

Helicopter-based in-water resuscitation with chest compressions: a pilot study

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ABSTRACT

Background Drowning is a relevant worldwide cause of severe disability and death. The delay of ventilations and chest compressions is a crucial problem in drowning victims. Hence, a novel helicopter-based ALS rescue concept with in-water ventilation and chest compressions was evaluated.

Methods Cardio pulmonary resuscitation (CPR) and vascular access were performed in a self-inflating Heliboat platform in an indoor wave pool using the Fastrach intubating laryngeal mask, the Oxylator resuscitator, Lund University Cardiopulmonary Assist System (LUCAS) chest compression device and EZ-IO intraosseous power drill. The time requirement and physical exertion on a Visual Analogue Scale (VAS) were compared between a procedure without waves and with moderate swell.

Results Measurement of the elapsed time of the various stages of the procedure did not reveal significant differences between calm water and swell: Ventilation was initiated after 02:48 versus 03:02 and chest compression after 04:20 versus 04:18 min; the intraosseous cannulisation was completed after 05:59 versus 06:30 min after a simulated jump off the helicopter. The attachment of the LUCAS to the mannequin and the intraosseous cannulisation was rated significantly more demanding on the VAS during swell conditions.

Conclusions CPR appears to be possible when performed in a rescue platform with special equipment. The novel helicopter-based strategy appears to enable the rescuers to initiate CPR in an appropriate length of time and with an acceptable amount of physical exertion for the divers. The time for the helicopter to reach the patient will have to be very short to minimise neurological damage in the drowning victim.

INTRODUCTION

Drowning is an important cause of severe injury and accidental death worldwide.¹ Drowning especially plays a central role in fatal accidents in children² and men as well as risk-seeking and intoxicated people.^{3–5} Drowning that occurs in open water presents a daunting challenge to the rescuer, as the lethality and long-term neurological disability and morbidity of these events are statistically higher than other circumstances in which drowning occurs.⁶ A likely explanation for the high degree of morbidity and mortality of drowning in open-water conditions is the long period of time taken to reach the victim and a considerable delay in resuscitation efforts. According to the German Life Saving Association Deutsche-Lebens-Rettungs-Gesellschaft (DLRG) 360 males and 85 females

Key messages

What is already known on this subject?

The delay of resuscitation measures in drowning accidents results in severe neurological injury and death. Ventilation during rescue swimming appears to improve the outcome of drowning victims. However, chest compression cannot be performed in the water by now, and the time to reach a drowning victim is crucial.

What this study adds?

In-water resuscitation including advanced airway management, mechanical ventilation and automated chest compressions appear possible in a special self-inflating helicopter rescue platform. The new strategy investigated in the present study might help to reduce the time to the initiation of ALS in drowning victims.

died from drowning in 2013 in Germany, with a relevant number of accidents in rivers and lakes that are not generally observed by lifeguard services.

Early restoration of oxygenation and ventilation is essential in drowning victims^{7,8} and in-water ventilation appears to result in a higher survival rate and a reduction of severe neurological damage.⁹ In-water ventilation in the pool has been demonstrated to be feasible when performed by experienced lifeguards,^{10,11} but difficult when performed in open water.¹²

The European Resuscitation Council currently recommends in-water ventilation and regards in-water chest compressions inefficient.¹³ A poor outcome has been reported in patients with a duration of cardiac arrest longer than 14 min until the onset of artificial ventilation.⁹ This timeframe can almost never be reached if the water rescue forces are not directly at the drowning site. Furthermore, ventilation without chest compressions does not appear to be beneficial after a longer drowning process.

A novel helicopter-based strategy, therefore, aims at a fast transfer of rescue divers to the drowning site and an initiation of ventilation and chest compressions as well as the administration of resuscitation medications while being on a stable platform at the site of rescue. To achieve this goal, two divers exit a helicopter with a self-inflating Heliboat rescue platform, dive to the patient,

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rescue him to the surface and afterwards initiate ventilation, automated chest compressions as an alternative to manual CPR and intraosseous cannulisation on the platform.

The present pilot study therefore investigated the feasibility and time requirement of the in-water resuscitation measures under controlled conditions in an indoor wave pool. Furthermore, the study compared the time requirement and physical exertion between a scenario with calm water and with moderate swell.

METHODS

The study was designed as a non-blinded randomised controlled cross-over trial, and no changes to the original design have been performed after the commencement of the study. The helicopter strategy is based on the BAYWAH 'Bavarian Water Rescue Concept with Helicopters,' which is successfully practiced at several German and European helicopter stations. In this concept, rescue divers jump off the helicopter close to the drowning victim (see online supplementary video 1) and use a self-inflating platform (see online supplementary video 2). The present study added the use of a chest compression device, a resuscitator and an intraosseous power drill. The study simulated resuscitation procedures without waves and with moderate swell in warm water.

Participants

Six rescue divers of the Bavarian Red Cross Water Rescue (BRK Wasserwacht) with experience in the field of in-water resuscitation were assessed for eligibility. The subjects were recruited from the local Bavarian water rescue units, and the experiments and data collection were performed in an indoor wave pool to create reproducible wave conditions near to reality. All subjects had passed a training with the Fastrach intubating laryngeal mask (LMA-Teleflex Medical Europe, Athlone, Ireland) and had performed 25 successful mannequin-intubations. Furthermore, all subjects performed a LUCAS (Jolife AB, Lund, Sweden) chest compression training with 25 successful applications of the LUCAS and an intraosseous cannulisation training (EZ-IO, Vidacare, Shavano Park, Texas, USA). Written informed consent was obtained from all subjects.

Eight persons were assessed eligible for the present study. One subject refused to participate and one subject was sick on the day of the experiments. The remaining six subjects performed both runs.

Interventions

All six rescue divers performed two rescue procedures in computer-randomised order, one without waves and one with moderate swell with a recovery interval of 30 min in between. The procedure was performed by two rescue divers, one operator placed in the rescue platform and one diver who rescued the mannequin, transported it to the rescue platform and assisted the operator. For each procedure, the diver and operator had been randomised.

Each rescue procedure consisted of eight steps (videos available in the online supplement):

1. Simulated jump from the helicopter from pool side into wave pool (figure 1 and see online supplementary video 2) of the divers equipped with an Helicopter Tauch Retter (HTR) miniaturised self-contained underwater breathing apparatus (Tatum GmbH, Beckum, Germany) from the pool edge into the water and inflation of the Heliboat rescue platform (Tatum GmbH, Beckum, Germany).

2. Boarding of the operator into the rescue platform (see online supplementary video 2).
3. Dive of the rescue diver to the mannequin and rescue of the mannequin to the surface while being secured with a safety leash (see online supplementary video 3).
4. Boarding of the mannequin into the rescue platform.
5. Tracheal intubation with the Fastrach intubating laryngeal mask performed by the operator (figure 2 and see online supplementary video 4).
6. Initiation of ventilation with the Oxylator resuscitator (CPR Medical Devices INC, Toronto, Canada) performed by the operator.
7. Initiation of chest compressions with the LUCAS performed by the operator (figure 3 and see online supplementary video 5).
8. Intraosseous cannulisation of the right tibia with the EZ-IO performed by the operator with the help of the diver (figure 4 and see online supplementary video 6).

Details on the selection of the individual devices are provided in the Discussion section.

The endpoint of this study was the completion of the eight steps. In a real drowning scenario, the platform would afterwards either be pulled to the shore with the helicopter via a leash and a TOST quick release coupling or the patient would be transferred to a later-arriving lifeboat.

Mannequin model

A modified Resusci Anne (Laerdal Medical, Stavanger, Norway) was used as mannequin. The buoyancy and towing characteristics equalled a human adult. The head of the mannequin was derived from a Laerdal airway management trainer. A Maquet anaesthetic test lung was used as lung of the mannequin to equal the characteristics of a human lung. The measurement of the characteristics of ventilation (eg, tidal volumes and minute volumes) and compression (eg, compression rate and depth) were impossible due to technical limitations in the waterproof, submergible mannequin.

Outcomes

The primary outcome was the time requirement and the secondary outcome physical exertion. The total elapsed time requirements for the eight rescue steps as well as the time requirements for each individual step were recorded by an observer. Video recording of each step was performed for subsequent analyses. Furthermore, the subjective physical exertion was ranked by the subjects on a visual analogue scale (0=no effort, 10=maximum exertion) immediately after each procedure. The time values obtained and the subjective ratings were compared between the scenario without waves and the scenario with moderate swell (waves).

Statistical analysis

Microsoft Excel 2010, Microsoft, Redmond, Washington, USA and SPSS 19, IBM, Armonk, New York, USA were used for statistical analysis. The comparison of time values was performed with paired samples *t* tests. The sample size of this first pilot study primarily depended on the availability of eligible (see subjects section) rescue divers.

RESULTS

The time requirements for the individual steps of the novel rescue and resuscitation procedure are presented in table 1. There was no significant difference in the times recorded between the rescue runs without waves and those with moderate swell except from the boarding of the operator which was significantly prolonged during swell.



Figure 1 Helicopter exit. The divers equipped with the rescue platform and the resuscitation equipment jump off the helicopter.

The overall rescue procedure did not seem to be critically demanding for any of the rescue divers. The median exertion scores were consistently lower than 4 out of 10 on the analogue scale, except for steps 7 and 8 of the rescue procedure. The subjective data concerning physical exertion are presented in [table 2](#). The intubation of the mannequin was performed without problems by all subjects. The attachment of the LUCAS was reported to be more exhausting because it was difficult to avoid relative movements between the upper part of the LUCAS and the back plate while hooking in the back plate to the LUCAS. Intraosseous cannulisation was more difficult to perform in the swell scenario due to excessive movement of the mannequin's leg.

DISCUSSION

Time requirement

The primary aim of the novel concept is to accelerate the timing of the implementation of resuscitation measures in open water drowning cases. An analysis of more than 20 000 emergencies

in Germany demonstrated that the helicopter emergency team is the first medical staff to reach the patient in more than one-third of the cases.¹⁴ The present concept appears to contribute to a reduction of the time span until both basic and advanced resuscitation measures can be implemented in-water.

The times for rescue and onset of ventilation appear to be quite short for the rescue of a submerged victim. By contrast, the placement of the LUCAS device, and the intraosseous cannulisation, were prolonged due to the difficulties as reported in the Results section.

There was no relevant difference between the procedure without waves and with moderate swell concerning all steps except from the boarding of the operator. This is promising with regard to the use under real open-water conditions.

A prolonged response time would adversely affect the potential for successful resuscitation without neurological disability.^{9 15} Hence, an effective helicopter-based system of rescue would require the earliest emergency call, a proper organisation of the rescue



Figure 2 Endotracheal intubation. The tracheal intubation of the mannequin is performed using the Fastrach Intubating Laryngeal Mask.



Figure 3 Chest compression. After the attachment of the LUCAS automated chest compression device, chest compressions are performed automatically via the gas driven LUCAS 1.



Figure 4 Intraosseous cannulisation. Intraosseous cannulisation is performed using the EZ-IO power drill.

diver pickup, and a dense network of helicopters performing the novel strategy so as to be close to the potential drowning site.

Rescue and boarding

Even though the rescue and boarding did not face a problem in the present study, pool conditions with clear water do not necessarily equal open-water conditions. Hence, the rescue of a submerged patient is only promising if the patient can be detected from the helicopter during flight. The special lowered aperture of the Heliboat ensured an easy boarding of the victim.

Intubation and ventilation

The intubation of real patients might be more difficult and time consuming than it is in the mannequin, especially because up to 86% of the drowning victims are vomiting during CPR.¹⁶

Face-to-face or side-to-face intubation is required based on the design of the Heliboat and the Fastrach intubating laryngeal mask has been reported to be successful in such scenarios.¹⁷ Mannequin training appears to achieve high success rates in

persons inexperienced with the device^{18 19} and the use appears to be intuitive.²⁰ Tracheal intubation aided by video laryngoscopy, for example, with the Glidescope or the Airtraq,¹⁷ might be an alternative to the Fastrach. It is well known that high peak and Positive End Expiratory Pressure (PEEP) pressures can be required in drowning victims.²¹ The use of supraglottic devices like the laryngeal tube/King airway results in lower ventilation seal pressures than ventilation with tracheal intubation and might, therefore, limit ventilation efficacy.¹³ Furthermore, they do not enable sufficient tracheal suctioning, which is frequently required in drowning victims.²² Furthermore, supraglottic devices have been reported to fail if high ventilation pressures are required.²³ Hence, tracheal intubation appears to be worthwhile. For cases of failed tracheal intubation, the Fastrach laryngeal mask offers a proper fallback method to support ventilation by using the laryngeal mask and omitting tracheal intubation. An alternative airway adjunct to the Fastrach might be the CombiTube, since the Fastrach and the CombiTube are the supraglottic devices with the best sealing at high pressures.^{23 24}

Since the suctioning characteristics of a human lung are not sufficiently mimicked by mannequins, tracheal suction was omitted in the present study. The Life Saving Products (LSP) aspirator (Allied Healthcare Products, St Louis, Missouri, USA) and a closed suction system have been successfully tested underwater and can therefore be recommended. Measurements of tidal and minute volumes were not performed in the present study, as the usability and efficacy of the Oxylator for in-water resuscitation²⁵ and with limitations, for underwater²⁶ purposes have already been demonstrated.

Chest compressions

If circulation has come to a standstill, chest compressions are essential. Manual chest compressions during in-water use are inefficient with regard to the compression depth and compression rate.²⁷ Even in the Heliboat, the patient would be pushed through the inflatable floor. Hence, we used the LUCAS

Table 1 Time requirements for the simulated rescue procedure

	No waves	Moderate swell	p Value
(A) Cumulative time requirement for the entire procedure			
Cumulative time requirement	Mean±SD (Min–Max)	Mean±SD (Min–Max)	
Jump and inflation of Heliboat	00:26±00:05 (00:19–00:35)	00:32±00:05 (00:28–00:41)	0.069
Boarding of the operator	00:41±00:10 (00:27–00:53)	00:53±00:06 (00:42–00:57)	0.011*
Rescue of the mannequin to the surface	01:22±00:12 (01:01–01:36)	01:30±00:11 (01:21–01:49)	0.302
Boarding of the mannequin	01:42±00:18 (01:14–02:10)	01:55±00:15 (01:42–02:22)	0.246
End of Fastrach intubation	02:30±00:18 (02:10–02:56)	02:52±00:25 (02:26–03:32)	0.238
Onset of Oxylator ventilation	02:48±00:14 (02:33–03:03)	03:02±00:26 (02:39–03:44)	0.264
Onset of LUCAS chest compression	04:20±00:55 (03:27–05:59)	04:18±00:18 (03:52–04:45)	0.908
End of EZ-IO intraosseous cannulisation	05:59±00:56 (04:30–07:06)	06:30±00:53 (05:46–08:14)	0.505
(B) Relative time requirement for the individual steps			
Relative time requirement	Mean±SD (Min–Max)	Mean±SD (Min–Max)	
Jump and inflation of Heliboat	00:26±00:05 (00:19–00:35)	00:32±00:05 (00:28–00:41)	0.069
Boarding of the operator	00:15±00:06 (00:08–00:25)	00:20±00:04 (00:14–00:26)	0.041*
Rescue of the mannequin to the surface	00:41±00:13 (00:21–00:58)	00:37±00:13 (00:25–00:58)	0.378
Boarding of the mannequin	00:20±00:08 (00:13–00:34)	00:26±00:05 (00:20–00:33)	0.270
End of Fastrach intubation	00:48±00:10 (00:33–01:03)	00:57±00:17 (00:40–01:14)	0.303
Onset of Oxylator ventilation	00:18±00:18 (00:07–00:53)	00:10±00:04 (00:06–00:15)	0.302
Onset of LUCAS chest compression	01:33±00:50 (00:54–02:56)	01:15±00:12 (01:01–01:35)	0.315
End of EZ-IO intraosseous cannulisation	01:38±00:38 (01:03–02:45)	02:13±00:59 (01:15–04:03)	0.378

Data are minutes:seconds. All data are presented as mean±SD (minimum–maximum).

*p<0.05.

The bold figures represent the mean and median values.

Table 2 Physical exertion

	No waves	Moderate swell	Increase in exertion during swell compared to no waves
Physical exertion	Median ; IQR 25–75 (Min–Max)	Median ; IQR 25–75 (Min–Max)	Median ; IQR 25–75 (Min–Max)
Jump and inflation of Heliboat	0; IQR 0.75 (0–2)	0.5; IQR 1.75 (0–2)	0; IQR 0.8 (0–1)
Boarding of the operator	2.5; IQR 1.75 (1–5)	3.5; IQR 1 (3–4)	1; IQR 0.8 (–1–2)
Rescue of the mannequin to the surface	2; IQR 0.75 (1–4)	3.5; IQR 1 (3–5)	1; IQR 1.5 (0–4)
Boarding of the mannequin	3.5; IQR 2.5 (1–4)	4; IQR 1.5 (1–6)	1.5; IQR 1.8 (0–3)
Fastrach intubation	1; IQR 0.75 (0–2)	1.5; IQR 2.5 (0–3)	0.5; IQR 1.0 (0–2)
Initiation of Oxylator ventilation	0; IQR 0 (0–2)	0.5; IQR 1 (0–3)	0.5; IQR 1.0 (0–1)
Attachment of the LUCAS and chest compression	3.5; IQR 1.75 (3–6)	5.5; IQR 2.5 (4–7)	1.5; IQR 1.0 (0–3)
EZ-IO intraosseous cannulisation	2; IQR 0 (0–3)	3.5; IQR 1 (1–5)	1.5; IQR 1.0 (0–3)

Exertion is ranked on a score 0=none to 10=maximum exertion. Data are median; IQR 25%–75% quantile (minimum–maximum). The bold figures represent the mean and median values.

automated chest compression device. This decision is further supported by the fact that the LUCAS is superior to manual compressions during helicopter²⁸ and ambulance²⁹ transport as well. Even though the LUCAS does not appear to enhance the survival rate and neurological outcome compared with manual CPR in an overall analysis,³⁰ it has to be stated that there are certain scenarios—like in-water resuscitation or helicopter transport—in which manual CPR is impossible. The use of automated devices like the LUCAS appears promising in these cases.

The compression depth achieved with the LUCAS is lower than the current guideline recommendations which can limit the compression efficacy in some patients.³¹ The electrically powered LUCAS 2 failed during pretests because of overheating due to waterproof sealed fan apertures. Therefore, the gas-driven LUCAS 1 was used for the experiments and did not cause any problems, even during a 1 min operation at 2 m depth. Possible alternatives that have not proven water resistant yet are a new miniaturised compression device or the Michigan Thumper.³² However, one problem with all these devices is the high consumption of compressed air or oxygen which might limit the usability for the in-water purpose. A watertight modification of the electrically powered LUCAS 2 with an alternative cooling system appears helpful.

Intraosseous cannulisation and Defibrillation

External defibrillation does not appear to be feasible in the water. On the other hand, ventricular fibrillation is reported to be rare in drowning victims. Transoesophageal defibrillation has already been performed with a 50% reduction in the defibrillation threshold in sheep³³ and pigs,³⁴ and might be an alternative for human use in the future.

Both, antiarrhythmic drugs³⁵ and adrenaline³⁶ during CPR do not result in a long-term survival benefit. The cannulisation with the EZ-IO power drill is fast and easy to perform³⁷ and appears to be the only realistic approach to vascular access, since peripheral venous lines do not appear to be feasible in moving, hypothermic and peripherally vasoconstricted patients in the platform. The in-water EZ-IO technique may be associated with an increased risk of microbial infection, although reported infections are rare during emergency³⁸ and military combat use.³⁹ Because the use of resuscitation drugs does not enhance the long-term outcome, the questionable advantages of intraosseous cannulisation have to be balanced against the disadvantages of this technique, especially if an analysis of the underlying heart rhythm cannot be performed due to a lack of an in-water monitoring device.

Limitations

The results of this mannequin study may not be completely transferable to human drowning victims. No present study-information is available about the flight to the patient and about the feasibility during heavy swell, in quickly flowing waters or in cold water, when the rescuer has to perform the skills with gloves. Additionally, we did not measure the efficacy of the chest compressions and ventilation due to technical limitations. The design of a waterproof mannequin with analysis of ventilation and chest compressions would be desirable.

The relatively high financial requirements of the new rescue concept might limit the applicability to wealthy regions. The financial issue is difficult. The costs of adding a winch, training the staff and potentially upgrading to a larger and more powerful airframe have to be balanced against the costs for the rescue platform, the LUCAS, and potentially for the training of rescue divers. Cost optimisation can only be achieved if the components are also used in other scenarios, for example, LUCAS and Oxylator for on-shore resuscitations. Nevertheless, the costs of the current concept are far lower than those of adding a winch to a pre-existing helicopter.

Further studies with a larger sample size are required to confirm the findings of the present pilot study. Open-water studies might help to assess the potential benefit of the novel strategy concerning time requirement and efficacy in comparison to traditional concepts. Human efficacy and outcome data can be derived if the novel strategy should be implemented at some helicopter stations.

Conclusions

The drowning terminology should differentiate between in-water ventilation and in-water resuscitation with chest compressions. The novel helicopter-based strategy appears to enable a relatively quick onset of both, ventilation and chest compressions. This might be of special interest in more remote areas, difficult shore conditions, drowning scenarios with a certain distance to the shore or in cases in which a lifeboat is unavailable. Intraosseous cannulisation is difficult to perform and potentially associated with an increased risk of infections. In areas with a pre-existing dense network of rescue helicopters, the new strategy could be a supplement to the existing components rescue by swimmers, jet skis and lifeboats. A fast pickup concept for the rescue divers and a dense network of helicopters is essential to reach the patient in time.

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Contributors BEW and C-MM designed the pilot study. BEW, JD, AK, FH and YPL performed and monitored the experiments. YPL, BEW, MG and JD performed the statistical analysis. BW, C-MM, FH and AK created the major parts of the manuscript. BW and C-MM are responsible for the overall content as guarantors.

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Helicopter-based in-water resuscitation with chest compressions: a pilot study

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