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EUROPEAN RESUSCITATION COUNCIL

Review

Resuscitation and emergency care in drowning: A scoping review

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Abstract

Background: The ILCOR Basic Life Support Task Force and the international drowning research community considered it timely to undertake a scoping review of the literature to identify evidence relating to the initial resuscitation, hospital-based interventions and criteria for safe discharge related to drowning.

Methods: Medline, PreMedline, Embase, Cochrane Reviews and Cochrane CENTRAL were searched from 2000 to June 2020 to identify relevant literature. Titles and abstracts and if necessary full text were reviewed in duplicate. Studies were eligible for inclusion if they reported on the population (adults and children who are submerged in water), interventions (resuscitation in water/boats, airway management, oxygen administration, AED use,

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bystander CPR, ventilation strategies, ECMO, protocols for hospital discharge (I), comparator (standard care) and outcomes (O) survival, survival with a favourable neurological outcome, CPR quality, physiological end-points).

Results: The database search yielded 3242 references (Medline 1104, Pre-Medline 202, Embase 1722, Cochrane reviews 12, Cochrane CENTRAL 202). After removal of duplicates 2377 papers were left for screening titles and abstracts. In total 65 unique papers were included. The evidence identified was from predominantly high-income countries and lacked consistency in the populations, interventions and outcomes reported. Clinical studies were exclusively observational in nature.

Conclusion: This scoping review found that there is very limited evidence from observational studies to inform evidence based clinical practice guidelines for drowning. The review highlights an urgent need for high quality research in drowning.

Keywords: Advanced life support, Basic life support, Drowning, Special circumstances, Submersion

Introduction

Drowning is the third leading cause of unintentional injury-related death worldwide.[1] The annual reported death toll from drowning likely represents the tip of the iceberg of total drowning incidents which occur globally.

Nearly twenty years ago, in partnership with the International Liaison Committee on Resuscitation (ILCOR), the Utstein drowning collaborators developed a standardised framework for the reporting of drowning incidents.[2] The framework, updated in 2017,[3] aimed to accelerate research and improve consistency of reporting outcomes related to drowning. In 2005 ILCOR developed consensus on science and treatment recommendations for drowning related to in-water resuscitation, removing victims from the water and adjuncts to ventilation.[4] More recently, ILCOR focused on the evidence base informing search and rescue operations.[5,6] Despite increasing research in drowning, synthesis of the available research to inform evidence based practice guidelines has been limited.

The ILCOR Basic Life Support Task Force and the international drowning research community considered it timely to undertake a scoping review of the literature to identify any new evidence related to this topic. A scoping rather than a systematic review was conducted in order to systematically map the published, peer reviewed literature as this was considered the most appropriate methodology in an area with limited research.[7] At the same time, such a systematic mapping would identify gaps in knowledge related to resuscitation of victims of drowning. Nine high priority domains were selected for review covering initial resuscitation, hospital-based interventions and criteria for safe discharge. The Population, Intervention, Comparator and Outcomes considered are summarised in Table 1.

Methods

The scoping review was registered *a priori* with the International Liaison Committee on Resuscitation. The review followed the methodological approach described by ILCOR.[8–10] The review is reported in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR).[11] The scoping review team followed a written protocol and used a standardised data extraction which is

Table 1 – Population, intervention, comparator, outcome, study design, timeframe summary.

Population: adults and children who are submerged in water	
Intervention	1. Resuscitation in water 2. Resuscitation in boats 3. Airway management 4. Oxygen administration 5. AED use 6. Bystander CPR 7. Ventilation strategies 8. ECMO 9. Protocols for hospital discharge
Comparison	No such interventions
Outcomes	Any clinical outcome (e.g. survival, survival with a favourable neurological outcome, hospitalisation) CPR quality Physiological end-points
Study Design	Randomized controlled trials (RCTs) and non-randomized studies (non-randomized controlled trials, interrupted time series, controlled before-and-after studies, cohort studies) are eligible for inclusion. Manikin studies will only be included if no human studies are available. Unpublished studies (e.g., conference abstracts, trial protocols), narrative reviews, animal studies. All languages are included as long as there is an English abstract It is anticipated that there will be insufficient studies from which to draw a conclusion, case series may be included in the initial search. The minimum number of cases for a case series to be included can be set by the Task Force Scoping Review team (default is $\geq$ 5).
Timeframe	From 2000 onwards

available on www.ilcor.org. Conflict of interest was managed in accordance with ILCOR guidelines. Where a reviewer was an author of a particular paper, the decision to include that study and data extraction were undertaken by other members of the review group.

Table 1 describes the eligibility criteria. The search strategy was developed and executed by an experienced information specialist (SJ) and is available in the Supplemental material. The search covered Medline, PreMedline, Embase, Cochrane Reviews and Cochrane CENTRAL. The search included studies published since 2000 (selected to capture contemporary practice) through to the end of October 2019. The search was updated in June 2020.

Teams of 2–3 reviewers were assigned to each topic. Review teams were briefed, and progress monitored through regular meeting by video conference. The search results were combined and duplicates removed before uploading to Rayyan.[12] In the first step, the titles and abstracts were reviewed independently by the assigned reviewers who were unaware of each other's decision to include or exclude articles. Articles excluded by both reviewers were removed whilst those where one or more reviewers considered potentially eligible were discussed amongst the review group. Where the group could not reach consensus, GDP and JB reviewed and provided a final decision. Following step one, the full text of potentially eligible articles was retrieved and a further review of eligibility was undertaken using the same approach as stage one. Reference lists of the included articles were screened for other relevant articles.

Data were extracted by one reviewer and checked by a second reviewer. Information relating to the setting, study design, population characteristics, intervention(s), comparator(s) and outcome(s) and other key findings were recorded on to a standardised form. Where deemed necessary, study authors were contacted to seek clarification on data presented in the selected studies. Whether the study reported results of a randomised trial or observational study was recorded but no formal critical appraisal of study quality was undertaken, in keeping with scoping review methodology.[7,13] The topic review groups met virtually to review the outputs and developed a narrative summary describing the breadth and depth of the evidence identified.

Results

The database search yielded 3242 references (Medline 1104, Pre-Medline 202, Embase 1722, Cochrane reviews 12, Cochrane CENTRAL 202). After removal of duplicates 2377 papers were left for screening titles and abstracts. The number of papers identified for full text review and final selections are summarised in Fig. 1 for each of the 9 topics. In total 65 unique papers were included. The number of cases and geographical regions are summarised in Fig. 2.

Table 2 describes study design, time period, setting, population, intervention, comparator and outcomes. There was variation in the populations covered in studies. These included drowning with or without cardiac arrest, drowning where resuscitation was attempted, drowning where cases presented to or were admitted to hospital or intensive care. The studies included children only (child defined as age less than 20, 18, 16, 14 or 13 years, n = 23), adults only (n = 3) or

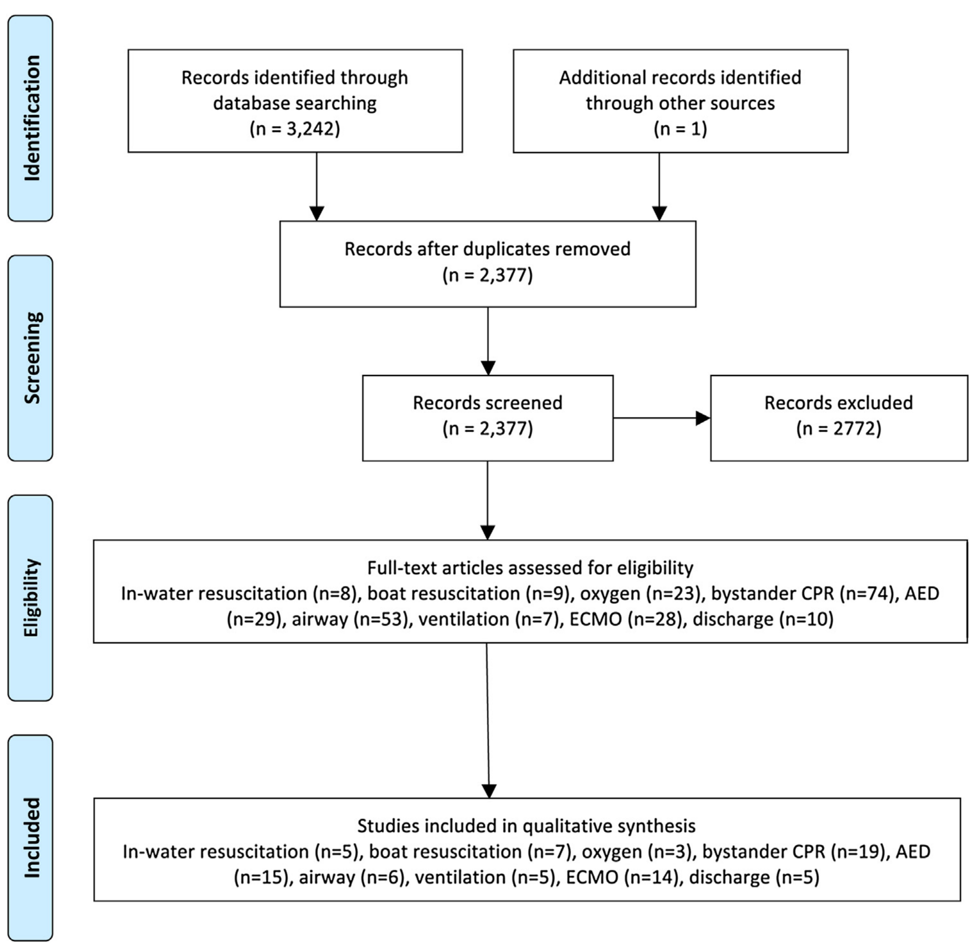

Fig. 1 – Article selection flow chart.

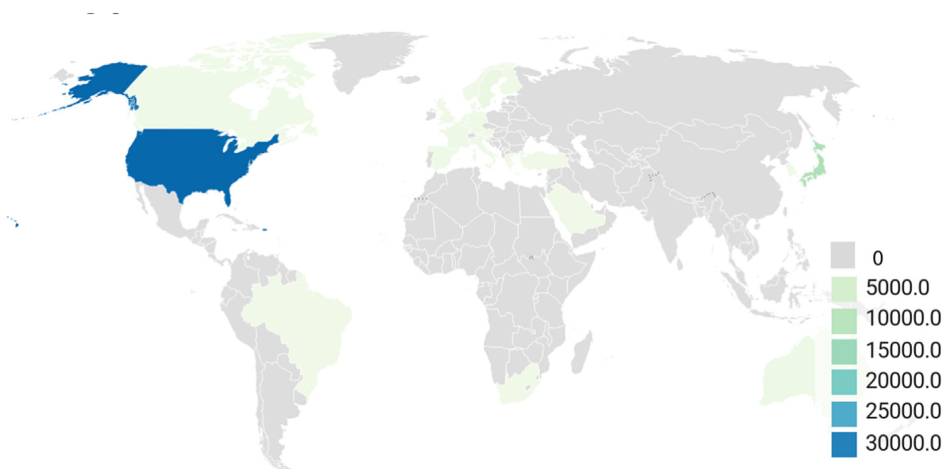

Fig. 2 – Map showing the countries where the papers which informed this review originated. The legend in the bottom right-hand corner indicates the number of cases reported from each region. It illustrates that there are minimal published papers from the developing countries, where the burden of drowning is highest.

adults and children (n = 30) or manikins (n = 9). There was variation in the outcomes reported. Fifteen studies reported return of spontaneous circulation, 29 reported hospital admission, 38 reported survival and 29 reported neurological outcome. The time point for survival and neurological outcomes varied — the commonest timepoint was hospital discharge (n = 16) followed by 30 days (n = 9) and longer term (>30 days) (n = 2). There was a lack of consistency in the tools used to report neurological outcomes. These included narrative descriptions, Cerebral Performance Category, Paediatric Cerebral Performance Category Glasgow Coma Score, Glasgow Outcome Score, and binary description of "good" or "poor" neurological outcome. Manikin studies also reported CPR quality, rescue time, effort/fatigue and AED performance. These outcomes were not reported in the clinical studies.

In-water resuscitation

Evidence summary

Five studies evaluated in-water resuscitation. A single retrospective observational study reported the outcomes of adults and children who were rescued unconscious and not-breathing from the ocean in Brazil.[14] The other four studies were manikin studies conducted in swimming pools[15,16] and open water.[16,17]

The clinical study reported survival status and neurological outcome of 19 patients who received in-water resuscitation compared with 27 patients who did not.[14] The in-water resuscitation protocol recommended performing up to 1 min of ventilations before attempting to bring the unconscious and not-breathing patient to the shore. For patients in deep water, in-water resuscitation required the availability of rescue flotation equipment or at least 2 rescuers. In the prehospital setting initial survival was significantly higher in the in-water resuscitation group (94.7% vs 37.0%, < 0.001). The rate of survival at hospital discharge was higher in the in-water resuscitation group (87.5% vs 25%, $p < 0.005$) as was favourable neurological outcome (52.6% vs 7.4%, $p < 0.001$).[14]

All other studies were crossover trials which evaluated the capacity of lifeguards[15–18] and laypeople[16] to perform in-water resuscitation while simulating a manikin water rescue. In-water resuscitation was technically difficult and physically demanding, particularly in open water. Some trained lifeguards[17] and laypeople[16] were unable to complete the rescue. In-water resuscitation increased rescue time and the number of submersions and aspiration of water by the manikin.[16–18] The use of ventilation adjuncts by well-trained lifeguards might facilitate in-water resuscitation.[17,18]

Resuscitation on a boat

Evidence summary

Seven studies evaluated resuscitation on a boat. Two were clinical studies undertaken in the Netherlands[19] and Hawaii[20] and 5 were manikin studies.[21–25]

A case series from the Royal Dutch Lifeboat Institution reported on 37 patients who had received resuscitation from lifeboat crews.[19] Twenty-four of these cases included resuscitation on a lifeboat or another ship. There were only 3 survivors, none of whom received resuscitation on a boat. An AED was used in 12 patients (7 drowned, 4 not drowned, 1 unknown location of use undefined). Three shocks were delivered; CPR quality was reported as sub-optimal (high compression frequency and long pauses in chest compressions). In the other case series, 6 resuscitations were attempted on a boat or lifeboat; there was only one survivor after one month who received BLS, ALS and tracheal intubation on board.[20]

Four simulation crossover studies evaluated the capacity of lifeguards[22,23,25] and fishermen[21] to perform CPR in inflatable rescue boats or fishing boats. These studies showed that resuscitation on a boat was feasibility, however the quality of the resuscitation was affected by the boat speed[21,22,25] and sea conditions.[23] CPR was physically demanding. [21–23] Resuscitation on a boat affected ventilations more than chest compressions.[23,25] A further simulation study showed that AED use on rigid inflatable rescue boats on calm water was feasible.[24]

Oxygen use

Evidence summary

No studies were identified which specifically examined the pre-hospital use of oxygen in adults or children who had sustained a submersion incident.

Table 2 – Summary of the characteristic of the studies included in the scoping review on the resuscitation and rescue in drowning.

Country	Paper [Ref]	n	Design	Setting	Population	Ages	Intervention	Comparator	Outcomes				
									ROSC	Hospital admission	Survival	Neuro outcome	CPR quality
1. In water resuscitation													
Brazil	Szpilman [14]	46	Observational	Coastal	D, RA	Adults and children	In-water resuscitation	No in-water resuscitation		●	●	●	
UK	Perkins [15]	3	Manikin	Indoor pool	Lifeguards	Adult manikin	In-water resuscitation	No in-water resuscitation					●
Germany	Winkler [16]	41	Manikin	Indoor pool	Lifeguards and lay persons	Adult manikin	In-water resuscitation	No in-water resuscitation					●
Germany	Lungwitz [17]	18	Manikin	Inland lake	Lifeguards	Adult manikin	In-water resuscitation	No in-water resuscitation					●
Germany	Winkler [18]	18	Manikin	Inland lake	Lifeguards	Adult manikin	In-water resuscitation	No in-water resuscitation					●
2. Resuscitation in a boat													
Netherlands	Seesink [19]	12	Observational	Coastal	D, RA	Adults and children	AED applied	No comparator	●		●		●
Hawaii	Kingdon [20]	6	Case series	Coastal	D, RA	Adults and children	Advanced life support	No comparator	●	●	●	●	
Spain	Fungueiriño-Suárez [21]	20	Manikin	Coastal	Fishermen	Adult manikin	Resuscitation in a boat	Resuscitation on the shore					●
Spain	Barcala-Furelos [22]	10	Manikin	Coastal	Lifeguards	Adult manikin	Resuscitation in a boat	Resuscitation on the shore					●
UK	Tipton [23]	9	Manikin	Coastal	Lifeboat crew	Adult manikin	Resuscitation in a boat	No comparator					●
Netherlands	De Vries [24]	18	Manikin	Coastal	AED	Adult manikin	AED on a boat	No comparator					
Spain	Barcala-Furelos [25]	13	Manikin	Coastal	Lifeguards	Adult manikin	Resuscitation in a boat	Resuscitation on the shore					●
3. Oxygen administration													
USA	Cantu [26]	91	Observational	Mixed	D, ED	Children < 18	NA	NA		●			
Israel	Cohen [27]	80	Observational	Mixed	D, ED	Children < 16	NA	NA		●			
Greece	Gregorakos [28]	43	Observational	Mixed	D, Adm	Adults	NA	NA					
Korea	Jung [29]	31	Observational	Mixed	D, Adm	Adults	NA	NA					
4. Bystander CPR													
Hawaii	Kingdon [20]	6	Case series	Coastal	D, RA	Adults and children	Advanced life support	No comparator	●	●	●	●	
Spain	Ballesteros [32]	43	Observational	Mixed	D, RA, ICU	Adults and children	Bystander CPR	No bystander CPR			●	●	
Canada	Buick [33]	132	Observational	Mixed	D, RA	Adults and children	Bystander CPR	No comparator					
Netherlands	Venema [44]	113	Observational	Mixed	D, RA	Adults and children	Bystander CPR	No bystander CPR			●		
Sweden	Claesson [34]	529	Observational	Mixed	D, RA	Adults and children	Bystander CPR	No bystander CPR		●	●		
Israel	Cohen [35]	70	Observational	Mixed	D, RA, ED	Children	Bystander CPR	No bystander CPR			●		
Japan	Fukuda [36]	12139	Observational	Mixed	D, RA	Adults and children	Bystander CPR	No bystander CPR	●		●	●	
Japan	Fukuda [37]	5121	Observational	Mixed	D, RA	Adults and children	CPR	Compression only CPR	●		●	●	
Saudi	Al-Mofadda [38]	28	Case series	Mixed	D, RA, PICU	Children < 13	Bystander CPR	No bystander CPR			●	●	
Slovenia	Grmec [38]	1173	Observational	Mixed	D, RA	Adults	Bystander CPR	No bystander CPR	●	●	●	●	

(continued on next page)

Table 2 *(continued)*

Country	Paper [Ref]	n	Design	Setting	Population	Ages	Intervention	Comparator	Outcomes				
1. In water resuscitation									ROSC	Hospital admission	Survival	Neuro outcome	CPR quality
Saudi	Al-Qurashi [39]	51	Observational	Mixed	D, RA, Adm	Children < 14	Bystander CPR	No bystander CPR					
France	Hubert [39]	291	Observational	Mixed	D, RA	Adults and children	Bystander CPR	No bystander CPR	●	●	●	●	
South Africa	Joanknecht [40]	75	Observational	Mixed	D, RA, Adm	Children < 14	Bystander CPR	No bystander CPR			●	●	
Japan	Nitta [41]	1737	Observational	Mixed	D, RA	Adults and children	Bystander CPR	No bystander CPR	●	●	●	●	
USA	Tobin [42]	919	Observational	Mixed	D, CA	Adults and children	Bystander CPR	No bystander CPR				●	
Finland	Vahatalo [43]	44	Observational	Mixed	D, RA	Children < 16	Bystander CPR	No bystander CPR	●	●	●	●	
South Korea	Youn [45]	131	Observational	Mixed	D, RA, Adm	Adults and children	Bystander CPR	No bystander CPR	●	●	●	●	
Sweden	Claesson [46]	250	Observational	Mixed	D, RA	Adults and children	Bystander CPR	No bystander CPR		●	●		
Sweden	Claesson [47]	255	Observational	Mixed	D, RA	Adults and children	Bystander CPR	No bystander CPR		●	●		
USA	Reynolds [48]	70	Observational	Mixed	D, RA, STD	Adults and children	Bystander CPR	No bystander CPR			●		
Netherlands	Kieboom [53]	160	Observational	Mixed	D, H, RA, Adm	Children < 16	Bystander CPR	No bystander CPR				●	
5. AED use													
Netherlands	Seesink [29]	12	Observational	Coastal	D, RA	Adults and children	AED applied	No comparator	●		●		
Canada	Buick [33]	132	Observational	Mixed	D, RA	Adults and children	AED use	No comparator					
Sweden	Claesson [34]	529	Observational	Mixed	D, RA	Adults and children	Shockable rhythm	No comparator		●	●		
Japan	Fukuda [36]	286	Observational	Not defined	D, RA	Adults and children	Shockable rhythm	No comparator					
USA	Tobin [42]	919	Observational	Mixed	D, CA	Adults and children	AED use	No AED				●	
Finland	Vahatalo [43]	58	Observational	Mixed	D	Children < 16	Shockable rhythm	No comparator					
Korea	Youn [45]		Observational	Mixed	D, RA, Adm	Adults and children	Shockable rhythm	No comparator					
Sweden	Claesson [46]	250	Observational	Mixed	D, RA	Adults and children	Shockable rhythm	No comparator		●	●		
Sweden	Claesson [47]	255	Observational	Mixed	D, RA	Adults and children	Shockable rhythm	No comparator		●	●		
USA	El-Assaad [51]	230	Observational	Not defined	D, CA	Children < 18	AED applied	No comparator					
Australia	Dyson [52]	336	Observational	Mixed	D, CA	Adults and children	Shockable rhythm	No comparator			●		
Netherlands	Kieboom [53]	160	Observational	Mixed	D, H, RA, Adm	Children < 16	Shockable rhythm	No AED				●	
USA	Reynolds [54]	776	Observational	Mixed	D, STD	Adults and children	Shockable rhythm	No comparator					
Belgium	Iserbyt [55]	616	Observational	NA	Lifeguards	Adult manikin	Shockable rhythm	No comparator					●
6. Airway													
France	Hubert [39]	291	Observational	Mixed	D, RA	Adults and children	Intubation	No intubation	●	●	●	●	
South Africa	Joanknecht [40]	75	Observational	Mixed	D, RA, Adm	Children < 14	Intubation	No intubation				●	
USA	Reynolds [48]	70	Observational	Mixed	D, RA, STD	Adults and children	Bystander CPR	No bystander CPR			●		
Netherlands	Kieboom [53]	160	Observational	Mixed	D, H, RA, Adm	Children < 16	Intubation	No intubation				●	
Australia	Garner [56]	42	Observational	Mixed	D, HEMS	Children < 16	Intubation	No intubation		●	●	●	
Spain	Ballestin [57]	131	Observational	Mixed	D, RA, PICU	Adults and children	Intubation	No intubation				●	
7. Ventilation													
Turkey	Caglar [58]	3	Case series	Mixed	D, Adm	Children	Non-invasive ventilation	No comparator			●	●	
Denmark	Onarheim [59]	1	Case series	Fresh water	D, ICU	Children	Surfactant	No comparator					
Italy	Ruggeri [60]	1	Case series	Coastal	D, ICU	Adults	Non-invasive ventilation	No comparator					
France	Micheleta [61]	88	Observational	Coastal	D, ICU	Adults and children	Non-invasive ventilation	Invasive ventilation and oxygen					

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Table 2 *(continued)*

Country	Paper [Ref]	n	Design	Setting	Population	Ages	Intervention	Comparator	Outcomes				
1. In water resuscitation									ROSC	Hospital admission	Survival	Neuro outcome	CPR quality
USA	Umapathi [62]	29347	Case series	Not defined	D, Adm	Children <20	Non-invasive ventilation	No ventilation			●		
8. ECMO													
USA	Bauman [63]	5	Case series	Mixed	D, CA	Children	ECMO	No ECMO			●	●	
Multi-centre	Burke [64]	251	Observational	Mixed	D, ICU	Adults and children	ECMO	No ECMO			●		
France	Champigneulle [65]	43	Case series	Fresh water	D, H, RA, Adm	Not defined	ECMO	No comparator		●	●	●	
Germany	Coskun [66]	13	Case series	Mixed	D, Adm	Children	ECMO	No comparator	●		●	●	
Multi-centre	Dunne [67]	247	Case series	Mixed	D, RA, Adm	Adults and children	ECMO	No comparator			●	●	
Germany	Eich [68]	12	Case series	Mixed	D, CA	Children < 14	ECMO	No comparator		●	●	●	
Norway	Hilmo [69]	19	Case series	Mixed	D, H, RA, Adm	Adults and children	ECMO	No comparator		●	●		
South Korea	Kim [70]	9	Case series	Mixed	D, RA, Adm	Adults and children	ECMO	No comparator		●	●	●	
Austria	Ruttmann [71]	22	Case series	Mixed	D, H, RA, Adm	Adults and children	ECMO	No comparator					
USA	Skarda [72]	7	Case series	Mixed	D, H, RA, Adm	Children	ECMO	No comparator	●	●	●		
Norway	Svendsen [73]	45	Case series	Mixed	D, H, RA, Adm	Adults and children	ECMO	No comparator	●	●	●	●	
USA	Umapathi [62]	135	Case series	Not defined	D, Adm		ECMO	No ECMO			●		
Denmark	Wanscher [74]	7	Case series	Coastal	D, H, RA, Adm	Adults and children	ECMO	No comparator	●	●	●	●	
Germany	Weuster [75]	9	Case series	Mixed	D, H, RA, Adm	Adults and children	ECMO	No comparator	●	●	●	●	
9. Discharge													
USA	Cantu [26]	90	Observational	Mixed	D, ED	Children < 18	Dicharge criteria	No comparator		●			
Israel	Cohen [27]	71	Observational	Mixed	D, ED	Children < 16	Dicharge criteria	No comparator		●			
USA	Causey [76]	48	Observational	Fresh water	D, ED	Children < 18	Dicharge criteria	No comparator		●			
USA	Brennan [77]	185	Observational	Fresh water	D, ED	Children < 18	Dicharge criteria	No comparator		●			
USA	Sehnoi [78]	278	Observational	Mixed	D, ED	Children < 18	Dicharge criteria	No comparator		●			

Indirect evidence from observational studies found associations between hypoxia, oxygen administration and worse outcomes.

Cantu et al. showed that desaturation (SpO_2 <92%) at the scene or during initial emergency department assessment was associated with a higher chance of hospital admission in univariate but not multivariate analysis.[26] Where as normal oxygen saturation (>95%) was associated with discharge from the emergency department (aOR 6.8 (1.07−43.8).[27] Gregorakos et al. did not find an association between PaO_2:FiO_2 ratio in the emergency department and the duration of hospital stay amongst 43 adults and children.[28]

In an observational study involving 31 adults, neurologic deficit or death (when compared with neurologically intact survival) was associated with lower baseline oxygen saturations (87% (13.4) versus 76.0 (7.94) p = 0.007) and a lower baseline PaO_2:FiO_2 ratio (255 (83.5) versus 133 (58.3) p = 0.004) in the emergency department.[29]

Bystander CPR

Evidence summary

19 observational studies were identified that discussed bystander CPR as an intervention for 23,337 adults and children following drowning.[20,30−48,53]

Only 2 cohort studies were designed to directly assess the impact of bystander CPR on neurological outcomes. Both studies found statistically significant associations between bystander CPR and improved outcomes.[36,42] Fukada et al. reported improved neurologically favourable survival (RR 2.19, p = 0.0076), one-month survival (RR 1.55, p = 0.0150) and prehospital ROSC (RR 1.30, p = 0.0296).[36] Tobin et al. similarly supported it as an intervention associated with neurologically favourable survival (aOR = 3.02, $p < 0.001$).[42]

Four other studies found significant positive associations with bystander CPR and survival.[34,35,38,39] Five studies found a positive trend towards survival.[30,31,41,43,44] and 3 found no association between bystander CPR and good outcomes.[40,45,47] One of those studies did find a significant association between survival and a shorter time from witnessing of the drowning event to BLS initiation ($p < 0.001$).[45] A study which examined long-term survival in patients alive at hospital discharge did not find an association between bystander CPR and long term mortality (adjusted hazard ratio 1.49 (0.90−2.47).[48]

Several studies examined the effect of conventional CPR versus compression-only CPR by bystanders on survival.[37,39,41] Tobin et al. reported that compared with compression only CPR, conventional CPR improved survival to discharge (all patients, aOR = 1.54; 95% CI, 1.01−2.36; p = 0.046) and neurological outcomes in children (aOR = 2.68; 95% CI, 1.10−6.77; p = 0.03).[49] Hubert et al. found a highly positive association between bystander ventilation and survival (OR 6.742, p = 0.002)[39] and Nitta et al. found a trend towards favouring conventional CPR for both survival (aOR = 1.87; 95%CI 0.83−4.20) and neurologically favourable outcome (aOR = 2.35; 95%CI 0.52−10.62).[41] By contrast, Fukada et al. reported similar outcomes for conventional and compression only CPR — both were better than no CPR.[37] It has been noted that the study populations in two of these studies[37,41] included mostly elderly people who drowned in hot tubs, limiting the generalisability of these findings.[50]

AED use in drowning

Evidence summary

There were no interventional, observational or case series reporting impact on outcome of on-site AED usage in OHCA due to drowning prior the arrival of emergency medical services.

Indirect evidence of AED use was found from 15 observational studies. Four studies involving 1044 patients, showed a range of AED usage in cases of suspected drowning prior the arrival of EMS of 5−32%.[19,33,42,51] In 12 studies involving 14,920 patients, a shockable rhythm in OHCA due to drowning was uncommon with a reported range of VF/VT between 2−14%.,[19,33,34,36,42,43,45−47,51−53]

Amongst seven observational studies involving 1846 patients in cardiac arrest after drowning, a shockable rhythm was not associated with better survival.[19,42,45,47,51−53] In one study with 776 drowning survivors, only 0.4% were defibrillated at the emergency department.[54] In one study involving 529 patients in a multivariable analysis, whilst a shockable rhythm did not improve survival to hospital admission, there was an association between shockable rhythm and increased 30 day survival OR 4.12 (95% CI: 1.13−13.71).[34]

In one simulation study testing 6 AEDs on 3 different boats in moderate sea conditions, use of AEDs seemed feasible.[24] A further simulation study with 616 lifeguards, reported the mean time from arrival to defibrillation was 62 s (SD 20).[55] In one study, a case of inappropriate shock delivered to a patient in asystole with artefacts on the ECG due to movements was described with no obvious consequences.[19]

No adverse events were reported in the studies identified in this review.

Airway management

Evidence summary

No studies specifically examined the effect of a particular airway management strategy over another, or no intervention, in the management of a submerged patient.

Six observational studies indirectly examined airway management strategies in 769 adults and children following drowning events.[39,40,48,53,56,57] One study reported outcomes in adults and children[39] whilst the other four studies reported only paediatric cases.[40,53,56,57] Some studies reported only those who sustained cardiac arrest due to drowning.[39,48,53]

In all studies intubation was an indication of the severity of the injury, with the most severe cases being intubated during cardiac arrest or facilitated with anaesthesia, without comprehensive adjustment for confounders. Two studies showed intubation was associated with worse outcome (OR for good outcome 0.25 (0.08−0.83)[53]; OR poor outcome 0.04 (0.01−0.2).[40] One study showed mobile medical team ventilation as associated with better outcomes (44% versus 17% survival to admission).[56] A study which examined long-term survival in patients alive at hospital discharge did not find an association between intubation and long term mortality (hazard ratio 0.91 (0.64−1.23).[48]

Ventilation strategies

Evidence summary

Five studies were identified which examined the use of ventilation strategies in 19,947 adults and children following drowning.[58−62]

Analysis of US national patient databases for children (ages 0−20) admitted to hospital following drowning identified 29,347 children of whom, 19,549 (68%) did not require ventilation, 461 (1%) received non-invasive ventilation and 9032 (31%) received invasive ventilation. Mortality was low in those who did not require ventilation (1.5%) or only required non-invasive ventilation (2.1%, adjusted OR 1.6 (0.74 −3.47)) and high in those who required invasive ventilation (35.1%, adjusted OR 28.4 (24.4−33.1).[62]

In a multicentre, retrospective observational study, across 7 French ICUs, 48 adult patients received non-invasive ventilation (NIV, both CPAP and BiPAP, average PEEP 8 ± 2 cm H_2O) to treat moderate to severe lung injury (mean PaO_2:FiO_2 ratio 156 mm Hg).[61] Compared to patients administered invasive mechanical ventilation, those receiving NIV had a better initial neurological (GCS 12 ± 3 vs 7 ± 4, $p < 0.05$) and hemodynamic status (MAP 77 ± 18 vs 96 ± 18 mmHg, $p < 0.001$). NIV was successful in 92% (44/48) with an average duration of ventilation of 1.4 days (standard deviation 0.7d). Both mechanical ventilation and NIV were associated with rapid improvement of oxygenation (within 6 h) and short ICU length of stay [3 days (1−14) and 2 days (1−7) respectively. Two further papers reported successful use of NIV to treat drowning related acute lung injury in haemodynamically stable adult[59,60] and 3 children.[58] In each case the GCS was >12, pressure support 10−18 cm H_2O and PEEP 5 −8 cm H_2O.

Extracorporeal membrane oxygenation

Evidence summary

Fourteen studies were identified which examined the use of extracorporeal support in 732 adults and children following drowning.[62−75] Some papers reported overlapping data — Dunne et al.[67] reported cases from three other case series[66,68,74] whilst Coskun et al.[66] and Eich et al.[68] appear to report the same cases.

Most studies reported the use of Venous-Arterial Extra Corporeal Membrane Oxygenation (VA-ECMO) for patients who were in cardiac arrest [65−69,71−75] whilst three studies reported using VA-ECMO for patients in cardiac arrest and Venous-Venous ECM0 (VV-ECMO) for respiratory failure.[63,64,70] Most uses of ECMO appeared in the context of patients who had been submerged in cold water leading to hypothermia (core temperature range 13−31 °C).[65,66,68,71,72,75] Where reported, the duration of submersion ranged from 15−90 min.[65,66,68,69,71,72,75] The duration of ECMO treatment was between 2 −260 h.[65,66,74,75]

The Extracorporeal Life Support Organisation registry reported on the use of ECMO amongst 251 patients treated for drowning from multiple centres internationally between 1986−2015.[64] Survival to discharge was highest (71.4%) for patients who did not experience a cardiac arrest. Survival was 57.0% for patients who required cardiopulmonary resuscitation but regain ROSC prior to ECMO and 23.4% in patients who received ECPR. Survival rates across the other studies for patients with cardiac arrest ranged from 10% to 100%. Survival with a favourable neurological outcome was between 5 and 57%. Outcomes were better for patients who required ECMO for respiratory support rather than E-CPR for cardiac arrest.[70]

Factors reported as associated with worse outcomes were requirement for E-CPR,[64] hyperkalaemia,[67,72] hypoxia as the primary cause of cardiac arrest,[67,73] asystole as an initial rhythm,[66] submersion duration >10 min,[72] low pH,[66] renal failure,[64] and requirement for CPR whilst on ECMO.[64] Factors associated with good outcomes were profound hypothermia (core body temperature <26 °C) and normal potassium.[65]

Discharge

Evidence summary

Five studies were identified that evaluated criteria for discharge from the emergency department for drowning patients.[26,27,76−78] All of these were retrospective observational studies, including one with both derivation and validation arms.[78] In total, 834 patients were analyzed, all of whom were under the age of 18.

All studies evaluated objective clinical findings to determine factors which could predict safe discharge early in the clinical phase. These factors include pulmonary examination (744 patients),[26,76−78] room air oxygen saturation (834 patient),[26,27,76−78] pulse rate (673 patients), [76−78] blood pressure (673 patients), [76−78] mental status (744 patients), [26,76−78] need for airway support (535 patients),[27,78] and dyspnea (744 patients).[26,76−78] Three studies evaluated specific safe discharge times, specifically 6 h[26,76] and 8 h,[78] with the remaining studies solely comparing discharged patients to admitted patients. Additional objective factors that were analyzed were chest radiography (341 patients)[26,27,77] and arterial blood gas results (161 patients).[26,27]

These studies found that for drowning patients under the age of 18, presenting to the emergency department with normal mentation, an observation period of at least 6 h appears to be sufficient to allow for any clinical deterioration to be revealed. Patients who remain with normal mentation, no need for supplemental oxygen, and normal age-adjusted vital signs appeared to be able to be considered for discharge at this time.

Discussion

This scoping review found evidence spanning eight of the nine core topics identified for review. No randomised controlled trials were identified for any of the topics reviewed. Study designs were observational ranging in size from 1 to 8690 participants. Across each of the topics, there was variation in how the population, intervention, comparators and outcomes were defined and reported.

Key findings from the review are that in-water resuscitation and resuscitation in a boat, appear feasible in the hands of specialist rescue teams. Despite an obvious rationale for the use of oxygen in drowning there was an absence of data to support or refute its use. In these circumstances it appears that ILCOR's treatment recommendation of using 100% inspired oxygen until arterial oxygen saturation or the partial pressure of arterial oxygen can be measured seems reasonable.[79] As cardiac arrest in drowning primarily arises due to hypoxia, initiating conventional CPR which includes ventilation and compressions appears supported by the data identified in this review. Adopting this approach is also concordant with ILCOR's treatment recommendation which suggests that those who are trained, able and willing to give rescue breaths as well as chest compressions do so for all adult patients in cardiac arrest.[80] Given the low incidence of a shockable rhythm in drowning, it seems reasonable to focus initially on high quality CPR whilst the defibrillator is prepared for application.[6] The review identified a small body of evidence examining clinical and physiological factors and their associations with hospital admission after a submersion incident. None of the studies prospectively tested a clinical decision rule to identify patients who can be safely discharged.

For advanced life support interventions, non-invasive ventilation appears feasible in patients with single organ failure and preserved conscious level. Whilst there is a patho-physiological rationale for early intubation in cardiac arrest due to drowning (low lung compliance, high risk of aspiration), there is a paucity of data to inform the optimal approach. In the absence of specific data, adopting an airway management strategy, based on the expertise of the airway operator, as recommended by the ALS Task Force, seems justified.[81] Given the absence of specific data on the optimal approach to ventilation, adoption of guidelines for the management of the acute respiratory distress syndrome seems reasonable.[82] The review found evidence confirming that extracorporeal oxygenation is feasible as a treatment option for cardiac arrest or severe respiratory failure caused by drowning. This supports the relevance of the ILCOR treatment recommendation for extracorporeal cardiopulmonary resuscitation (E-CPR) which suggests E-CPR may be considered as a rescue therapy for selected patients with cardiac arrest when conventional cardiopulmonary resuscitation is failing in settings where this can be implemented.[83]

The Utstein guidelines for uniform reporting of data from drowning were developed to establish consistency in the reporting of drowning-related studies.[3,84] A recent review of 14 studies based on the Utstein guidelines confirmed their usefulness to compare drowning resuscitation outcome studies.[2] Despite these efforts, the present review found evidence of variation in the reporting of population, intervention, comparators and outcomes. Similar to the observations from a systematic review in cardiac arrest,[85] this was particularly pronounced in the reporting of outcomes. This heterogeneity will limit the opportunities to pool studies for future meta-analyses. The drowning research community might consider developing a core outcome set, similar to that developed for cardiac arrest,[86] to improve consistency of outcome reporting.

Drowning is a global problem which accounts for around 300,000 premature deaths each year.[87] A higher proportion of deaths occurs in low to middle sociodemographic countries with over half of deaths occurring in China, India, Pakistan and Bangladesh in 2017. By contrast, the research identified in this review has come predominantly from higher sociodemographic countries. No studies came from the countries with the highest incidence of drowning. This represents an important research gap.[88]

This review was informed by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews[11] and International Liaison Committee on Resuscitation guidance for Scoping Reviews. Key methodological strengths were the *a priori* designation of the research questions, selection of articles by two or more reviewers, who were unaware of the initial choices of their reviewer partner, standardised data extraction and checking. Limitations of the review were its focus on peer reviewed publications and exclusion of grey literature, the focus on clinical rather than animal studies and absence of formal assessment of the certainty of evidence.

Conclusion

This scoping review found that there is relatively limited evidence from observational studies to inform evidence based clinical practice guidelines for drowning. The evidence identified was from predominantly high-income countries and lacked consistency in the populations, interventions and outcomes reported. The review highlights an urgent need for high quality research in drowning.

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GDP (volunteer roles International Liaison Committee on Resuscitation, European Resuscitation Council, Resuscitation Council UK; Editor Resuscitation); Medico-legal advice related to drowning). JB (medical advisor Royal Dutch Lifeboat Institution — KNRM; volunteer roles Advising-governor Royal Dutch Society to Rescue People from Drowning, established in 1767 — KMRD; international representative Royal Dutch Lifesaving Association).

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