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Review

A systematic review of interventions for resuscitation following drowning

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Abstract

Objectives: The International Liaison Committee on Resuscitation, in collaboration with drowning researchers from around the world, aimed to review the evidence addressing seven key resuscitation interventions: 1) immediate versus delayed resuscitation; (2) compression first versus ventilation first strategy; (3) compression-only CPR versus standard CPR (compressions and ventilations); (4) ventilation with and without equipment; (5) oxygen administration prior to hospital arrival; (6) automated external defibrillation first versus cardiopulmonary resuscitation first strategy; (7) public access defibrillation programmes.

Methods: The review included studies relating to adults and children who had sustained a cardiac arrest following drowning with control groups and reported patient outcomes. Searches were run from database inception through to April 2023. The following databases were searched Ovid MEDLINE, Pre-Medline, Embase, Cochrane Central Register of Controlled Trials. Risk of bias was assessed using the ROBINS-I tool and the certainty of evidence was assessed using Grading of Recommendations Assessment, Development and Evaluation. The findings are reported as a narrative synthesis.

Results: Three studies were included for two of the seven interventions (2,451 patients). No randomised controlled trials were identified. A retrospective observational study reported in-water resuscitation with rescue breaths improved patient outcomes compared to delayed resuscitation on land ($n = 46$ patients, very low certainty of evidence). The two observational studies ($n = 2{,}405$ patients), comparing compression-only with standard resuscitation, reported no difference for most outcomes. A statistically higher rate of survival to hospital discharge was reported for the standard resuscitation group in one of these studies (29.7% versus 18.1%, adjusted odds ratio 1.54 (95% confidence interval 1.01–2.36) (very low certainty of evidence).

Conclusion: The key finding of this systematic review is the paucity of evidence, with control groups, to inform treatment guidelines for resuscitation in drowning.

Keywords: Drowning, Cardiac Arrest, International Liaison Committee on Resuscitation, Resuscitation

Introduction

Drowning is the third leading cause of unintentional injury related deaths around the world.[1] Morbidity after initially successful resuscitation can be high, with survivors experiencing unfavourable neurological outcomes due to brain hypoxia.[2,3] Developing evidence-based treatment recommendations to aid those attempting to resuscitate people following drowning is therefore a high priority. During the last twenty years, some building blocks for resuscitation

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research regarding drowning have been established. This includes the establishment of a definition of drowning in 2002,[4] the 2015 revised Utstein-style recommended guidelines for uniform reporting of data from drowning-related resuscitation,[5] and several systematic,[6–9] scoping[10,11] and other structured reviews[12,13] of drowning research. Despite the inclusion of drowning in resuscitation guidelines,[14] there has been little systematic synthesis of evidence to inform such guidelines.

The International Liaison Committee on Resuscitation (ILCOR), in collaboration with drowning researchers from around the world, led a scoping review to identify the breadth of available literature on key topics relating to resuscitation from drowning.[15] After reviewing the available evidence,[16] ILCOR decided to proceed with a systematic review addressing seven key resuscitation interventions in drowning to enable the generation of evidence based Consensus on Science and Treatment Recommendations.[17]

Methods

Protocol and registration

This systematic review was commissioned by the International Liaison Committee on Resuscitation (ILCOR) Basic Life Support Task Force. A review group comprising experts in drowning prevention and resuscitation, resuscitation science and systematic review methods was appointed to conduct the review. A protocol was developed in accordance with the ILCOR framework. The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[18] and ILCOR guidelines.[17] The review was registered on 7th October 2021 at the International Prospective Register of Systematic Reviews (PROSPERO; CRD42021259983).

Eligibility criteria and outcomes

The review looked for evidence relating to adults and children who had sustained a cardiac arrest following drowning. In accordance with the Utstein consensus the World Health Organisation's (WHO) definition of drowning was used: "the process of experiencing respiratory impairment from submersion/immersion in liquid".[4] A broad definition of cardiac arrest was used including those who are unconscious and not breathing normally or those requiring resuscitation interventions (e.g., ventilation, chest compressions, defibrillation).

The review examined seven interventions: (1) immediate versus delayed resuscitation; (2) compression first (CAB) versus ventilation first (ABC) strategy; (3) compression-only CPR versus standard CPR (compressions and ventilations); (4) ventilation with and without equipment; (5) oxygen administration prior to hospital arrival; (6) use of an automated external defibrillator (AED) first versus cardiopulmonary resuscitation (CPR) first; and (7) public access defibrillation (PAD) programmes. A priori defined critical outcomes were (1) survival with favourable neurological outcome to discharge / 30 days or later; (2) survival to discharge / 30 days or later; and (3) return of spontaneous circulation. Safety was added as an outcome for the PAD Programme question.

Randomized controlled trials (RCTs) and non-randomized studies (non-randomized controlled trials, interrupted time series, controlled before-and-after studies, cohort studies) were eligible for inclusion. Unpublished studies (e.g., conference abstracts, trial protocols), manikin studies, narrative reviews and animal studies were excluded. All languages were included as long as there was an English abstract or an English full-text article.

Search strategy and information sources

Search strategies were developed by an Information Specialist (co-author SJ) in collaboration with the review group. The search strategies built on search terms used in prior reviews on drowning related topics.[9,15] Searches were initially run from database inception through to October 2021. Searches were re-run to cover the period October 2021 through to April 2023. The following databases were searched: Ovid MEDLINE, Pre-Medline, Embase, Cochrane Central Register of Controlled Trials. The search strategies for the various questions are included in the supplemental material. Duplicates were removed and search results uploaded to Rayyan for review.[19] The reference lists of included articles were reviewed for potential additional articles.

Study selection

Review teams comprising of 2–3 co-authors were identified for each of the 7 topics. Studies identified in the search strategy were reviewed independently by at least two reviewers. At stage one article titles and abstracts were reviewed to create a short list of studies potentially eligible for inclusion. The full text of those articles were then reviewed. Any disagreements between reviewers were adjudicated by a third reviewer. Final study selection was reviewed and approved by the Basic Life Support (BLS) Task Force.

Data extraction

Review teams used a pre-defined standardized data extraction form to extract data from individual papers. Data were extracted on the source of reported data, patient characteristics (age, sex), setting, country, intervention, comparator and outcomes. If necessary, clarification on reported data was obtained from the study authors. Any discrepancies in the extracted data were identified and resolved via discussion.

Risk of bias assessments and certainty of evidence

Risk of bias was assessed for individual studies using the ROBINS-I tool for observational studies by two reviewers from the expert drowning group and checked by the senior author (GDP).[20] The certainty of evidence was assessed using Grading of Recommendations Assessment, Development and Evaluation (GRADE) methodology and classified within one of four categories: very low, low, moderate, or high certainty of evidence.[21]

Data synthesis

The appropriateness of pooling study findings for meta-analysis were assessed by the review teams, with input from the BLS Task Force. As expected, based on the findings of our scoping review, there were either no eligible studies or substantial heterogeneity of study design, settings and outcomes which precluded pooling of data. Study findings are therefore presented as a narrative synthesis covering each of the 7 topics.

Results

The original search strategies identified between 261 and 2266 articles across the 7 topics. After removal of duplicates between 164 and 1849 papers went forward for title and abstract review. From these between 8 and 59 papers were selected for full text review. The updated search identified 715 additional papers, 2 of which were selected for full text review. A detailed breakdown by topic is presented in Table 1. The commonest reason for exclusion was due to studies being unrelated to drowning or lacking a relevant comparator group. Following the review of articles, 3 observational studies met the review eligibility criteria and were included. No randomised controlled trials were identified. The number of articles for each topic were (1) immediate versus delayed resuscitation (n = 1); (2) compression first (CAB) versus ventilation first (ABC) strategy (n = 0); (3) compression-only CPR versus standard CPR (compressions and ventilations) (n = 2); (4) ventilation with and without equipment (n = 0); (5) oxygen administration prior to hospital arrival (n = 0); (6) an automated external defibrillation (AED) first versus cardiopulmonary resuscitation (CPR) first strategy (n = 0); (7) and public access defibrillation (PAD) programmes (n = 0).

Immediate versus delayed resuscitation

This topic was broken down to consider two settings (i) initiation of resuscitation whilst the patient was still in the water or (ii) initiation of resuscitation on a boat.

In-water resuscitation versus waiting until arriving on land

A retrospective observational study reported the outcomes of 86 patients who were found unconscious and not breathing and rescued by lifeguards in the coastal area of Rio de Janeiro, Brazil, between 1995 and 2000.[22] The intervention comprised initiating ventilations in-water resuscitation if sufficient lifeguards/equipment was available to do this effectively. The control group comprised those where the lifeguard transferred directly to land without attempting in-water resuscitation.

For the critical outcome of survival with favourable neurological outcome, 10/19 (52.6%) of those receiving in-water resuscitation compared to 2/27 (7.4%) of those who did not receive in-water resuscitation experienced a good outcome (relative risk 7.1 [95% CI 1.8 to 28.8]). The study was assessed as providing very low certainty evidence (downgraded due to very serious risk of bias and serious risk of imprecision, Table 2).

For the critical outcome of survival to hospital discharge, 16/19 (52.6%) of those receiving in-water resuscitation compared to 4/27 (16.7%) of those who did not receive in-water resuscitation experienced a good outcome (relative risk 5.7 [95% CI 2.3 to 14.3]). The study was assessed as providing very low certainty evidence (downgraded due to very serious risk of bias and serious risk of imprecision).

For the critical outcome of return of spontaneous circulation (ROSC) data were extrapolated from pre-hospital survival status. Those who survived to reach hospital alive were considered to have achieved ROSC. ROSC was achieved in 18/19 [94.7%]) of those who received in-water resuscitation compared to 10/27 (37.0%) who did not receive in-water resuscitation (relative risk 0.0836 [95% CI 0.012 to 0.58]). The study was assessed as providing very low certainty evidence (downgraded due to very serious risk of bias and serious risk of imprecision).

Manikin and simulation studies included in the scoping review were excluded as this review focused on studies reporting clinical outcomes.[23–25]

Resuscitation on a boat versus waiting until arriving on land

No studies were identified which directly compared starting resuscitation on a boat with delaying resuscitation until arrival on land in patients with cardiac arrest following drowning. Manikin and simulation studies included in the scoping review were excluded as this review focused on studies reporting clinical outcomes.[26–30] Studies without control groups were also excluded.[31,32]

Compression first (CAB) versus ventilation first (ABC)

No studies were identified which directly compared a compression first strategy with a ventilation first strategy during the resuscitation of patients with cardiac arrest following drowning.

Compression-only CPR versus standard CPR

Two observational studies were identified which compared compression-only CPR with standard CPR, which includes ventilation and compression, during the resuscitation of patients with cardiac arrest following drowning.[33,34]

Tobin et al. analysed data collected by US Cardiac Arrest Registry for Enhanced Survival (CARES) (2013–2017) amongst 548 adults and children who required resuscitation following drowning.[33] Amongst these patients, 309 received compression-only CPR and 239 received standard CPR. Fukuda et al. analysed data from a government-led registry in Japan (2013–2016) which included 5,121 adults and children who were transported to an emergency hospital due to a cardiac arrest following drowning.[34] Amongst these patients, 4,153 received compression-only CPR and 968 received standard CPR. From this cohort, 928 patients in each group were selected for a propensity score matched analysis.

Table 1 – Summary of the results of the search strategy. The table reports the number of records identified by the searching Ovid MEDLINE, Pre-Medline, Embase, Cochrane Central Register of Controlled Trials, the number which underwent review of titles and abstracts after removal of duplicates, the number of full text articles reviewed and final number of articles included.

	Immediate resuscitation	CAB vs ABC	CPR vs CO	Ventilation equipment	Oxygen	AED first vs CPR first	PAD programmes vs No PAD programmes
Records identified	283	1225	1225	2649	872	343	343
Title and abstract screened after removal of duplicates	170	805	805	2141	711	243	243
Full text reviewed	10	9	24	22	60	34	8
Articles included	1	0	2	0	0	0	0

Abbreviations: CAB = Circulation, Airway, Breathing; ABC = Airway, Breathing, Circulation; CPR = Cardiopulmonary resuscitation; CO = Compression only CPR; AED = Automated External Defibrillator; PAD = Public Access Defibrillator.

Table 2 – Risk of bias assessments for included studies.

Study	Overall	Confounding	Selection	Intervention definition	Intervention deviation	Missing data	Measurement	Reporting
Szpilman 2004	Critical	Critical[a]	Serious[b]	Low	Low	Low	Low	Moderate[e]
Fukuda 2019	Critical	Critical[a]	Critical[c]	Low	Moderate[d]	Low	Low	Moderate[e]
Tobin 2020	Critical	Critical[a]	Critical[c]	Low	Moderate[d]	Low	Low	Moderate[e]

[a] Key variables such as submersion duration was not available.
[b] Although there was a resuscitation protocol the reason why some patients received in-water resuscitation and others did not was likely related to lifeguard and / or patient characteristics.
[c] Interventions provided were likely due to different levels of training amongst bystanders and / or patients characteristics (e.g. airway soiling).
[d] There is a moderate likelihood of cross over between interventions.
[e] The studies were not registered and protocols were not available to review for reporting bias.

Table 3 – Critical and important outcomes for standard cardiopulmonary resuscitation (CPR) (with ventilations) and compression-only CPR.

		Standard CPR	Compression -only CPR		P value
Tobin	Favourable neurological outcome	59/239 (24.7%)	50/309 (16.2%)	Adj OR 1.35 (0.86–2.10)	0.190
Fukuda	Favourable neurological outcome	70/928 (7.5%)	61/929 (6.6%)	RR 1.15 (0.82–1.60)	0.4147
Tobin [a]	Survival	71/239 (29.7%)	56/309 (18.1%)	Adj OR 1.54 (1.01–2.36)	0.046
Fukuda [b]	Survival	97/928 (10.5%)	80/928 (8.6%)	RR 1.21 (0.91–1.61)	0.1791
Tobin [c]	ROSC	127/239 (53.1%)	133/309 (34.0%)	Adj OR 1.29 (0.91–1.84)	0.157
Fukuda [d]	ROSC	98/928 (10.6%)	83/928 (8.9%)	RR 1.18 (0.89–1.56)	0.2405

[a] Tobin et al reported survival at hospital discharge.
[b] Fukada reported at 30 days.
[c] Tobin reported ROSC at hospital admission.
[d] Fukada reported prehospital ROSC.

Both studies assessed survival with a favourable neurological outcome using the Glasgow-Pittsburgh cerebral performance category (CPC) at one month. A CPC score of 1–2 was considered a favourable neurological outcome and scores 3–5 a poor outcome. Tobin et al. reported survival at hospital discharge whilst Fukuda et al reported survival at 30 days.[34] Tobin et al. reported the outcomes for ROSC at hospital admission, [33] while Fukada et al. reported pre-hospital ROSC.[34]

For the critical outcome of survival with a favourable neurological outcome at hospital discharge/30-days, very-low certainty evidence (downgraded for serious risk of bias) was identified. Whilst both studies showed a numerically higher rate of survival with a favourable neurological outcome with standard CPR, the confidence intervals were wide and included the possibility of both benefit and harm (see Table 3).

For the critical outcome of survival at hospital discharge/30-days, very-low certainty evidence (downgraded for serious risk of bias) was identified. Tobin et al found a statistically higher survival rate in the standard CPR group (29.7% versus 18.1%, adjusted odds ratio 1.54 (1.01–2.36).[33] Whilst the Fukuda study[34] showed a numerically higher rate of survival with standard CPR, the confidence intervals were wide and included the possibility of both benefit and harm (see Table 3).

For the critical outcome of ROSC, very-low certainty evidence (downgraded for serious risk of bias) was identified. Whilst both studies showed a numerically higher rate of ROSC when CPR included compressions and ventilations, the confidence intervals were wide and included the possibility of both benefit and harm (see Table 3).

The other studies 17 identified in the scoping review[15] were excluded as they did not compare compression only CPR with compressions and ventilations.

Ventilation with versus without equipment

No studies were identified which directly compared the use of equipment (e.g. pocket mask, bag-valve-mask, airway adjuncts, supraglottic and tracheal tubes) with not using equipment during the resuscitation of patients with cardiac arrest following drowning.

Oxygen administration versus no oxygen administration prior to hospital arrival

No studies were identified which directly compared the oxygen prior to hospital arrival with not using oxygen during the resuscitation of patients with cardiac arrest following drowning.

AED first versus CPR first strategy

No studies were identified which directly compared AED first versus CPR first strategy during the resuscitation of patients with cardiac arrest following drowning.

PAD programme versus no PAD programme for cardiac arrest following drowning

No studies were identified which directly compared the effectiveness of PAD programmes in and around aquatic environments with not having such programmes during the resuscitation of patients with cardiac arrest following drowning.

Discussion

The key finding of this systematic review is the paucity of evidence to inform treatment guidelines for the resuscitation of adults and children who sustain a cardiac arrest following drowning. Despite a modest body of evidence (65 studies) being identified in the scoping review,[15] only three studies, [22,33,34] were eligible for inclusion in the systematic review. The high attrition was primarily due to few studies including a control group to enable comparison with the interventions under investigation.

There are important pathophysiological differences in cardiac arrest primarily due to a cardiac cause, where the heart suddenly stops and a reservoir of oxygen is still available in the body at the start of CPR, and one caused by drowning. In most cardiac arrests following drowning, the oxygen reservoir is gradually emptied resulting in gradual cardiac function decrease until an arrest occurs.[35] Once a cardiac arrest has occurred, CPR is performed in a patient with a depleted oxygen reservoir.

Experimental and clinical data support the importance of early reversal of hypoxia as a critical intervention for improving outcomes.[36–40] Outcomes are significantly better in those only requiring treatment for respiratory rather than cardiac arrest.[35,37,41] The logical extension of these findings is to initiate resuscitation as soon as possible. Immediate ventilation, even before the victim is on land, is feasible while the person is still in the water[22,41–44] whilst full CPR, including defibrillation, is possible on a boat.[45–50] This review identified a single study supporting immediate in-water ventilation performed by trained lifeguards over delayed resuscitation upon arrival on land.[22] If attempted, evidence from manikin studies highlight the importance of avoiding unintentional submersion of the patient[42,43,51], and the risks of fatigue leading to a failed rescue.[42,51] Whilst no comparative studies were identified for resuscitation on a boat, given the evidence it is feasible, it seems reasonable to consider resuscitation on boats when environmental conditions and the training of the rescuers permits.

Early resuscitation guidelines advocated an Airway, Breathing, Circulation (ABC) approach to CPR.[52] Very low certainty evidence from four manikin studies showed a compression first (CAB) strategy led to earlier initiation of resuscitation.[53] The present systematic review found no relevant studies for adults and children who required resuscitation following drowning. As a result of this, ILCOR recommend a compression first (CAB) strategy for lay-persons providing resuscitation for adults in cardiac arrest following drowning to maintain consistency and simplicity of messaging.[54] By contrast, those with a duty to respond (e.g. lifeguards) and healthcare professionals are encouraged to start with ventilations (ABC strategy), based on indirect evidence suggesting that earlier ventilations may improve outcomes.[22,35,37,41] No evidence was found to support a specific number of initial ventilations.

Evidence, predominantly from cardiac and medical causes of cardiac arrest, suggested that a compression-only approach to CPR can result in similar outcomes to standard CPR (which includes ventilation)[55–57], and is simpler to teach and may reduce barriers to starting resuscitation.[58,59] This has led to campaigns promoting “hands only” CPR for lay persons.[60,61] The added value of ventilation in prolonged cardiac arrests[62] or in those with higher likelihood of having a respiratory cause, such as children, is recognised, and guidelines recommend the addition of ventilations when possible.[63] The present review identified two studies,[33,34] amongst which Tobin et al. noted improved survival to discharge where standard CPR including ventilation. Although not defined *a priori* as a designated sub-group in this review, one of the studies also reported a post-hoc subgroup analysis in children aged 5 to 15 years, observing an increased odds of favourable neurological outcome (aOR = 2.68; 95% CI, 1.10 to 6.77; p = 0.03).[33] Based on this evidence and the importance of reversing hypoxia in drowning, it seems reasonable that those that are trained, willing and able to provide chest compressions with ventilations do so.

The review found no direct evidence for or against the use of airway / ventilation adjuncts during CPR following drowning. Observational studies in this area[64–67] will likely be limited by resuscitation time bias[68] – in other words those who receive advanced airway management such as intubation are likely to have been in cardiac arrest longer than those who recover with only simple airway adjuncts, which may falsely lead to associations with poor outcome. Specific concerns relating to the use of supraglottic airways include low lung compliance and high airway resistance in drowning which may lead to ineffective ventilation.[69,70] Whatever approach is adopted, it is required that those delivering advanced ventilation and airway interventions are appropriately trained, monitored and evaluated.

Given the association between hypoxia and adverse outcomes, the use of oxygen to reduce hypoxia during resuscitation has strong face validity.[38,39,71,72] In the absence of specific data to the contrary, adopting the generic ILCOR recommendations for paediatric and adult advanced life support of administering high inspired oxygen concentrations during resuscitation seems reasonable.[63,73] There are practical considerations which will likely vary by country in relation to access to oxygen, the legal requirements to administer oxygen, costs and storage requirements, which will require careful assessment prior to implementing oxygen in practice.

ILCOR recommends implementing PAD programs for patients with OHCA.[53] While no direct evidence was found relating to the use of PAD programmes during resuscitation following drowning, drowning may occur in high-use public areas where AED placement can be utilized by both drowning and non-drowning victims of cardiac arrest. It was also recognised that only a small minority of patients sustaining OHCA following drowning may present with a shockable rhythm.[15] However as studies have demonstrated it is feasible to use AEDs in and around aquatic environments[45,74], it seems reasonable to consider their deployment around aquatic areas with high visitor numbers or high inherent risk of cardiac arrest. Given the high priority for reversal of hypoxia in drowning and as the incidence of the initial rhythm is less likely to be shockable in drowning, compared to cardiac causes of cardiac arrest,[15] it is reasonable to start cardiopulmonary resuscitation prior to attaching the AED.

When interpreting the evidence identified in this review and formulating guidelines there is a balance to strike between keeping guidelines simple and uniform to optimize the retention and recall of the guidelines versus tailoring them to the specific needs of the OHCA caused by drowning. The papers identified in this review involved treatments being administered by members of the public, lifeguards and healthcare staff with advanced life support skills. If extended skills such as oxygen administration, ventilation / airway adjuncts, in-water resuscitation are to be considered, it is essential that those providing the skills are appropriately and regularly trained to enable them to deliver the skills effectively.[42,75]

Strengths of this review were the inclusion of experts in the field of drowning and resuscitation as content experts for the design of search strategies, article selection, data extraction and interpretation of findings. The review was informed by findings of a scoping review[15] and drew on the framework evidence evaluation framework of the ILCOR evidence evaluation process.[17] It further benefitted by a period of public consultation, the results of which can be viewed on https://costr.ilcor.org. There, however, remains the possibility that there may be studies that were not identified through this review process. The review focused on summarising the literature identified rather than providing treatment recommendations and clinical guidelines which can be found on the ILCOR website (www.costr.ilcor.org) and associated consensus on science and treatment recommendations.[54]

Conclusion

There is a lack of high certainty evidence to inform treatment recommendations in relation to adults and children who sustain a cardiac arrest in the context of drowning. Empirical evidence suggests that priority should be placed on rapid reversible of hypoxia through ventilations, chest compressions and oxygen.

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Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: This systematic review was part of the ILCOR continuous evidence evaluation process, which is guided by a rigorous conflict of interest policy (see www.ilcor.org). GDP declares roles as co-chair of ILCOR, Director of Science and Research for the European Resuscitation Council, Vice President of the Resuscitation Council UK and Editor roles with Resuscitation and Resuscitation Plus journals. He is supported by the National Institute for Health Research (NIHR) Applied Research Collaboration (ARC) West Midlands. The views expressed are those of the author(s) and not necessarily those of the NIHR or the Department of Health and Social Care. JB declares her role as an Associate Editor for Resuscitation Plus. The paper was handled by Associate Editor Keith Couper.

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Appendix A. Supplementary data

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REFERENCES

1. Organisation WH. Factsheet on Drowning. 2021. https://www.who.int/news-room/fact-sheets/detail/drowning (accessed 27 January 2023.
2. Manglick MP, Ross FI, Waugh MC, Holland AJA, Cass DT, Soundappan SSV. Neurocognitive outcomes in children following immersion: a long-term study. Arch Dis Child 2018;103:784–9.
3. El Sibai R, Bachir R, El Sayed M. Submersion injuries in the United States: Patients characteristics and predictors of mortality and morbidity. Injury 2018;49:543–8.
4. Idris AH, Berg RA, Bierens J, et al. Recommended guidelines for uniform reporting of data from drowning: the “Utstein style”. Resuscitation 2003;59:45–57.
5. Idris AH, Bierens J, Perkins GD, et al. 2015 revised Utstein-style recommended guidelines for uniform reporting of data from drowning-related resuscitation: An ILCOR advisory statement. Resuscitation 2017;118:147–58.
6. Wallis BA, Watt K, Franklin RC, Taylor M, Nixon JW, Kimble RM. Interventions associated with drowning prevention in children and adolescents: systematic literature review. Inj Prev 2015;21:195–204.
7. Thom O, Roberts K, Devine S, Leggat PA, Franklin RC. Treatment of the lung injury of drowning: a systematic review. Crit Care 2021;25:253.
8. Dunne CL, Madill J, Peden AE, et al. An underappreciated cause of ocean-related fatalities: A systematic review on the epidemiology, risk factors, and treatment of snorkelling-related drowning. Resusc Plus 2021;6 100103.
9. Quan L, Bierens JJ, Lis R, Rowhani-Rahbar A, Morley P, Perkins GD. Predicting outcome of drowning at the scene: A systematic review and meta-analyses. Resuscitation 2016;104:63–75.
10. Scarr JP, Jagnoor J. Identifying opportunities for multisectoral action for drowning prevention: a scoping review. Inj Prev 2022;28:585–94.
11. Roberts K, Thom O, Devine S, Leggat PA, Peden AE, Franklin RC. A scoping review of female drowning: an underexplored issue in five high-income countries. BMC Public Health 2021;21:1072.
12. Venema AM, Absalom AR, Idris AH, Bierens J. Review of 14 drowning publications based on the Utstein style for drowning. Scand J Trauma Resusc Emerg Med 2018;26:19.
13. Koon W, Clemens T, Bierens J, Quan L. Studying outcome predictors of drowning at the scene: Why do we have so few answers? Am J Emerg Med 2020.
14. Lott C, Truhlář A, Alfonzo A, et al. European Resuscitation Council Guidelines 2021: Cardiac arrest in special circumstances. Resuscitation 2021;161:152–219.
15. Bierens J, Abelairas-Gomez C, Barcala Furelos R, et al. Resuscitation and emergency care in drowning: A scoping review. Resuscitation 2021;162:205–17.
16. Wyckoff MH, Singletary EM, Soar J, et al. 2021 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations: Summary From the Basic Life Support; Advanced Life Support; Neonatal Life Support; Education, Implementation, and Teams; First Aid Task Forces; and the COVID-19 Working Group. Circulation 2022;145:e645–721.
17. Morley PT, Atkins DL, Finn JC, et al. Evidence Evaluation Process and Management of Potential Conflicts of Interest. Resuscitation 2020;156:A23–34.
18. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372 n71.
19. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan-a web and mobile app for systematic reviews. Syst Rev 2016;5:210.
20. Sterne JA, Hernan MA, Reeves BC, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. BMJ 2016;355 i4919.
21. Guyatt GH, Oxman AD, Vist GE, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ 2008;336:924–6.
22. Szpilman D, Soares M. In-water resuscitation–is it worthwhile? Resuscitation 2004;63:25–31.
23. Perkins GD. In-water resuscitation: a pilot evaluation. Resuscitation 2005;65:321–4.
24. Winkler BE, Eff AM, Ehrmann U, et al. Effectiveness and safety of in-water resuscitation performed by lifeguards and laypersons: a crossover manikin study. Prehosp Emerg Care 2013;17:409–15.
25. Lungwitz YP, Nussbaum BL, Paulat K, Muth CM, Kranke P, Winkler BE. A novel rescue-tube device for in-water resuscitation. Aerosp 2015;86:379–85.
26. Fungueirino-Suarez R, Barcala-Furelos R, Gonzalez-Fermoso M, et al. Coastal Fishermen as Lifesavers While Sailing at High Speed: A Crossover Study. Biomed Res Int 2018;2018:2747046.
27. Barcala-Furelos R, Abelairas-Gomez C, Palacios-Aguilar J, et al. Can surf-lifeguards perform a quality cardiopulmonary resuscitation sailing on a lifeboat? A quasi-experimental study *Emerg Med J* 2017;34:370–5.
28. Tipton M, David G, Eglin C, Golden F. Basic life support on small boats at sea. Resuscitation 2007;75:332–7.
29. de Vries W, Bierens JJ, Maas MW. Moderate sea states do not influence the application of an AED in rigid inflatable boats. Resuscitation 2006;70:247–53.
30. Barcala-Furelos R, Abelairas-Gomez C, Aranda-Garcia S, et al. Is it feasible “scoop and run while playing” resuscitation on a rescue water craft? A randomized simulation study with lifeguards. Am J Emerg Med 2020;38:618–23.
31. Seesink J, Nieuwenburg SAV, van der Linden T, Bierens JJLM. Circumstances, outcome and quality of cardiopulmonary resuscitation by lifeboat crews. Resuscitation 2019;142:104–10.
32. Kingdon D, Stapleton E, Successful SE, Resuscitation,. Novel Partnership between Paramedics and U.S. Coast Guard. Prehosp Emerg Care 2016;20:432–8.
33. Tobin JM, Ramos WD, Pu Y, Wernicki PG, Quan L, Rossano JW. Bystander CPR is associated with improved neurologically favourable survival in cardiac arrest following drowning. Resuscitation 2017;115:39–43.
34. Fukuda T, Ohashi-Fukuda N, Hayashida K, Kondo Y, Kukita I. Bystander-initiated conventional vs compression-only cardiopulmonary resuscitation and outcomes after out-of-hospital cardiac arrest due to drowning. Resuscitation 2019;145:166–74.

35. Mtaweh H, Kochanek PM, Carcillo JA, Bell MJ, Fink EL. Patterns of multiorgan dysfunction after pediatric drowning. Resuscitation 2015;90:91–6.
36. Szpilman D, Morgan PJ. Management for the Drowning Patient. Chest 2021;159:1473–83.
37. Shenoi RP, Koerner CE, Cruz AT, et al. Factors Associated With Poor Outcome in Childhood Swimming Pool Submersions. Pediatr Emerg Care 2016;32:669–74.
38. Spindelboeck W, Schindler O, Moser A, et al. Increasing arterial oxygen partial pressure during cardiopulmonary resuscitation is associated with improved rates of hospital admission. Resuscitation 2013;84:770–5.
39. Cantu RM, Pruitt CM, Samuy N, Wu CL. Predictors of emergency department discharge following pediatric drowning. Am J Emerg Med 2018;36:446–9.
40. Sik N, Senol HB, Caglar A, Yilmaz D, Duman M. Early application of non-invasive ventilation for children with pulmonary edema after drowning. Pediatr Int 2022;64:e14858.
41. Manolios N, Mackie I. Drowning and near-drowning on Australian beaches patrolled by life-savers: a 10-year study, 1973-1983. Med J Aust 1988;148:165–7.
42. Winkler BE, Eff AM, Ehrmann U, et al. Effectiveness and safety of in-water resuscitation performed by lifeguards and laypersons: a crossover manikin study. Prehosp Emerg Care 2013;17:409–15.
43. Winkler BE, Eff AM, Eff S, et al. Efficacy of ventilation and ventilation adjuncts during in-water-resuscitation–a randomized cross-over trial. Resuscitation 2013;84:1137–42.
44. Perkins GD. In-water resuscitation: a pilot evaluation. Resuscitation 2005;65:321–4.
45. Seesink J, Nieuwenburg SAV, van der Linden T, Bierens J. Circumstances, outcome and quality of cardiopulmonary resuscitation by lifeboat crews. *Resuscitation* 2019;142:104–10.
46. Fungueirino-Suarez R, Barcala-Furelos R, Gonzalez-Fermoso M, et al. Coastal Fishermen as Lifesavers While Sailing at High Speed: A Crossover Study. Biomed Res Int 2018;2018.
47. Tipton M, David G, Eglin C, Golden F. Basic life support on small boats at sea. Resuscitation 2007;75:332–7.
48. Venema AM, Sahinovic MM, Ramaker AJDWR, van de Riet YN, Absalom AR, Wietasch JKG. Performance of Basic Life Support by Lifeboat Crewmembers While Wearing a Survival Suit and Life Vest: A Randomized Controlled Trial. *Front.* Public Health 2021:9.
49. Barcala-Furelos R, Abelairas-Gomez C, Palacios-Aguilar J, et al. Can surf-lifeguards perform a quality cardiopulmonary resuscitation sailing on a lifeboat? A quasi-experimental study. Emergency Medicine Journal 2017;34:370.
50. Barcala-Furelos R, Abelairas-Gómez C, Alonso-Calvete A, et al. Safe On-Boat Resuscitation by Lifeguards in COVID-19 Era: A Pilot Study Comparing Three Sets of Personal Protective Equipment. Prehospital and Disaster Medicine 2021;36:163–9.
51. Lungwitz YP, Nussbaum BL, Paulat K, Muth CM, Kranke P, Winkler BE. A novel rescue-tube device for in-water resuscitation. Aerosp Med Hum Perform 2015;86:379–85.
52. Guidelines for basic life support. A statement by the Basic Life Support Working Party of the European Resuscitation Council, 1992. Resuscitation 1992;24:103–10.
53. Olasveengen TM, Mancini ME, Perkins GD, et al. Adult Basic Life Support: International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. Resuscitation 2020;156:A35–79.
54. Wyckoff MH, Greif R, Morley PT, et al. 2022 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations: Summary From the Basic Life Support; Advanced Life Support; Pediatric Life Support; Neonatal Life Support; Education, Implementation, and Teams; and First Aid Task Forces. Resuscitation 2022;181:208–88.
55. Ashoor HM, Lillie E, Zarin W, et al. Effectiveness of different compression-to-ventilation methods for cardiopulmonary resuscitation: A systematic review. Resuscitation 2017;118:112–25.
56. Zhan L, Yang LJ, Huang Y, He Q, Liu GJ. Continuous chest compression versus interrupted chest compression for cardiopulmonary resuscitation of non-asphyxial out-of-hospital cardiac arrest. Cochrane Database Syst Rev 2017;3:CD010134.
57. Kitamura T, Kiyohara K, Nishiyama C, et al. Chest compression-only versus conventional cardiopulmonary resuscitation for bystander-witnessed out-of-hospital cardiac arrest of medical origin: A propensity score-matched cohort from 143,500 patients. Resuscitation 2018;126:29–35.
58. Matsuyama T, Scapigliati A, Pellis T, Greif R, Iwami T. Willingness to perform bystander cardiopulmonary resuscitation: A scoping review. Resusc Plus 2020;4 100043.
59. Aldridge ES, Perera N, Ball S, Finn J, Bray J. A scoping review to determine the barriers and facilitators to initiation and performance of bystander cardiopulmonary resuscitation during emergency calls. Resusc Plus 2022;11 100290.
60. Sayre MR, Berg RA, Cave DM, Page RL, Potts J, White RD. Hands-Only (Compression-Only) Cardiopulmonary Resuscitation: A Call to Action for Bystander Response to Adults Who Experience Out-of-Hospital Sudden Cardiac Arrest: A Science Advisory for the Public From the American Heart Association Emergency Cardiovascular Care Committee. Circulation 2008;117:2162–7.
61. Iwami T, Kitamura T, Kiyohara K, Kawamura T. Dissemination of Chest Compression-Only Cardiopulmonary Resuscitation and Survival After Out-of-Hospital Cardiac Arrest. Circulation 2015;132:415–22.
62. Kitamura T, Iwami T, Kawamura T, et al. Time-dependent effectiveness of chest compression-only and conventional cardiopulmonary resuscitation for out-of-hospital cardiac arrest of cardiac origin. Resuscitation 2011;82:3–9.
63. Maconochie IK, Aickin R, Hazinski MF, et al. Pediatric Life Support: 2020 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. Resuscitation 2020;156:A120–55.
64. Garner AA, Barker CL, Weatherall AD. Retrospective evaluation of prehospital triage, presentation, interventions and outcome in paediatric drowning managed by a physician staffed helicopter emergency medical service. Scand J Trauma Resusc Emerg Med 2015;23:92.
65. Hubert H, Escutnaire J, Michelet P, et al. Can we identify termination of resuscitation criteria in cardiac arrest due to drowning: results from the French national out-of-hospital cardiac arrest registry. Journal of evaluation in clinical practice 2016;22:924–31.
66. Joanknecht L, Argent AC, van Dijk M, van As AB. Childhood drowning in South Africa: local data should inform prevention strategies. Pediatr Surg Int 2015;31:123–30.
67. Kieboom JK, Verkade HJ, Burgerhof JG, et al. Outcome after resuscitation beyond 30 minutes in drowned children with cardiac arrest and hypothermia: Dutch nationwide retrospective cohort study. BMJ 2015;350 h418.
68. Andersen LW, Grossestreuer AV, Donnino MW. “Resuscitation time bias”-A unique challenge for observational cardiac arrest research. Resuscitation 2018;125:79–82.
69. Baker PA, Webber JB. Failure to ventilate with supraglottic airways after drowning. Anaesth Intensive Care 2011;39:675–7.
70. Ryan KM, Bui MD, Dugas JN, Zvonar I, Tobin JM. Impact of prehospital airway interventions on outcome in cardiac arrest following drowning: A study from the CARES Surveillance Group. Resuscitation 2021;163:130–5.
71. Jung CY, Cha SI, Jang SS, et al. Clinical Feature of Submersion Injury in Adults. Tuberc Respir Dis 2003;55:287–96.
72. Patel JK, Schoenfeld E, Parikh PB, Parnia S. Association of Arterial Oxygen Tension During In-Hospital Cardiac Arrest With Return of Spontaneous Circulation and Survival. J Intensive Care Med 2018;33:407–14.
73. Soar J, Berg KM, Andersen LW, et al. Adult Advanced Life Support: 2020 International Consensus on Cardiopulmonary Resuscitation

and Emergency Cardiovascular Care Science with Treatment Recommendations. Resuscitation 2020;156:A80–A119.
74. Buick JE, Lin S, Rac VE, Brooks SC, Kierzek G, Morrison LJ. Drowning: an overlooked cause of out-of-hospital cardiac arrest in Canada. CJEM 2014;16:314–21.
75. Adelborg K, Dalgas C, Grove EL, Jorgensen C, Al-Mashhadi RH, Lofgren B. Mouth-to-mouth ventilation is superior to mouth-to-pocket mask and bag-valve-mask ventilation during lifeguard CPR: a randomized study. Resuscitation 2011;82:618–22.