Review articles

Evidence for simulation-based education in hyperbaric medicine: A systematic review

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Hyperbaric oxygen; Education; Systematic review; Performance; Safety

Abstract
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Introduction: Evidence from many areas of healthcare suggests that skills learned during simulation transfer to clinical settings; however, this has not yet been investigated in hyperbaric medicine. This systematic review aimed to identify, summarize, and assess the impact of simulation-based education in hyperbaric medicine.
Methods: Eligible studies investigated the effect of simulation-based education for learning in hyperbaric medicine, used any design, and were published in English in a peer-reviewed journal. Learning outcomes across all Kirkpatrick levels were included. MEDLINE, Embase, and the Cochrane Central Register of Controlled Trials were searched. Pairs of independent reviewers assessed references for study eligibility.
Results: We found no article assessing the impact of simulation-based education in hyperbaric medicine published in English. Only one potentially relevant paper published in German was found.
Conclusions: More research is needed to determine how the hyperbaric medicine community and their patients may benefit from simulation-based education to optimize both practice and patient care.

Introduction

Simulation-based education is effective for teaching technical and non-technical skills to both individuals and teams across many specialties, particularly in acute care.[1–4] Since simulation poses no risk to actual patients,[1,5] it is used across the continuum of education from undergraduate and postgraduate training to continuing professional development. Evidence suggests that skills learned during simulation transfer to clinical settings, improve team performance,[3] and in turn may improve patient outcomes.[6]

Hyperbaric oxygen therapy (HBOT) is widely used across the world to treat patients of all ages with urgent and non-urgent conditions.[7–14] Effective medical management of HBOT requires both individual and team-level clinical competencies, especially in emergency situations or when complications occur.[15] For example, HBOT can involve safety events such as hyperbaric chamber fires, acute respiratory failure or seizure, and complex cases such as patients who are mechanically ventilated.[16] Healthcare providers involved in the provision of HBOT must therefore master technical and non-technical skills, including interprofessional collaboration, for effective teamwork.

In many countries, training to be a certified hyperbaric healthcare professional currently only includes didactic lectures.[15] Training for the initial certification does not routinely involve simulation-based education and there is no formally recognized simulation course tailored to hyperbaric medicine. Based on the evidence supporting the impact of simulation practice in other areas of healthcare,[3,6] we hypothesize that a simulation-based curriculum in hyperbaric medicine may improve provider performance at both the individual and team levels, and may also benefit patients. Before we can develop a simulation-based education curriculum, it is necessary to conduct a systematic review of the evidence for using simulation-based education in hyperbaric medicine. This has not yet been done but is an important starting point for future curriculum development.

This systematic review aimed to identify, summarize

Table 1
Classification of learning outcomes according to Kirkpatrick (modified by Phillips, 1997[19])

Outcome level	Descriptor
Level 1: Reaction	Participants' view on the learning experience
Level 2a: Modification of attitudes	Changes in attitudes towards hyperbaric medicine technical and non-technical skills
Level 2b: Acquisition of knowledge and skills	Changes in technical/non-technical skill or knowledge or skill performance
Level 3: Behavioural change	Transfer of technical/non-technical learning to the practice setting
Level 4: Benefits to patients	Improvement in patient health or well-being
Level 5: Return on investment	Monetary benefits compared to the costs of training

and assess the impact of simulation-based education in hyperbaric medicine.

Methods

PROTOCOL

The protocol was developed *a priori* following 'A Measurement Tool to Assess Systematic Reviews' (AMSTAR-2) standards.[17] This systematic review is reported in adherence to the 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' (PRISMA) checklist.[18] The protocol (CRD42018111678) was registered with the International Prospective Register of Systematic Reviews (PROSPERO).

ELIGIBILITY CRITERIA

Eligibility criteria were predetermined. The population of interest was any healthcare provider (any profession or specialty providing care in hyperbaric medicine either as individual or as a team) at any level (trainees or not) or patients undergoing hyperbaric oxygen therapy. We included studies investigating simulation-based education. In this review, we used a broad conceptualisation of simulation including, for example, part-task trainers, full body mannequin, screen simulator, virtual reality, human simulation or a standardized patient. The goal of the simulation intervention could be either formative or summative assessment. When a comparator was present, it could be either no education, education with or without a simulation component, didactic teaching or any other comparative educational intervention. The outcome of interest was learning, which was categorized based on the Kirkpatrick model of educational outcomes, as modified by Phillips[19] (Table 1). Outcomes across all Kirkpatrick levels were included; however, from level 2b and above, studies relying only on self-reported outcomes were excluded because healthcare workers' self-assessments tend to be inaccurate and unreliable.[20,21] For levels 1 and 2a, we included self-assessed outcomes since this is the only option to explore these Kirkpatrick levels. All study designs were eligible for inclusion (e.g., observational, case series, experimental). Studies were only considered for inclusion if they were published in English in a peer-reviewed journal. Conference abstracts were not included.

SEARCH STRATEGY AND INFORMATION SOURCES

The search strategy was developed by an experienced information specialist (AD) in close collaboration with the research team (Appendix A). It was then reviewed by a second information specialist, following the 'Peer Review of Electronic Search Strategies' (PRESS) guidelines.[22] The databases MEDLINE, EMBASE, and the Cochrane Central Register of Controlled Trials were searched without language restrictions, from inception to 19 September 2018. The reference lists of included studies were also searched in addition to the online 'Database of Randomized Controlled Trials in Diving and Hyperbaric Medicine'.[23] We also reviewed references of relevant book chapters[24,25] and consulted content experts for completeness and relevance of the final list of included studies.

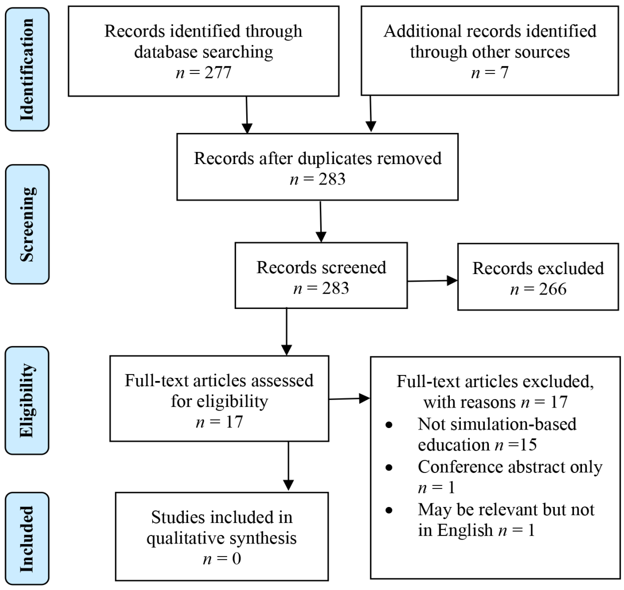
STUDY SELECTION

Identified studies were uploaded to a web-based systematic review software, DistillerSR (Evidence Partners, Ottawa, Canada), and duplicates were removed. A screening tool was developed by the research team and piloted with 20 randomly selected articles (Appendix B). This tool was iteratively refined until acceptable inter-rater reliability was established (minimum Kappa = 0.60). Pairs of independent reviewers (OCB, LM, TH) first assessed titles and abstracts for eligibility, followed by the full-texts of articles of included studies and those deemed 'unclear'. Screening for inclusion at each level was always conducted in duplicate, with disagreements resolved by consensus or involvement of a third reviewer as needed (SB, NE).

DATA EXTRACTION

A data extraction form was developed and we planned to have pairs of independent reviewers to extract relevant information with DistillerSR. We planned to extract data including publication details (e.g., first author name, year of publication, country of data collection, funding, trial

Figure 1
PRISMA flow diagram for the literature search



registration), study characteristics (e.g., study design, sample size, inclusion/exclusion criteria), patient demographics, intervention and comparator details, the type of surgical procedure and anesthesia, and the effect of intervention on reported clinical outcomes.

RISK OF BIAS

The independent reviewers were expected to assess each included study for risk of bias using the 'Effective Practice and Organisation of Care Group' (EPOC) tool[26] for interrupted time series studies, repeated measures studies, non-randomized trials, cluster randomized trials, controlled before-after studies, and randomized controlled trials; and the 'Newcastle-Ottawa Quality Assessment Scale'[27] for cohort studies as appropriate.

DATA SYNTHESIS

We planned to conduct a narrative summary of results if included studies were heterogeneous and a meta-analysis if included studies were homogeneous.

Results

STUDY SELECTION

The search yielded 277 publications. An additional seven references were identified from book chapters and one duplicate was removed, leaving 283 references for title and abstract screening. Of these, 17 studies proceeded to full text-screening. After review of the full text of these articles, all 17 were excluded: one was published in German; one was a conference abstract; and 15 did not actually describe simulation-based education. Therefore, no article assessing the impact of simulation-based education in hyperbaric medicine and published in English was identified in this systematic review. The study flow is shown in Figure 1.

Although our inclusion criteria prespecified publication in English, we identified one article published in German that was relevant to simulation-based education and hyperbaric medicine.[28] According to the abstract published in English, this study reports the implementation and impact of in situ simulation training for emergencies in hyperbaric medicine. The authors concluded that mandatory yearly in situ simulation training of all hyperbaric medicine staff was well perceived and effective for improving performance (Kirkpatrick level 3).[28]

When consulting book chapters on education for hyperbaric medicine, we noted that the word "*simulation*" (or variations, e.g. simulated or simulator) was not mentioned at all by several references.[24,25,29–31] Others referred to simulation in statements such as "*some training in emergencies is necessary in a simulated form*"[32] but with no evidence to support this statement. The 'Educational and Training Standards for Physicians in Diving and Hyperbaric Medicine', produced by the Joint Educational Subcommittee of the European Committee for Hyperbaric Medicine (ECHM) and the European Diving Technical Committee (EDTC), recommended to "*treat a number of simulated diving casualties (probably at lesser depths) with the emphasis on the practical difficulties of a unit in a remote location*." However, the evidence to support this statement is unclear.[33]

Discussion

This systematic review is the first to assess the state of simulation-based education in hyperbaric medicine. No English language article assessing the impact of simulation-based education in hyperbaric medicine was identified. Only one potentially relevant paper published in German was found.

Our findings may be surprising given that simulation-based education has been widely adopted over the last two decades in most healthcare fields, including interprofessional education in acute care.[3,4,34] Hyperbaric medicine is interprofessional by nature as treatments require close collaboration between several professions, including physicians of different specialties, chamber operators, technicians, nurses and/or respiratory therapists.

While teamwork skills are important in routine hyperbaric oxygen treatments, they are even more crucial for life-threatening emergencies (i.e., crisis resource management (CRM) situations), which require coordinated and urgent actions between different professions for safe patient care. For example, when a hyperbaric patient develops a pneumothorax during treatment in a multiple place chamber, the physician, chamber operator and nurse must communicate and coordinate effectively to quickly identify the complication and make the required treatment decisions. Examples of other crisis situations in hyperbaric medicine include seizure, cardiac arrest, and fire. Whether these crises occur in the operating room, intensive care, emergency department, obstetrics or hyperbaric medicine, positive patient outcome require optimal collaboration among interprofessional teams.

Interestingly, simulation-based education, including interprofessional simulation, has been largely adopted in many of these other fields. As defined by The World Health Organization, interprofessional education is "*when two or more professionals learn about, from, and with each other to enable effective collaboration and improve health outcomes*".[35] Interprofessional simulation typically aims to practice a simulated case together followed by a debriefing. Both the simulated practice and the debriefing are done as a team, which allows participants to learn with and from each other. For example, simulated practices for operating room interprofessional teams show long-term translation of positive communication and teamwork behaviours in clinical settings.[36] Simulated practice for multidisciplinary critical care unit teams led to subsequent improved teamwork and patient management.[37] Overall, evidence seems to consistently show that simulation-based education translates to improved behaviours of healthcare professionals into their clinical setting and is promising for improving patient outcome.[6] Evidence is particularly strong for the positive effect of interprofessional simulation on CRM skills of teams.[3] Hyperbaric medicine seems to be an exception to interprofessional simulation-based education, even though it requires effective teamwork in managing urgent conditions and responding to life-threatening complications.

This systematic review highlights the need for the hyperbaric medicine community to take concrete actions to join the evidence-based simulation education movement occurring in other healthcare disciplines. Currently, teaching in hyperbaric medicine is largely limited to didactic teaching, and simulation-based education is not part of any existing certification course. Simulation training is only occasionally conducted at hyperbaric conferences, such as the hyperbaric emergency team simulation course, hosted by the Canadian Undersea and Hyperbaric Medical Association.[38] One possible next step to advance simulation-based education in hyperbaric medicine may be to develop, implement, and evaluate a standardized simulation curriculum across hyperbaric centers.

Although this systematic review identifies an important knowledge gap in hyperbaric medicine, some limitations should be noted. Specifically, we included only published studies in English. However, only one potentially relevant non-English study was identified. We also focused only on hyperbaric rather than diving medicine; however, our inclusion criteria were relatively broad as we considered all Kirkpatrick levels and most study designs.

Conclusions

This systematic review found no English language publication assessing the impact of simulation-based education in hyperbaric medicine. More research is needed to determine how the hyperbaric medicine community and their patients may benefit from simulation-based education to optimize both practice and patient care.

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Conflicts of interest and funding: nil

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Appendix A

Literature search algorithm

Database: Ovid MEDLINE(R) and Epub Ahead of Print, In-Process and Other Non-Indexed Citations and Daily <1946 to 2018 September 19>

Search Strategy:

1 Hyperbaric Oxygenation / (11224)
2 hyperbaric oxygen*.tw,kw. (9380)
3 hyperbaric chamber*.tw,kw. (773)
4 hyperbaric medicine.tw,kw. (295)
5 or / 1-4 (13637)
6 SIMULATION TRAINING / or COMPUTER SIMULATION / or PATIENT SIMULATION / (180403)
7 simulat*.tw,kw. (453193)
8 Virtual reality / or virtual reality.tw,kw. (7711)
9 Manikins / (4590)
10 (manikin* or mannikin* or mannequin*).tw,kw. (4072)
11 high fidelity.tw,kw. (7020)
12 CURRICULUM / or curriculum.tw,kw. (85625)
13 "*Internship and Residency*" / (44153)
14 exp Education, Medical / (152716)
15 or / 6-14 (756026)
16 5 and 15 (203)

Database: Embase Classic+Embase <1947 to 2018 September 19>

Search Strategy:

1 hyperbaric oxygen therapy / (1492)
2 hyperbaric oxygen*.tw. (12264)
3 hyperbaric chamber*.tw. (1064)
4 hyperbaric medicine.tw. (378)
5 or/1-4 (13584)
6 manikin / (1194)
7 (manikin* or mannikin* or mannequin*).tw. (5967)
8 simulator / or simulation training / or patient simulation / or high fidelity simulation training / (13535)
9 simulat*.tw. (469033)
10 high fidelity.tw. (8362)
11 virtual reality / or virtual reality.tw. (16630)
12 exp medical education/ (307670)
13 curriculum / or curriculum.tw. (98179)
14 residency education/ (25781)
15 or/6-14 (836551)
16 5 and 15 (204)

Database: EBM Reviews – Cochrane Central Register of Controlled Trials <August 2018>

Search Strategy:

1 Hyperbaric Oxygenation / (335)
2 hyperbaric oxygen*.tw,kw. (889)
3 hyperbaric chamber*.tw,kw. (87)
4 hyperbaric medicine.tw,kw. (10)
5 or/1-4 (948)
6 SIMULATION TRAINING / or COMPUTER SIMULATION / or PATIENT SIMULATION / (2090)
7 simulat*.tw,kw. (12675)
8 Virtual reality / or virtual reality.tw,kw. (1782)
9 Manikins / (747)
10 (manikin* or mannikin* or mannequin*).tw,kw. (1327)
11 high fidelity.tw,kw. (579)
12 CURRICULUM/ or curriculum.tw,kw. (3607)
13 "*Internship and Residency*" / (1069)
14 exp Education, Medical / (2914)
15 or/6-14 (20049)
16 5 and 15 (17)

Appendix B

Screening questions

Screening 1:

1- Is this study about simulation-based education (could be training or assessment)?
Yes
No
Unsure

2- This study is about:
Hyperbaric medicine (most often includes hyperbaric oxygen treatment)
Diving medicine (does NOT include any hyperbaric oxygen treatment)
Unrelated field
Unsure

3- Is this reference an ORIGINAL study?
Yes, it is an original study (i.e. publication that aims to create new knowledge)
No, it is not an original study but rather repeats or combines existing knowledge
Unsure

4- This study looks like it is about simulation-based education AND hyperbaric medicine but is NOT in English
I confirm that it is NOT in English
It actually looks in English
Unsure

5- Open comment (e.g. note here duplicates when noticed)

Screening 2:

1- Is this study about simulation-based education (could be for training or assessment)?
Yes
No
Unsure

2- This study is about:
Hyperbaric medicine (most often includes hyperbaric oxygen treatment) Diving medicine (does NOT include any hyperbaric oxygen treatment)
Unrelated field
Unsure

3- Study design is:
Observational or case series → Include and go to question 4
Experimental (RCT, quasi randomized)
Quasi experimental (CBA, ITS)
Case report
Other (specify)
Unsure

*4- Is this study about training (simulation **for** learning) or assessment (simulation **of** learning, i.e., test)?*
Training
Assessment
Both
None
Unsure

5- This paper meets one of the exclusion criteria:
It is NOT published in English
It is NOT published in a peer-reviewed journal
It only measures outcomes with self-assessment
It is only a conference abstract
Other (justify)

6- Open comment (e.g., note here duplicates when noticed)