Published online: 2019-05-13

Simulation-Based Training of Ultrasound-Guided Procedures in Radiology – A Systematic Review

Simulationsbasiertes Training bei ultraschallgestützten Verfahren – eine systematische Übersicht

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Key words

ultrasonography, simulation training, clinical competence, educational measurement, image-guided biopsy

received 06.02.2019

accepted 03.04.2019

Bibliography

DOI https://doi.org/10.1055/a-0896-2714

Published online: May 13, 2019

Ultraschall in Med 2019; 40: 584–602

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ISSN 0172-4614

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ABSTRACT

Purpose To perform a systematic review of the effect of simulation-based training (SBT) of percutaneous abdominal and thoracic ultrasound-guided procedures and to assess the transfer of procedural competence to a clinical context.

Materials and Methods This systematic review was conducted in accordance with the PRISMA statement. Pubmed, Embase, Web of Science, and the Cochrane Library were searched for studies assessing procedural competence after SBT. Two authors independently reviewed all studies and extracted data. Risk of bias was assessed using the Cochrane tool for randomized studies (RoB) and non-randomized studies (ROBINS-I). Quality of evidence was assessed using the GRADE approach.

Results 42 studies were included. 6 were randomized controlled, 3 non-randomized controlled, and 33 non-randomized non-controlled. 26 studies examined US-guided abdominal procedures, 13 examined thoracic procedures, and 3 examined both. The results favored SBT compared to other educational interventions and found that training was superior to no training. Only two studies examined the transfer of procedural skills to a clinical context. All studies had a high or critical risk of bias. Thus, the quality of evidence for the effect of SBT on procedural competence was low, and evidence for its transfer to a clinical context was very low.

Conclusion The evidence supporting SBT of percutaneous abdominal and thoracic US-guided procedures remains insufficient due to methodological problems and a high risk of bias. Future studies should be randomized and single-blinded, use assessment tools supported by validity evidence, compare different educational strategies, and examine the transfer of skills to a clinical setting.

ZUSAMMENFASSUNG

Ziel Systematische Übersicht der Auswirkungen von simulationsbasiertem Training (SBT) bei perkutanen abdominalen und thorakalen ultraschallgestützten Verfahren und die Bewertung der Übertragung der Anwendungskompetenz in den klinischen Kontext.

Material und Methoden Diese systematische Überprüfung wurde nach der PRISMA-Checkliste durchgeführt. Pubmed, Embase, Web of Science und die Cochrane-Library wurden nach Studien durchsucht, die die Anwendungskompetenz nach SBT bewerteten. 2 Autoren überprüften unabhängig voneinander alle Studien und extrahierten die Daten. Das Risiko für Verzerrung wurde für randomisierte Studien mit dem Risk-of-Bias (RoB)-Tool nach Cochrane und für nicht randomisierte Studien (ROBINS-I) bewertet. Die Qualität der Evidenz wurde mit der GRADE-Methodik bewertet.

Ergebnisse 42 Studien wurden eingeschlossen; davon waren 6 randomisiert und kontrolliert, 3 nicht randomisiert und kontrolliert sowie 33 nicht randomisiert und nicht kontrolliert. 26 Studien untersuchten US-gestützte abdominale Verfahren, 13 untersuchten thorakale Verfahren und 3 untersuchten beide. Die Ergebnisse favorisierten SBT im Vergleich zu anderen Ausbildungsmethoden und es wurde festgestellt,

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dass eine Ausbildung besser war als keine. Nur 2 Studien untersuchten die Übertragung des verfahrenstechnischen Könnens in den klinischen Kontext. Alle Studien hatten ein hohes oder kritisches Bias-Risiko. Folglich war die Qualität der Evidenz bezüglich der Auswirkung der SBT auf die Anwendungskompetenz gering und für die Übertragung in den klinischen Kontext äußerst gering.

Schlussfolgerung Die Evidenz für SBT bei perkutanen abdominalen und thorakalen US-gestützten Verfahren ist aufgrund methodischer Probleme und eines hohen Bias-Risikos nach wie vor unzureichend. Zukünftige Studien sollten randomisiert und einfach-verblindet sein, Bewertungsmethoden verwenden, die durch Validitätsevidenz gestützt werden, unterschiedliche Ausbildungsmethoden vergleichen und den Transfer der Fähigkeiten in den klinischen Kontext untersuchen.

ABBREVIATIONS AND ACRONYMS

US	ultrasound
SBT	simulation-based training

Introduction

Using ultrasound (US) to guide percutaneous procedures has gained widespread acceptance as it reduces the risk of complications and increases the chance of a successful procedure [1–7]. The ability to perform US-guided procedures is a core skill for radiologists, and is thus central to the specialist curriculum [8]. Currently, US skills are mainly taught through apprenticeship-based training in a clinical setting [9, 10]. This educational model has several shortcomings: It demands a high level of supervision from experienced practitioners; the curriculum is not standardized as it is based on the available patient cases at the institution; and it often uses non-standardized assessment tools for evaluating novices' procedural competence [11]. Furthermore, there is a risk of undue complications as patients are exposed to trainee learning curves [12–14].

These issues can be addressed through SBT where trainees practice procedures without involving patients, e. g. by using virtual reality simulator, physical phantoms, live animals, or human cadavers. This approach can lead to a faster and more complete achievement of procedural competence [15–17]. It allows the novice to train in a stress-free and low-risk environment, which in turn spares patients from undue complications [18]. This coincides with WHO's recommendation of SBT of medical professionals [19].

A recent needs assessment of SBT in radiology identified US-guided procedures as a top priority [20]. However, SBT has potential drawbacks as simulators are expensive, training can be time-demanding for faculty, and the transfer of skills to a clinical setting may vary [21–23]. Therefore, it is important to ensure that a training program is evidence-based, includes efficient educational strategies and simulators, and that skills learned in a simulated setting are transferred into a clinical context.

There are no comprehensive reviews on the subject, and our aim is to perform a systematic review of the effect of SBT of percutaneous abdominal and thoracic US-guided procedures and to assess the transfer of procedural competence to a clinical context.

Methods

This systematic review was done in accordance with the PRISMA statement [24]. Searches, study selection, data extraction, bias assessment and assessment of quality of evidence were done independently by two authors (NKR and TTA). Consensus was achieved through discussion.

Inclusion and exclusion criteria

We included experimental studies exploring the effect of SBT of percutaneous abdominal or thoracic US-guided procedures. Studies were eligible if participants included medical students, medical doctors, sonographers, or nurses. All outcome measures were accepted. We excluded studies with only non-medical participants or studies examining interventions not commonly performed by radiologists (e. g. central venous access). Only studies published in English were eligible. No limitation on publication year was imposed.

Search methods and data collection

Search strategies were developed in close collaboration with an experienced research librarian. Systematic searches were done in PubMed, Embase, Web of Science, and the Cochrane Library (search strategies are presented in Appendix 1). Reference lists of all included studies were examined, and PubMed and Embase were searched for citing articles that were potentially eligible.

All titles and abstracts were assessed. Potentially eligible studies were retrieved as full-text and reviewed. Consensus was reached after each round of the selection process. A predefined table was used for data extraction. It included: study design, characteristics of participants and controls, description of educational intervention and simulator, outcome measures, validity evidence for assessment tool, and the study conclusion.

Risk of bias

Randomized controlled studies were assessed for risk of bias using the Cochrane Collaboration risk of bias assessment tool for randomized studies (RoB) [25]. The following domains were assessed: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective outcome reporting, and other bias (e. g. lack of validity evidence for assessment tools). Non-randomized studies with control groups were asses-

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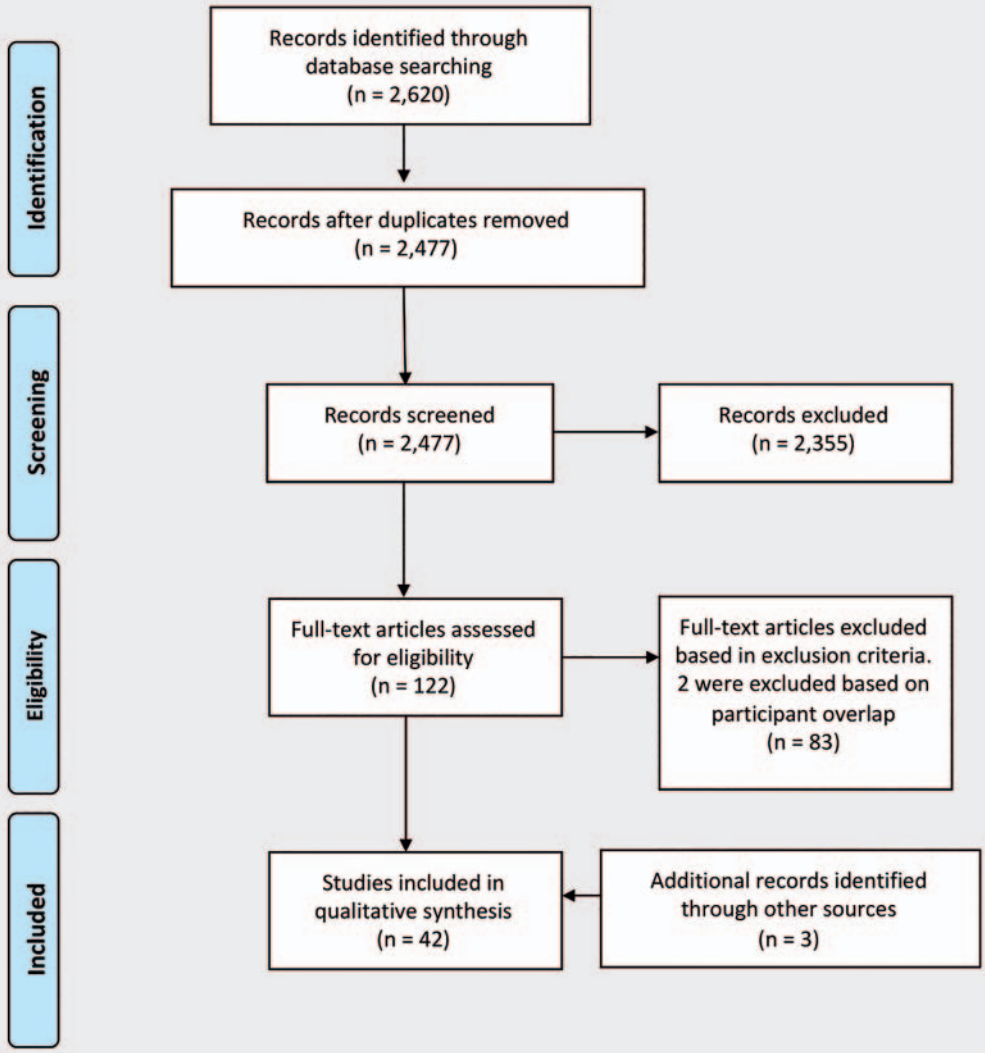

▶ **Fig. 1** Modified PRISMA flowchart demonstrating the selection process of the included studies.

sed with the Cochrane Collaboration tool for assessment of risk of bias in non-randomized studies of interventions (ROBINS-I) [26]. The remaining non-randomized non-controlled studies were not independently assessed for bias as they were assumed to have an inherent high risk of bias.

Quality of evidence

Quality of evidence for SBT on procedural competence in a simulated setting and a clinical setting was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach [27]. The quality of evidence was downgraded from high quality by one level for serious limitations (two levels for very serious limitations) depending on assessments of risk of bias, indirectness of evidence, serious inconsistency, imprecision of effect estimates, or potential publication bias.

Results

Study selection

The initial search identified 2477 studies after duplicates were removed. These were screened based on title and abstract, and 2355 were excluded. We reviewed 122 studies in full text and 81 were excluded based on the predefined exclusion criteria, and 2 were excluded as they analyzed the same data as two other eligible studies. 39 studies were included in the review. Two relevant studies were found in the reference lists of the included studies, and one eligible citing article was identified, resulting in a total of 42 included articles (▶ **Fig. 1**) [28–69]. The final search was conducted on 8/29/2018.

Study characteristics

The 42 included studies were published between 1994 and 2018. 5 were published between 1994–2009 [34, 43, 44, 53, 63], and

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37 were published between 2010–2018. 6 studies were randomized controlled studies (▶ **Table 1**), 3 were non-randomized controlled studies (▶ **Table 2**), and 33 were non-randomized non-controlled studies (▶ **Table 3, 4**). Participants were recruited from different medical specialties: radiology, surgery, nephrology, urology, internal medicine, emergency medicine, and medical students. Participants ranged from novices to experienced US practitioners.

Randomized controlled studies

Two studies examined thoracentesis and paracentesis, one examined breast biopsy, and three examined liver biopsies (▶ **Table 1**). In one study participants were allocated to faculty-guided or self-guided thoracentesis and paracentesis training [28]. Both groups received the same educational co-interventions and were assessed using a diagnostic OSCE (objective structured clinical examination). Participants were asked to assess their own competence. In another study the same procedures were trained, and participants were allocated to faculty-guided SBT (and educational co-interventions) or a half-day training course [29]. Self-estimated competence was assessed before and after training. Both studies concluded that SBT was superior to self-guided training. A study compared liver biopsy training on a physical phantom to a virtual reality phantom [32]. Participants received 15 minutes of training, and diagnostic and biopsy precision was assessed. An expert group evaluated the simulators. The study concluded that the virtual reality simulator was superior to the physical phantom. Another study compared 30 minutes of SBT of liver biopsies to a reading assignment, and tested both groups on the simulator used for training. [33]. The study found that SBT yielded better results and higher self-estimated confidence. SBT of liver biopsies was compared to a lecture or no educational intervention in another study [31]. Groups were tested on the simulator used for training. The study concluded that SBT was superior. The last study compared three hours of SBT of breast biopsies (as well as lectures and videos) to no educational interventions [30]. Participants were assessed on the phantom used for training. The study found that SBT improved procedural competence. Only one of the six studies used blinded assessors [33]. None of the studies used assessment tools supported by contemporary standards of validity.

Non-randomized, controlled studies

Three studies had control groups but were not randomized (▶ **Table 2**). One study compared training of kidney biopsies on a 3 D printed high fidelity phantom to a low fidelity phantom [36]. Participants were tested after the first day and final day of training. Participants were filmed, and a blinded assessor assessed procedure time. The 3 D printed phantom was better rated. The study concluded that training on the 3 D phantom was superior, even though participants training on the low fidelity phantom had a shorter procedure time. The assessment tool was not supported by validity evidence. Two studies compared training of thoracentesis [34] and kidney biopsies [35] to no training. Both studies used clinical outcome (pneumothorax or blood loss) as measures for procedural competence. These were compared to historical controls. In both studies participants trained on phantoms. The study on kidney biopsies had several educational co-interventions [35]. The other study had non-educational interventions [34]. Among these were mandatory use of US guidance, limiting personnel to five experienced performers, and standardization of procedure and equipment. Both studies concluded that SBT reduced complication rates.

Non-randomized, non-controlled studies

33 studies were non-randomized and did not use control groups (▶ **Table 3, 4**). They examined SBT but did not compare training to any other educational interventions. 12 studies examined thoracic procedures (▶ **Table 3**). Two examined thoracentesis (one also examined paracentesis) [37, 38], three examined pericardiocentesis [39–41], and seven examined breast biopsies [42–48]. All used physical phantoms, and five studies had educational co-interventions such as lectures [38, 41, 43–45]. Six studies measured performance on simulators [37, 42–45], and ten used written assessment of self-estimated competence or evaluations of simulators. Simulators and SBT were well received and training resulted in improved confidence. One study tested performance before and after training and found that participants improved their procedural competence [43].

21 studies examined abdominal procedures (▶ **Table 4**). Five examined liver biopsies [52–56], six examined kidney procedures [58–63], one examined both liver and kidney biopsies [57], six examined unspecified abdominal procedures [64–69], and PTC drainage [50], abscess drainage [51], and paracentesis [49] were examined by a single study, respectively. Nine studies used homemade phantoms [49, 51, 54, 55, 58, 61–63, 68], seven studies used virtual reality simulators [50, 52, 56, 64, 65, 67, 69], three studies used commercially available phantoms[53, 60, 66], and two used human cadavers [57, 59]. Simulation based training was accompanied by educational co-interventions in six of the studies [49, 55, 57, 60, 66, 68]. In nine studies performance was assessed on the simulator either as a pre-posttest [49, 51, 53], posttest [64, 66, 68] or as measurements during training [52, 67, 69]. One study used an assessment tool supported by validity evidence [68] and two studies used blinded assessors [49, 68]. 17 studies used self-estimated confidence or evaluations of simulators as outcome measures. All simulators were well received by participants. All studies concluded that SBT improved procedural competence and self-estimated confidence.

Risk of bias

All randomized controlled studies (▶ **Table 1**) had a high risk of bias. The main sources for bias were unknown randomization methods, non-blinded outcome assessment, selective reporting and other sources of bias (lack of validity evidence for assessment tools). Non-randomized controlled studies (▶ **Table 2**) had a critical risk of bias. The main sources of bias were confounding, selection bias, and reporting bias. Non-randomized, non-controlled studies were considered inherently biased. All bias assessments are presented in Appendix 2.

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▶ **Table 1** Six randomized, controlled studies of simulation-based training of US-guided abdominal and thoracic procedures.

study	procedure	participants				educational intervention		outcome measures		conclusion	risk of bias[1]
		group	n	specialty	experience level	simulation training	co-interventions	performance assessment	written assessment		
Alba G et al. [28] 2013	thoracentesis paracentesis	intervention 1	36	internal medicine	residents (1st year)	2-hour simulator training, faculty-guided	lecture, online teaching, practical US instructions	skill assessment: OSCE exam on simulator (diagnostic focus) by non-blinded assessor using a non-valid assessment tool	post-intervention questionnaire on self-estimated competence	faculty-guided training significantly improved procedural competence compared to self-guided training. Both self-guided and faculty-guided simulation training improved self-assessed competence.	High risk
		intervention 2	36	internal medicine	residents (1st year)	2-hour simulator training, self-guided	lecture, online teaching, practical US instructions				
Mourad M et al. [29] 2012	thoracentesis paracentesis	intervention	16	internal medicine	residents	supervised hands-on simulation and a half-day simulation course	10 didactic teaching sessions, 3 interactive computer modules on best practice, independent reading		pre/post-questionnaire on self-estimated confidence and knowledge	educational intervention significantly increased self-estimated competence. The effect was sustained after one year.	high risk
		control	41	internal medicine	residents	half-day simulation course					
Hassard MK et al. [30] 2013	breast biopsy	intervention	6	radiology (4), general surgery (2)	4 novices, 2 with limited experience	3-hour training session on a homemade breast phantom	instructional video and lecture	skill assessment on phantom using standardized performance metrics by non-blinded assessors using a non-valid tool.		training session improved externally assessed skills	high risk
		control	6	radiology	3 novices, 3 with limited experience	none					

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▶ **Table 1** (Continuation)

study	procedure	participants				educational intervention		outcome measures		conclusion	risk of bias[1]
		group	n	specialty	experience level	simulation training	co-interventions	performance assessment	written assessment		
Filippou P et al. [31] 2016	liver biopsy	intervention 1	3	urology	residents (1st–6th year)		lecture	skill assessment on simulator using standardized performance metrics by non-blinded assessors using a non-valid tool.	pre/post-questionnaire on self-estimated confidence	simulation-based training with individualized feedback increased procedural competence.	high risk
		intervention 2	5	urology	residents (1st–6th year)	training on abdominal phantom with liver lesions and individualized feedback	lecture				
		control	7	urology	residents (1st–6th year)	none					
Francesconi M et al. [32] 2015	liver biopsy	intervention 1	14	radiology and general surgery	residents	15-min. training on physical phantom	presentation	skill assessment on simulator using standardized performance metrics and non-blinded assessors using a non-valid tool.	evaluation by expert group of realism and educational usefulness of simulator	hybrid group performed better than physical group. Expert group found the simulator useful as a teaching tool.	high risk
		intervention 2	14	radiology and general surgery	residents	15-min. training on augmented reality phantom.	presentation				
		expert group	5	radiology (n = 4) and general surgery (n = 1)	expert level	none					
Fulton N et al. [33] 2016	liver biopsy	intervention	20	radiology	RESIDENTS (1st–4th year)	30-min. training session on abdominal phantom with liver lesions		skill assessment on simulator using standardized performance metrics measured by simulator, and standardized, non-valid, non-reliable assessment by blinded assessor.	pre/post-questionnaire on self-estimated confidence and performance evaluation of realism and educational usefulness of simulator	simulation-based training improves procedural competence. Results not significant.	high risk
		control	20	radiology	residents (1st–4th year)		reading assignment				

[1] Risk of bias assessed using the Cochrane Collaboration risk of bias assessment tool for randomized studies (RoB) [25].

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▶ **Table 2** Three non-randomized, controlled studies of simulation-based training of US-guided abdominal and thoracic procedures.

study	procedure	participants				educational intervention		outcome measure		conclusion	risk of bias[1]
		group	n	specialty	experience level	simulation training	co-intervention	performance assessment	written assessment		
Duncan DR et al. [34] 2009	thoracentesis	intervention	44	pulmonology	varied (residents and attendings)	half-day thoracentesis workshop with training on cadavers and phantoms, 10 thoracenteses performed on humans under supervision with a subjective cut-off for mastery	mandatory use of US for all thoracenteses, standardization of equipment and procedure, requirement of pre-procedural verification of patient, support staff to assist; and limiting the people who performed procedures to 5 experienced users	post-intervention complications incl. pneumothorax on 362 patients		the rate of iatrogenic pneumothorax declined following the implementation of a multifaceted intervention that included simulation-based training	critical
		historical control	na	pulmonology	varied (residents and attendings)			historical data of pneumothorax rate on 58 patients			
Dawoud D et al. [35] 2012	kidney biopsy	intervention	10	nephrology	fellows	training on homemade phantom with guidance and feedback from the experienced operator	lecture on US-guided renal biopsy procedures, and observation of several biopsies performed by experienced operators	successful retrieval of biopsy, Hb loss in patient from 32 biopsies performed by the participants	pre/post- questionnaire on self-estimated confidence (10 participants)	simulation-based training increased self-estimated confidence in participants, and patient Hb loss was lower compared to historical controls.	critical
		historical control	8	nephrology	fellows			successful retrieval of biopsy, Hb loss in patients from 21 biopsies from historical controls			

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▶ **Table 2** (Continuation)

study	procedure	partici-pants				educational intervention		outcome measure		conclusion	risk of bias[1]
		group	n	specialty	experi-ence level	simulation training	co-intervention	performance assessment	written assessment		
Ristolainen A et al. [36] 2014	nephrostomy	group 1	5	radiology	residents	2.5-day simula-tion-based training on 3 D printed, patient-specific kidney phantom	lecture on procedure and US	pre/post-interven-tion skill assessment on simulator. Pre-test on patient-specific phantom (for all participants) after a full day of training. Posttest on a third self-made phantom. Assessment tool: procedural time. Procedure was video-taped and assessed by a blinded assessor. pre/post-question-naire: evaluation of both phantoms (rea-lism, usefulness)		participants who practiced on the homemade low-fi simulator demon-strated shorter procedural times pre- and post-intervention. The patient-specific phantom received a better evaluation.	critical
		group 2	4	radiology	residents	2.5-day simula-tion-based training on homemade low-fi kidney phantom (fruit in gelatin)	lecture on procedure and US				

[1] Risk of bias assessed using the Cochrane Collaboration tool for assessment of risk of bias in non-randomized studies of interventions (ROBINS-I) [26].

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▶ **Table 3** Twelve non-randomized, non-controlled studies of simulation-based training of US-guided thoracic procedures

study	procedure	participants			educational intervention		outcome measures		conclusion
		n	specialty	experience level	simulation training	co-interventions	performance assessment	written assessment	
Vetrugno L et al. [37] 2016	thoracentesis	31	internal medicine and intensive care	20 novices 11 experts	training on commercial thoracentesis simulator until trainee performed two correct procedures		skill assessment on simulator. Two independent assessors who were blinded to the level of experience assessed skills using standardized performance metrics.		the developed assessment tool could not differentiate between levels of competence in residents
Keddis MT et al. [38] 2011	thoracentesis paracentesis	75	internal medicine	residents	80-min. training of US-guided thoracentesis and paracentesis on cadavers	40-min. didactic session		pre/post-questionnaire on self-estimated confidence	self-estimated confidence increased following simulation-based training
Campo Dell'orto M et al. [39] 2013	pericardiocentesis	67	medical doctors	41 no experience, 17 some US procedure exp., 9 with pericardiocentesis exp.	training on homemade pericardiocentesis phantom			post-questionnaire on self-estimated confidence evaluation of phantom realism and educational usefulness	participants found the simulator realistic and useful as a teaching tool. Training increased self-estimated confidence.
Daly R et al. [40] 2017	pericardiocentesis	23	emergency medicine (20) medical students (3)	residents	participants trained on two different pericardiocentesis phantoms during a simulation course			post-questionnaire on self-estimated confidence evaluation of phantom realism	training on simulator increased self-estimated confidence.
Sullivan A et al. [41] 2018	pericardiocentesis	19	emergency medicine (16) medical student (3) physician ass. student (1)	2nd and 3rd year residents	participants trained on homemade pericardiocentesis phantom during a simulation course.	25-min. intro lecture, 10-min. orientation and instructions		post-questionnaire on self-estimated confidence evaluation of phantom realism and educational usefulness	participants found phantom realistic. Training increased self-estimated confidence.

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▶ **Table 3** (Continuation)

study	procedure	participants			educational intervention		outcome measures		conclusion
		n	specialty	experience level	simulation training	co-interventions	performance assessment	written assessment	
Gresens A et al. [42] 2012	breast biopsy	22	general surgery	residents year 1 – 5	5-min. training session on homemade simulator		post-intervention skill assessment on simulator using standardized performance metrics, assessed by non-blinded assessors. Assessment tool was non-valid.	post-questionnaire on self-estimated confidence evaluation of phantom realism and educational usefulness	training increased self-estimated confidence. Participants found phantom realistic.
Harvey JA et al. [43] 1997	breast biopsy	13	radiology	residents	15-min. training session with 1:1 supervision	30-min. lecture on breast biopsy	pre/post-intervention skill assessment on simulator. Standardized performance metrics assessed by non-blinded assessors. assessment tool was non-valid.	pre/post-questionnaire on self-estimated confidence and anxiety.	training session improved externally assessed competence and self-estimated confidence
Hoover S et al. [44] 2008	breast biopsy	13	general surgery	4th and 5th year residents	2.5-hour training session with individualized feedback. Followed by 8 self-guided biopsies	lectures, instructional literature and computer-based teaching module	post-intervention skill assessment on simulator using standardized performance metrics, assessed by non-blinded assessors. assessment tool was non-valid.	pre-/posttest on theoretical knowledge pre/post-questionnaire on self-estimated confidence	self-estimated confidence and number of correct test answers improved following training session.
Law MT et al. [45] 2010	breast biopsy	14	general surgery	residents	procedure workshop: practical part: a hands-on tutorial supervised by experienced clinical tutors on a homemade and a commercial phantom	theoretical part: a series of lectures and reading material	post-intervention skill assessment on simulator using standardized performance metrics, assessed by non-blinded assessors. assessment tool was non-valid.		training session improved externally assessed skills.

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▶ **Table 3** (Continuation)

study	procedure	participants			educational intervention		outcome measures		conclusion
		n	specialty	experience level	simulation training	co-interven-tions	performance assessment	written assessment	
Meng K et al. [46] 2011	breast biopsy	13	radiology	residents	training session on a homemade phantom practi-cing percuta-neous US-guided cyst aspiration, core biopsy, and vacuum core biopsy.		non-blinded assessor reviewed PACS images for correct intervention and annotation of ima-ges from interventional procedures. assessment was done after intervention and the method was non-valid.	pre/post-questionnaire on self-estimated confidence	training resulted in non-significant increase of self-estimated confidence.
Roark AA et al. [47] 2017	breast biopsy	21	radiology	residents	1-hour training session on homemade breast phantom			pre-/posttest on theoretical knowledge pre/post-questionnaire on self-estimated confidence	training on simulator increased self-estima-ted confidence/
Sutcliffe J et al. [48] 2013	breast biopsy	20	radiology	residents	simulation train-ing of biopsy and cyst aspiration with individua-lized feed-back on homemade breast biopsy phantom			pre/post-questionnaire on self-estimated confi-dence	self-estimated confi-dence improved follow-ing training session.

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▶ **Table 4** 21 non-randomized, non-controlled studies of simulation-based training of US-guided abdominal procedures.

study	procedure	participants			educational intervention		outcome measures		conclusion
		n	specialty	experience level	simulation training	co-interventions	performance assessment	written assessment	
Barsuk JH et al. [49] 2012	paracentesis	58	internal medicine	Residents (1st year)	14 ultrasound training sessions on homemade phantom with directed feedback	3-hour lecture New England Journal of Medicine paracentesis video	pre/post-skill assessment on simulator using standardized performance metrics. assessment was done by blinded assessors, and tested for inter-rater reliability. Assessment tool was non-valid.	post-questionnaire on self-estimated confidence evaluation of simulator realism and educational usefulness	the simulation-based training program significantly increased paracentesis skills and self-estimated confidence.
Fortmeier D et al. [50] 2016	PTC drainage	16	medical students	na	training needle placement on self-developed virtual reality simulator			post-questionnaire on self-estimated confidence evaluation of simulator realism and educational usefulness	training on simulator increased self-estimated confidence.
Mohr A et al. [51] 2014	abscess drainage	16	physicians, medical students	8 experienced in diagnostic US 8 inexperienced	training abscess drainage on homemade phantom under supervision		pre/post-skill assessment on phantom for successful intervention and time. Assessed by unblinded assessor using non-valid tool	pre/post-intervention questionnaire on self-estimated confidence realism evaluation of phantom	training on phantom increased externally assessed skills, self-estimated confidence. Participants found simulator realistic.
Johnson SJ et al. [52] 2012	liver biopsy	40	interventional radiology	26 residents, 14 consultants	completion of one simulated liver biopsy procedure on a homemade virtual reality simulator		performance metrics measured by simulator during training	evaluation of simulator educational usefulness	performance metrics could differentiate between different levels of experience. most participants found the simulator useful.
Nicotra JJ et al. [53] 1994	liver biopsy	3	radiology	2 residents (1st and 4th year), 1 attending	2 × 20-min. practice sessions on breast phantom. Refresher session before test		pre/post-skill assessment on beef liver. Posttest 5 months after pretest. Standardized performance metrics assessed by non-blinded assessors. Assessment tool was non-valid and non-reliable.		training on simulator improved biopsy skills on liver phantom.

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▶ **Table 4** (Continuation)

study	procedure	participants			educational intervention		outcome measures		conclusion
		n	specialty	experience level	simulation training	co-interventions	performance assessment	written assessment	
Pacioni A et al. [54] 2015	liver biopsy	15	radiology	5 residents, 10 experts	15-min. training session on a homemade patient-specific 3D printed liver phantom and a commercial liver phantom (CIRS)			evaluation of phantom realism	participants found both phantoms realistic.
Sekhar A et al. [55] 2014	liver biopsy	38	radiology	residents	90-min. practice session on home-made porcine liver phantom	20-min. didactic lecture		pre-/posttest on theoretical knowledge pre/post-questionnaire on self-estimated confidence	training session increased self-estimated confidence and knowledge on procedure.
Wu W et al. [56] 2014	liver ablation	70	interventional radiology	50 consultants, 20 specialist registrars	1-hour training session on virtual reality simulator combined with commercial physical phantom			evaluation of phantom realism and educational usefulness	participants found simulator useful and realistic.
Meek M et al. [57] 2018	kidney and liver biopsy	55	medical students	1st year	training kidney and liver biopsy on lightly embalmed corpses	procedure "workshop" (no further description)		post-questionnaire on self-estimated confidence evaluation of phantom realism and educational usefulness	participants found the phantom realistic and useful.
Hunt A et al. [58] 2014	kidney biopsy	7	radiology	residents	five-day interventional training course. residents practiced in parallel on a traditional phantom and on a homemade phantom			evaluation of phantom realism and educational usefulness	participants found the phantom realistic and useful.

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▶ **Table 4** (Continuation)

study	procedure	participants			educational intervention		outcome measures		conclusion
		n	specialty	experience level	simulation training	co-interventions	performance assessment	written assessment	
Oliver SW et al. [59] 2015	kidney biopsy	na	nephrology	trainees	one-day course: supervised training of US localization of kidney, biopsy demonstration, and biopsy practice on human cadaver			post-questionnaire: unstructured candidate feedback	participants found that human cadavers were useful as simulators when learning to perform kidney biopsies.
Sharma SG et al. [60] 2018	kidney biopsy	21	nephrology	17 fellows, 4 attendings	training of US-guided kidney biopsies on a physical phantom (Blue Phantom™) and cadavers	diagnostic US on patients, kidney pathology on homemade models, kidney anatomy with dissected cadavers, and microscopic assessment of kidney biopsies		pre-/posttest on theoretical knowledge pre/post-questionnaire on self-estimated confidence	training increased self-estimated confidence
Woywodt A et al. [61] 2013	kidney biopsy	16	nephrology	trainees	participants had to complete one correct biopsy on a homemade phantom (gelatin and porcine kidney)			post-questionnaire on self-estimated confidence evaluation of phantom realism and educational usefulness	trainees found the phantom realistic, useful and that it increased confidence.
Qiu Z et al. [62] 2011	percutaneous renal access and intra-renal procedures	122	urology	NA	3-day course on US-guided procedures on a homemade phantom supervised by two experienced endourologists			evaluation of educationally usefulness of phantom	most trainees found the phantom useful as a teaching tool.

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▶ **Table 4** (Continuation)

study	procedure	participants			educational intervention		outcome measures		conclusion
		n	specialty	experience level	simulation training	co-interventions	performance assessment	written assessment	
Zhang Y et al. [63] 2008	nephrostomy	42	urology	"partial" experience	nephrostomy training on a homemade phantom supervised by two experienced endourologists			evaluation of educational usefulness of phantom	most trainees found the phantom useful as a teaching tool.
Chan WI et al. [64] 2012	abdominal, un-specified	21	na	3 have experience on simulators	10-min. practice on homemade virtual reality simulator		post-intervention skill assessment using performance metrics from simulator. Assessment is not supported by validity evidence.		performance metrics improved with number of trials during test.
Magee D et al. [65] 2012	abdominal, un-specified	60	interventional radiology	34 consultants, 26 specialty registrars	intro to self-made virtual reality simulator followed by simulated session			evaluation of educational usefulness of phantom	participants found the phantom realistic and useful.
Mendiratta-Lala M et al. [66] 2010	abdominal, un-specified	29	radiology	residents	training session in groups and individual supervision by attending interventional radiologist using a commercial advance medical technologies phantom	training session included an online web-based module the educational intervention was followed by 6 months to practice the procedure at participants own convenience	post-intervention skill assessment on simulator. Standardized tool that was not supported by validity evidence. Assessors were non-blinded	pre/post-test on theoretical knowledge pre/post-questionnaire on self-estimated confidence and proficiency evaluation of simulator realism and educational usefulness test of knowledge	participants improved their externally assessed competence, theoretical knowledge of procedures, and self-estimated proficiency.

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▶ **Table 4** (Continuation)

study	procedure	participants			educational intervention		outcome measures		conclusion
		n	specialty	experience level	simulation training	co-interventions	performance assessment	written assessment	
Ni D et al. [67] 2011	abdominal, un-specified	16	radiology	4 consul-tants, 12 residents	training session on virtual reality biopsy simulation system simulator assess-ment, trainee vs. expert (6 biopsy training sessions) learning curve for trainees: 10 biop-sy attempts		performance metrics collected during training for both sessions. As-sessment tool not supported by validity evidence.	post-questionnaire: data collected, but not reported	performance metrics for trainees improved during training.
Sevak S et al. [68] 2018	abdominal, un-specified	50	medical students, general surgery	34 (students), 16 residents	training session on homemade gelatin phantom teaching US-guided cyst as-piration, biopsy and drainage	12-min. didactic session	post-intervention skill assessment from video using OSATS and three blinded assessors (inter-rater reliability)	24-question test on US and procedure knowledge pre/post-questionnaire on self-estimated confidence	simulation-based train-ing improved theoretical knowledge and self-esti-mated confidence
Tabriz DM et al. [69] 2011	abdominal, un-specified	12	various specialties (4 radiology, 3 anesthesiol-ogy, 2 ne-phrology, 2 medical students, 1 internal medicine)	na	participants performed 10 simulated procedures on a homemade virtual reality phantom		performance metrics measured by simulator during training. Assess-ment tool not supported by validity evidence		performance metrics could be used to differ-entiate between levels of experience.

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Quality of evidence

The quality of evidence for the effect of SBT of US-guided procedures on procedural competence in a simulated setting was downgraded to low. This was supported by randomized controlled studies, but the quality was downgraded due to a high risk of bias. The quality of evidence for the effect of SBT of US-guided procedures on clinical procedural competence was downgraded to very low, as only two non-randomized studies explored the transfer of skills from a simulated setting to a clinical setting [34, 35]. Both studies had a critical risk of bias.

Discussion

This systematic review identified 42 studies that all concluded that SBT of US-guided procedures had a favorable impact on procedural competence. All studies had a high or critical risk of bias. Consequently, the quality of evidence was low for the effect of SBT on procedural competence, and was very low for the transfer of skills to a clinical context. The included studies were heterogeneous with respect to study design, participants, simulators, educational strategy, and outcome measures (▶ **Table 1–4**) and all had methodological problems commonly seen in educational research [70]. The majority of studies were published in recent years, which emphasizes an increasing interest in this field.

Participants were generally heterogeneous in terms of specialty and level of experience. This made studies susceptible to bias, especially as few studies were randomized [71]. Five studies used a "pre-test/post-test" test setup to control for baseline differences. However, when tests are the same before and after an intervention, bias is introduced in the form of "learning to the test" [71]. This type of bias is also introduced as training and testing was mainly done on the same or similar simulators. Baseline differences can be smoothed out and render pre-testing unnecessary by using a randomized controlled study design with an appropriate number of participants. In addition, participants ought to reflect the population that will eventually benefit from the intervention, and could comprise inexperienced US practitioners [72]. 33 studies did not use control groups, and many studies used pre/post-testing or control groups that did not receive training. In effect, these studies compared training to nothing. Every educational intervention has an effect, and consequently studies like these are considered redundant [70, 73]. None of the included studies explicitly compared apprenticeship-based training to SBT, but six studies compared different educational strategies. Contrary to what has formerly been established, two studies found that faculty-guided training was superior to self-guided training [28, 29], and two studies concluded that virtual reality and high fidelity simulators were superior training tools [74]. These results could be attributed to a high risk of bias. Most of the included studies had educational co-interventions such as lectures, reading material, or online modules. Improvement of theoretical knowledge has been shown to improve procedural competence [75], and thus educational co-interventions can blur the effect of SBT and bias results.

Only two studies examined transfer of skills from a simulated setting to a clinical setting [34, 35]. Both studies concluded that SBT resulted in reduced complication rates. Due to several co-interventions, it could not be estimated to what extent this could be attributed to SBT.

Self-estimated competence and confidence were the most prevalent outcome measures. However, self-assessed competence correlates poorly with externally assessed competence [76], and poor performers tend to overestimate their own level of competence [77]. Consequently, it is an imprecise outcome measure with little study conclusion merit. Similarly, participant evaluations of simulators represent opinions, and offer little evidence to support their educational value [76]. Six studies assessed theoretical knowledge [44, 47, 55, 60, 66, 68], but assessment of theoretical knowledge is a poor predictor for procedural competence [78]. A fundamental methodological problem related to performance assessment. Ideally, performance is assessed with reliable tools that are supported by validity evidence collected in accordance with contemporary standards [79]. Without validity evidence, there is no way of knowing if an assessment tool measures what it is supposed to measure, and thus there is no way of knowing if results support the conclusions of the study [72]. A single study used an assessment tool supported by contemporary standards for validity [68]. It has been demonstrated before that the lack of sound validity remains a crucial weakness in studies of SBT [79–81]. A reliable assessment tool supported by validity has yet to be developed for US-guided procedures. Such a tool is needed for future studies. Only five studies reported blinding of assessors [33, 36, 37, 49, 68]. A lack of blinding inadvertently introduces a risk of bias that must be avoided [71].

A large meta-analysis concluded that SBT increases procedural competence [73]. However, studies on its effectiveness compared to other educational strategies, the transfer of skills to a clinical context, and cost-effectiveness are needed. In respiratory medicine and gynecology, studies have been performed that compared SBT to existing educational models [17, 82]. These studies used a randomized, controlled and single-blinded study design; a comprehensive training curriculum that addressed both theoretical and technical aspects of the procedure; a cut-off for mastery before participants were allowed to perform clinical procedures; and a test of participant performance in a clinical setting, using blinded assessors and reliable assessment tools supported by validity evidence. The studies showed that SBT improved procedural competence, that skills were transferred to a clinical context, and that the observed effect was sustained. Similar methodological standards should be applied in research of SBT of abdominal and thoracic US-guided procedures.

Conclusion

The evidence supporting SBT of percutaneous abdominal and thoracic US-guided procedures remains insufficient, as all included studies have a high risk of bias due to recurrent methodological problems. Future studies should compare SBT of US-guided procedures to existing educational models and explore the effect of SBT on clinical procedural competence. Furthermore, they should be randomized, single-blinded, and use assessment tools supported by contemporary standards of validity.

Conflict of Interest

The authors declare that they have no conflict of interest.

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