No. 3

corpuls science

ESSAYS, RESEARCH AND INFORMATION



History of Defibrillation
From the Leyden jar to the corpuls 200

It takes a system
Improving the system through digitalisation of the chain of survival and systematisation of training

Upcoming research
Current studies on resuscitation: Double sequence defibrillation and energy vs. current based defibrillation

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DEAR READERS,

since corpuls was founded over 40 years ago, it has endeavoured to support saving patients' lives and facilitate the work of emergency medical services through the combination of research and engineering. In particular, resuscitation has been a central priority from the beginning. We are therefore very pleased to be able to assist basic life support and start the chain of survival with the corpuls aed, on to advanced life support with corpuls3 and corpuls cpr, right through to debriefings with the help of corpuls.manager REVIEW. Additionally, corpuls.manager ANALYSE facilitates the use of mission data for research and quality management.



Michael Heller

- STANDING ON THE SHOULDERS OF GIANTS -

With the publication of the new Guidelines for Resuscitation in 2025, now is a good time to take a look back at the early days of resuscitation and defibrillation to see how far we have come. On the following pages, we are pleased to provide you with both interesting information on these topics and insights into current studies.

In addition, two researchers gave us a glimpse into their work: Matthias Irrgang on his case report on the successful resuscitation of a child using the corpuls cpr and Dr. Stephan Katzenschlager on the DOSEVF-2 study on double sequential defibrillation.

To round off this issue of the corpuls.science, we were able to win over a very special interviewee: company founder Günter Stemple told us how he has witnessed and shaped the history of defibrillation firsthand.



Sarah Dopfer

Thank you very much and enjoy the following articles.

Michael Heller

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HISTORY OF DEFIBRILLATION

The origins of defibrillation can be traced back to the early days of electrical industrialisation. In particular, the discovery of the Leyden jar as a powerful prototype of a capacitor in 1745 enabled a multitude of novel experiments. Soon, researchers began to investigate whether electricity could offer any medical benefits. And remarkably there are early descriptions of successful resuscitations with Leyden Jars. However, both the pathological conditions and the technical circumstances surrounding these cases suggest that the outcomes were likely coincidental rather than scientifically reproducible. While the idea of using electricity to restore life aroused considerable scientific curiosity, further advancements were hindered by the technological limitations of the early era, lack of knowledge about cell physiology and the transmission of electricity in the heart, and thus about the causes of arrhythmias underlying sudden cardiac death. In addition, there were concerns among the general public from the outset about experiments that crossed the line between life and death. [1]

Nevertheless, research on this topic continued, and continuous insights into the physiology of cardiac conduction and technical advances mutually paved the way for life-saving defibrillation.

During the 19th and early 20th century, several physiologists advanced our understanding of cardiac electrical conduction by identifying the network of specialized fibers throughout the heart. In recognition of their contributions, some of these structures and experimental techniques were named after their discoverer – most famously, the His bundle and Purkinje fibers [1].

Experiments with dogs had already shown that chaotic fibrillation could be artificially triggered by weak electric shocks. It was also understood that this chaotic state causes the heart's pumping function to fail and is therefore incompatible with life. [2]

> **"A long series of experiments on the mammalian heart has convinced me that in ordinary circumstances sudden cardiac failure does not usually take the form of a simple ventricular standstill in diastole; indeed, such a mode of failure is, in my experience, very exceptional, if one exclude those cases in which there has been some very obvious cause acting from without upon the heart [...]. It assumes, on the contrary, the form of violent, though irregular and incoordinated, manifestation of ventricular energy. Instead of quiescence, there is tumultuous activity, irregular in its character and wholly ineffective as regards its results."**
>
> *John Alexander McWilliam 1889*

At this time, scientists already knew that in most cases, a dying heart does not simply stop beating but rather enters a chaotic intermediate state. This striking behaviour has already been observed frequently in animal experiments, and in 1874, Edmé Vulpian gave it a name – mouvement fibrillaire – the origin of the modern term 'fibrillation'. [3]
In 1899, the two physiologists Prevost and Battelli found (parallel to the American scientist Cunningham) that a strong electric shock can end fibrillation which was induced with a weak electric current before. [4,5]

Based on the preliminary work of Augustus Waller, who recorded the first ECG in 1887 [6], the Dutch physician Willem Einthoven advanced the development of this technology to such an extent that, by the beginning of the 20th century, it was possible to record and interpret meaningful ECGs. His aim to unify and standardise the electrical derivatives resulted in the famous Einthoven triangle which is still the basis for the standardised limb leads I, II and III today. [7,8]

> **"The first and chief point to determine is whether or not the electrical variation is physiological, and not due to a mechanical alteration of contact between the electrodes and the chest wall caused by the heart's impulse. To ascertain this point accurate time-measurements are necessary; a physiological variation should precede the movement of the heart, while this could not be the case if the variation were due to altered contact."**
>
> *Augustus Waller 1887*

The history of defibrillation has been marked by a series of innovative breakthroughs, which, however, were initially unable to fulfil their full potential due to historical circumstances. For example, as early as the 1910s, scientist Louise Rabinovitch developed a portable resuscitation device for use in ambulances. She had already recognised that resuscitation success is linked to the time since cardiac arrest. She therefore suggested that electrodes be applied to the patient during anaesthesia as a preventive measure, so that ventricular fibrillation that might occur could be treated immediately. However, a lack of under-

THE PULSE OF PROGRESS

CHRONOLOGY OF **LIFESAVING INNOVATIONS**

1745 ▶▶▶ DISCOVERY OF THE **THE LAYDEN JAR**

1874 ▶▶▶ MOUVEMENT **FIBRILLAIRE**
THE ORIGIN OF THE MODERN TERM 'FIBRILLATION'
Edmé Vulpian [4]

1887 ▶▶▶ RECODRING OF **THE FIRST ECG**
Augustus Waller [7]

1910s ▶▶▶ PORTABLE **RESUSCITATION DEVICE FOR AMBULANCES**
Louise Rabinovitch [1]

1947 ▶▶▶ FIRST **DOCUMENTED DEFIBRILLATION ON A HUMAN PATIENT**
Claude Beck [1]

1954 ▶▶▶ "ACCIDENTAL" **DISCOVERY OF CHEST COMPRESSIONS AS CRUCIAL PART OF SUCCESSFUL RESUSCITATION**
William Kouwenhoven, Guy Knickerbocker [1,9]

1955 ▶▶▶ FIRST **MODEL FOR HUMAN EXTERNAL DEFIBRILLATOR**
William Kouwenhoven, Paul Zoll [9,14]

standing of the underlying physiology and the outbreak of the First World War restricted the impact of this innovative concept. [1,8]

After the war, research on resuscitation was again pushed by research institutes and industry in the USA. In the 1920s American scientists around William Kouwenhoven at Johns Hopkins University, continued the work of Prevost and Battelli. They rediscovered the possibility to terminate shock-induced fibrillation by providing a countershock. Later, one of Kouwenhoven's Ph.D. candidates, Guy Knickerbocker, discovered a temporal arterial blood pressure increase when the heavy defibrillator paddles were pushed against the chest wall to lower the impedance for defibrillation. They immediately understood the significance of this observation and thereby accidentally discovered chest compressions as crucial part of successful resuscitation. [1,9].

At this time, alternating current had prevailed over direct current in industry, and American research was based primarily on the development of alternating current generators. Once again, it was the historical circumstances that slowed down scientific and technological progress. At the institute of Professor Lina Solomonowna Stern in Moscow (a former associate of Prevost in Geneva), her Ph.D. candidate Naum Gurvich investigated the effectiveness of defibrillation shocks already several years earlier. Together with Dr. G.S. Yuniev he found that AC shocks damage the myocardium which prevents restoration of a normal sinus rhythm and that DC shocks are safer and more effective [10,11]. Later, Peleška proposed to use a biphasic waveform as for the optimal defibrillation pulse by integrating an inductivity additional to the capacitor. This modified circuit lowered the peak voltage and increased the shock duration which was then attributed to the pulse length being closer to the physiological thresholds of the cells [12]. Although this waveform has now become established worldwide thanks to its superiority, these findings did not make it through the Iron Curtain at the time. [1,13] Unaware of these developments in the UDSSR, Claude Beck, a surgeon in Cleveland developed an AC defibrillator for internal defibrillation as a continuation of the work of Kouwenhoven and his team. In 1947 this led to the first documented defibrillation on a human patient.

"Richard Heyard, aged 14, was undergoing surgery to correct a "hollow chest" breastbone malformation. Near the end of the procedure, his heart suddenly entered ventricular fibrillation. The surgeon immediately started direct heart massage, keeping Heyard's blood in circulation, but the fibrillation showed no indication of stopping spontaneously. Beck requested permission to perform his experimental procedure, connecting two electrodes directly to Heyard's exposed heart. After four shocks of 110 V, the fibrillation ceased, and this time mere seconds of heart massage sufficed to restore heartbeat. Richard made a complete recovery."

Hana Akselrod 2009

Although there were certain doubts among experts that defibrillation could also be possible through the closed chest wall, Harvard cardiologist Paul Zoll and also William Kouwenhoven believed in the possibility of external defibrillation. In the end, Zoll won the race on publication of the first model for human external defibrillation first used in 1955 and published in 1956 [14]. Accordingly, four patients were effectively defibrillated and restored to sinus rhythm. The total of 11 shocks were all successful in terminating ventricular fibrillation but only one of the 4 patients survived to hospital discharge. Kouwenhoven succeeded about the same time and reported on "Closed chest defibrillation of the heart" in the scientific journal Surgery in 1957 [15]. However, these external defibrillators which were developed in collaboration with industry were heavy and bulky, so that they could only be moved with difficulty on wheels. The most bulky part was the transformer, which converted the available mains power to 1000 V.

In the following years, the modern emergency medical services (EMS) system was established in the USA, accompanied by the standardization of professional qualifications for paramedics. Additionally, chest compressions became a routine component of emergency care and were combined with mouth to mouth ventilation by a team around Peter Safar and James Jude. In the 1960s, the American Heart Association further advanced public health by enabling laypeople to receive training in this life-saving technique. [1,9,16,17]

In 1962 the Boston Cardiologist Bernard Lown found that AC defibrillators were not safe for cardioversion (still unaware of the findings of Gurvich and his colleagues several years earlier). Together with a Hungarian engineer they developed the first external DC defibrillator most likely based on the concepts of Gurvich and Peleška. In the early 1980s Michel Mirowski successfully engineered the first implantable defibrillator for clinical use in humans, with a size to fit in a single hand. Further optimisation of this technology ultimately led to the biphasic waveform becoming established as the most efficient and safest option also in external defibrillators. [1]

And so, after a long history marked by pioneering spirit and scientific commitment, but also by the turbulence of world history, the bold visions of the early scientists were finally realised. Since the 1980s, defibrillators have evolved into reliable, life-saving devices – powerful tools that have transformed emergency medicine and continue to save countless lives around the world. ■

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PHYSIOLOGICAL AND TECHNICAL FOUNDATIONS OF DEFIBRILLATION

To understand the defibrillating effect of biphasic shocks, a precise knowledge of cardiac electrophysiology is essential. The deliberate optimisation of shock parameters such as current intensity, pulse duration and phase relationship requires careful consideration of cell physiology and the complex functioning of heart muscle cells. In the following, the basic underlying concepts and the current state of the scientific knowledge are described.

PRINCIPLE OF DEFIBRILLATION

Ventricular fibrillation is a life threatening state of the heart which is characterized by the chaotic propagation of excitation without effective cardiac output. A strong electrical shock can interrupt this chaotic behaviour by means of cell physiology. As in the rest of the body, the conduction of electrical impulses in the heart is based on the formation of action potentials. These are generated by a complex interaction of ion channels creating electrical gradients between the intracellular and extracellular space. Directly after an action potential has occurred, the involved myocytes temporarily enter an inactive state (the refractory phase), during which no further action potential can be triggered [1]. Successful defibrillation requires that critical number of myocardial cells are simultaneously driven into the refractory phase. This interrupts the chaotic electrical activity and allows for an organized restart of the cardiac rhythm by the sinus node as the natural pacemaker.

DEFIBRILLATION THRESHOLD

To achieve this, the transmyocardial current must be sufficiently high to maximize the probability of triggering an action potential in a critical number of myocardial cells. However, the maximum permissible defibrillation current is constrained by the threshold at which myocardial damage occurs.

Currents, that are too weak (weak in comparison to a defibrillation shock) can induce fibrillation, even in a healthy heart. This occurs because only a subset of myocytes enters the refractory state, thereby disturbing the normal propagation of excitation and impairing coordinated electromechanical coupling. Scientists found that there exists a specific pulse strength, the upper limit of vulnerability, beyond which arrhythmias are no longer able to be induced [2].

Around the 1990s, the defibrillation threshold (the minimum pulse strength to successfully end fibrillation) has been investigated in many scientific studies [3–6]. However, the technical details of all these pulses differ so greatly that it has never been possible to derive generally applicable values for the optimal current for transthoracic defibrillation.

The European Resuscitation Council Guidelines of 2021 describe the optimal defibrillation energy qualitatively as the energy that achieves defibrillation while causing a minimum of myocardial damage. However, they state that the quantitative value is unknown and base their recommendations on careful literature review [7]. In a review, Walcott et al. conclude that for both monophasic and biphasic shocks, the threshold for cell damage caused by the electrical current is significantly higher than the standard energy values of up to 5 J/kg body weight (i.e. 360 J for a 72 kg patient) [8].

DEFIBRILLATION WAVEFORM

It has been demonstrated that biphasic waveforms require lower peak currents and lower total energy than monophasic waveforms to achieve successful defibrillation [9–14]. In the ERC Guidelines of 2021, biphasic defibrillation is described as a safe and effective, well established procedure and biphasic waveforms are now state of the art in modern defibrillators. The ERC Guidelines distinguish between biphasic truncated exponentials (BTE), rectilinear biphasic (RLB) waveforms and pulsed biphasic waveforms (PBW) based on technical differences in the modification of the underlying exponential capacitor discharge. The authors state that there is no evidence that one biphasic waveform or device is more effective than another. [7] Several mechanisms have been proposed to explain the superiority of biphasic defibrillation, among them are the theory of charge burping and the theory of virtual electrode polarization [15,16].

Research has shown that the defibrillation threshold decreases with increasing pulse duration, up to approximately 10–12 ms, beyond which it begins to rise again. Interphase delays above 8 ms seem to require significantly higher shock strength than phase separation up to 6 ms [4]. Modern control technology now enables almost instantaneous switching. The optimal charge ratio between the first and second phase of biphasic waveforms has also been investigated. It was found that it is advantageous if approximately 1/3 of the charge is available for the second phase [6].



IMPEDANCE COMPENSATION

From a technical point of view, the total energy which can be stored in the capacitor is a key parameter. From a biophysical standpoint, the current (-density) over time at the cellular level is the critical defibrillating factor. The energy delivered to the patient is related to the current by $E = R \cdot I^2 \cdot t$, where R is the impedance. In clinical practice, energy (in joules) has become the standard control parameter due to its technical feasibility and clarity in training and communication. However, this shift has led to a disconnect between the controlled variable (energy) and the physiologically relevant quantity (current × time). Recent resuscitation guidelines recommend specific energy levels rather than current ranges. Consequently, patients with higher transthoracic impedance receive less current at the myocardium when a fixed defibrillation energy is applied. To address this, different partial impedance compensation techniques can be employed:

- Pulse duration extension, commonly used in BTE (biphasic truncated exponential) and pulsed waveforms (PBW).
- Adjustment of stored capacitor energy, typically in RLB (rectilinear biphasic) waveforms.[17]

The latter strategy allows for the delivery of a consistent average current across a wide range of patient impedances, while maintaining pulse durations within the physiologically optimal range.

Based on these profound insights into cellular electrophysiology and the mechanisms of transthoracic defibrillation, increasingly compact, reliable and clinically highly effective defibrillators have been developed in recent years. As our understanding of cardiac bioelectricity continues to evolve, future defibrillation technologies may become even more adaptive, intelligent, and integrated into broader cardiovascular care systems. ■

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INDICATIONS AND CONTRAINDICATIONS OF DEFIBRILLATION AND ELECTRICAL CARDIOVERSION: A GUIDELINE-BASED OVERVIEW

Electrical defibrillation and cardioversion are fundamental interventions in the management of cardiac arrhythmias with or without cardiac arrest, respectively. According to the European Resuscitation Council (ERC) and European Society of Cardiology (ESC) guidelines, these procedures are differentiated by synchronisation with the cardiac cycle and are applied based on the type and hemodynamic stability of the arrhythmia [1].

Defibrillation is an unsynchronised high-energy shock and indicated in cardiac arrest with ventricular fibrillation (VF) or pulseless ventricular tachycardia (VT) [1]. Defibrillation is the only treatment option for terminating VF and must be performed as quickly as possible [2]. Although the shock success rate for fine VF is significantly lower than for coarse VF [3] and unnecessary shocks are to be avoided, the 2021 ERC Guidelines explicitly recommend defibrillation also for fine VF [1]. In this context, fibrillation waveform analysis has already shown promising results in predicting shock success [4], but current evidence is insufficient to support routine use to guide the optimal timing for a shock attempt [1].

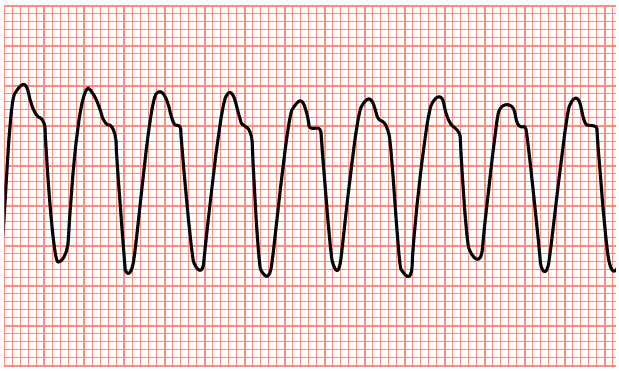


Figure 1: Ventricular tachycardia, 25 mm/s

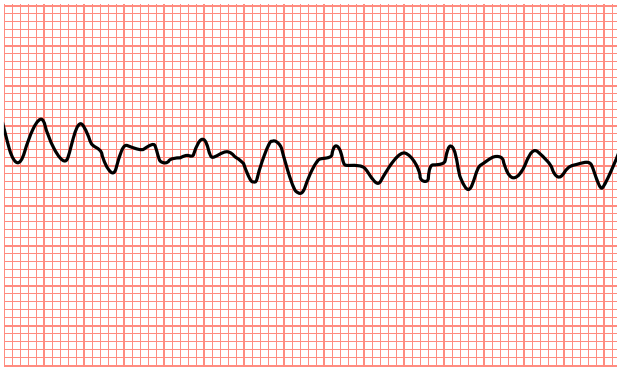


Figure 2: Ventricular fibrillation, 25 mm/s

Recommended energy levels depend on the waveform type of the defibrillator. For rectilinear biphasic (RLB) waveforms (as used in corpuls3), the initial shock should be no lower than 120 J. For biphasic truncated exponentials (BTE) it should be 150 J, for pulsed biphasic waveforms, the initial energy should be 120 -150 J [1].

In the event of VF or pulseless VT, there are no contraindications for defibrillation unless there are reasons that generally prohibit resuscitation (obvious signs of irreversible death, resuscitation-limiting advanced directive).

Electrical cardioversion, in contrast, is a synchronised shock timed to the R-wave of the QRS complex. It is primarily indicated for atrial fibrillation (AF), atrial flutter (AFL), supraventricular tachycardia (SVT), and ventricular tachycardia (VT) with a pulse, particularly when the patient is hemodynamically unstable or when drug therapy failed to restore sinus rhythm.

Synchronisation is essential to avoid delivering the shock during the vulnerable repolarization phase (T-wave), which can precipitate VF—a phenomenon known as R-on-T. However, in cases of sustained VT where synchronisation fails or the patient deteriorates rapidly and where postponing cardioversion could lead to cardiac arrest, unsynchronised shocks may be necessary.

For emergency cardioversion (in cases of hemodynamic instability) there are no strict contraindications provided that a corresponding arrhythmia is present (see indications). Since patients undergoing cardioversion of atrial fibrillation are at increased risk of stroke and thromboembolism, adequate anticoagulation or transoesophageal echocardiography to exclude cardiac thrombus is recommended for elective cardioversion [5]. Also, the individual risk of anaesthesia/sedation required for electrical cardioversion needs to be considered [6].

Recommended energy levels depend on the type of arrhythmia. While for AF, an initial shock at maximum defibrillator output is recommended, 70-120 J for AFL / SVT and 120-150 J for VT with pulse may be sufficient for the initial shock. If this first shock fails to achieve sinus rhythm, a stepwise increase of energy levels should be considered. [1,7]

In summary, the choice between defibrillation and cardioversion hinges on rhythm type, patient stability, and synchronisation capability. Adherence to ERC and ESC Guidelines ensures optimal outcomes and minimises procedural risks.

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DIGITALISATION IN THE CHAIN OF SURVIVAL: APP-BASED ALERTING OF FIRST RESPONDERS

The importance of rapid resuscitation by first responders

Sudden cardiac death is one of the most common causes of death in Europe [1]. The survival rate after out-of-hospital cardiac arrest depends largely on the immediate initiation of cardiopulmonary resuscitation and early defibrillation. Since professional emergency services often take several minutes to arrive, first responders play a crucial role in the so-called 'chain of survival' by starting resuscitation and early defibrillation.

A shorter interval without treatment until the start of chest compressions leads to a two- to threefold increase in long-term survival [2]. Early defibrillation can terminate ventricular fibrillation or ventricular tachycardia as the cause of cardiac arrest and lead to survival rates of 50 to 70% if performed within three to five minutes [2].

Nevertheless, the proportion of lay resuscitations in the resuscitation registers of different countries varies greatly (13 to 83%, mean 58%) [1].

STRATEGIES FOR RAPID INITIATION OF RESUSCITATION

In addition to resuscitation guidance (telephone CPR) provided by dispatcher center calltakers, the targeted alerting of first responders with resuscitation skills is also becoming increasingly important [2]. Since more than 60% of out-of-hospital cardiac arrests occur in the home environment, app-based alerting in the immediate vicinity is a strategy for alerting first responders to life-threatening situations [3].

There are also various minimum requirements for participants in the programmes. For example, medical qualifications or completed BLS training may be minimum requirements for active alerting [5].

RESUSCITATION TRAINING

To increase resuscitation readiness, initiatives focus on low-threshold training courses (CPR in schools, public

training campaigns) and on simplifying the measures (e.g. emphasising chest compressions without ventilation for untrained helpers). These are usually also advertised intensively as part of the implementation of app-based alert systems. A side effect of this is to create a general willingness and awareness of the importance of lay resuscitation [2].

AED USE BY FIRST RESPONDERS

Overall, the proportion of defibrillations performed by first responders is low (3.8 to 59%) [1]. The reasons for this can range from inhibitions due to lack of knowledge or uncertainty to the lack of availability of AEDs. Every minute of delay in defibrillation reduces the chance of survival by about three to five percent [6].

App-based alerting projects offer the opportunity to combine resuscitation training for the general public with exercises on the use of AEDs. At the same time, existing AED locations can be actively 'promoted' through the systems, or new AED locations can be created through increased awareness [5].

EFFECTIVENESS OF APP-BASED ALERTS

In order to assess the overall effectiveness of resuscitation, data must be collected in registries [7]. International data shows that app-based systems can significantly reduce the time it takes to start resuscitation measures [8]. The impact of these systems on the long-term survival of patients after cardiac arrest remains an open research question [9]. Nevertheless, the lack of (clear) scientific evidence in a complex mix of influencing factors should not lead to a reduction in efforts to develop a system for increasing the number of survivors after cardiac arrest.

CONCLUSION

The survival of patients after cardiac arrest can be significantly improved by the integration of early resuscitation. In addition to instructions for chest compressions given over the phone during an emergency call, the early availability of first responders with basic resuscitation skills as well as rapid rhythm control and, if necessary, defibrillation are crucial factors to save lives. ■

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ELECTRODE POSITIONING STRATEGIES FOR EXTERNAL DEFIBRILLATION

Electrode placement in external defibrillation

Correct placement of defibrillation electrodes is a key issue for proper shock transmission. The principal aim of electrode positioning is to maximise transmyocardial current density by ensuring that the fibrillating myocardium lies between the two pads. Proper electrode attachment, e.g. good skin contact, is essential to minimise transthoracic impedance.

To achieve this, two electrode positions are well established in practice: the anterior-lateral (AL) and the anterior-posterior (AP) configuration. The AL position is considered the default and recommended option in ALS, with the anterior pad placed below the right clavicle and the apical pad in the left mid-axillary line, approximately level with the V6 ECG electrode. The AP position, by contrast, involves the anterior pad over the left precordium and the posterior pad on the patient's back, typically inferior to the left scapula. [1]

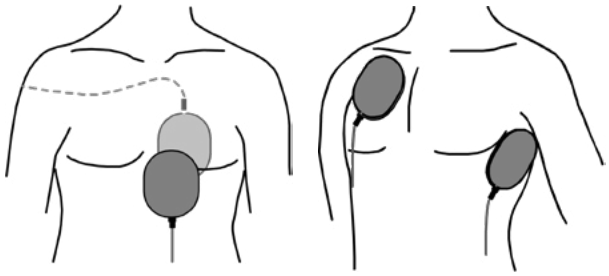


Figure: The anterior-posterior (left) and anterior-lateral (right) electrode position.

In cases of refractory VF after multiple defibrillation attempts, switching defibrillation pads from AL to AP may enhance the likelihood of successful defibrillation.

Vector change and double sequential defibrillation

The vector-change (VC) defibrillation strategy refers to the repositioning of pads from the standard AL to the AP configuration after unsuccessful shocks. The rationale is that altering the current pathway may result in a higher voltage gradient in the posterior part of the ventricle, where fibrillation is most likely to restart or fail to terminate after standard pad positions [2]. While evidence remains inconclusive, both the ERC guidelines [1] and systematic reviews up to 2025 [3] acknowledge that vector change defibrillation may be beneficial in these challenging scenarios.

A further treatment approach under scientific investigation is double sequential external defibrillation (DSED), in which two defibrillators are used to deliver nearly simultaneous shocks, using both AL and AP placed pads. This results in different vectors as well as increased current flow. One recent study by Cheskes et al. (2022) examined treatment strategies for out-of-hospital cardiac arrest with refractory VF [4]. In a cluster-randomized crossover trial across six Canadian EMS regions, adult patients were allocated to continued standard defibrillation, VC defibrillation with altered pad placement, or DSED using two defibrillators. Although the trial had to be stopped early in intervention because of COVID19-related staffing shortages and longer response times, data suggested that VC may improve current flow across the left ventricle, while DSED showed potential survival benefits but is less practical because it requires two devices. Overall, the study indicated that VC is a simple, feasible option for refractory VF, while the role of DSED remains promising but requires further research.

Due to the limited evidence available in 2021 the current ERC Guidelines of 2021 advise against using DSED outside of research settings.

Outlook

In summary, the AL position should be considered the first-line approach, as stated by current guidelines, with the option of vector change by AP placement for refractory VF. While DSED is under active investigation, its use should currently be confined to research settings. Further research will be essential to clarify whether alternative electrode strategies can meaningfully improve survival and neurological outcomes after refractory VF. ■

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INTERVIEW DR. MED. STEPHAN KATZENSCHLAGER

MOTIVATION & BACKGROUND DOSEVF-2 TRIAL

How did you come up with the idea of initiating a prospective study on double sequential external defibrillation (DSED)?

The DOSEVF-2 trial is intended to be the confirmation trial in a different Emergency Medical Service (EMS) setting from the trial conducted by Sheldon Cheskes et al. The results from the initial trial were motivating, and DSED was relatively unknown in Germany at the time.

What scientific gaps do you want to fill, and what triggered this project?

The survival rate decreases as the number of defibrillation attempts increases. The defibrillation itself does not cause this, but indicates a more extended period of low-flow and potentially a more severe cardiac condition. Additionally, observational data have shown that placing the defibrillator pads in the anterior-posterior position may improve the chances of successful defibrillation by capturing more viable myocardium and reducing impedance. The initial trial by Cheskes et al was conducted in an EMS service that had used DSED for a couple of years. This is not the case in this trial, as some of the services will learn how to perform DSED during the transition period. Whether the results from the DOSEVF trial can be reproduced in another EMS system is one of ILCOR's knowledge gaps that we aim to fill.

Characteristics of the method

Can you explain what opportunities, but also what risks, you see in the use of DSED, also in comparison with the previous approach?

The current defibrillation strategy, recommended by the European Resuscitation Council guidelines, involves using one defibrillator in the anterior lateral position. Using DSED introduces a second set of defibrillator pads in the anterior-posterior position, which targets additional myocardium and boosts the chances of ROSC and survival with good neurological outcomes. A potential risk to



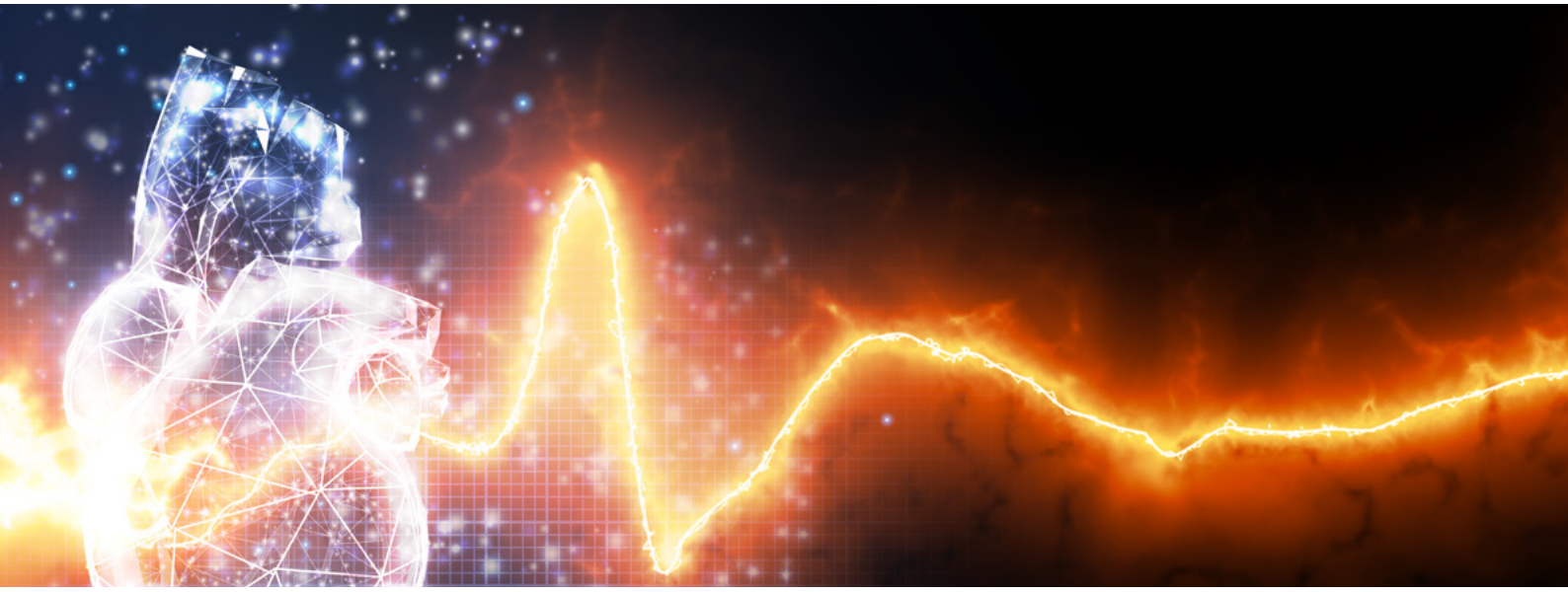
Dr. med. Stephan Katzenschlager

providers or defibrillators has been rarely reported. Proper training helps reduce the risk of extended hands-off times. Defibrillator damage has only been noted when two defibrillators from different manufacturers are used or when shocks are delivered simultaneously rather than sequentially.

Study design and organisation

The DOSEVF2 study is planned as a large multicentre study in Germany with a stepped-wedge design. Why did you choose this approach and how do you ensure that the method is implemented equally across the study centres?

This study is conducted as a cluster-randomized stepped-wedge trial. We decided to use this method due to the benefit of randomizing the study centers and training them one by one in the transition phase. Otherwise, we would have to train them all before the start and possibly during the study period as well, which would have delayed the study's commencement and required significantly more funding. Additionally, we saw the challenge of randomizing patients in the field. As most of the centers have not conducted prehospital randomized controlled trials, they are not familiar with the randomization process. This could lead to exclusion due to non-randomized patients. During the transition phase of the study, we will train EMS physicians and paramedics at their site to ensure the safe and effective execution of DSED.



Patients, endpoints and analysis

Which patients are eligible for inclusion, which criteria exclude participation, and which endpoints are measured to evaluate the benefits of DSED?

We will include out-of-hospital cardiac arrest (OHCA)s patients, ≥18 years with initial ventricular fibrillation or ventricular tachycardia or confirmed AED shock, subsequent three failed defibrillations, and presumed cardiac cause of the arrest. Patients with any-ROSC before the 4th shock, a non-shockable rhythm before the 4th shock, or pregnant women will be excluded. We will also exclude traumatic cardiac arrest patients due to the different entity of cardiac arrest. The primary endpoint will be assessed using a hierarchical testing method. First, we will determine the rates of ROSC at hospital admission, as this is the most proximal endpoint for the technique. Second, survival after 24 hours, and third, survival at hospital discharge with a good neurological outcome. This enables us to analyze DSED-specific endpoints and patient-centered outcomes.

Can you also explain which key parameters are particularly interesting beyond this?

Further, we are looking at the defibrillator data to analyze pre- and post-shock pauses and timing between the two defibrillations. Additional subgroup analyses will be conducted based on the results. We will factor in the rates of eCPR, as some study centers have a pre- or in-hospital eCPR program.

Significance and outlook

What do you expect from the results of this study – both for clinical practice and international guidelines as well as for patients?

We hypothesize that DSED is better than standard defibrillation for the primary endpoints mentioned above. That's what we based the sample size on. The results will show us if we were right. When this effect is demonstrated, I hope that DSED will be adopted in every EMS system outside of a study setting, possibly even earlier, before the 4th shock. Patients with refractory VF, who initially have the best chances of survival due to a shockable rhythm, can be saved with this defibrillation technique. This could potentially save the lives of cardiac arrest victims.

And how might the role of DSED in EMS and emergency medicine in general evolve if your hypotheses are confirmed?

Currently, two defibrillators are required to perform DSED. In Germany and Austria, this is not an issue because at least two vehicles, each equipped with a defibrillator, respond to an OHCA. Moving forward, we should be able to perform DSED with just one defibrillator from the very first shock. This reduces the risk of damaging the defibrillator and helps ensure proper timing between shocks.


DATA MANAGEMENT
SIMULATION
AED
COMPACT MONITORING
& DEFIBRILLATION
MODULAR MONITORING
& DEFIBRILLATION



IT TAKES A SYSTEM TO SAVE A LIFE

Out-of-hospital cardiac arrest (OHCA) is best understood through the interaction of three core dimensions: the patient, the event, and the system [1] (See ***Figure 1***).

Patient-related factors include demographic and clinical characteristics such as age, sex, cardiovascular risk profile, comorbidities, and ongoing medical therapy. These variables determine the physiological reserve and significantly influence survival after OHCA.

Event-related factors describe the circumstances of the arrest. Key determinants include whether the arrest is witnessed, the time of day, the location (public versus private), and - most importantly - the initial cardiac rhythm. Survival is highest when OHCA occurs in public, is witnessed, and presents with a shockable rhythm. [1]

System-related factors encompass the entire chain of response: bystanders, first responders, emergency medical services (EMS), hospitals, and the wider resuscitation network, including professionals, lay rescuers, and communities. Effective engagement and coordination across these actors are critical for survival [1].

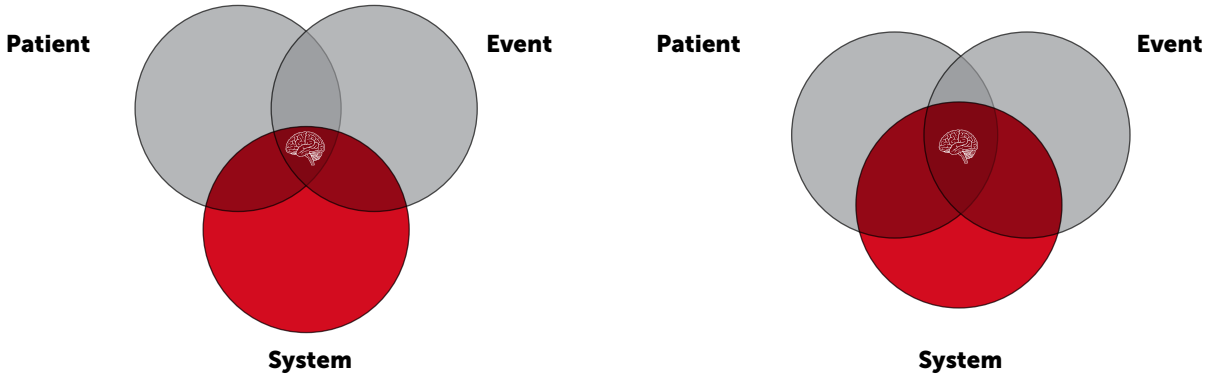


Figure 1: In the three-dimensional model of out-of-hospital cardiac arrest, the highest probability of survival is located at the intersection of all three dimensions, represented by the small brain at the centre. The likelihood of survival further increases as the 'system' dimension improves and enlarges the overlap.

The outcome of OHCA is determined by the complex interplay of these three dimensions.

Where the three dimensions overlap, the probability of survival is maximized. Crucially, while patient and event dimensions are largely immutable, the system can be directly influenced. The Utstein Formula of Survival (See *Figure 2*) provides a conceptual framework illustrating those systematic improvements - such as dispatcher-assisted CPR, high-performance EMS, public access defibrillation, and post-resuscitation care - expand the system's contribution, thereby enlarging the area of intersection with patient and event dimensions [2].

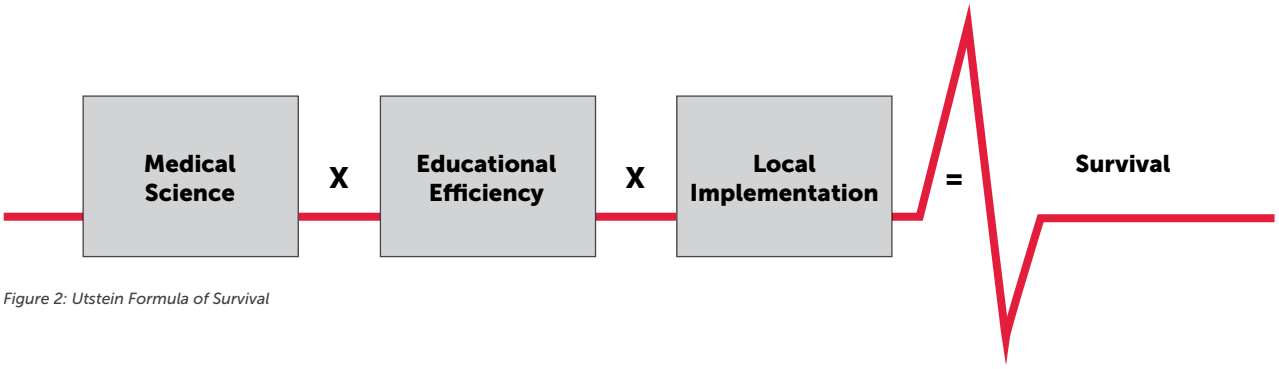


Figure 2: Utstein Formula of Survival

Impact of the current and upcoming developments on healthcare workforce

Healthcare professionals are widely recognized as being highly purpose-driven, with their motivation closely tied to providing meaningful care to patients. This orientation has been conceptualized as autonomous motivation or public service motivation, and is consistently associated with higher quality of care, proactive work behaviors, and stronger commitment to patients and organizations [3,4,5]. Conversely, when this intrinsic drive is undermined by external constraints, it can give rise to moral distress and moral injury.

Moral distress arises when healthcare workers know the ethically appropriate action to take but are unable to act due to institutional or contextual barriers [6]. Systematic reviews have shown a consistent positive association between moral distress and emotional exhaustion, burnout, and intent to leave the profession [7]. In nursing and other care professions, higher levels of moral distress have also been linked to decreased job satisfaction, increased turnover, and impaired patient safety [8]

Moral injury is a related but distinct construct, referring to the lasting psychological, spiritual, or social harm that results from involvement in, or exposure to, events that transgress deeply held moral beliefs. A systematic review and meta-analysis reported that nearly 45% of healthcare workers experienced clinically significant symptoms of moral injury, with strong associations to depression, anxiety, and post-traumatic stress symptoms. [9] The COVID-19 pandemic amplified these exposures, as professionals frequently faced potentially morally injurious events such as resource scarcity, triage dilemmas, and

organizational directives conflicting with patient-centered values [10, 11].

The cumulative moral impact of these experiences has profound consequences: reduced professional well-being, higher moral injury, deteriorating mental health, and compromised patient safety.

At the organizational level, the persistence of moral distress and injury contributes to workforce attrition, exacerbating staffing shortages and creating a vicious cycle of under resourced care.

Emerging research highlights moral resilience as a potential protective factor, with higher resilience linked to lower moral injury and turnover intention [12].

However, the literature consistently emphasizes that individual coping strategies are insufficient without structural reforms: adequate staffing, ethical support, organizational transparency, and leadership commitment to aligning clinical practice with professional values.

The "Frame of Survival" – the foundation to build a future proven system

The Frame of Survival (See ***Figure 3***) denotes the system-level infrastructure that surrounds and enables the Chain of Survival. In Global Resuscitation Alliance (GRA) materials, the chain captures the time-critical actions at the scene, whereas the frame comprises leadership, policy, funding, training, measurement, continuous quality improvement (CQI), public programs (e.g., AED and responder networks), and - above all - accountability. Together, chain and frame nurture, sustain, and define a high-quality EMS system; in the GRA's formulation, the frame coheres around accountability as a guiding principle [13].



Figure 3: Frame of Survival

Conceptually, the frame operationalizes the Formula for Survival (Survival = Science × Education × Implementation), translating scientific guidance into population-level benefit through education and local implementation. This aligns with the ERC's Systems Saving Lives perspective, which emphasizes that outcomes improve not via isolated actions but through coherent system design, implementation, and ongoing optimization [14,15,16].

Core components of the frame include: (i) governance and policy (leadership, sustainable funding, equity mandates) to set direction and remove structural barriers; (ii) measurement and transparency via Utstein-standardized registries and public reporting to drive learning and accountability; (iii) CQI loops (e.g. defibrillator downloads, event reviews, debriefing) to close the gap between intended and delivered care; (iv) capability building - T-CPR programs, high-performance CPR, first-responder activation, and public-access AED strategy - to lift bystander intervention and early defibrillation; and (v) population-level education, such as Kids Save Lives in schools, to raise bystander CPR/defibrillation at scale.

Functionally, a robust frame links data to action: systems capture standardized outcomes and process metrics (Utstein), review CPR quality and dispatch performance, publish results, and iteratively adjust training, protocols, AED deployment, and citizen-responder coverage. Regions that deliberately build such a frame (registry → feedback → public reporting → targeted interventions) achieve

sustained gains, whereas chain elements alone underperform without these enabling conditions.

Amid anticipated demographic ageing, rising multimorbidity, a continuing shift of illness and end-of-life care into private residences, workforce constraints, and environmental stressors, a robust frame of survival - the system-level infrastructure for governance, financing, measurement, transparency, and continuous quality improvement (CQI) - is increasingly pivotal to sustain out-of-hospital cardiac arrest (OHCA) outcomes. By anchoring standardized registries (Utstein) and public reporting to accountability mechanisms, the frame links data to action through iterative audit-and-feedback cycles that adjust protocols, training, and resource deployment in real time. Operationalizing the Formula for Survival (Science × Education × Implementation), the frame converts guideline knowledge into reliable, equitable population benefit, reduces unwarranted regional variation, and preserves performance despite rising case complexity and resource strain. Jurisdictions that deliberately invest in this infrastructure - leadership oversight, registry-enabled CQI, and equity-oriented policy - demonstrate durable improvements in OHCA systems, whereas settings lacking such foundations repeatedly fail to translate evidence into practice at scale.

Consequently, the frame of survival reflects also the capacity of OHCA response systems to adapt to emerging challenges over time. The extent to which this framework is designed for rapid adaptation, grounded in rigorous data-driven decision-making, will determine the system's ability to effectively respond to the dynamic influences arising within the patient, event, and system dimensions.

Strengthening the frame through technology: the corpuls role

corpuls provides digital solutions - in combination with medical devices, but not exclusively - to strengthen the frame of survival by directly addressing workforce stressors while improving operational efficiency. Real-time tele-consultation (tele-physician/tele-paramedic/tele-nurse, etc.) provides immediate expert back-up on complex scenes aiming to reduce decisional burden, isolation, and moral distress - key determinants of moral injury and turnover. Remote guidance for termination-of-resuscitation criteria, post-ROSC pathways, and direct cardiac-arrest-centre activation shortens scene time and handovers, improving unit availability and perceived workload fairness.

Our guiding principle - Focus On Patients - continues to underpin our daily practice. We now explicitly couple it with a responsibility to reduce system-level burden, thereby not only safeguarding but further help improving survival after out-of-hospital cardiac arrest (OHCA) through implementing digital solutions. Coupled with secure devices and purposeful software, the aim is to help stabilize the workforce and accelerate productivity - turning the frame of survival into a continuously learning, supportive, and high-performing system. ■

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LIFESAVER IN ACTION

CORPULS CPR IN PEDIATRIC RESUSCITATION

Paediatric emergencies are particularly stressful and challenging for rescue service personnel. In addition to the psychological factors, there are anatomical and physiological differences to consider, as well as the fact that emergencies involving children are comparatively rare. This contributes to a degree of uncertainty, especially regarding the use of mechanical resuscitation devices (mCPR) in children. Also, particularly because the corpuls cpr is the only mechanical chest compression device approved for use in children aged 8 years and up.

That makes cases like this all the more encouraging: last year, a ten-year-old boy in Aachen was successfully resuscitated with the aid of the corpuls cpr. corpuls spoke with Matthias Irrgang, who was the attending emergency physician on scene...

Mr Irrgang, could you briefly describe the case for us? What goes through your mind when your pager says "child resuscitation"?

The ambulance and rapid response vehicle were dispatched to the alert "unconscious child after a fall". So, on the drive there, we were expecting a completely different situation. During the journey, we discussed various possible causes for this kind of alert, but none of us had considered that it might involve resuscitation.

When I began assessing the scene, I immediately saw the paramedic about ten metres ahead of me with his back turned and his upper body moving rhythmically up and down. I remember calling out to him as I ran towards him, asking whether we were in fact dealing with a resuscitation.

How did you proceed?

I instructed our driver to notify Dispatch to escalate the call to "child resuscitation" and thereby request the attendance of our lead EMS physician. By the time we arrived, the resuscitation itself was already running well and the initial "chaotic, orientation phase" was over. At my instruction, my anaesthetist colleague took charge of the airway. An attempt at establishing an IV line was unsuccessful, and after I had secured an intraosseous access, I was able to coordinate the procedures, gather information from the boy's father, and develop a structured plan.

How and why did you decide to use the corpuls cpr?

After the third unsuccessful shock and administration of medication, the case met the definition of persistent ventricular fibrillation. However, under chest compressions the child was showing defensive movements and consistently good end-tidal CO_2 values. It was clear to me that the child still had a genuine chance, but that if we were to succeed at all, it would not be through continuing resuscitation on site. For me, the "stay and play" approach was therefore not an option.

I registered the child for evaluation of extracorporeal CPR (eCPR) at the Aachen University Clinic RWTH, which was located about three kilometres away as the crow flies. In our area, if the necessary criteria for eCPR are met, the protocol is transport under ongoing resuscitation with the aim of initiating ECMO. During this time the team be-

gan preparing for transport under mechanical resuscitation. Everyone understood: we had to get the child to hospital as quickly as possible without any loss of chest compression quality and without endangering the staff involved. And that was only achievable through the use of the corpuls cpr.

The boy arrived in the emergency room of Aachen University Clinic RWTH 38 minutes after the initial alert, still under on-going resuscitation. What happened then, and how is the child today?

In the emergency room, ECMO was initiated, and investigations began to determine the cause of the cardiac arrest. This revealed a previously undiagnosed heart condition. Fortunately, the child recovered, received a pacemaker, and was discharged three weeks later. The boy suffered no neurological damage from the incident itself, although he is now waiting for a donor heart.



How did the corpuls3 and corpuls cpr integrate into the course of the mission?

The corpuls3 is our primary monitoring device in Aachen's ambulance service and is used on a daily basis. My personal experience with the device has been positive, whether at the mission site or during transfers. The corpuls cpr, on the other hand, is used far less frequently. We determine the indication for its use on current recommendations. The application itself is relatively straightforward, but as with any other mCPR device, it requires very good communication and careful planning to avoid unnecessarily long hands-off time.

Did the corpuls cpr in this particular case contribute to the child surviving without harm?

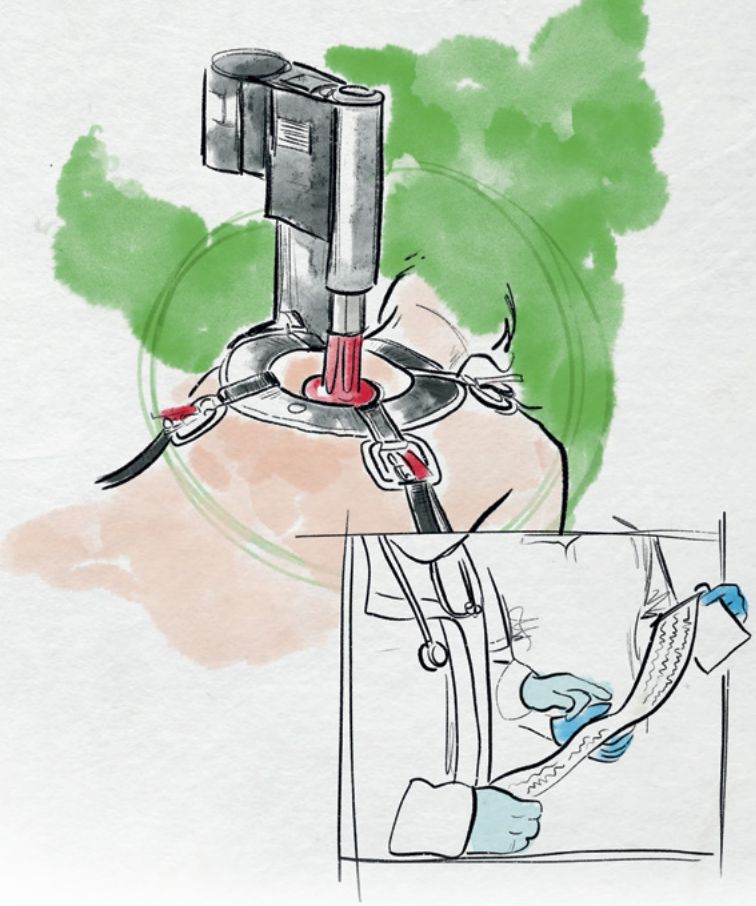
The corpuls cpr enabled us to cover the distance to Aachen University Clinic RWTH in just under nine minutes. Without an mCPR device, we would probably have had to drive slower for safety reasons while carrying out manual chest compressions. Anyone who has ever performed resuscitation in the back of an ambulance knows how difficult the circumstances are. That is why I believe that with manual compressions, we would have achieved neither the same speed nor the same quality.

What else contributed to the positive outcome of this mission?

First and foremost, the father's immediate resuscitation efforts laid the foundation for everything that followed, without that, valuable time would have been lost. Secondly, the excellent teamwork. Paediatric resuscitation probably ranks among the top three worst situations one can face in the ambulance service. Yet everything ran calmly and in a structured manner. Which is a good example of how ad-hoc teams can work together outstandingly well under exceptional circumstances.

And finally, certainly a large portion of luck. Until shortly beforehand, the family had been much further outside the city, which would have meant longer response times for all emergency services. As it happened, the ambulance was, almost literally, just around the corner when the call came in and was on scene within two minutes. Each responding unit had a third crew member, meaning





we had sufficient personnel from the outset to work effectively. Most importantly, I was accompanied by a second anaesthetist, which meant that in the early phase I was less tied up in direct patient care and could quickly focus on coordinating the mission.

This must also have been an extraordinary experience for you personally. What do you take away from it, and what can we all learn?

Firstly: mental preparation for a call-out is important, but, as in this case, our preconceptions can turn out to be completely wrong. That is why, during missions, we must always remain open-minded and assess each case individually to avoid fixation errors.

Secondly: when using mCPR, particular attention must be paid to time management in order to ensure the best possible, guideline-based care.

And thirdly: appropriate aftercare following stressful missions is absolutely essential. It is important to take the time to process what has happened - even if it means you do not go out on another call that day.

In conclusion: under what circumstances do you consider it sensible to use the corpuls cpr for paediatric resuscitation?

The use of the device in children will always remain a case-by-case decision. Checklists and indication catalogues can help teams decide for or against its use. In any case, the system should not simply become the "default measure", not least because once mCPR has been initiated it can sometimes be more difficult for both the team and the parents to terminate resuscitation compared to manual chest compressions.

In my view, mCPR devices demonstrate their greatest strengths particularly when patients are thought to have a realistic chance through transport to hospital. Whether in a stairwell, on a turntable ladder, or in the back of an ambulance, mCPR devices allow safe transport under effective chest compressions. However, the decision to transport under on-going resuscitation should be made as early as possible, and not as a "last resort" when, after a prolonged unsuccessful resuscitation, the team is uncertain how to proceed and hesitant to terminate measures.





Matthias Irrgang



SYNCHRONISED CPR

A COMPARISON OF HANDS-OFF TIME FOR MANUAL AND SYNCHRONISED DEVICE OPERATION

INTRODUCTION

The ERC Guidelines [1] recommend keeping the interruption of chest compression to an absolute minimum. Accordingly, the pre-shock pause can be reduced to less than 5 s for manual defibrillators [1]. A peri-shock pause of less than 20 s is associated with better survival, while it seems to be mostly driven by the pre-shock pause which should be less than 10 s [2].

To simplify the device handling and hands-off time, corpuls offers the synchronised operation of the corpuls cpr via the corpuls3. Therefore, the devices can be connected wirelessly and the controlling of the corpuls cpr can be handled via the corpuls3-monitor. The synchronisation of the devices enables an automated stop of the CPR for rhythm analysis, which additionally reduces the operational steps and further simplifies the handling.

To ensure a guideline conform handling via the synchronisation, the hands-off times for this function were tested and analysed in a usability test. Therefore, four use cases were performed and analysed. A complete cycle of the resuscitation algorithm was performed, from stopping mechanical CPR, analysing heart rhythm, performing preshock CPR, delivering a shock and starting CPR again. Two cycles were performed with a manual operation (sep) for the corpuls cpr and the corpuls3, two with a synchronised operation (sync), one of each with an AED mode rhythm analysis and the other with a manual rhythm analysis.

RESULTS

Comparison of hands-off time

The hands-off time includes the entire time in which no chest compression is performed, including analysis pause and peri-shock pause.

In experiments showed a significant reduction in the total hands-off time in synchronised mode. For the AED mode, separated control is with a mean hands-off time of 14.68 ± 1.09 s highly significant above synchronised operations, which has a hands-off time of 11.94 ± 0.46 s (18.65 % reduction; $p < 0.0001$). However, even in the manual mode, in which the analysis of the ECG was performed manually by the subjects, there was a significant reduction in hands-off time of approximately 1 s (11.57 %) in the synchronised mode (sync: 7.39 ± 1.50 s; sep: 8.36 ± 2.39 s; $p = 0.0178$).

However, since the hands-off time includes both the CPR pause for analysis of the ECG and the peri-shock pause, we now want to clarify whether synchronisation of the devices influences both pause lengths, or whether possibly only one of the two pauses is affected.

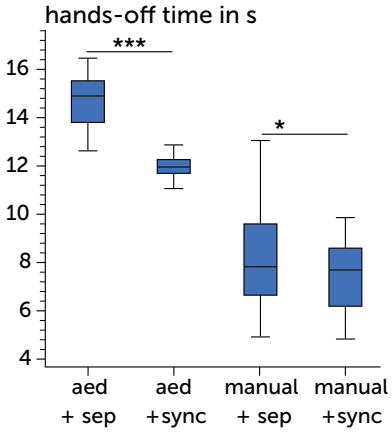


*Figure 1: Total Hands-off time with synchronised (sync) and separated (sep) device operation for AED and manual rhythm analysis (man). The boxplots show the respective mean values (n = 23). The boxes include 50 % of all measured values while the whiskers show the minimum as well as maximum values. The p values of the statistical test are indicated with * for p < 0.05 as significant, and *** for p < 0.001 as highly significant. sep = separated; sync = synchronised.*

Comparison of the peri-shock pause

The peri-shock pause (including pre- and post-shock pause) is defined as the pause for the purpose of defibrillation. During all use cases, pre-shock CPR was performed, therefore there was no interruption to CPR while the defibrillator was charging.

A mutual comparison shows a significant difference between the synchronised and the separated mode regarding the peri-shock pause. In the AED mode, the peri-shock pause with synchronisation is on average significantly shorter by 1.28 s than in the separated mode (40.13 % reduction; 1.91 ± 0.32 s for synchronised vs. 3.19 ± 0.65 s for separated; $p < 0.0001$). In manual mode with a median of 2.07 s (Iqa: 0.27 s) with synchronisation, a significantly shorter pause was measured than the mean peri-shock pause of 3.29 ± 0.78 s with separated devices (36.39 % reduction; Wilcoxon $p < 0.0001$).

In summary, it can be stated that the synchronization of the devices corpuls cpr and corpuls3 leads to a significant reduction of the total hands-off time and peri-shock pause of 1 to 2.7 s.

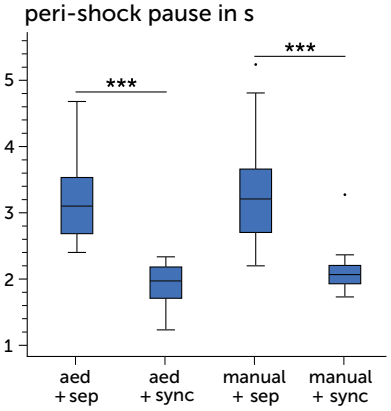


*Figure 2: Durations measured for the peri-shock pause with synchronised (sync) and separated (sep) device operation for AED and manual rhythm analysis (man). The boxplots show the respective mean values of the pauses including 50 % of all measured values (n = 23). The whiskers show the minimum as well as maximum values, while the dots indicate outliers. The p values of the statistical test are indicated with *** for p < 0.001 as highly significant. sep = separated; sync = synchronised.*

DISCUSSION

The peri-shock interval was less than the limit of 20 s described by Cheskes et al. 2014 [2] in any of the cases. The maximal duration of the peri-shock pauses was 3.19 s and therefore under 5 s, which is associated with a higher survival rate [2, 3] and is conform with the recommendation of the ERC guidelines for manual defibrillators [4]. Thus, it can be shown here that all four operating variants promise very good and qualitative CPR regarding hands-off times.

The total hands-off time is on average 16.08 % (1.85 ± 1.66 s) shorter with synchronised CPR than with separate operation. ■

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CONTINUOUS TRAINING IN RESUSCITATION: HOW EDUCATION HELPS TO SAVE LIVES

The chain of survival typically comprises the following elements: early detection of emergencies, immediate resuscitation (CPR), early defibrillation, as well as early advanced cardiac life support and post-resuscitation care. Additional requirements apply to professionals in (pre-) clinical settings, e.g. leading a resuscitation team, making decisions under time pressure, special circumstances and using technical aids such as mechanical cpr.

THE ROLE OF TRAINING IN PRECLINICAL AND CLINICAL SETTINGS

Improving competence and maintaining skills

A fundamental challenge is that skills in resuscitation and the use of defibrillators decline over time without regular training. The ACFASP review shows that both laypeople and medical professionals often experience significant forgetting processes within the first year after training if no refresher training takes place [6].

A key finding comes from a study on refresher intervals for laypeople: A randomised three-stage research design showed that a retraining interval of 3 months resulted in the highest pass rate in resuscitation training after one year (100% vs. 78.9% at 6 months vs. 19% at 12 months; $p < 0.001$) [2].

Although this study addresses laypeople, it can be inferred that more frequent, short training courses or refresher courses are also useful for professionals in order to maintain skills and interrupt the process of forgetting.

Attitude, self-confidence & readiness

Another important factor is the psychological component: Fear and uncertainty are inhibitions and can delay life-saving intervention. Well-planned training programmes reduce these barriers by creating routine, enabling practice under 'stressful' conditions and thus instilling confidence. The literature often emphasises that education must address not only technical knowledge in the use of medical technology, but also motivation and willingness to learn.



Example of 3D animated skilltraining for pacing with the corpuls3.

Innovative methods: simulation, feedback and digital technologies

Modern training formats expand on traditional classroom courses and additionally focus on the topics of motivation and willingness to learn:

- **CPR feedback:**
  According to a systematic review, such devices (e.g. sensors in mannequins) increase skill attainment and retention over time [3].

- **Blended learning (digital + face-to-face):**
  A randomised study showed that a mix of online learning and face-to-face training was no worse than traditional training, with similar skill retention after 6 and 12 months [4].

- **Resuscitation training in virtual 3D worlds:**
  Virtual 3D worlds offer promising opportunities to efficiently supplement resuscitation and defibrillation training. In a study, Aksoy (2020) was able to show that serious games in virtual 3D worlds can offer advantages within a blended learning concept in preparation for face-to-face training [7].

- **Simulation & scenario-based training:**
  These enable realistic exercises, even with stress factors, and promote the interaction of technical and non-technical skills.

- **Virtual reality (VR)/augmented reality (AR):**
  VR/AR-supported training models are being evaluated in newer approaches. Initial reports indicate that these approaches deliver similar training quality while also increasing motivation and engagement [8].

SPECIAL FOCUS: WHY CONTINUOUS TRAINING IS CRUCIAL

Continuous training in realistic environments makes a significant difference for a number of reasons.

1. **High probability of use**
   Clinical environments such as intensive care units, emergency rooms, cardiology departments, operating theatres and emergency services tend to experience more frequent resuscitation cases. Specialist staff must not only be reactive but also act quickly under variable conditions.



2. **Independent defibrillation capability**
   Usually a medical emergency team is not immediately on site. If nursing staff and emergency services personnel are trained to perform defibrillation themselves, the time to defibrillation can be significantly reduced. Such processes can be promoted through targeted training (e.g. programmes such as nurse defibrillation training) [1].

3. **Leadership and coordination**
   Specialist personnel often have to take on a leadership role, make decisions, control processes and communicate with other parties involved. Without regular practice, these skills can be lost outside of routine cases.

4. **Complexity and special cases**
   Resuscitation in a (pre-)clinical setting is complex: comorbidities, drug therapies, invasive devices, special arrhythmias, paediatric resuscitation, etc.. Professionals must be prepared for those special circumstances, even if they do not occur regularly in everyday professional life.

5. **Quality assurance and sustainability**
   Quality standards can only be maintained if training is institutionalised, evaluated and carried out regularly. Feedback from real cases, audits, simulation experiences and continuous training are essential for this.

CHALLENGES AND HURDLES

Despite the clear benefits, there are obstacles to implementing effective education programmes in everyday clinical practice:

- **Resource requirements:**
  personnel, equipment, simulators, training rooms
- **Lack of time:**
  professional demands make regular participation difficult
- **Forgetting curve:**
  skills and knowledge decay without refresher training
- **Motivation and prioritisation:**
  people misjudge their own skills and therefore do not prioritise training
- **Standardisation and accreditation:**
  different training programmes, lack of standards
- **Measurability of benefits:**
  direct impact on patient safety is difficult to measure, as many factors influence its use

RECOMMENDATIONS FOR TRAINING PROGRAMMES FOR HEALTHCARE PROFESSIONALS

Based on the literature, the following recommendations can be derived:

1. **Regular refresher courses**
   Intervals of 6 to 12 months are considered reasonable, but shorter intervals (e.g. 3 months) can achieve better quality results when resources are in high demand (especially among laypeople) [2, 6]. For professionals, a six-month cycle or a combination of short modular units and annual training is recommended.

2. **Integration of simulation/scenarios**
   Training should be realistic, with stressors, time pressure and team roles. Simulation allows technical and non-technical skills to be trained simultaneously.

3. **Use of feedback systems**
   Training mannequins with sensors or software systems (e.g. measurement of compression depth, frequency, interruptions) provide immediate feedback and promote quality.

4. **Blended learning models**
   Preparation via e-learning, tutorial videos or apps, combined with face-to-face exercises, reduces the amount of face-to-face time required and optimises the learning effect [4].

5. **Virtual worlds**
   The use of virtual, 3D animated training scenarios facilitates the transfer to reality with a significantly lower error rate [7].

6. **Institutional anchoring & policy**
   Success depends on training being mandatory, recognised and supported (e.g. through time budgets, reward systems, quality management).

7. **Monitoring & feedback from practice**
   Evaluation of real resuscitation cases, measurement of time to defibrillation, feedback to staff, continuous optimisation of processes.



CONCLUSION

Continuous training in resuscitation and defibrillation is more than just a nice-to-have: it is an essential prerequisite for both laypeople and medical professionals to be able to act effectively, quickly and safely in an emergency. Especially in the (pre-)clinical environment, targeted training of professionals has enormous potential to save valuable minutes, improve technical and non-technical skills and thus increase the chances of survival for patients. ■

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ENERGY- VS. CURRENT-BASED DEFIBRILLATION

The standard approach to shock dosing in external defibrillators relies on energy selection, typically measured in joules. However, emerging evidence and physiological insights suggest that current - specifically the peak or average current delivered during the positive phase of the shock - may be a more accurate determinant of defibrillation success.

Energy Selection in Contemporary Defibrillators

Modern defibrillators allow the electric shock to be dosed by selecting an energy level, commonly ranging from 120 to 360 joules. Since optimal energy levels for defibrillation are still not known, ERC guidelines recommend at least 120 J for RLB waveforms and at least 150 J for BTE waveforms (Soar et al. 2021). It is also unclear whether protocols with fixed-energy (repeated shocks at the same energy level) or escalating-energy protocols (increased energy with each shock) are preferable. Despite the focus on energy, defibrillation is fundamentally a current-driven process. The depolarisation of myocardial cells - necessary to terminate fibrillation - is mediated by the electrical current passing through the heart. Studies have demonstrated that current, rather than energy or voltage, is the best predictor of successful defibrillation (Kerber et al. 1988; Lerman et al. 1988; Ristagno et al. 2013), with average current appearing to be superior to peak current (Chen et al. 2014). These findings are supported by a recent retrospective study which revealed no significant association between the energy of the first shock (measured in Joules per kilogram) and outcomes such as return of spontaneous circulation (ROSC) or survival to hospital discharge (Smida et al. 2025).

In order to establish sufficient electrical current flow even in patients with higher transthoracic impedance (TTI), modern biphasic defibrillators adjust shock parameters in real time to counteract changes in TTI, whereas current-based compensation techniques in rectilinear waveforms seem to be more effective than a duration-based compensation technique in biphasic truncated waveforms (Li et al. 2009). Despite impedance compensation, a patient with a high impedance still receives less current than a patient with a low impedance. In unfavorable cases, a 200 J shock may deliver 25 A in a patient with low impedance but only 10 A in a high-impedance patient. Thus, energy selection alone does not guarantee consistent current delivery across patients, despite impedance compensation techniques. ■



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PROTOCOL FOR ANALYSIS OF THE EFFECT OF HIGHER CURRENT ON DEFIBRILLATION SUCCESS

INTRODUCTION

Background

The standard method for administering shocks with external defibrillators is based on selecting the shock energy. The optimal energy is still not defined, and the ERC Guidelines recommend only minimum energy settings of 120-150 J, dependent on the waveform [1]. Scientific studies indicate the correlation of shock success with mean current instead of energy [2–5]. Therefore, current would be a better parameter to define the defibrillation dose. As current is highly dependent on the patient's transthoracic impedance, it must be compensated consequently. Modern biphasic defibrillators adjust different parameters of the impulse waveform dependent on the impedance [6]. Despite the compensation methods, patients with high impedances still receive less mean current than patients with lower impedances. The definition of the defibrillation waveform via the energy settings is despite impedance compensation no guarantee for a consistent mean current. Although, the delivery of a sufficient electrical current to the myocardium and effectively depolarizing a critical mass of cardiac cells is essential for a successful defibrillation [7].

MAX-option

The MAX-variant of the corpuls3 is a CE certified variant of the corpuls3, which offers the MAX-option (MAX) in addition to the common selection of discrete energies. The MAX-variant requires a software version 4.1 or newer and includes a 100 µF capacitor. As common for the corpuls3, it delivers an impedance-compensated, rectilinear biphasic (RLB) shock with a fixed duration of 6 ms for the first and 4 ms for the second phase. The MAX-variant of the corpuls3 regulates the current (instead of voltage or energy) durign shock delivery and delivers the technichally highest possible mean current for the actual transthoracic impedance (TTI). This impedance-dependent current was determined in preliminary tests and is stored in the device. Across all impedances, the MAX-option delivers approximately 11 % higher mean current than defibrillation with 200 J (Table 1). As a result, selecting the MAX-option results in higher energy outputs of up to 255 J. In patients with very low TTI (25 Ω), the current is limited to 28 A to protect against myocardial damage, resulting in lower energies for these impedances.

E \ TTI [Ω]	25	50	75	100	125	150	175	precision
200 J	151.1	197.2	197.9	187.7	189.9	196.9	193.9	±15%
MAX	143.8	238.5	249.1	248.2	255.4	250.0	235.4	±15%

Table 1: Energies delivered for the 200 J and the MAX settings dependent on the patient's transthoracic impedance.

PMCF STUDY

Study design

Within a post-market clinical follow up (PMCF) study, device data of the corpuls3 were collected prospectively for defibrillations with 200 J setting and MAX setting. The data were collected simultaneously in four different German emergency medical services (EMS) from October 2022 to June 2024. They were recorded by the devices from the standard care of patients with out-of-hospital cardiac arrest.

The study centres Mittelhessen, Bodensee-Oberschwaben, Cologne and Dresden cover urban regions as well as rural regions. The data collected therefore can be assumed to represent a typical patient population and can be regarded as real-world data.

For a better comparability the data for both groups (200 J and MAX) were collected from the same regions during the same period. It was a pragmatic, multicentre, quasi-randomized study. The CE-approved defibrillator/monitoring devices corpuls3 were evenly distributed across

emergency vehicles in all study regions regarding the preset energy setting. Which device and setting preset was used in a given resuscitation depended on the location and availability of the responding vehicle, resulting in a random-like allocation of patients to one of the two default settings. During real-life resuscitations, emergency personnel were able to deviate from the preset energy setting.

Analysis

In the analysis, the shock success of the corpuls3 was retrospectively evaluated with MAX in comparison with the standard 200 J energy setting. Patients were evaluated according to the actually delivered shock energy (as-treated analysis). A common outcome for analysing defibrillation is shock success. A successful defibrillation shock is defined as a shock that resulted in the absence of ventricular fibrillation (VF) or ventricular tachycardia (VT) (either asystole or organized rhythm) at 5 seconds following shock delivery, as determined by the defibrillator's post-shock ECG data.

Termination of VF/VT 5 s post shock (TOF) is a parameter directly associated with the electrical shock and its effectiveness, and therefore, this is used as the primary outcome parameter. It offers a good comparability of the two settings. The second outcome parameter is defined as overall shock success. From a clinical perspective, this offers a better assessment option, as all shocks, which also includes refibrillation. Furthermore, the return of organised rhythm was analysed, as this is a parameter closely associated with the return of spontaneous circulation.

Additionally, the device data offer potential analysis of the delivered current, the patient's impedance as well as the final delivered energy.

DISCUSSION

As stated in the introduction previous scientific studies indicate the correlation of shock success with mean current [2–5]. Therefore, it is conceivable that MAX achieves the same or even a better shock success than 200 J. Although, regarding the first shock success there is no evidence for a significant difference between 150 J and 200 J [8, 9] or 200 J and 360 J energy settings [10]. ■

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MAKE THE MOST OF AS LITTLE AS POSSIBLE

AN INTERVIEW WITH GÜNTER STEMPLE

In the early 1970s, American cardiologists Bernard Lown and Barouh Berkovits succeeded in developing and patenting the first safe and portable direct current defibrillators [Akselrod, 2009]. This laid the foundation for modern defibrillation.

Despite this milestone, the devices were initially bulky and not well-suited for use in emergency medical services. In the years that followed, technological progress accelerated rapidly – a dynamic that would go on to transform emergency medicine profoundly.

We had the opportunity to speak with Günter Stemple, the founder and former president of corpuls. He is a pioneer who witnessed this development first-hand and also played a key role in shaping it through his inventive spirit and visionary thinking.

corpuls.science:
During our research about the history of defibrillation, it became clear how closely technological breakthroughs and clinical needs are intertwined. You not only witnessed this development, but also actively shaped it – do you remember the first time you came across the topic of defibrillation?

Günter Stemple: I first came into contact with the subject of defibrillation after completing my studies in communications engineering at the Technical University of Munich. I was working for a medium-sized company that was broadly oriented: monitor systems, microwaves, electrical stimulation therapy and also defibrillation. That's where I came into contact with Peleška (the Czech scientist Bohumil Peleška, editor's note). The Peleška coil was well-known at that time! It was an optimised air coil in an aperiodically damped oscillating circuit. It was practically the first biphasic defibrillation device. However, it was quite large for its performance – quite a substantial 2 kg block. Then the coil was made smaller and smaller, until basically nothing was left of the pulse. Unfortunately, the times were not yet ready for the biphasic impulse.

corpuls.science:
In the further course of your professional career, you have been intensively occupied with the development of defibrillators. How would you describe the state of the art at that time – and what were the particular challenges from your point of view?

Günter Stemple: The challenge was that the defibrillators were very heavy. There were the large Bosch capacitors. They were made for current compensation and not for defibrillation. At that time, the paramedic system, was being introduced in the USA. Here in Germany, the equipment was still very limited. Basically, the paramedics were using hospital equipment. Devices that were actually built for hospitals were then taken outdoors – with all the consequences that entailed. It was disastrous. So, I teamed up with some patent attorneys I knew and set up a company, and we developed the MATU, which was the first TÜV-certified device.



corpuls.science:
What were the characteristics of this device?

Günter Stemple: It was a defibrillator with an emergency pacemaker and a replaceable battery. It could be charged in 10 minutes using a quick-load tray – for approx. 200 shocks until completely discharged. The MATU was the first device that was specified for use at temperatures down to -20°C, splash-proof and submersible (a few centimetres). The only thing it couldn't do was swim... (laughter). It had the first membrane keyboard in medical technology. It was a PVC film that was specially developed for the Bundeswehr, for the windows of tents. It was very stable and showed virtually no signs of ageing. Phenomenal stuff! It could then be welded sequentially onto the membrane keyboard as a front panel. When you see the film today, it's quite amazing. It's still very soft, but it's 50 years old. The MATU was relatively heavy and stable, but it was also used in helicopters. It also had its own stories – sometimes it was apparently also used as a stool because it was so robust (laughs).

corpuls.science:
In the video 'The corpuls Story', you say that your existing sales network essentially provided you with a guarantee: if you developed a good product, it would find buyers. What was your vision for this product?

Watch the **"The corpuls Stoy"** now on YouTube

Günter Stemple: I had seen the dilemma with other manufacturers' battery systems, because the batteries had to be replaced constantly. An exchangeable battery system has always been promoted in America – even up to the present day. However, this was problematic. Publications reported that 70-80% of defibrillator failures were due to the battery: power supply, battery management, everything related to it (not charged, empty battery taken along, etc.). It was clear to me that the device had to be small, robust and simple. It had to be suitable for outdoor use in terms of temperature range and humidity. And then, of course, it had to be self-sufficient in terms of power supply, regardless of whether it was in vehicles or helicopters. For a long time, there was no charging option in vehicles, let alone sockets.

corpuls.science:
What were the biggest hurdles on the remaining path to corpuls 200?



Günter Stemple: First of all, customers were used to the replaceable battery system. They initially felt uncertain about the corpuls devices. Over the years, we had to prove that it was safe and that the wall mount in the vehicle was a valid fallback option.

The other challenge was the introduction of semiconductor technology. We replaced the existing relays with a thyristor chain. The problem was that the standard specified how the air gap in the relay had to be designed. Of course, a thyristor has no air gap, but every thyristor has leakage currents. So that was clearly against the standard. So, we created a shunt system. When the device boots up, the leakage currents are diverted via the shunt, and when the pulse is emitted, the shunt is opened. The whole thing was checked by a routine when the device was switched on. If an error had occurred, the device would not have uploaded. We presented this to the TÜV and convinced them. At that time, it was the only device that switched up to almost 4kV using semiconductor technology.

corpuls.science:
At that time, there were no lithium batteries and no charge level indicators. How did you improvise here?

Günter Stemple: At that time, nickel-cadmium batteries were the non-plus-ultra. But today we know that this type of battery has its flaws. The big problem is that it needs to be charged and discharged. Just like with a drill. That's ideal, because it's run down until the machine stops and then recharged. And then it goes up and down. In contrast, there's the operation of an emergency device, where it always has to be fully charged, but may not be used for days. That causes the batteries to break down in no time.

And that's when we developed CABM (Computer Aided Battery Management). It's roughly the same idea as with a marine diesel engine. If one cell fails, you can remove it and it will still continue to run. We basically created a relay matrix and corresponding software that tested all cells in the entire battery once every 14 days. Each cell was tested individually. This meant we always had a capacity measurement for each cell and the memory effects were refreshed once in each cell. Of course, this was a very fine-grained warning system. As a result, we achieved battery lifetimes of 7-8 years with the corpuls 08/16.



corpuls.science:
Mr. Stemple, how did you always find out about technical innovations so quickly? There was no internet back then. Do you have any tips or tricks for us and our readers?

Günter Stemple: Yes, I mean, there are lots of things you can do. It's hard to imagine today, but that's how it was. (laughs heartily). The important thing is to seek personal contact! There's simply no substitute for that. There's a kind of rapid interaction that simply can't happen any other way and doesn't happen anywhere else. You always have to observe your customers to understand their needs. That's one thing. And the other is practical experience. Of course, I can simulate everything today. But that tempts you to think a little less for yourself. You should get a feeling for things yourself, repair something that you could actually throw away. My motto is: make the most of as little as possible!

As the conversation continues, we learn how a fully-featured monitoring system with special battery management was installed in the 08/16 alongside the defibrillator – a technology that was previously only available in hospitals. The modular design of the corpuls3 ultimately addressed the long-standing issue of cable clutter, frequently raised at trade fairs. This directly fulfilled a wish expressed by customers of the helicopter rescue service, even though this challenge initially seemed almost impossible to solve.

Mr. Stemple arrived for our interview on his bike and effortlessly followed our 'reporters' up the stairs to the second floor. After almost two hours of intense conversation, our 83-year-old company founder said goodbye, explaining that he had to go home to work in his garden. We were left feeling inspired by the wealth of ideas, optimistic perseverance and modesty that came across in all the exciting stories. We would like to express our sincere thanks for these fascinating insights into the history of defibrillation from the heart of Kaufering. ■



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