical compression. Emerg Med J. doi:10.1136/ emermed-2012-201142
3. Gates S, Smith JL, Ong GJ, Brace SJ, Perkins GD (2012) Effectiveness of the LUCAS device for mechanical chest compression after cardiac arrest: systematic review of experimental, observational and animal studies. Heart 98(12):908–913. doi:10.1136/heartjnl-2011-301571
4. Halperin HR, Paradis N, Ornato JP, Zviman M, Lacorte J, Lardo A, Kern KB (2004) Cardio pulmonary resuscitation with a novel chest compression device in a porcine model of cardiac arrest: improved hemodynamics and mechanisms. J Am Coll Cardiol 44(11):2214–2220. doi:10.1016/j.jacc.2004.08.061
5. Steen S, Liao Q, Pierre L, Paskevicius A, Sjoberg T (2002) Evaluation of LUCAS, a new device for automatic mechanical compression and active decompression resuscitation. Resuscitation 55(3):285–299
6. Timerman S, Cardoso LF, Ramires JA, Halperin H (2004) Improved hemodynamic performance with a novel chest compression device during treatment of in-hospital cardiac arrest. Resuscitation 61(3):273–280. doi:10.1016/j.resuscitation.2004.01.025
7. Babbs CF (2006) Design of near-optimal waveforms for chest and abdominal compression and decompression in CPR using computer-simulated evolution. Resuscitation 68(2):277–293. doi:10.1016/j.resuscitation.2005.06.025
8. Betz AE, Menegazzi JJ, Logue ES, Callaway CW, Wang HE (2006) A randomized comparison of manual, mechanical and high-impulse chest compression in a porcine model of prolonged ventricular fibrillation. Resuscitation 69(3):495–501. doi:10.1016/j.resuscitation.2005.09.026
9. Jung E, Babbs CF, Lenhart S, Protopopescu VA (2006) Optimal strategy for cardiopulmonary resuscitation with continuous chest compression. Acad Emerg Med 13(7):715–721. doi:10.1197/j. aem.2006.03.550
10. Sunde K, Wik L, Naess PA, Ilebekk A, Nicolaysen G, Steen PA (1998) Effect of different compression–decompression cycles on haemodynamics during ACD-CPR in pigs. Resuscitation 36(2):123–131
11. Tomte O, Sjaastad I, Wik L, Kuzovlev A, Eriksen M, Norseng PA, Sunde K (2010) Discriminating the effect of accelerated compression from accelerated decompression during highimpulse CPR in a porcine model of cardiac arrest. Resuscitation 81(4):488–492. doi:10.1016/j. resuscitation.2009.12.028
12. Bankman IN, Gruben KG, Halperin HR, Popel AS, Guerci AD, Tsitlik JE (1990) Identification of dynamic mechanical parameters of the human chest during manual cardiopulmonary resuscitation. IEEE Trans Biomed Eng 37(2):211–217. doi:10.1109/10.46262
13. Neurauter A, Nysaether J, Kramer-Johansen J, Eilevstjonn J, Paal P, Myklebust H, Wenzel V, Lindner KH, Schmolz W, Pytte M, Steen PA, Strohmenger HU (2009) Comparison of mechanical characteristics of the human and porcine chest during cardiopulmonary resuscitation. Resuscitation 80(4):463–469. doi:10.1016/j.resuscitation.2008.12.014
14. Nysaether JB, Dorph E, Rafoss I, Steen PA (2008) Manikins with human-like chest properties–a new tool for chest compression research. IEEE Trans Biomed Eng 55(11):2643–2650. doi:10.1109 TBME.2008.2001289
15. Tomlinson AE, Nysaether J, Kramer-Johansen J, Steen PA, Dorph E (2007) Compression force-depth relationship during out-of-hospital cardiopulmonary resuscitation. Resuscitation 72(3):364–370. doi:10.1016/j.resuscitation.2006.07.017
16. Tsitlik JE, Weisfeldt ML, Chandra N, Effron MB, Halperin HR, Levin HR (1983) Elastic properties of the human chest during cardiopulmonary resuscitation. Crit Care Med 11(9):685–692
17. Higano ST, Oh JK, Ewy GA, Seward JB (1990) The mechanism of blood flow during closed chest cardiac massage in humans: transesophageal echocardiographic observations. Mayo Clin Proc 65 (11):1432–1440
18. Huemer G, Kolev N, Zimpfer M (1996) Transoesophageal echocardio graphic assessment of mitral and aortic valve function during cardiopulmonary resuscitation. Eur J Anaesthesiol 13(6):622–626
19. Kouwenhoven WB, Jude JR, Knickerbocker GG (1960) Closedchest cardiac massage. JAMA 173:1064–1067
20. Mair P, Kornberger E, Schwarz B, Baubin M, Hoermann C (1998) Forward blood flow during cardiopulmonary resuscitation in patients with severe accidental hypothermia. An echocardiographic study. Acta Anaesthesiol Scand 42(10):1139–1144
21. Criley JM, Niemann JT, Rosborough JP, Ung S, Suzuki J (1981) The heart is a conduit in CPR. Crit Care Med 9(5):373–374
22. Haas T, Voelckel WG, Wenzel V, Antretter H, Dessl A, Lindner KH (2003) Revisiting the cardiac versus thoracic pump mechanism during cardiopulmonary resuscitation. Resuscitation 58(1):113–116
23. Rich S, Wix HL, Shapiro EP (1981) Clinical assessment of heart chamber size and valve motion during cardiopulmonary resuscitation by two-dimensional echocardiography. Am Heart J 102(3 Pt 1):368–373
24. Rudikoff MT, Maughan WL, Effron M, Freund P, Weisfeldt ML (1980) Mechanisms of blood flow during cardiopulmonary resuscitation. Circulation 61(2):345–352
25. Dean JM, Koehler RC, Schleien CL, Atchison D, Gervais H, Berkowitz I, Traystman RJ (1991) Improved blood flow during prolonged cardiopulmonary resuscitation with 30% duty cycle in infant pigs. Circulation 84(2):896–904
26. Kramer-Johansen J, Myklebust H, Wik L, Fellows B, Svensson L, Sorebo H, Steen PA (2006) Quality of out-of-hospital cardiopulmonary resuscitation with real time automated feedback: a prospective interventional study. Resuscitation 71(3):283–292. doi:10.1016/j.resuscitation.2006.05.011
27. Mendoza Garcia A, Eichhorn S, Polski M, Knoll A (2014) Simulation of an electro-mechanical resuscitation device for cardiopulmonary resuscitation. Comput Cardiol Conf Proc 2014:1049–1052

corpuls cpr generates higher mean arterial pressure than LUCAS II in a pig model of cardiac arrest

S. Eichhorn[1] · A. Mendoza[3] · A. Prinzing[1] · A. Stroh[1] · L. Xinghai[1] · M. Polski[1] · M. Heller[5] · H. Lahm[1] · E. Wolf[4] · R. Lange[1, 2] and M. Krane[1, 2]

1 Clinic for Cardiovascular Surgery, Department of Experimental Surgery, German Heart Center, Munich, Technische Universität München, Germany.
2 DZHK (German Center for Cardiovascular Research) – partner site Munich Heart Alliance, Munich, Germany.
3 Fakultät für Informatik, Robotics and Embedded Systems, Technische Universität München, Germany
4 Gene Center, LMU Munich, Munich, Germany
5 GS Elektromedizinische Geräte GmbH, Kaufering, Germany

Correspondence should be addressed to S. Eichhorn; eichhornst@gmail.com

Received 15 September 2017; Revised 25 October 2017; Accepted 23 November 2017; Published 17 December 2017

Academic Editor: Hideo Inaba

Copyright© 2017 S. Eichhorn et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

According to the European Resuscitation Council guidelines, the use of mechanical chest compression devices is a reasonable alternative in situations where manual chest compression is impractical or compromises provider safety.The aim of this study is to compare the performance of a recently developed chest compression device (**corpuls cpr**) with an established system (LUCAS II) in a pig model. Methods. Pigs (*n*= 5/group) in provoked ventricular fibrillation were left untreated for 5 minutes, after which 15 min of cardiopulmonary resuscitation was performed with chest compressions. After 15 min, defibrillation was performed every 2 min if necessary, and up to 3 doses of adrenaline were given. If there was no return of spontaneous circulation after 25 min, the experiment was terminated. Coronary perfusion pressure, carotid blood flow, end-expiratory CO2, regional oxygen saturation by near infrared spectroscopy, blood gas, and local organ perfusion with fluorescent labelled microspheres were measured at baseline and during resuscitation. Results. Animals treated with **corpuls cpr** had significantly higher mean arterial pressures during resuscitation, along with a detectable trend of greater carotid blood flow and organ perfusion. Conclusion. Chest compressions with the **corpuls cpr** device generated significantly higher mean arterial pressures than compressions performed with the LUCAS II device.

Background

According to the 2015 European Resuscitation Council (ERC) guidelines, the use of mechanical chest compression devices is a reasonable alternative in situations where manual chest compression is impractical or compromises provider safety. The aim of this study is to compare the performance of a recently developed chest compression device (**corpuls cpr**) with an established system (LUCAS II) in a pig model of cardiac arrest.

Methods

Pigs (n=5/group) in provoked ventricular fibrillation were left untreated for 5 minutes, after which 15 min of cardiopulmonary resuscitation (CPR) was performed with chest compressions and a Ruben bag. After 15 min, defibrillation was performed every 2 min if necessary, and up to 3 doses of adrenaline were given. If there was no return of spontaneous circulation (ROSC) after 25 min, the experiment was terminated. Coronary perfusion pressure (CPP), carotid blood flow, end expiratory CO2, regional oxygen saturation by near infrared spectroscopy (NIRS), blood gas, and local organ perfusion with fluorescent labelled microspheres were measured at baseline and during resuscitation.

Results

Animals treated with **corpuls cpr** had significantly higher mean arterial pressures during resuscitation, along with a detectable trend of greater carotid blood flow and regional organ perfusion. NIRS regional oximetry, local organ perfusion measured by microspheres, coronary perfusion pressure and blood gas values showed no difference between the two groups.

Conclusion

Chest compressions with the **corpuls cpr** device generated significantly higher mean arterial pressures than compressions performed with the LUCAS II device, along with a slight increase in carotid flow. No differences could be detected concerning CPP, local organ perfusion or local oxygen saturation measured with NIRS.

Introduction

Chest compressions are crucial for maintaining coronary and cerebral perfusion during cardiac arrest. The efficiency of manual chest compressions during cardiopulmonary resuscitation (CPR) decreases over time [1, 2], and it is difficult to perform efficient chest compressions during transportation or during interventional procedures, e.g. in a catheter lab.

In order to address these problems, a variety of devices that perform mechanical chest compressions have been developed and tested in animal experiments, experimental investigations using manikins and clinical studies [3-7].
The 2015 European Resuscitation Council (ERC) guidelines for CPR recommend mechanical chest compression devices as a reasonable alternative in situations where delivery of high performance chest compressions is impeded or would compromise provider safety [8].

These devices should offer maximal flexibility for adaptation to the individual constitution of the patient, as well as adequate battery capacity, low weight, and mechanical stability that allows compressions of sufficient depth even at high chest stiffness values. The LUCAS II device is currently one of the most widely used chest compression machines in clinical practice. This device has a closed frame that surrounds the patient to provide a maximum of stability.

corpuls cpr (GS Elektromedizinische Geräte G. Stemple GmbH, Kaufering, Germany) is a newly introduced electric device for chest compressions. Compression is generated by a single, flexible, adaptable arm that is locked in a spine board or to a small baseplate positioned under the patient. The device works with a duty cycle of 50% and typically has an average battery capacity of 90 min. It offers an adjustable compression frequency from 80 -120 compressions / minute, and a compression depth of 20 – 60 mm. The therapy mode can be changed between 30:2 / 15:2 and continuous mode. The position of the stamp is checked after each ventilation break or 100 compressions (continuous mode) and compensated if a sunken thorax is detected [9-11].

The aim of the present study is to compare the effects of the performance of this device with the clinically-established LUCAS II device in a pig model of cardiac arrest.

Materials and Methods

A total of 10 female German Landrace pigs weighing 25 ± 2.5 kg were used in the study. All animals received care in compliance with the European convention for the protection of vertebrate animals used for experimental and other scientific purposes. The study protocol was approved by the local government (Regierung von Oberbayern, Ref-Nr. 55.2-1-54-2532-205-2013)

Ketamine (15 mg/kg), azaperone (2 mg/kg), and atropine (0.02 mg/kg) were injected intramuscularly (neck region according to swindle et al. [12]) for premedication. The pigs were placed in a supine position and endotracheal intubation via tracheotomy was performed after intravenous bolus injection of propofol (10 mg/kg) and fentanyl (0.04 mg). Anaesthesia was maintained by continuous infusion of propofol (8 mg/kg/h) and fentanyl (25 µg/kg/h) and intravenous Ringer´s solution (10-15 ml/kg/h) was administered to maintain a mean arterial pressure of 80 -90 mmHg.

Volume-controlled ventilation (tidal volume 8 to 10 ml/kg, PEEP 5 cm H2O, FIO2 0.21 to 0.3, and Pmax 45 mbar) was performed using an Evita II respirator (Draeger, Luebeck, Germany). Oxygen was added to maintain a saturation > 95 %. End-expiratory CO2 (mainstream technique) and oxygen saturation (sensor placed at the tongue) as well as the electrocardiogram (ECG) based on pads (Ambu Blue Sensor, Ambu Germany, Friedheim) were monitored by a Corpuls 3 device (GS Elektromedizinische Geräte G. Stemple GmbH, Kaufering, Germany). Respiratory frequency was adjusted to maintain an end-expiratory CO2 partial pressure between 35 and 40 mmHg before cardiac arrest. Arterial blood gas samples were taken from the introducer placed in the femoral artery every 15 min during preparation, and the ventilation was adjusted accordingly.

An ultrasonic flow probe (Transonic 202, Ithaca, USA) was placed around the right carotid artery, and a temporary pacemaker wire was inserted into the right ventricle via the right external jugular vein. Additionally, a catheter for sampling aortic blood was placed via the subclavian artery. Micromanometers (Millar-TIP SPC 350, Houston, TX, USA) were placed in the ascending aorta and the right atrium via bilateral femoral cutdown, and a pigtail catheter was placed in the descending aorta from the left femoral arteria. Blood pressure was monitored at the femoral artery with a fluid-filled line and pressure transducer (Xtrans, PVB Codan Critical Care, Forstinning, Germany).

Near infrared spectroscopy (NIRS) sensors (Equanox, Nonin, North Plymouth, MN, USA) were placed in the frontal region of the scull, in submental position ,and on the lower left quadrant of the abdomen for monitoring regional oxygen saturation (%RO2) in accordance with the protocol for humans weighing <40 kg (NO80004CB). Each area was shaved and cleaned thoroughly with isopropanol prior to placement of the sensors.

Hemodynamic data were recorded continuously at a frequency of 1 kHz with Powerlab 8.0 (AD Instruments, Oxford, UK).
Fluorescent labelled microspheres (Molecular Probes, 15 µm, Life Technologies, Eugene, OR, USA) were used to measure local organ perfusion at baseline and after 5 min of resuscita-

tion, as follows: 106 microspheres /10 kg body weight were injected via the pigtail catheter, which was directly above the aortic valve, and reference samples were taken via syringe pump over a catheter placed in the decending aorta at a rate of 10 mL/min for 4 minutes.

Before initiation of ventricular fibrillation, the pigs were randomised into two groups, **corpuls cpr** (CCPR) or LUCAS II CPR, by a sealed envelope method. Pigs that received **corpuls cpr** were secured to a v-shaped board prior to induction of ventricular fibrillation and those that were treated with the LUCAS II device were secured inside the device by padding on the left and right sides between the pig and the load frame (**Fig. 1**).
Resuscitation was performed according to the protocol outlined in **Fig 1**. Ventricular fibrillation was induced by a 14 V direct current pulse via the pacemaker and the pigs were left untreated for 5 min. The respirator was disconnected and the infusion of propofol and fentanyl was stopped. After 5 min, CPR was initiated. Both devices were operating with 100 compressions /min in continuous mode and a compression depth of 50 mm with a duty cycle 50%. 10 ventilations per minute were performed with a Ruben bag supplied with 100% oxygen.

The fluorescent microspheres were injected at 5 min of resuscitation. After 15 min of continuous resuscitation the compressions were stopped and defibrillation was performed with a 150 J biphasic impulse in cases of ongoing ventricular fibrillation. Compressions were then resumed for 2 min, and up to 3 doses of epinephrine (0.01 mg/kg mg) were given after 3 cycles of 2 min chest compression after defibrillation. If there was no return of spontaneous circulation (ROSC) after 6 defibrillations and 3 doses of epinephrine the experiment was stopped. Necropsies were performed with special attention to compression-related chest injuries that might have affected ROSC (Pericardial Effusion, Pneumothorax, Hemothorax).

Blood gas samples were collected every 5 min after initiation of cardiac arrest; the sampling included lactate measurement by Siemens Rapid Point 500 (Siemens, Erlangen, Germany). Cardiac perfusion pressure (CPP) was calculated according to the end diastolic method [13] using an average of 10 compression cycles. Mean arterial pressure (MAP), mean carotid blood flow (CBF), regional oxygen saturation (%RO2) by NIRS, and end expiratory CO2 (ETCO2) were also measured to evaluate the performance of the resuscitation devices. The data was recorded continuously using powerlab and Labchart (AD Instruments, Sydney, Australia). For evaluation, Baseline data before initiation of ventricular fibrillation, 5 minutes of cardiac arrest and during resuscitation (1; 5; 10; 15; 20 minutes) were taken.
Normal distribution of the data was analysed using the Kolmogorov-Smirnov test. Comparison of variables between the 2 groups was performed with student´s t-test for unpaired observations. A p-value of <0.05 was regarded as an indicator of statistically significant differences between the groups. All statistical analyses were carried out using IBM SPSS V20.

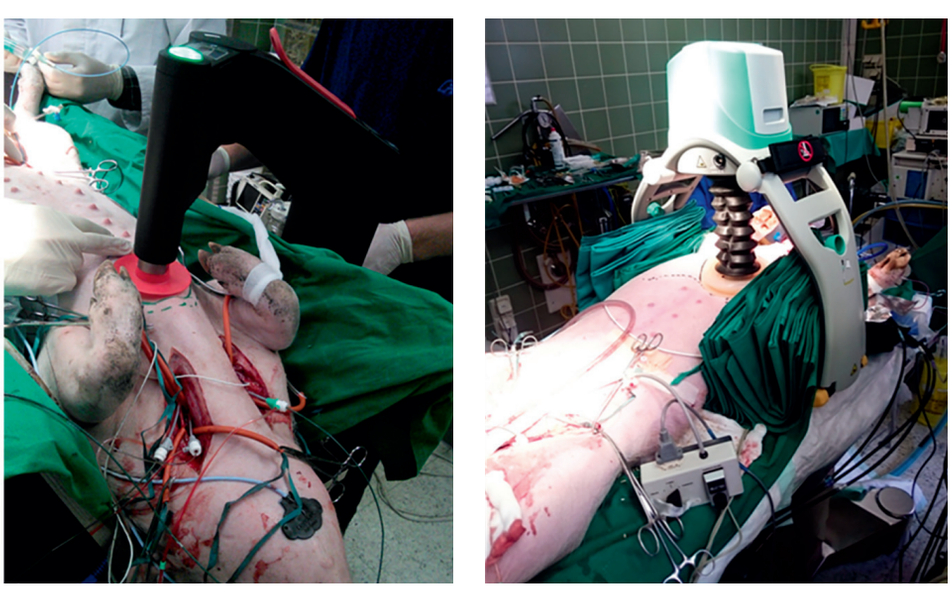
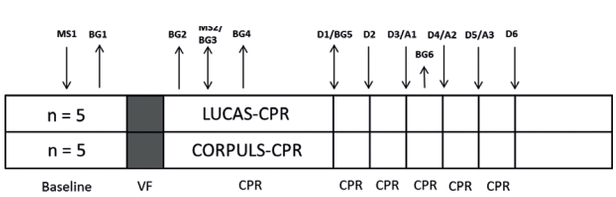


Fig. 1:
Left side: Pig in a v-shaped board during treatment with the **corpuls cpr**,

Right side: Pig fixed with cushions in the LUCAS II.



Lower side: Description of the study protocol, MS: Microsphere injection, BG: Blood Gas sample, D: Defibrillation, A: Administration of adrenaline.

Results

MAP measured at the femoral artery was significantly higher during **corpuls cpr** throughout resuscitation period (MAP=approximately 43 mmHg, **corpuls cpr**, vs. 23 mmHG, LUCAS II).

CBF declined to 30% of the baseline value at the beginning of resuscitation and decreased to 20% of the initial value at the end of the resuscitation period. CBF was significantly higher in the **corpuls cpr** group after 20 min of resuscitation and after administration of vasopressors. Detailed results are shown in **Table 2** and **Fig. 3**.

There were no significant differences between the groups in baseline ETCO2, MAP, CPP, CBF, %RO2, lactate levels, or degree of local organ perfusion by microspheres. Detailed results are presented in **Table 1**.

CPP during resuscitation was similar between the groups, measuring approximately 20 mmHg for both.

There was also no significant difference between groups in the degree of local organ perfusion by microspheres after 5 min of resuscitation. Cerebral perfusion levels of 23 ± 7.5% of baseline were recorded for the **corpuls cpr** group, compared to 12.6 ± 6.7% of baseline in the LUCAS II group. Cardiac perfusion of 26 ± 9% of baseline was detected in the **corpuls cpr** group, compared to a cardiac perfusion of 17 ± 2% of baseline in the LUCAS II group. Renal perfusion decreased to 19.4 ± 7.8% of baseline in the **corpuls cpr** group and to 20.2 ± 4.9% of baseline in the LUCAS II group. Hepatic perfusion also declined, to 12.1 ± 7.3 % of baseline in the **corpuls cpr** group and 8.9 ± 2.9% in the LUCAS II group.

NIRS measurements did not differ significantly between the groups. Measurements taken with the submental sensor indicated a decrease in oxygen saturation of about 20% from baseline after 5 min of cardiac arrest. Regional oxygen saturation increased by approximately 10% during CPR. Measurements obtained by probes in the frontal position showed a decrease in oxygen saturation to approximately 65% of baseline at 5 min after cardiac arrest and this value increased to approximately 70% of baseline during CPR. The peripheral sensors indicated regional oxygen saturation of approximately 80% of baseline at 5 min after arrest; this increased to 90% of baseline during CPR. There were no significant differences in %RO2 between groups at any of the sensor positions. Detailed results are shown in **Fig 2**.

Finally, there were no significant differences in ETCO2, potassium levels, lactate levels, or pH values between the two groups. There was a slight increase of CO2 detected after 5 min of resuscitation, which decreased again (Table 2) during resuscitation. pH values were decreased in both groups from a baseline of approximately 7.4 to 7.25 after 20 min of resuscitation. Potassium levels increased during treatment, from approximately 4.2 mmol/L at baseline to 6.8 mmol/L at the end of the experiment. The lactate levels increased from approximately 1.55 mmol/L at baseline to 8.2 mmol/L at the end of the experiment (Table 3) . Three animals from each group received defibrillation; 2 animals per group were asystolic after 15 min of CPR; and no pig in either group had ROSC. At autopsy, in the macroscopic inspection of the opened chest we detected no rib fractures that caused harmful injuries influencing ROSC like pneumothorax, hemothorax or pericardial effusions in either group.

Table 1
Baseline values in the two groups showed no statistical difference

	MAP [mm Hg]	CPP [mm Hg]	Av. CBF [ml/min]	ET CO2 [mmHg]]	PH	Lac [mmol/L]
corpuls cpr	79 ± 2.6	56.8 ± 4.7	82 ± 23	37.9 ± 3.1	7,4 ± 0.02	1.5 ± 0,38
LUCAS II	82 ± 12.1	57.2 ± 13.1	79.6 ± 15.4	37.2 ± 0.75	7.4 ± 0.04	1.59 ± 0.34
Local Perfusion	**Brain [ml/min100g]**	**Heart [ml/min100g]**	**Kidney [ml/min100g]**	**Liver [ml/min100g]**		
corpuls cpr	36.6 ± 5.08	93.8 ± 18.68	236 ± 38.2	28.6 ± 8.55		
LUCAS II	36 ± 3.63	110.4 ± 6.53	230.6 ± 48.2	25 ± 3.3		

MAP:
mean arterial pressure; CPP: cerebral perfusion pressure; Av. CBF: average cerebral blood flow; ET CO2: end-tidal carbon dioxide; Lac: lactate; CCPR: **corpuls cpr**.

Table 2
Mean arterial pressure, local Perfusion, Et CO_2 and carotid blood flow during resuscitation

MAP [mm Hg]	**MAP 1 minute**	**MAP 5 minutes**	**MAP 10 minutes**	**MAP 15 minutes**	**MAP 20 minutes**
corpuls cpr	49.4 ± 7.58	42.2 ± 7.11	45.6 ± 13.7	43.4 ± 9.2	43.2 ± 10.7
LUCAS II	25.9 ± 6.53	25,54 ± 6.53	23.0 ± 6.7	21.6 ± 6.4	21.9 ± 6.6
CBF [ml/min]	**CBF 1 minute**	**CBF 5 minutes**	**CBF 10 minutes**	**CBF 15 minutes**	**CBF 20 minutes**
corpuls cpr	26.6 ± 8.45	26.4 ± 5.68	24.0 ± 3.85	18.8 ± 4.7	18.2 ± 4.8
LUCAS II	20.82 ± 8.01	18.9 ± 9.34	15.5 ± 8.43	11.66 ± 5.21	6.48 ± 3.23
Et CO_2 [mmHg]	**Et CO_2 1 minute**	**Et CO_2 5 minutes**	**Et CO_2 10 minutes**	**Et CO_2 15 minutes**	**Et CO_2 20 minutes**
corpuls cpr	22.62 ± 9.27	34.6 ± 25.76	23.1 ± 12.64	17.68 ± 7.08	15.94 ± 8.42
LUCAS II	22.58 ± 5.49	22.88 ± 9.31	22.84 ± 10.5	19.88 ± 9.96	15.9 ± 4.17
Local Perfusion at 5 min	**Brain [ml/min100g]**	**Heart [ml/min100g]**	**Kidney [ml/min100g]**	**Liver [ml/min100g]**	
corpuls cpr	8.24 ± 2.17	25 ± 8.39	45 8 ± 18.5	3.4 ± 2.06	
LUCAS II	4.54 ± 2.41	18.8 ± 1.94	46.6 ± 11.3	2.24 ±0.73	

MAP:
Mean arterial pressure. *Mean arterial pressure was significantly higher in the **corpuls cpr** group throughout the entire resuscitation period.
CBF: Carotid blood flow. *Carotid blood flow was significantly higher in the **corpuls cpr** group at 20 min.

Discussion

The haemodynamic parameters at baseline and during resuscitation in our experiments corresponded with the results of previous evaluations of mechanical resuscitation devices. Halperin et al. [6] generated CPP between 14 and 21 mm Hg, cerebral flow of approximately 0.2 mL/min/g, and MAP of approximately 36 mmHg during CPR using a load distributing band (Autopulse). Steen et al. [7], in an evaluation of a LUCAS device, measured CBF of approximately 30% of baseline and MAP of approximately 40 mmHg, and Liao et al [14] reported CPP of >20 mmHg and a CBF of approximately 30 to 35% of baseline during CPR with the LUCAS II device in pig models. The LUCAS II system is presently the most widely used mechanical chest compression system, and a number of experiments and clinical trials have been performed to evaluate its efficacy [15-20]. Therefore, we used the LUCAS II system as the reference device for comparison with the **corpuls cpr** device.
We found that the **corpuls** device was able to generate a significantly higher MAP than the LUCAS device. There was also a trend to greater CBF and improved local organ perfusion with the **corpuls** device, although this was not statistically significant.

The ability of **corpuls cpr** to generate higher MAP and CBF might be related to a difference in the compression waveform [9], or to the different shape of the chest compression plate. Neither of the compression plates that were used in our experiments have a feature for active chest recoil, and the diameters of the contact areas are comparable. Thus, the difference in flow and pressure is probably not related to the compression plate.

On the other hand, **corpuls cpr** produces a slightly more trapezoidal compression waveform than the LUCAS II device. Using an artificial chest model with integrated blood flow we could measure the compression waveform of the two devices and produce analogue results concerning MAP and arterial blood flow comparing the LUCAS II and the **corpuls cpr** [9] . Kramer-Johansen et al. [1] have reported similar results secondary to modifications of the compression waveform in a computer simulation as well as in a pig model. There are two effects that are mentioned in Literature causing blood circulation during CPR, the direct cardiac compression and the thoracic pump theory [21, 22]. If the flow is predominantly created by the thoracic pump, a more trapezoid compression waveform with prolonged compression time will increase the flow. In the chest of a pig the ventricles are embedded with loung tissue from all sides, and the compressions given to the thorax are affecting the heart and the big vessels much more by the thoracic pump mechanism, than by the direct compression mechanism than in humans [14]. This might also be an explanation that although having similar cardiac perfusion pressures in the group of **corpuls cpr** a higher MAP could be generated.

In a study performed by Paradis et al. [23] only patients with a CPP of 15 mm Hg or higher reached ROSC. Similar findings for pigs were obtained by Steen et al. [7] .In our study, CPP values of >15 mmHg were reached in all animals during CPR, and there were no signs of pericardial effusion or pneumothorax at necropsy that would have been affecting ROSC. However, none of the animals had ROSC. In a pig model with a compa-

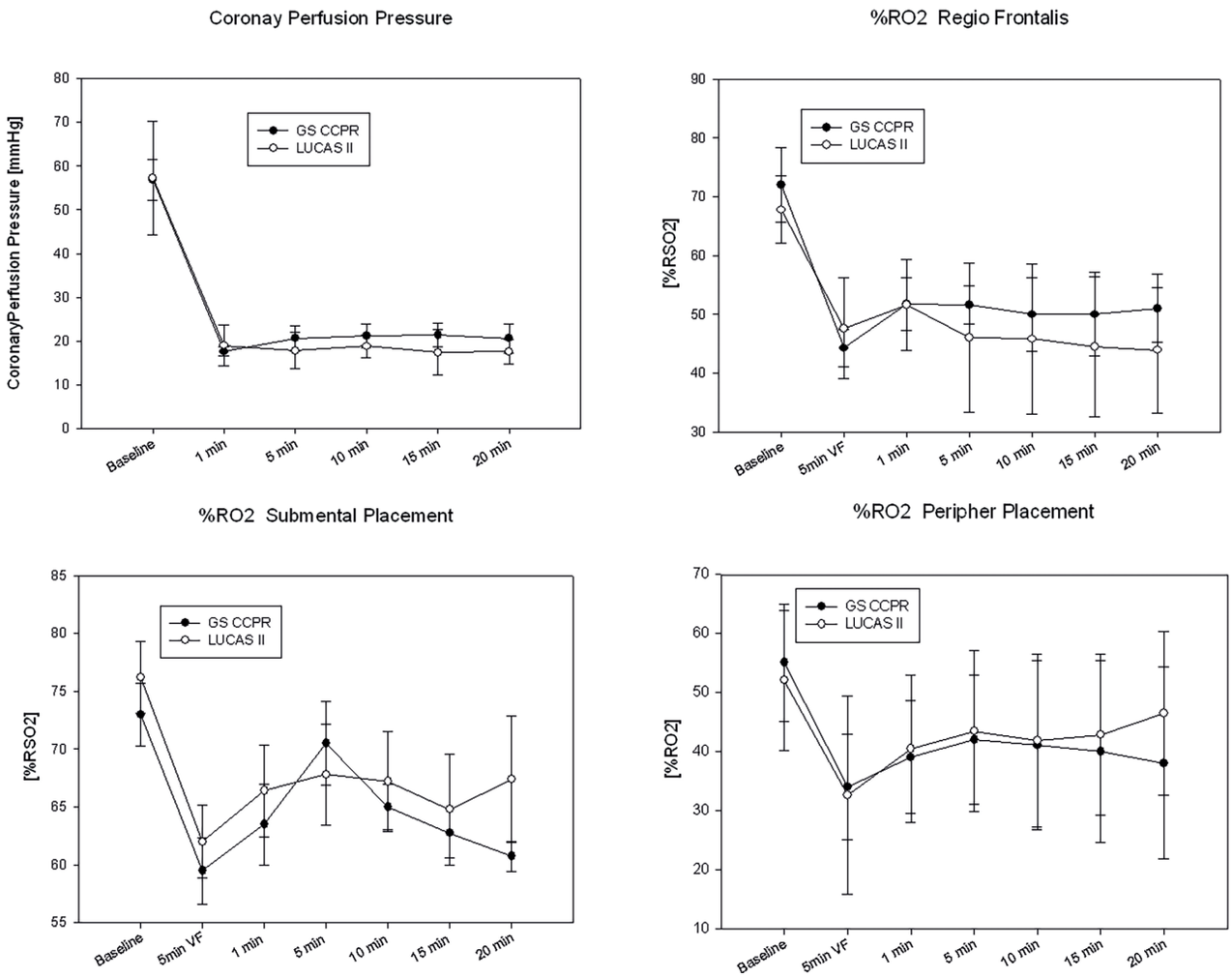


Fig. 2:
Coronary perfusion pressure and regional oxygen saturation (Regio frontalis, submental placement, periphery placement) during resuscitation. No significant difference was detectable over the whole period (p> 0.05). Submental placement seems to produce the highest changes in%RO2 between the different measurement points in our pig model.

rable study design Liao et al reached a ROSC rate of 100 % using the LUCAS II device [14]. In difference to our examination they used a suction cup that provides active chest recoil. Consecutively this resulted in significantly lower pressure in the right atrium during the decompression phase, and additionally in a higher intrathoracic aortic pressure during the end decompression phase. We used the german model of LUCAS II with holes in the suction cup, that allows no active chest recoil in the decompression phase.

Another difference to the examination of Liao et al are the animals they used in their study. In contrast to us they used Swedish domestic pigs with a mean weight of 31 kg, we were using german landrace pigs with a mean weight of 25 kg. There could be an influence caused by the breed or more probably due to the lower weight of the animals. In contrast to their study, we also had found pigs having asystole after 15 minutes of CPR in both groups. Also the vasoconstrictive effect of the administered adrenaline could not be detected significantly. These two additional findings can also be related to the compression without active chest recoil, or breed and weight.

Our protocol was designed to characterize the differences in flow and pressure related to the chest compression device, with minimized influence of defibrillation or drugs. This is why we chose to allow a long interval of ventricular fibrillation (5 min), compared to prior investigations in which the untreated interval was only 60 to 90 s [6, 7, 24]. With this consideration, we accepted a lower chance of ROSC in exchange for study conditions that favoured evaluation of the influence of different compression devices on haemodynamic performance.

Additionally, in our protocol, the first 15 min of resuscitation included only mechanical chest compressions and Ruben bag ventilation. No additional treatments, i.e. defibrillation or medications, were provided during this period. It has been shown that survival rates and neurological outcome are worse after a longer duration of fibrillation in men and in pig [25-28], and

early defibrillation and administration of antiarrhythmic drugs or vasopressors would have most likely increased the rate of ROSC in our study.

Peak forces of up to 600 N have been reported during chest compression [29-31]. The frame of a resuscitation device must be very rigid to reach a compression depth of 50 mm. Examination of the recorded data of the LUCAS II device used in 59 cases of cardiac arrest by Beesems et al. [32] showed that the LUCAS II device was able to generate sufficient compression of 50 mm in all cases.

There was initial concern that the flexible open frame of the **corpuls cpr**. Device would not have sufficient rigidity to ensure proper compression depths in different chest profiles. In previous experiments based on a mechanical chest model [9] and in the animal experiments, there were no difficulties reaching the recommended compression depth of 50 mm with the **corpuls** device in any case, and no immoderate bending or moving of the stamp on the compression area was noted.
Several studies have been performed to determine the usefulness of NIRS as a neuromonitoring tool for prediction of outcomes, detection of ROSC, or evaluation of the quality of brain perfusion during CPR [33]. We found a significant difference in %RO2 between baseline, after 5 min of cardiac arrest, and after 5 min of CPR. We also found a very high level of interindividual deviation of the absolute values of %RO2, which might indicate, that the chosen sensor system that was designed for the human brain is not suitable for examination in pigs.

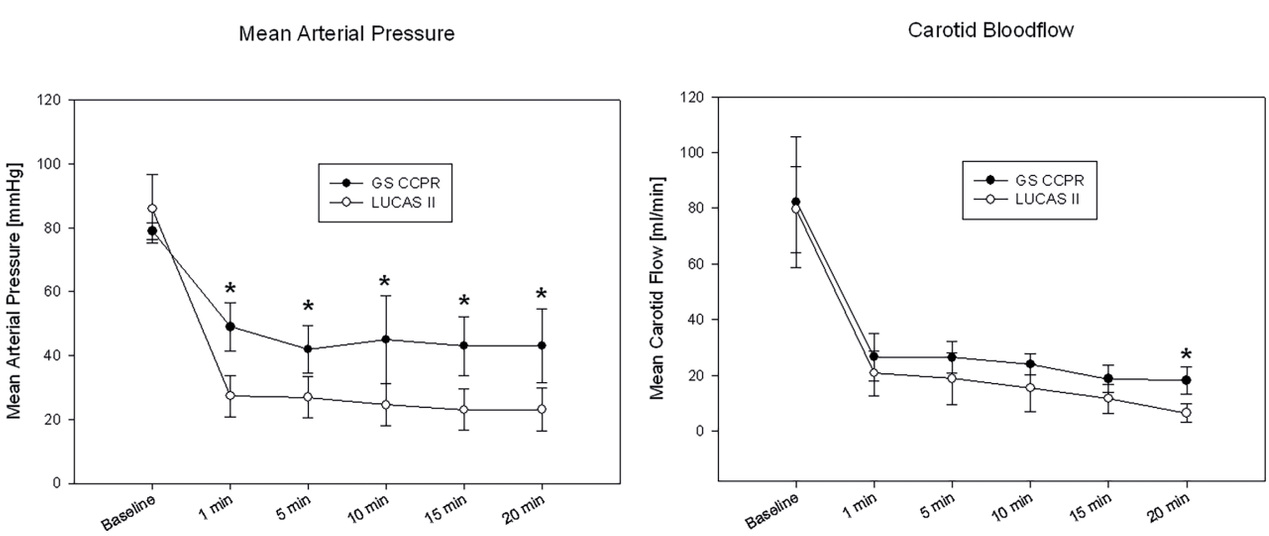


Fig. 3:
Mean arterial pressure and carotid bloodflow during resuscitation (* =p<0.05). **corpuls cpr** is generating a significantly higher mean arterial pressure during the whole resuscitation period. Carotid blood flow seems to be higher by trend during the resuscitation period, after 20 minutes of resuscitation a significant difference could be detected.

We were using the smallest available paediatric sensors for NIRS monitoring, which are designed for human use. The dimensions of the skull and brain of the pig are anatomically different than those of the human, and this might explain the large interindividual spread of the recorded values. In our opinion, in experiments with a pig model, submental sensor placement is preferable to frontal region placement for monitoring cerebral perfusion. We found that the most impressive changes with the least interindividual deviation were detected when the sensors were placed in the submental position. This might be due to better adaption of the sensor to the tissue in the submental region, as the plane area for correct sensor placement in the frontal region is limited.

We were able to use NIRS to measure baseline oxygen saturation values before cardiac arrest. The usefulness of information obtained from NIRS measurements during resuscitation might be limited without prior baseline measurements, as is often the case in real world emergency situations. Nonetheless, our results support the conceptual premise that regional oxygen saturation can detect changes in cerebral perfusion brain during CPR. Whether this method is suitable to predict ROSC or the neurological outcome, as other authors have suggested [34, 35], or whether it can provide further information regarding the quality of CPR, cannot be finally answered based on the design and results of our study. Further investigations focusing especially on the use of NIRS in CPR are necessary.

Table 3
Blood gas values at baseline and during resuscitation (Mean and SD)

pH Value	Baseline	1 min Resuscitation	5 mins Resuscitation	10 mins Resuscitation	15 mins Resuscitation	20 mins Resuscitation
corpuls cpr	7.41 ± 0.02	7.44 ± 0.1	7.37 ± 0.07	7.23 ± 0.12	7.19 ± 0.21	7.25 ± 0.16
LUCAS II	7.42 ± 0.04	6.86 ± 1.18	7.39 ± 0.14	7.35 ± 0.1	7.34 ± 0.11	7.31 ± 0.08
Potassium [mmol/l]	**Baseline**	**1 min Resuscitation**	**5 mins Resuscitation**	**10 mins Resuscitation**	**15 mins Resuscitation**	**20 mins Resuscitation**
corpuls cpr	4.2 ± 0.28	5.02 ± 0.95	6.39 ± 0.34	6.06 ± 0.39	6.15 ± 0.38	6.76 ± 0.85
LUCAS II	4.11 ± 0.24	4.77 ± 0.49	6.72 ± 0.54	6.34 ± 0.83	6.21 ± 0.8	6.81 ± 0.75
Lacatate [mmol/l]	**Baseline**	**1 min Resuscitation**	**5 mins Resuscitation**	**10 mins Resuscitation**	**15 mins Resuscitation**	**20 mins Resuscitation**
corpuls cpr	1.52 ± 0.38	2.91 ± 1.97	5.68 ± 2.41	6.87 ± 1.88	7.65 ± 1.48	8.69 ± 1.76
LUCAS II	1.59 ± 0.34	2.1 ± 0.35	5.35 ± 1.44	6.27 ± 1.3	6.6 ± 1.19	8.1 ± 1.35

Conclusion

In conclusion, we found that the **corpuls cpr** device was equivalent or superior to the LUCAS II system in terms of blood pressure and flow during resuscitation in a pig model of cardiac arrest. Chest compressions with the **corpuls cpr** device generated significantly higher MAP compared to compressions with a Lucas II device.

The examination was funded by Bayerische Forschungsstiftung, project "automation of an electrical driven resuscitation device, AZ1012-12".

Ethics approval

All animals received care in compliance with the European convention for the protection of vertebrate animals used for experimental and other scientific purposes and the study protocol was approved by the local government.

Competing interest

Michael Heller is employed at GS Elektromedizinische Geräte G. Stemple GmbH.

Funding

The examination was funded by Bayerische Forschungsstiftung, project "automation of an electrical driven resuscitation device, AZ1012-12".

Author´s contributions

SE designed the examination, performed experiments and wrote most parts of the manuscript. AM designed and performed experiments. AP performed the surgical part of the experiments AS helped to design the study and performed anesthesia during the experiments, XL performed the surgical part of the experiments and analyzed experimental data, MP helped to perform the experiments and data analyses. MH helped to perform the experiments and the company GS Elektromedizinische Geräte G. Stemple Gmbh supplied the **corpuls cpr** device, HL contributed in writing and study design, EW contributed in editing the manuscript and study design, RL contributed in writing the manuscript, MK contributed in study design and editing the manuscript. All authors read and approved the final manuscript.

Literature

1. Kramer-Johansen J, Myklebust H, Wik L, et al. Quality of out-of-hospital cardiopulmonary resuscitation with real time automated feedback: a prospective interventional study. Resuscitation 2006; 71:283-292.
2. Wik L, Kramer-Johansen J, Myklebust H, et al. Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest. JAMA 2005; 293:299-304.
3. Putzer G, Braun P, Zimmermann A, et al. LUCAS compared to manual cardiopulmonary resuscitation is more effective during helicopter rescue-a prospective, randomized, cross-over manikin study. Am J Emerg Med 2013; 31:384-389.
4. Harrison-Paul R Resuscitation great. A history of mechanical devices for providing external chest compressions. Resuscitation 2007; 73:330-336.
5. Timerman S, Cardoso LF, Ramires JA, et al. Improved hemodynamic performance with a novel chest compression device during treatment of in-hospital cardiac arrest. Resuscitation 2004; 61:273-280.
6. Halperin HR, Paradis N, Ornato JP, et al. Cardiopulmonary resuscitation with a novel chest compression device in a porcine model of cardiac arrest: improved hemodynamics and mechanisms. J Am Coll Cardiol 2004; 44:2214-2220.
7. Steen S, Liao Q, Pierre L, et al. Evaluation of LUCAS, a new device for automatic mechanical compression and active decompression resuscitation. Resuscitation 2002; 55:285-299.
8. Monsieurs KG, Nolan JP, Bossaert LL, et al. European Resuscitation Council Guidelines for Resuscitation 2015: Section 1. Executive summary. Resuscitation 2015; 95:1-80.
9. Eichhorn S, Mendoza Garcia A, Polski M, et al. Corpuls cpr resuscitation device generates superior emulated flows and pressures than LUCAS II in a mechanical thorax model. Australas Phys Eng Sci Med 2017; 40:441-447.
10. GS Elektromedizinische Geräte G. Stemple Gmbh **corpuls cpr**. https://corpuls.world/en/products/corpuls-cpr
11. Prinzing A, Eichhorn S, Deutsch MA, et al. Cardiopulmonary resuscitation using electrically driven devices: a review. J Thorac Dis 2015; 7:E459-467.
12. Swindle MM, Smith AC Best practices for performing experimental surgery in swine. J Invest Surg 2013; 26:63-71.
13. Otlewski MP, Geddes LA, Pargett M, et al. Methods for calculating coronary perfusion pressure during CPR. Cardiovasc Eng 2009; 9:98-103.
14. Liao Q, Sjoberg T, Paskevicius A, et al. Manual versus mechanical cardiopulmonary resuscitation. An experimental study in pigs. BMC Cardiovasc Disord 2010; 10:53.
15. Gates S, Quinn T, Deakin CD, et al. Mechanical chest compression for out of hospital cardiac arrest: Systematic review and meta-analysis. Resuscitation 2015; 94:91-97.
16. Gates S, Smith JL, Ong GJ, et al. Effectiveness of the LUCAS device for mechanical chest compression after cardiac arrest: systematic review of experimental, observational and animal studies. Heart 2012; 98:908-913.
17. Perkins GD, 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; 385:947-955.
18. Anantharaman V, Ng BL, Ang SH, et al. Prompt use of mechanical cardiopulmonary resuscitation in out-of-hospital cardiac arrest: the MECCA study report. Singapore Med J 2017; 58:424-431.
19. 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 2014; 311:53-61.
20. Tranberg T, Lassen JF, Kaltoft AK, 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.
21. Criley JM, Niemann JT, Rosborough JP, et al. The heart is a conduit in CPR. Crit Care Med 1981; 9:373-374.
22. Kouwenhoven WB, Jude JR, Knickerbocker GG Landmark article July 9, 1960: Closed-chest cardiac massage. By W. B. Kouwenhoven, James R. Jude, and G. Guy Knickerbocker. JAMA 1984; 251:3133-3136.
23. Paradis NA, Martin GB, Rivers EP, et al. Coronary perfusion pressure and the return of spontaneous circulation in human cardiopulmonary resuscitation. JAMA 1990; 263:1106-1113.
24. 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.
25. Martin TG, Hawkins NS, Weigel JA, et al. Initial treatment of ventricular fibrillation: defibrillation or drug therapy. Am J Emerg Med 1988; 6:113-119.
26. Weaver WD, Copass MK, Bufi D, et al. Improved neurologic recovery and survival after early defibrillation. Circulation 1984; 69:943-948.
27. Gu W, Hou X, Li C Effect of different resuscitation strategies on post-resuscitation brain damage in a porcine model of prolonged cardiac arrest. Chin Med J (Engl) 2014; 127:3432-3437.
28. Indik JH, Shanmugasundaram M, Allen D, et al. Predictors of resuscitation outcome in a swine model of VF cardiac arrest: A comparison of VF duration, presence of acute myocardial infarction and VF waveform. Resuscitation 2009; 80:1420-1423.
29. Bankman IN, Gruben KG, Halperin HR, et al. Identification of dynamic mechanical parameters of the human chest during manual cardiopulmonary resuscitation. IEEE Trans Biomed Eng 1990; 37:211-217.
30. Gruben KG, Guerci AD, Halperin HR, et al. Sternal force-displacement relationship during cardiopulmonary resuscitation. J Biomech Eng 1993; 115:195-201.
31. Neurauter A, Nysaether J, Kramer-Johansen J, et al. Comparison of mechanical characteristics of the human and porcine chest during cardiopulmonary resuscitation. Resuscitation 2009; 80:463-469.
32. Beesems SG, Hardig BM, 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.
33. Genbrugge C, Dens J, Meex I, et al. Regional Cerebral Oximetry During Cardiopulmonary Resuscitation: Useful or Useless? J Emerg Med 2016; 50:198-207.
34. Asim K, Gokhan E, Ozlem B, et al. Near infrared spectrophotometry (cerebral oximetry) in predicting the return of spontaneous circulation in out-of-hospital cardiac arrest. Am J Emerg Med 2014; 32:14-17.
35. Parnia S, Nasir A, Shah C, et al. A feasibility study evaluating the role of cerebral oximetry in predicting return of spontaneous circulation in cardiac arrest. Resuscitation 2012; 83:982-985.

Practical aid for effortless resuscitation? User report "corpuls cpr"

Dr. Philipp Reinke M.Sc. in BI., Paramedic, post@philipp-reinke.de

There is mixed opinion regarding mechanical chest compression aids. Even from a scientific standpoint, there are not many reliable comments, therefore, reference is based on a few studies and user reports. This article reports the experiences of an implementation for test purposes in the rescue service in the district of Gütersloh (NRW).

Possible indication

In 2015, 10.130 resuscitation events were recorded in Germany via the resuscitation registry, of which in 1.153 resuscitations a mechanical chest compression aid was used to assist. As yet, use is not recommended as standard across the board by the ERC. Nevertheless, with reference to the 2015 ILCOR Consensus, the guidelines open up the possibility of considering use under certain circumstances, including: resuscitation in a moving ambulance (personnel safety), to bridge longer periods of resuscitation, preventing fatigue and thus a decrease in chest compression quality (for example with hypothermia or during PCI).

Functionality

There are different techniques, but common to all of them is that they perform the external chest compressions that a helper would have carried out. To do this, external force is directed onto the thorax. Depending on the manufacturer, there are systems that completely enclose the thorax and produce force in a circular fashion or systems that use a single arm with a built-in "stamp" which produces force on a selected point over the sternum. The effectiveness of the systems depends respectively on their construction method, sensors and ultimately, the training of the users. These factors can definitely produce differences in quality.

The continuous monitoring and control of compression frequency and rate allows safe adherence to the recommended frequency of 100 – 120 compressions per minute. By measuring the thoracic resistance, some devices also allow the complete release of the thorax thus refilling the heart with blood more effectively. However, these devices do not relieve the user of their duty of care in terms of training, handling and use.

Restrictions and dangers

In certain situations, these systems can be a good support to emergency medical personnel. However, depending on the design and operation there are also limitations and possible problems that must be considered. First, is the shortest possible interruption of chest compressions. Additionally, after the compression aid has been put into operation, it is important to monitor the quality of the therapy regarding movement/slipping of the compression site, incorrect initial setup of the system or incorrect setting of the system parameters, in order to avoid serious errors.

corpuls cpr

The **corpuls cpr** is a new generation thorax compression device from corpuls/GS Elektromedizinische Geräte G. Stemple GmbH. It has been on the market since the end of 2015. The long-term development of the device incorporated experience from the practical use of other devices and current study results, which differentiates the **corpuls cpr** from other manufacturers products. The **corpuls cpr** has a single swivel arm, which is directed from either the left or right side of the thorax (over the shoulder or hip) to the sternum. This allows use in confined space conditions, e.g. in a cath lab or if necessary, during a flight under resuscitation conditions giving free access to the patient's thorax at the same time. The swivel arm is securely mounted on the radiolucent board, which is placed under the patient and can be fixed to the stretcher. The arm with the motor and stamp unit is stabilised by the patient's body weight. This allows for quick positioning, alignment and activation of the system as the resuscitation aid does not need to be, for example, strapped to the patient. The lightweight carbon fibre construction results in an ergonomic and stable system that is suitable for preclinical use.

To align the arm, first release the locking device which allows the arm to be accurately positioned via two pivotable axles. After manually adjusting the height, the system is activated, and the electro-mechanical stamp vertically aligns itself. This automatic height adjustment also takes place during ongoing resuscitation (during the 30:2/15:1 respiration pauses) without interruptions, so that in the case of a sunken thorax for example, the stamp is automatically recalibrated, thus ensuring guideline-compliant compression depth. The parameters are modifiable - for example, you can set 30:2 or continuous resuscitation with variable speed where respiration pauses are signalled acoustically. Compression depth of 2 – 6 cm and compression rate of 80 – 120 compressions per minute are selectable.

In regard to patient's body size, a thorax height of 14 – 34 cm and a thorax width of up to 48 cm is supported – the device is therefore also useable on obese patients. In continuous

operation, the device has a battery life of about 90 minutes, which should cover most scenarios. If a longer resuscitation is required, a quick battery replacement is possible also mains power supply (12 V and 220 V) can be used. These characteristics make the **corpuls cpr** an appropriate resuscitation aid in special situations such as prolonged resuscitation (e.g. during systemic lysis therapy) or during the transport of patients in order not to endanger personnel and to ensure sufficient resuscitation despite centrifugal/inertial forces while driving.

Trial operation in the district of Gütersloh

In the district of Gütersloh about 220 resuscitation attempts are carried out by the rescue service every year. Of these, about 100 people reach a hospital and about 20 of them under ongoing resuscitation. Devices from Zoll Medical and Physio Control were also tested here a few years ago. The trial run with two **corpuls cpr** devices took place from 29.12.2015 to 16.4.2016. During the study period, there were 57 missions with preclinical cardiopulmonary resuscitation, of which 21 people reached a hospital with a Return of Spontaneous Circulation (ROSC). 70 % of the resuscitations took place in the home environment. 11 patients were treated with one of the **corpuls cpr** devices during this period. Of these, one patient with ROSC reached the hospital. Of the 11 patients, seven were transported to the hospital under resuscitation; here the **corpuls cpr** presumably contributed to the safety of the personnel. In all of these patients, a longer resuscitation phase was bridged until further therapy. Of course, it should be noted that the **corpuls cpr** has only been tested on a handful of patients over a limited time period. Therefore, no long-term conclusions can be drawn from this.

Conclusion

Mechanical chest compression devices can, under certain conditions, be of great help to rescue service personnel. However, it is important to consider the medical facts/prognoses and ethics: Even if a resuscitation with this technique can be carried out more or less "effort-free", the decision regarding the subsequent death of the patient should be based on the same criteria as with a "normal" resuscitation. If transport under ongoing resuscitation is required, a mechanical compression aid may be useful from the point of view of personnel safety alone as the Emergency Physician and Paramedic / Critical Care Paramedic can be seated and belted in while driving. The "**corpuls cpr**" system proved itself during the test period in the district of Gütersloh and was hence purchased for all five doctor cars.

*This text is a short version of the article "Practical aid for effortless resuscitation? User report **corpuls cpr**". Published in the magazine RETTUNGSDIENST 10/2016*

Literature

1. Deutsches Reanimationsregister (2016) Jahresstatistik präklinische Datenerfassung 2015 – Standortkennung Kreis Gütersloh – Deutsches Reanimationsregister. Erstellt 29.3.2016
2. Soar J, Nolan J, Böttiger B et al. (2015) Erweiterte Reanimations maßnahmen für Erwachsene (..adult advanced life support") – Kapitel 3 der Leitlinien zur Reanimation 201 5 des European Resuscitation Council. Notfall Rettungsmed 18: 770
3. Ca llaway CW, Soar J, Aibiko M et al. (2015) 20 15 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations – Part 4: Advanced Life Support. Circulation 132: S84-S 145





The corpuls cpr User Test – Interview

The magazine RETTUNGSDIENST spoke with Bernd Strickmann, Medical Director of the EMS Gütersloh on the subject of "Practical experience with the corpuls cpr".

RETTUNGSDIENST:
Mr. Strickmann, why did you decide to test the corpuls cpr in your rescue service area?

Strickmann:
Due to our good contact to the manufacturer we were asked early on if we would like to take part in a test phase. In my opinion, we have good circumstances to achieve interesting results: we have over 200 resuscitations per year with a ROSC rate of just under 50%. It's becoming more and more common that patients need to be transported to a hospital under resuscitation.

RETTUNGSDIENST:
In what situations do you look to an external chest compression device to support the work of the ambulance service?

Strickmann:
The ERC guidelines suggest that such a device should not be used as standard practice on every patient. Nevertheless, there are indications where there are clear benefits for use. Employee safety is very important to us therefore, we generally use the device whenever a patient is transported under resuscitation. This way, we can avoid colleagues having to stand in the vehicle and perform resuscitation while driving, especially under lights and sirens. The requirement to alternate every two minutes makes the activity even more dangerous. However, resuscitation carried out during transport is only useful if further therapy options follow in the hospital (cardiac catheter, heart-lung machine) or if the resuscitation is expected to take longer (status post systemic lysis, hypothermia).

RETTUNGSDIENST:
What advantages do you expect from use?

Strickmann:
Mechanical chest compression devices allow a constant application of force to the thorax at a constant compression depth and rate, thereby ensuring no decrease in quality due to fatigue. This results in high-quality resuscitation, which

has been proven to improve organ perfusion and thus the probability of survival. If the device has been properly applied, this leaves one more assistant to perform other tasks (e.g. drug delivery and such). Additionally, the doctor and Emergency Paramedics / Critical Care Paramedics can sit buckled in while driving and not run the risk of injuring themselves unnecessarily in the event of sudden braking or cornering. Manual compression quality suffers considerably even on an accident-free journey.

RETTUNGSDIENST:
What potential problems do you see using this technology?

Strickmann:
It is important to be aware that an already deceased patient is not transported to the emergency room. In my opinion, this device allows for good chest compression over a long period of time, providing that it is necessary - it does not work wonders on patients who have been dead for a long time. Therefore, it must not be tempting to artificially prolong the medical and ethical decision on patient death simply because you can perform resuscitation with the device with less effort. In addition, good training is essential - the device does not mean you are not required to check your own and other processes again and again. Therefore, for example the position of the device must be checked often.

RETTUNGSDIENST:
How do you rate your experience with the corpuls cpr?

Strickmann:
The **corpuls cpr** is in my opinion a very suitable device for chest compressions, providing that the indication for a longer-lasting resuscitation was made. As it the case, for example, with preclinical lysis. The design also makes it faster in our experience than other devices as it consists of just a board and an arm with a punch. This eliminates a strap as with other devices. The manufacturer's waiving of disposable items also ensures fast and constant readiness for use and the elimination of sourcing errors.

Mission investigation with corpuls.web REVIEW

The **corpuls cpr** continuously stores all settings and sensor data during patient treatment. This includes compression depths and rates as selected by the user at each point in time, as well as movement and force feedback values during each individual compression.

The free software tool **corpuls.web REVIEW** provides the ability to gain insights into this data. The entire mission is displayed as a scrollable timeline, showing compressions, settings, pauses and events. Debriefings and CPR trainings among other things can be significantly improved by consulting the recorded real-time data – also the patient file can create PDF reports from the **corpuls cpr**, safeguarding the resuscitation team in the case of complaint proceedings.

Additional insights on a larger scale can be obtained via the companion server software **corpuls.web ANALYSE**. Important questions about CPR quality and device usage can be quickly answered using the entire set of recorded missions. Key performance indicators can be displayed on the data analytics dashboards. This solution can help to improve the CPR quality and other measures for the entire organisation.

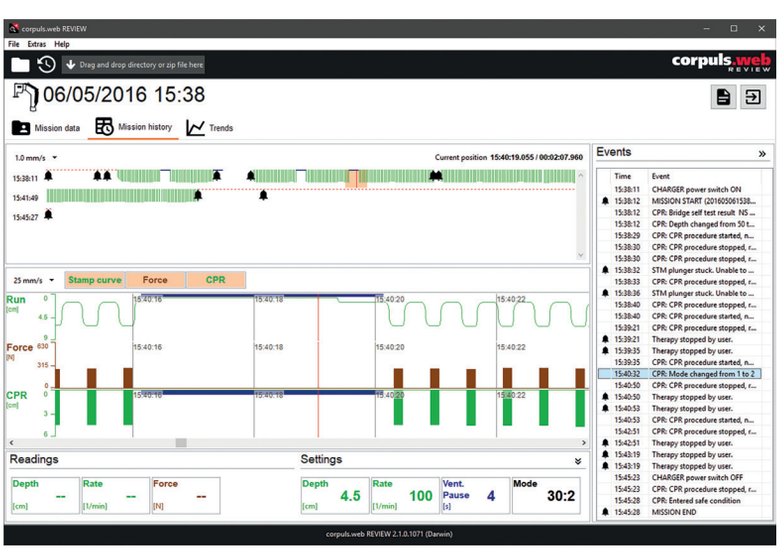


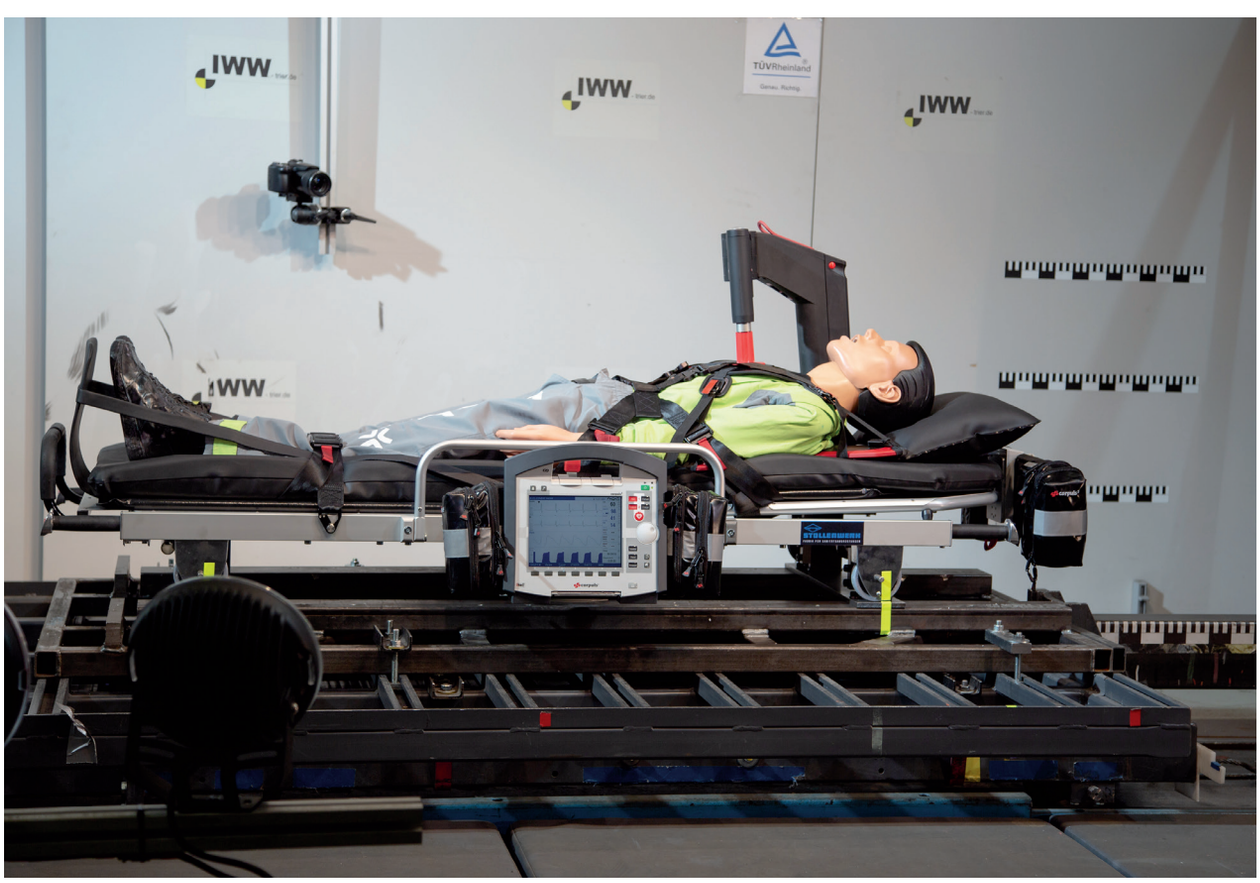
Fig. 1:
corpuls.web REVIEW, Screenshot

High Safety for Patient and Rescuers

The corpuls cpr is a high-quality mechanical chest compression device, characterized by its simple and intuitive handling, ability to relieve rescue service personnel and provide maximum safety for the user and the patient. To prove its safety, numerous standardized test procedures have been carried out:

- EN 60068-2-6:2008 Vibration (sinusoidal)
- EN 60068-2-27:2009 Shock
- EN 60068-2-64:2008 Vibration, Broadband random and guidance
- EN 60529:2014-09 Degrees of protection provided by enclosures (IP-Code)
- IEC 60601-1-12:2014 Medical electrical equipment – Part 1-12: General requirements for basic safety and essential performance
- EN 13718-1:2014 Medical vehicles and their equipment – Air ambulances – Part 1: Requirements for medical devices used in air ambulances;
- DO160G:2016 Section 7, Category A; Section 8, Category U/U2 Environmental Conditions and Test procedures for Airborne Equipment
- EN 1789:2007+A2:2014 Medical vehicles and their equipment – Road ambulances;

Additionally, with the support of company Stollenwerk & Cie and the University of Trier a further dynamic crash test was carried out which proves that the **corpuls cpr** can perform high-quality chest compressions even in the extreme situations of an accident without endangering the patient or rescue service personnel. To test this, a simulation of an ambulance stretcher set up was mounted to a slide and excelled downward with a force of 10 G while the **corpuls cpr** performed chest compressions on a resuscitation dummy.



*Dynamic crash test of **corpuls cpr** and **corpuls³** (10 G)*

Introduction COMPRESS Abstract

Past studies with various mechanical chest compression devices have demonstrated the safety of these such devices. Although no superiority has been proven so far, but rather an equivalence in the comparison of manual chest compression to devices, these devices can guarantee high-quality compressions over a longer period of time. (Gässler et al. 2016)

Proof of the safety and efficacy of comparable devices has already been shown in existing interventional studies with strong evidence. (Luxen et al. 2015) Therefore, the COMPRESS study on the corpuls® cpr is designed to monitor that the findings thus far also apply to this device. Additionally, questions and patient groups for which there is little or no evidence to date are investigated. (Bernhard et al. 2016)

Literature

Bernhard, Michael; Hossfeld, Bjorn; Kumle, Bernhard; Becker, Torben K.; Böttiger, Bernd W.; Birkholz, Torsten (2016): Don't forget to ventilate during cardiopulmonary resuscitation with mechanical chest compression devices. In: European Journal of Anaesthesiology. DOI: 10.1097/EJA.0000000000000426.

Gässler, Holger; Helm, Matthias; Lampl, L. (2016): Mechanische Thoraxkompressionsgeräte. Aktueller Stand und mögliche Einsatzgebiete.

Der Notarzt 3 • 2016. In: Der Notarzt 32 (3), S. 130–139. DOI: 10.1055/s-0042-107181.

Luxen, J. P.; Birkholz, Torsten; Hatz, A.; Kanz, K.-G.; Königer, J.; Meier, M. et al. (2015): Nutzen mechanischer Reanimationshilfen bei der kardiopulmonalen Reanimation. In: Notfall Rettungsmed 18 (2), S. 119–129. DOI: 10.1007/s10049-014-1956-2.

COMPRESS – Comparing Observational Multi-Centre Prospective Registry Study on Resuscitation

S. Dopfer[1] · B. Jakisch[2] · J. Wnent[2, 3] · M. Heller[1]
J.-T. Gräsner[2, 3]

1 GS Elektromedizinische Geräte G. Stemple GmbH, Medical Research and Application
2 Institut für Rettung- und Notfallmedizin, Universitätsklinikum Schleswig-Holstein
3 Klinik für Anästhesiologie und Operative Intensivmedizin, Universitätsklinikum Schleswig-Holstein, Campus Kiel



Literature

1. Gässler H, Helm M, Lampl L: Mechanische Thoraxkompressionsgeräte: Aktueller Stand und mögliche Einsatzgebiete. Der Notarzt 3 • 2016. Der Notarzt 2016;32(3):130-9. doi: 10.1055/s-0042-107181
2. Perkins GD, Handley AJ, Koster RW, Castrén M, Smyth MA, Olasveengen T, et al: European Resuscitation Council Guidelines for Resuscitation 2015: Section 2. Adult basic life support and automated external defibrillation. Resuscitation 2015;95:81-99. doi: 10.1016/j.resuscitation.2015.07.015. PubMed PMID: 2647742.
3. Bernhard M, Hossfeld B, Kumle B, Becker TK, Böttiger BW, Birkholz T: Don't forget to ven - tilate during cardiopulmonary resuscitation with mechanical chest compression devices. Eur J Anaesthesiol 2016. doi: 10.1097/EJA. 0000000000000426. PubMed PMID: 26854661

Objective

Since its introduction in 2015, the **corpuls cpr** has pioneered a new generation of mechanical chest compression devices. This is due to its extraordinary flexibility in terms of adaptability to patient needs and usage situations. While large studies have investigated the clinical benefits of comparable devices, currently there is a lack of similar studies for the **corpuls cpr** [1]. Therefore, this study analyses the criteria of high quality chest compressions according to the 2015 ERC Guidelines [2]. In addition, ventilation parameters and resuscitation-related injuries are also analysed to examine both the safety and performance of the device and the safety of the patient.

Method

For this multi-centre observational study, routine data on resuscitation missions is gathered in several preclinical centres over a period of three years and collected in the German Resuscitation Registry. The patients are divided into different groups based on their age and the form of treatment. Minors up to the end of their 18th year of age, adults from the end of their 18th year of age until the end of their 65th year of age and adults from the end of their 65th year of age. Within the respective age group, a distinction is made between the group of manually resuscitated patients and patients in whom the **corpuls cpr** was also used.

Results

The results will be published after the final analysis at the end of the three-year collection period. After half of the collection period, an interim analysis of the data collected to that point will be carried out.

Interpretation

In addition to the goal of monitoring the clinical performance of the **corpuls cpr**, the study offers the potential to investigate other factors. Particular attention will be paid to the resuscitation of pediatric patients and ventilation strategy and quality [3].



corpuls cpr – a unique device

The **corpuls cpr** is the most modern device for mechanical chest compression currently available. One of the goals for this device is to minimise the therapy-free interval during resuscitation. Therefore, emphasis is placed on very intuitive operation, among other things.

Basically, the **corpuls cpr** system consists of an arm and one of several possible radiolucent boards. To set up the system, the board is placed underneath the patient and the arm is connected to the board with a bayonet lock. It can be easily disconnected by turning the lock.

The **corpuls cpr** can be quickly adjusted to the patient's body. With the help from 2 swivel axles and the extendable arm the **corpuls cpr** can lock into the correct position with a central locking lever - all the adjustable components on the device are marked in red, to make them quickly identifiable. Finding the correct position over the compression point is aided by a pressure sensor. Therapy is then activated by pressing the green start button.

The **corpuls cpr** automatically compensates for a sunken thorax due to long-term resuscitation. As a result, consistent



compression depth is ensured even with longer usage. If automatic compensation is no longer possible in the current position, the user is informed optically and acoustically that the device needs to be repositioned.

The design concept of the arm extending above the patient ensures clear access to the thorax at all times. Offering, among other things, more possibilities for imaging in the cath lab and constant access to and vision of electrodes.

The arm can be placed at four different positions: to the right and left of the head and to the right and left of the lower thorax.

With a battery life of 90 minutes, the **corpuls cpr** guarantees uninterrupted therapy. This is particularly useful in the preclinical setting, where often long transport times to a suitable treatment facility must be bridged. If the battery life is insufficient, it can be replaced in seconds with a second battery. Also, charging via 220V and 12V is possible - even during therapy or while in the transport bag. Connection to the mains power supply is via a magnetic plug, that automatically releases when removed from the bag. The remaining running time is shown to the user on the display in minutes.

Using the 2.4" colour display as well as the four softkeys, numerous parameters can be set, or device information called up. For example, regarding therapy parameters - the mode (15:2; 30:2; continuous), compression depth (2 - 6cm) and compression frequency can be changed. These can be permanently stored in the device as a standard setting and can also be changed during therapy. Also, shortcuts allow the display to be inverted or rotated without having to open the menu.

For preclinical use, the IP54 dust and splash proof rating and the wide operating temperature range of -20°C to +45°C are an advantage. Ensuring the **corpuls cpr** can be used under the most adverse conditions.

Numerous accessories are available for use with the **corpuls cpr**.

Versatile accessories





Quadboard

Designed for clinical use, the Quadboard is radiolucent and easy to disinfect. Thanks to the big handle it can be quickly positioned under the patient.

Recboard

The Recboard was developed for preclinical use. Together with the specially developed attachment straps and the Fixation Ring, it can be securely fixed to all common stretcher systems.



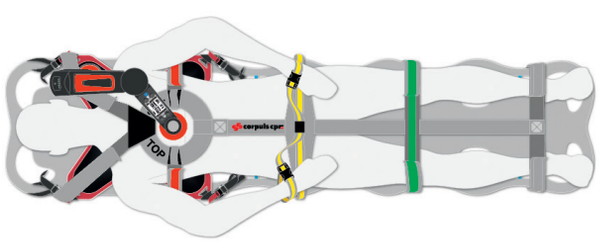
Scoopboard

The scoopboard was designed to use the **corpuls cpr** even under the difficult conditions of a technical rescue of injured people. Due to its shape it can be combined perfectly with any kind of scoop stretcher.



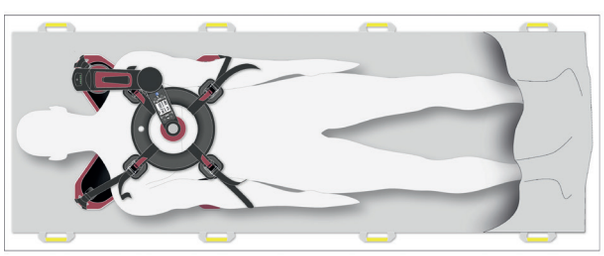
Bag / Backpack

As well as the **corpuls cpr** arm, the bag also carries the spare battery, stamp, power supply and ne of the boards including Fixation Ring and attachment straps.
Additionally, various handling options are possible with backpack or shoulder straps.



Strap System with spineboard

The easy-to-clean strap system allows the patient to be immobilized on a spinal board during therapy. Optionally the strap system can be supplemented with hand straps, which allow the patient's hands to be fixed.



Fixation Ring corpuls cpr with carrying sheet

The Fixation Ring together with the attachment straps holds the patient in a safe position on the Recboard or Scoopboard during transport.



Specifications

Compression parameters:

- Compression rate:
  80 to 120 compressions
  per minute
  (adjustable in increments
  of 1 compression per minute)
- Compression depth: 2-6 cm
  (adjustable in increments of
  0.1 cm)
- Therapy mode: 30:2 / 15:2 /
  continuous (secure airway)

Patient parameters:

- Chest Height: 14 to 34 cm
- No restrictions on the width of
  the patient
- No restriction on the weight
  of the patient
- 8 years and older

Operating parameters:

- Power source: electric
- Battery: Lithium Polymer (LiPo)
- Operating time 90 minutes (typical)
- Displays the remaining run time in minutes
- LED indication of battery charge level in
  20% increments
- Battery charging time
  (via magnetic connector, no therapy):
  105 min 0-80%
  30 min 80-100%
- Intuitive user interface: Therapy start/stop
  button with alarm and 4 softkeys
- Simultaneous display of operating mode,
  compression depth, compression rate, time /
  therapy time and remaining runtime of the
  battery shown in minutes and percentage
- At least 300 charging cycles

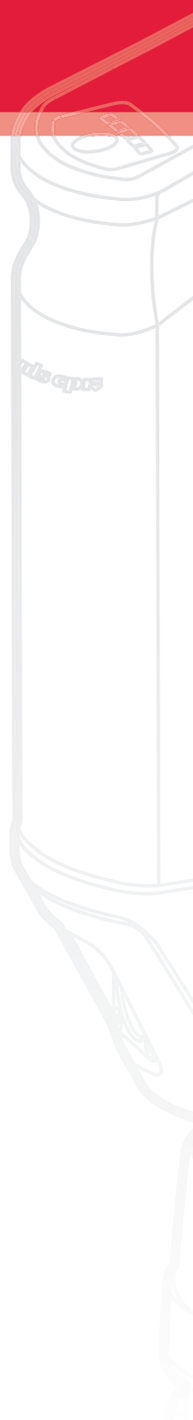
General Specifications:

- Color display 2.4“ with
  LED backlighting
- Operating temperature:
  -20 °C to +45 °C
- Dust and splash proof (IP54)
- Power supply: 12-33V DC
  (on-board power),
  110-240V AC
  (Mains 50-60 Hz)
- Operating noise: 70 dB
- Data interface: SD card
- Integrated alarm management
- RTCA DO 160 G (emc tested)

Dimensions and weights:

- **corpuls cpr** arm with
  stamp / battery:
  45 x 43 x 9 cm / 5.5 kg
- Recboard:
  47 x 47 x 3.5 cm / 2.2 kg
- Quadboard:
  46 x 46 x 13 cm / 1.7 kg
- Scoopboard:
  45 x 35 x 83 cm / 1.6 kg

Find out more on **www.corpuls.world**



About corpuls

For over 35 years, **corpuls**® has developed and produced innovative high-end equipment for emergency and intensive care medicine. Today, in our headquarters in Kaufering, over 250 hearts each beat around 50,000 times every working day, aspiring to meet the high standards of rescue workers from over 60 countries across the world.

corpuls defibrillators, patient monitoring systems and chest compression devices have set the standard since day one in the realisation of the most advanced insights in medical science, as well as in terms of innovation and ergonomics and so guarantee reliable and trusted aid in the struggle for the preservation of human lives.

The long-standing deployment of the equipment under the most difficult conditions and tens of thousands of satisfied customers are the best evidence of the success of the route we have taken and are the daily motivation for our team.

Where applicable – counrty availability is dependent on the successful product registration with the National Authority of that country.
Please read the complete Instructions For Use that come with the product.

corpuls®

GS Elektromedizinische Geräte G. Stemple GmbH
Hauswiesenstrasse 26 | 86916 Kaufering

Telephone +49 8191 65 722-0
Fax +49 8191 65 722-22
E-Mail info@corpuls.com
Web www.corpuls.world

CE 0123

corpuls® Products may not be available in all markets because product availability is subject to the regulatory and/or medical practices in individual markets. For availability please contact info@corpuls.com. Printing errors as well as construction and design modification reserved. All mentioned names of products are registered trademarks of the respective owners. Art.-Nr. 76139.65020 Vers. 1.0 (05/18)