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ORIGINAL ARTICLE

Evaluation methods and impact of simulation-based training in pediatric surgery: a systematic review

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Abstract

Purpose The aim of this study was to identify (1) the type of skill evaluation methods and (2) how the effect of training was evaluated in simulation-based training (SBT) in pediatric surgery.

Methods Databases of PubMed, Cochrane Library, and Web of Science were searched for articles published from January 2000 to January 2017. Search concepts of Medical Subject Heading terms were "surgery," "pediatrics," "simulation," and "training, evaluation."

Results Of 5858 publications identified, 43 were included. Twenty papers described simulators as assessment tools used to evaluate technical skills. Reviewers differentiated between experts and trainees using a scoring system (45%) and/or a checklist (25%). Simulators as training tools were described in 23 papers. While the training's effectiveness was measured using performance assessment scales (52%) and/or surveys (43%), no study investigated the improvement of the clinical outcomes after SBT.

Conclusion Scoring, time, and motion analysis methods were used for the evaluation of basic techniques of laparoscopic skills. Only a few SBT in pediatric surgery have definite goals with clinical effect. Future research needs to demonstrate the educational effect of simulators as assessment or training tools on SBT in pediatric surgery.

Keywords Surgical education · Evaluation · Competency · Training impact

Introduction

The simulation-based training (SBT) can be valuable for patients and training staff for safety. The evidence of skill transferability from SBT to the clinical environment has been reported [1]. In pediatric education, a meta-analysis showed that SBT was a highly effective educational modality [2]. However, given the lower number of cases and the technical complexity due to small working space in pediatric surgery than in general surgery, carefulness and safety are required; thus, SBT would have an important role in pediatric surgery. In fact, the use of SBT in pediatric surgery has been expanding and, in recent years, various simulators are emerging with the development of medical engineering technology [3]. Considering the effectiveness of training methods, competency assessment tools are essential. Recently, a systematic review on the validity and strength of SBT in pediatric surgery [4] described the current SBT models' validity and level of evidence and provided recommendations. However, the role of simulators as assessment

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tools and the effect of training of using simulators on the field of pediatric surgery are still unclear. In this study, we aimed to examine the use of simulators in measuring surgical competence and to evaluate the effectiveness of SBT in pediatric surgery.

Methods

The conducting and reporting of the current systematic review conformed to the Preferred Reporting Items for Systematic Review and Meta- analysis (PRISMA) guidelines.

Study search strategy

This study was designed with the help of librarians to minimize sampling biases and a third party for the increased generalizability. Comprehensive literature searches were undertaken using the PubMed, Cochrane Library, and Web of Science databases from January 2000 to July 2017. A broad search was employed comprising four separate search concepts of Medical Subject Heading terms using "OR" to define the elements of "surgery," "pediatrics," "simulation," and "training, evaluation." The search results for each concept area were combined using "AND." Data saturation was achieved through hand search from the papers' reference lists.

Study extraction and data analysis

Two investigators reviewed all extracted studies independently. Studies that reported SBT which evaluated subject's performance and/or training effects were included. Inclusion criteria were SBT for residents, fellows, and faculty members using a trainer box, virtual reality simulator, physical simulator, cadaver, or animal models. The objective SBT range was prepared based on Accreditation Council for Graduate Medical Education (ACGME) Program Requirements for Graduate Medical Education in Pediatric Surgery and the Japanese Society of Pediatric Surgeons requirements [5, 6]. No language limits were applied. We excluded studies that had only an evaluation of the simulators themselves. Exclusion criteria included SBT for medical school, pharmacology, and analgesia. Letters to editor, conference abstracts, and review articles were also excluded. Any discrepancies in interpretation were resolved through consensus adjudication. These studies were classified based on the training effects using the Kirkpatrick model and classified into four levels: level 1, reaction, if a trainee perceived value of the training; level 2, learning, if trainee's knowledge or skill improved; level 3, behavioral change, if trainee's behavior changed in the clinical environment, and level 4, results, if the training affected patient outcomes [7].

Results

A total of 5858 unique citations were retrieved based on the research question, and 1390 duplicates were removed electronically. The remaining 4468 abstracts were screened by titles and content. Finally, 67 articles were reviewed using full text analysis. Two additional articles were found through hand searching the reference list, and the final data were extracted from 43 articles (Fig. 1). These reports were mainly from the US, Japan, and Canada (30%, 28%, and 16%, respectively). A total of 81% of the studies were published after 2010. Settings, measures, and recourses of selected studies were described from the viewpoints of assessment and training of simulation as follows.

Assessment tools

Twenty papers described simulators as assessment tools used for the evaluation of technical skills of trainer [8–27]. Table 1 describes 20 simulators regarding procedure contents, types of simulators, evaluation subjects, and evaluation methods (Table 1). Of 20 studies, 10 evaluated basic techniques of laparoscopic surgery, and most of these studies went through technical evaluation based on scoring, time, and penalties [8–17]. Six studies focused on thoracoscopic surgical training [20–25]. In contrast, most studies on thoracoscopic surgical training evaluated specific procedures such as diaphragmatic hernia repair, esophageal atresia, and trachea-esophageal fistula. The metrics that differentiated between novices and experts were time, accuracy, and/or performance assessment scales.

Evaluation of training effects

Twenty-three papers evaluated the effectiveness of SBT [28–50]. They used simulators for the training of endoscopic basic surgical skills, fundoplication, airway foreign body, gastroschisis, trauma, acute care, extracorporeal membrane oxygenation cannulation, urology, fetal therapy, and cardiology. Table 2 shows a description of training outlines and training effects. While most training subjects were residents, two studies were targeted for fellows in acute care or urology [42, 47]. The required time for the training courses was between 3 h and 2 days for basic laparoscopic skills, 2 days for fundoplication, and between 1 h and one day for foreign body aspiration. One study about the training of acute care procedure for the faculty evaluated the length of the retention and it was 6 months [42]. Training efficiency was evaluated using mainly performance assessment scales (52%) and/or surveys (43%).

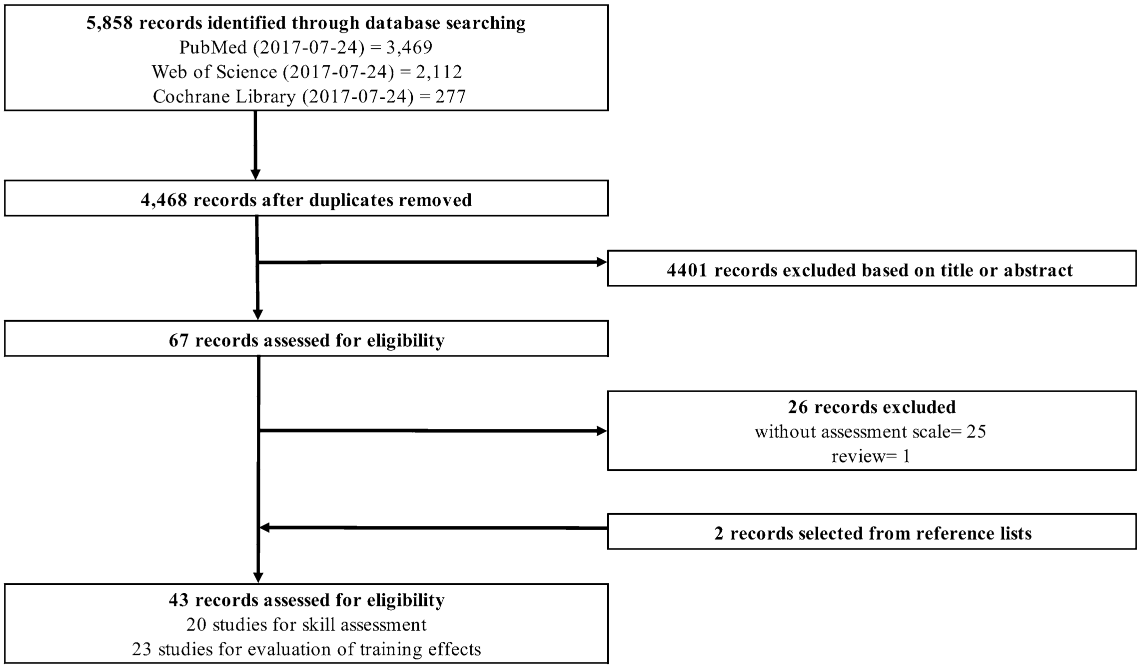

Fig. 1 Study identification and selection flowchart. A total of 5858 unique citations were retrieved based on our research question and 43 articles were reviewed by full text analysis

Considering the Kirkpatrick model for evaluation of education, all studies were classified to levels 1 or 2, and no training model had a clinical effect that corresponded to level 3 or 4.

Discussion

In this review, we examined the evaluation methods and impact of SBT in pediatric surgery. The evaluation to discriminate the trainers was undertaken using objective assessment methods such as scoring or a checklist, so that the risk of subjective assessment is reduced. In terms of educational outcomes, basic skill training involves accumulating evidence; however, limited studies have assessed the long-term retention of the training effect and no training method has been tested for skill acquisition in the clinical environment or improvement in patients' clinical outcomes.

An appropriate assessment method is important in competency-based training [51]. A previous study showed that in-training evaluation reports by faculty members were at risk of subjective assessments [52]. In our review, one-fourth of the articles used an objective assessment scale such as the fundamentals of laparoscopic surgery (FLS), pediatric laparoscopic surgery (PLS), and objective structured assessment of technical skill, which had been previously validated. Therefore, the risk of subjective assessment could be reduced. In particular, the PLS simulator is considered the most effective assessment tool for basic laparoscopic procedures [8, 11, 15, 16]. The PLS simulator is a modified FLS trainer for pediatric use. It could distinguish experts, intermediates, and novices by motion analysis in addition to basic laparoscopic skills such as peg transfer, pattern cutting, ligating loop, extracorporeal suturing, and intracorporeal suturing. According to our review, half of the papers used time, path length, and suturing tension as objective evaluation scales for basic laparoscopic surgery, and they could properly distinguish expert from novice surgeons depending on the training content and targets. Thus, it would be useful to apply validated evaluation tools to SBT for more advanced or complex procedures in the future studies.

The metrics called time and accuracy, which include the time to complete the tasks and precision or error, are simple to interpret the results and do not require specific tools. However, from a clinical point of view, it is clear that a faster procedure does not always mean a secure outcome. To effectively use the metrics for surgical performance, it would be better if there was an expert who could provide supplementary feedback at the qualitative evaluation to lead to clinical practices [53]. Motion analysis has recently been well introduced, especially in the training of endoscopic surgery [10–15, 18, 19, 21, 28, 29, 31]. This metric measures various aspects of movements objectively such as velocity, acceleration, roll, range, and path length depending on the algorithm of the setting. As this metric can assess separate segments individually, it has potential to be used for

Table 1 Assessment tools to evaluate technical skills

Procedure contents	Types of simulator	Evaluation target		Assessment methods	References
		n	Objects		
Basic laparoscopic skills					
Peg transfer, pattern cutting, ligating loop, extracorporeal suturing, and intracorporeal suturing	Trainer box	84	E/I/N	PLS score (time and penalties)	Azzie et al. [8]
Pattern cutting	Trainer box	25	E/I	Score (time and penalties)	Nasr et al. [9]
Intracorporeal suturing	VRS	29	P/G	Score (time and errors) Motion analysis	Hamilton et al. [10]
Intracorporeal suturing	Trainer box	75	E/I/N	Motion analysis	Nasr et al. [11]
Intracorporeal suturing	Physical simulator	30	Ex/In-ex	Time Motion analysis	Harada et al. [12]
Intracorporeal suturing	Physical simulator	53	E/N	Checklist Score (errors) Time Motion analysis	Takazawa et al. [13]
Peg transfer, pattern cutting, and intracorporeal suturing	Trainer box	28	E/I/N	Time Motion analysis	Retrosi et al. [14]
Intracorporeal suturing	Trainer box	60	E/I/N	PLS score Motion analysis	Trudeau et al. [15]
Peg transfer, pattern cutting, ligating loop and intracorporeal suturing	Trainer box (single port surgery)	41	E/I/N	PLS score	Herbert et al. [16]
Peg transfer, pattern cutting, ligating loop, extracorporeal suturing, and intracorporeal suturing	Trainer box	18	Ex/Mod-ex/In-ex	Score (time and penalties)	Shephered et al. [17]
Laparoscopic skills					
Fundoplication suturing	Physical simulator	26	E/N	Score (time, motion analysis, accuracy)	Ieiri et al. [18]
Fundoplication suturing	Physical simulator	39	Pex/Pn/G	Time Score (accuracy) Motion analysis	Jimbo et al. [19]
Thoracoscopic skills					
Diaphragmatic hernia	Animal model	25	E/N	Time Score (accuracy and penalties)	Usón-Casaús et al. [20]
Diaphragmatic hernia	Physical simulator	29	Ex/In-ex	Time Accuracy Motion analysis	Obata et al. [21]
Esophageal atresia and tracheoesophageal fistula	Physical simulator	20	E/N	OSATS	Barsness et al. [22]
Esophageal atresia	Physical simulator	28	E I/N	Score (checklist, errors) Time Number of needle manipulations	Takazawa et al. [23]
Esophageal atresia and tracheofistula	Physical simulator	39	Ex/In-ex	Errors Time	Maricic et al. [24]
Thoracoscopic intracorporeal suturing	Physical simulator	74	Ex/In-ex	Checklist Errors Time	Deie et al. [25]
Otolaryngology					
Transcanal endoscopic ear surgery	3- dimensional printed model	6	R/F	Time	Barber et al. [26]
Neurosurgery					
Endoscopic third ventriculostomy	3- dimensional printed model	17	R/F	OSATS	Weinstock et al. [27]

n number, *E* expert, *I* intermediate, *N* novice, *P* pediatric surgeon, *G* general surgeon, *Pex* pediatric surgeon expert, *Pn* pediatric surgeon novice, *Ex* experienced, *Mod-ex* moderate experienced, *In-ex* in-experienced, *R* resident, *F* fellow, *PGY* post graduate year, *PLS* pediatric laparoscopic surgery, *OSATS* Objective structured assessment of technical skill, *VRS* virtual reality simulator

Table 2 Evaluation of training effects

Training contents	Training methods	Types of simulator	Training objects		Settings	Total training duration	Evaluation of training effects	Kirkpatrick level	References
			n	objects					
Basic laparoscopic skills									
Peg transfer, pattern cutting, clip application, and wire twisting	Lecture Hands-on	Box trainer	9	E/I	Programed course	3 h	Pre- and post-scores (precision, efficiency, and speed) by VRS	Level 2	Nakajima et al. [28]
Peg transfer, running string, pattern cutting, knot tying, suturing, dissecting and clipping	Lecture Hands-on	Box trainer, VRS, and animal model	477	P/G	Programed course	2 days	Pre- and post-scores (time, accuracy, errors, and motion analysis)	Level 2	Ieiri et al. [29]
Advanced laparoscopic skills									
Pediatric and neonatal laparoscopic surgery	Lecture Hands-on	Physical simulator, and animal model	54	P	Programed course	21 h	Post-self-report	Level 1	Pérez-Duarte et al. [30]
Laparoscopic Nissen fundoplication	Lecture Hands-on	Box trainer, physical simulator, and animal model	7	P	Programed course	2 days	Pre- and post-time, suturing accuracy, and motion analysis	Level 2	Jimbo et al. [31]
Foreign body aspiration									
Aerodigestive endoscopy	Role-playing simulation	Physical simulator	9	F/R	During residency or fellowship program	1.5 to 2 h	Post-self-report	Level 1	Deutsh et al. [32]
Fiber optic intubation	e-Learning Hands-on	Physical simulator	21	R	Programed course	90 min	Time and score (accuracy)	Level 2	Binstadt et al. [33]
Airway foreign body retrieval	Lecture Hands-on	Physical simulator	17	R	During residency program	Half-a-day	Pre- and post-OSATS	Level 2	Jabbour et al. [34]
Pediatric airway foreign body	Pre-test Practice trials Feedback Post-test	Physical simulator	12	R	During residency program	75 to 90 min	Pre- and post-OSATS	Level 2	Griffin et al. [35]
Airway endoscopy skill development	Lecture Hands-on	Physical simulator, and VRS	55	Fa/F/R	Programed course	1 day	Post-self-report	Level 1	Deutsch et al. [36]
Acute care									
Gastroschisis	Scenario tasks Feedback	Physical simulator	17	C/Midt/Junt	N/A	N/A	Post-self-report	Level 1	Dabbas et al. [37]

Table 2 (continued)

Training contents	Training methods	Types of simulator	Training objects		Settings	Total training duration	Evaluation of training effects	Kirkpatrick level	References
			n	objects					
Trauma	Lecture Scenario tasks	Animal model	124	P/G	Programed course	2 days	Post-self-report	Level 1	Tugnoli et al.[38]
Trauma patients care	Lecture Scenario tasks Video-based debriefing	Physical simulator	18	Pphy/Pnur	Programed course	1.5 day	Pre- and post-self-report	Level 1	Lehner et al. [39]
Emergency intubation	Scenario tasks	Physical simulator	26	F/Pnur	Programed course	1 h	Time	Level 2	Nishisaki et al. [40]
Team training of pediatric resuscitation	Lecture Scenario tasks	Physical simulator	12	A/F/R	Programed course	N/A	Score (basic assessment skills, airway/breathing, circulation, and human factors)	Level 2	Reid et al. [41]
Acute care procedure Team management Communication	Scenario tasks Feedback	Physical simulator	22	F	N/A	2.5 day	Post-self-report (after training and 6-months)	Level 2	Nishisaki et al. [42]
Acute care Team management	Scenario tasks Video-assisted debriefing	Physical simulator	48	F/R/Nur/Res	During fellowship program	2 years	Post-self-report	Level 1	Cheng et al. [43]
Resuscitation	Scenario tasks Debriefing	Physical simulator	60	R/Nur	During residency program	9 months	Pre- and post-scores (team performance)	Level 2	Stone et al. [44]
ECMO									
Crisis resource management	Videoed-simulated scenario Video-assisted debriefing	Physical simulator	8	Pcar/Pi/Pa/Perf/Pnur	Programed course	2 h	Post-self-report	Level 1	Atamanyuk et al. [45]
ECMO cannulation	Scenario tasks Video-assisted debriefing	Physical simulator	10	Ct	During residency or fellowship program	3 months	Time and score (GRS, CECS)	Level 2	Allan et al. [46]
Urology									
FLS tasks Pyeloplasty Ureteral reimplantation	Lecture Hands-on	Box trainer, and animal model	18	F	Programed course	3 days	Pre- and post-FLS scores, and tests	Level 2	Brydges et al. [47]

Table 2 (continued)

Training contents	Training methods	Types of simulator	Training objects		Settings	Total training duration	Evaluation of training effects	Kirkpatrick level	References
			n	objects					
Vesicoureteral reflux	Lecture Demonstration Hands-on	Animal model	11	Ut	Programed course	2 h	Pre- and post-scores (endoscopic skill to correct vesicoureteral reflux)	Level 2	Soltani et al. [48]
Fetal therapy									
Twin–twin transfusion syndrome Fetoscopic laser surgery	Lecture Hands-on	Physical simulator	10	E/N	Programed course	1 day	Time and scores (surgical performance checklists, and errors)	Level 2	Peeters et al. [49]
Cardiology									
Congenital heart surgery	Lecture Hands-on	3-D printed model	81	S	Programed course	2 h to 2.5 days	Post self-report	Level 1	Yoo et al. [50]

n number, *N* novice, *E* expert, *I* intermediate, *P* pediatric surgeon, *G* general surgeon, *Pex* pediatric surgeon expert, *Pn* pediatric surgeon novice, *Ex* experienced, *In-ex* in-experienced, *R* resident, *F* fellow, *PGY* post graduate year, *S* surgeon, *Fa* faculty, *C* consultant, *Midt* middle grade trainee, *Junt* junior trainee, *Pphy* pediatric physician, *Pnur* pediatric nurse, *Nur* nurse, *A* attending, *Res* respiratory therapist, *Pcar* pediatric cardiologist, *Pi* pediatric intensivist, *Pa* pediatric anesthetist, *Perf* pediatric perfusionist, *Ct* cardiothoracic surgery trainee, *Ut* urology trainee, *MTP* modular training program, *PICU* cardiorespiratory pediatric intensive care unit, *CICU* cardiac intensive care unit, *ICC* Intraclass correlation coefficients, *VRS* virtual reality simulator, *GRS* global rating scale, *CECS* composite ECMO cannulation score, *ECMO* extracorporeal membrane oxygenation formative assessment [54]. Considering the purpose of the evaluation, intended use, and the way of interpretation in advance would support the targeted assessments.

Given the limited opportunities for trainees to perform pediatric surgery, SBT is becoming increasingly important. Regarding the evaluation of training effects, half of these reviewed articles have focused on emergency initial treatments, which was common in the field of pediatrics, and only one-fourth focused on training for specific procedures. While there were relatively many level 2 studies in the field of basic skills or overlapping with pediatrics, such as those on acute care and foreign body aspiration, only two level 2 studies [31, 49] were found in the field of advanced pediatric surgery. The ultimate goal of training is to increase clinical effectiveness; however, no training model corresponding to level 3 or 4 was found in this review. Because of the ease of evaluation, the evidence of the Kirkpatrick model 1 or 2 for basic skill training has gradually accumulated. However, it will be necessary to prove the effect of SBT on more advanced and specific procedures and the outcome of Kirkpatrick model 3 or 4 with higher impact.

Although the retention of the training effect is also an important point in training, in our review, the programed training method had focused on the short-term training effect and did not evaluate the retention of the long-term training effect, except one study [42]. According to a systematic review of the spacing of surgical skill training sessions for medical trainees, distributed training sessions are possibly better than mass training, but no evidence was obtained about the optimal assessment interval [55]. There is little evidence about the long-term retention of training effects; thus, it is difficult to make recommendations at this time.

With regard to impact of the simulation training on clinical outcomes, Cox et al. reviewed Kirkpatrick's level 4 studies in 2015 and reported 12 appreciable articles [56]. Among the literature, Zendejas et al. reported the simulation training of laparoscopic totally extraperitoneal (TEP) inguinal hernia repair [57]. This training was for residents and consisted of two elements: a web-based online cognitive part and a simulation-based skill training part. The clinical effect was measured by the improvement in operative time, operative performance score, complication rate, and length of hospitalization. The used operative performance score was the Global Operative Assessment of Laparoscopic Skills (GOALS), which was a valid and reliable tool to assess technical skills during a variety of procedures [58]. In general surgery, a more procedure-specific assessment tool that had the reliability and validity of the scores in the operating room and the skills laboratory, the GOALS-Groin Hernia (GOALS-GH), was used [59, 60]. Hernia repair was also a common procedure in pediatric surgery, and the laparoscopic percutaneous extraperitoneal closure (LPEC) method [61] is recently in use. However, to our knowledge, there are no such tools to show the transferability from a bench model to the clinical setting. It is necessary to provide evidence of the transferability of performance improvement and its quality as effects of SBT. However, Barsness et al. [3] reported that it was difficult to address this issue within the field of pediatric surgery because of limits related to infrastructure, knowledge, or time. They suggested referring to the evidence obtained in the educational field of general surgery. Transferability certainly could not be achieved without information of the number of cases. In future studies, collaboration research of multi-institutes for SBT in pediatric surgery would be necessary.

This study provides a review of simulators measuring technical competence and evaluates the effectiveness of SBT in pediatric surgery. As for the training effects, no study on its clinical outcomes was found. It is necessary to accumulate evidence on SBT transferability to clinical practice in pediatric surgery.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest for this study.

Ethical approval Not applicable, since the study is a systematic review.

Informed consent Not applicable, since the study is a systematic review.

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