Innovationinfo

Journal of
Biomedical Research and Reviews

ISSN: 2581-7388

Volume 4: 2

J Biomed Res Rev 2021

The Impact of Fidelity-Based Simulated Medical Undergraduate Education: A Systematic Review and Meta-Analysis of Randomised Controlled Trials

Tao Yu*[1]
Yan Hua[2]
Xiaoyan Cen[2]
Sha Niu[1]

[1]Department of Neurosurgery, Research Center for Functional Maintenance and Reconstruction of Viscera, The First Affiliated Hospital of Wannan Medical College (Yijishan Hospital of Wannan Medical College), China
[2]School of Anesthesiology, Wannan Medical College, Anhui, China

Abstract

This study aims to compare the effectiveness of the fidelity level of the simulation on undergraduate medical education through meta-analysis. 15 studies met the inclusion criteria. Six studies evaluated students' theoretical knowledge between high-fidelity and low-fidelity simulators, five of these studies reported no significant difference between low-fidelity simulation and high-fidelity simulation groups, and one of these studies reported that high-fidelity simulators are more effective than low-fidelity simulators. Twelve studies evaluated students' skill performance between high-fidelity and low-fidelity simulators, seven of these studies reported no significant difference between low-fidelity simulation and high-fidelity simulation groups, four of these studies reported that high-fidelity simulators are more effective than low-fidelity simulators, and one of these studies reported that low-fidelity simulation performs better than high-fidelity simulation in several sub items. Seven studies evaluated students' confidence between high-fidelity and low-fidelity simulators, three of these studies reported no significant difference between low-fidelity simulation and high-fidelity simulation groups, and one of these studies reported that students in the high-fidelity manikin simulator group recorded higher scores than students in the low-fidelity manikin simulator group. Due to the different interventions used in each study and the different evaluation methods used for outcome indicators, it is difficult to determine which intervention is more effective through meta-analysis. Although some results are positive, it seems that there was no significant difference between high-fidelity simulation and low-fidelity simulation in terms of students' theoretical knowledge, clinical skills or improved confidence. With the wide application of simulation in medical education, further research should focus on the influence of simulation level on continuing medical education.

Keywords: Simulator, Medical student, Education, Meta-analysis.

Introduction

Since its birth in the 1960s and with the rapid development of human model simulators, simulation-based teaching has been integrated into most clinical courses [1]. Moreover, many experiments have fully demonstrated the positive effects of simulation-based theoretical knowledge and clinical skills [2,3]. Lack of clinical practice is a common problem in undergraduate medical education. Training and teaching based on simulation can provide medical students with

Article Information

Article Type: Meta-Analysis
Article Number: JBRR-152
Received Date: 08 November, 2021
Accepted Date: 21 December, 2021
Published Date: 28 December, 2021

***Corresponding author:** Tao Yu, Department of Neurosurgery, Research Center for Functional Maintenance and Reconstruction of Viscera, The First Affiliated Hospital of Wannan Medical College (Yijishan Hospital), China. Tel: +86 18855392038; E-mail: yutao201103@gmail.com

Citation: Yu T, Hua Y, Cen X, Niu S (2021) The Impact of Fidelity-Based Simulated Medical Undergraduate Education: A Systematic Review and Meta-Analysis of Randomised Controlled Trials. J Biomed Res Rev Vol: 4, Issu: 2. (09-15).

practical application experience. Training and teaching based on simulation is an ideal teaching mode to provide medical students with theoretical knowledge and hands-on practice by constructing simulation environments instead of real scenes; this approach is considered to have great development potential. With the development of modern technology and advances in synthetic materials technology, current simulators are able to provide a very realistic environment, reproducing realistic changes and providing feedback. High-fidelity simulation (HFS) can be used for training and to immerse users in complex and realistic scenarios by providing realistic feedback. However, some simulators with limited functions can only provide a specific simulation environment and cannot provide all realistic feedback; this is called low-fidelity simulation (LFS). Studies have found that compared with LFS, HFS can not only fail to improve students' abilities in terms of knowledge and skills but can also cause them to have blind confidence and seriously overestimate their abilities. This is an undesirable outcome because one of the most common cognitive biases that leads to clinical diagnosis errors is overconfidence [4]. The impact of fidelity based on simulated theoretical knowledge, skill performance, or confidence is unlcear. Therefore, to explore the effect of simulator fidelity on undergraduate medical education, a meta-analysis based on existing studies is necessary. This study aims to compare the theoretical knowledge, skill performance and confidence of undergraduate medical students between LFS and HFS through meta-analysis according to the fidelity level of the simulator.

Materials and Methods

Search strategy

Literature retrieval: Two researchers (Y.H. and XY. C) independently searched PubMed, the Cochrane Library, and Embase online and collected randomised controlled studies on HFS and LFS in medical undergraduate education; the date range was January 1, 1995, to October 20, 2020. The online search was supplemented by a manual search and follow-up search, and the authors were asked for the full text and original data. Search keywords: ("high patient simulators" or "high fidelity simulation") and ("low fidelity simulation" or "static" or "low patient simulators) and ("medical education" or "undergraduate education").

Data screening and extraction

Inclusion criteria: 1. Type of study: randomised controlled study on the differences in theoretical knowledge, skill performance and confidence between LFS and HFS; 2. Research objects: Students receiving undergraduate medical education; 3. Intervention measures: A high-fidelity simulator was used in the experimental group, and a low-fidelity simulator was used in the control group. Specific information on the simulator was mentioned in the paper, and the sizes of the experimental group and control group were clear. 4. Outcome indicators: theoretical knowledge, skill performance and confidence.

Exclusion criteria: 1. Data repeat; 2. The ending is not related; 3. The result is incomplete; 4. Result cannot be obtained or extracted

Study selection: All possible eligible study titles were screened by two independent reviewers (Y.H. and XY. C), not excluding abstracts and full text. After filtering based on the titles of the articles, both reviewers reviewed the remaining papers and identified articles that met the inclusion criteria. Differences between the two reviewers were resolved by discussion or by arbitration by the third investigator. We define the fidelity of the simulator as the physical properties of the simulator. High-fidelity simulators are "those that provide physical examination, display vital signs, physiological responses, intervention (through a computer interface) and allow certain operations to be performed on them (endotracheal intubation, intravenous intubation, face mask, etc.)." Low-fidelity simulators, on the other hand, are "static models that are otherwise limited by these capabilities" [5].

Grading the evidence

Data collection: Two independent reviewers (Y.H. and XY. C) used spreadsheet data extraction to extract the results of the randomised controlled trials. To evaluate the quality of the included studies reporting and randomisation, degree of blinding and concealed allocation, we applied the Cochrane bias risk tool, and discussion or arbitration by a third researcher was used to settle differences in the evaluation [6]. If the articles reported uncertain data or had missing data, the author was contacted to obtain the missing details so that enough original data could be obtained for the meta-analysis.

Endpoints

The main end point is to compare low-fidelity simulators and high-fidelity simulators in terms of the theoretical knowledge and skill performance of medical undergraduate students. The secondary endpoint is a comparison of the confidence of participants between those taught with low-fidelity simulators and those taught with high-fidelity simulators. Theoretical knowledge is defined as the degree of mastery of the clinical knowledge system. Skill performance is defined as the performance of clinical skills and thinking ability. Confidence is defined as the level of self-satisfaction and self-efficacy.

Results

Using the above search strategy, we identified 4,568 potentially relevant studies. Fifteen of the studies met the criteria (Figure 1). The characteristics of the 15 studies included in this meta-analysis and review are listed in table 1. Random assignment was used in all the studies. Thirteen studies compared high-fidelity simulators with low-fidelity simulators, and two studies compared high-fidelity simulators with static simulators. Figure 2 summaries the risk of bias assessment. Eight studies did not describe the method of random allocation [7-14]. Three studies detailed the generation of allocation. Four studies used a blinded method, while one study clearly indicated that no blinding was used [4,15-18]. Six studies blinded the evaluators; participants in one study were randomly assigned, but the researchers who assessed their scores were not [4,7-9,16,17,19]. One study had a risk of bias due to missing

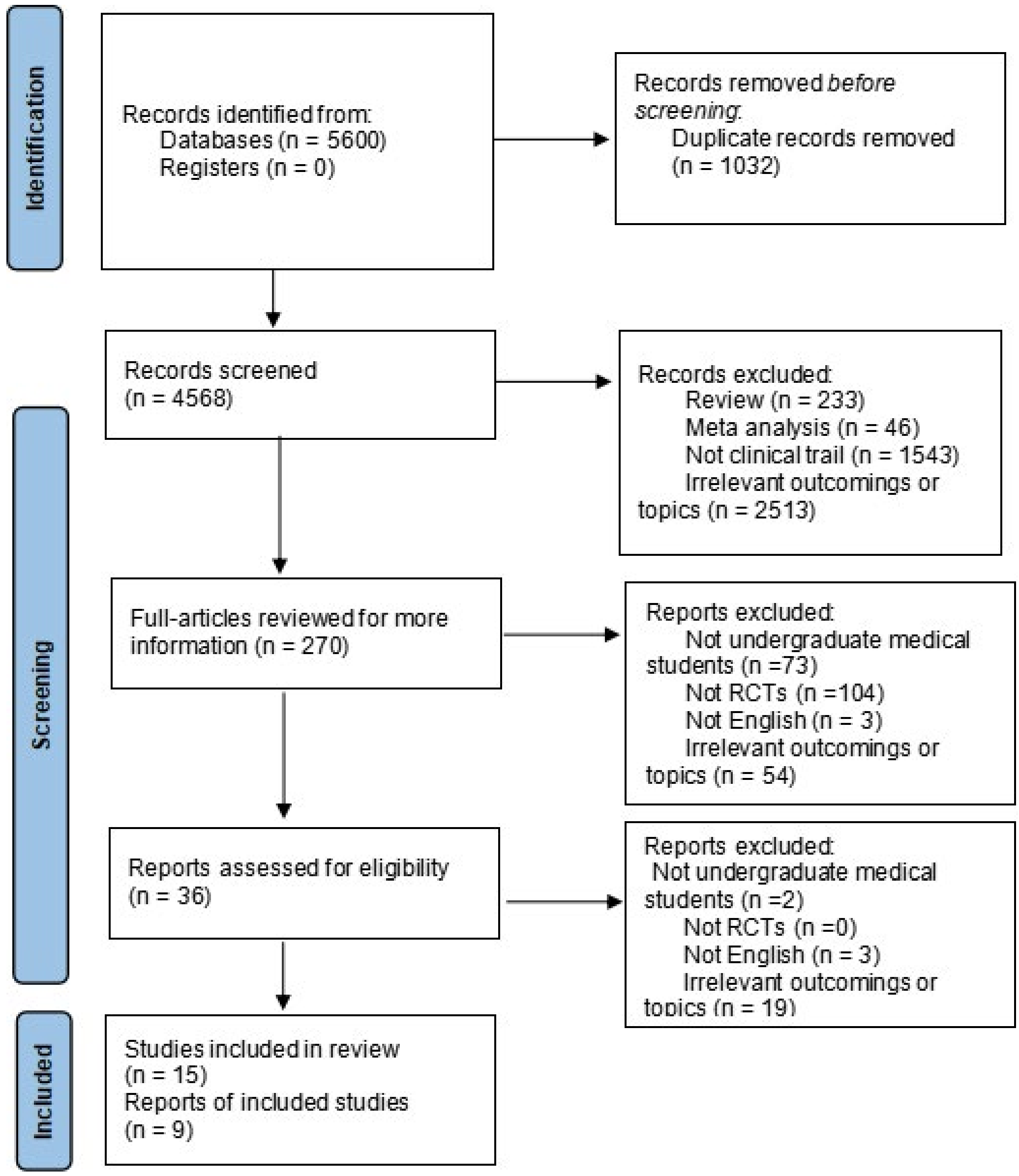

Figure 1: Flow chart of study screening.

results [12]. There was a low risk of publication bias in all the studies.

Outcomes

Six studies quantitatively compared the mastery of theoretical knowledge of undergraduate medical students exposed to HFS and LFS [4,7,9,13,19,20]. Five of these studies reported no significant difference between low-fidelity simulation and high-fidelity simulation groups [4,7,13,19,20]. One of these studies reported that high-fidelity simulators are more effective than low-fidelity simulators [9]. King and Reising compared the effectiveness of static simulation and HFS in the teaching of advanced heart life support guidelines [11]. The results showed that there was no significant difference in theoretical knowledge between the static simulation group and the HFS group (P=0.1455, a=0.05).

Twelve studies evaluated students' skill performance between high-fidelity and low-fidelity simulators, seven of these studies reported no significant difference between low-fidelity simulation and high-fidelity simulation groups, and four of these studies quantitatively compared the professional skill performance of undergraduate medical students taught via HFS and LFS [4,7-12,15-19]. Four of these studies obtained positive results: Banaszek et al., King and Reising, Mills et al. and McCoy et al. The results showed that the clinical skills performance of students in the HFS group after receiving HFS teaching was significantly different from that of students in the LFS group (P<0.05) [11,12,15,18]. One of these studies reported that low-fidelity simulation performs better than high-fidelity simulation in several subitems.

Seven studies evaluated students' confidence between high-fidelity and low-fidelity simulators [4,10,12,14,16,17,19]. Three of these studies quantitatively compared participants' confidence after receiving HFS and LFS teaching and training [10,14,17]. Three of these studies reported no significant difference between low-fidelity

Author (Year), Study setting and participants	Description of method		Measurements of outcomes	Outcomes		
	Experimental group;Sample size(n)	Control group;Sample size(n)		Knowledge	Skill Performance	Confidence
Adams et al. (2015, USA)[7];Random assignment;1st-2nd year medical students AND 1st-year physician assistant students	high-fidelity simulation activities (n=9)	Low-fidelity simulation: a DARTsim electrocardiogram (ECG) software simulator (n=10)	Written posttest and Megacode performance were assessed	No significant difference between Low-fidelity simulation and high-fidelity simulation groups	Low-fidelity simulation was statistically equivalent to high-fidelity simulation	Not evaluated
Ahad et al. (2013, USA)[8];Random assignment;3rd-4th year medical students	High-Fidelity Model (n=16)	Low-Fidelity Model (n=16)	Performances was assessed by computer-based evalution parametera used on AccuTouch colonoscopy simulator	Not evaluated	No significant difference between High-Fidelity Model and Low-Fidelity Model groups	Not evaluated
Banaszek et al. (2017,Canada)[15];Random assignment; preclerkship level medical students	a high-fidelity virtual reality arthroscopic simulation (n=16)	low-fidelity simulation: a bench-top arthroscopic setup (n=16)	Procedural efficiency was evaluated by using the Golbal Rating Scale	Not evaluated	Positive outcome:high-fidelity simulation group was superior to low-fidelity simulation group	Not evaluated
Chen et al. (2015, Canada)[9];Random assignment;senior undergraduate nursing students	high-fidelity simulation: human patient simulator (n=21)	low-fidelity simulation: digital sounds on a computer (n=21)	auscultation tests of respiratory and cardiac sounds, observer-rated performances	Not evaluated	No significant difference between high-fidelity simulation and low-fidelity simulation groups	Not evaluated
Curran et al. (2015,Canada)[10];Random assignment;3rd-year medical students	high-fidelity manikin simulator (n=31)	low-fidelity manikin simulator (n=35)	megacode performance of integrated skills station; participant satisfaction and confidence	Not evaluated	No significant difference between high-fidelity manikin simulation and low-fidelity manikin simulation groups	Positive outcome: students in the high-fidelity manikin simulator group recorded high score than students in the low-fidelity manikin simulator group did
Denadai et al. (2014, Brazil)[17];Random assignment;1st-2nd year medical students	high-fidelity chicken leg skin (n=12)	low-fidelity rubberized line (n=12)	Flap performances using the Global Rating Scale; self-perceived confidence	Not evaluated	No significant difference between high-fidelity simulation and low-fidelity simulation groups	No significant difference between between high-fidelity simulation and low-fidelity simulation groups
King and Reising (2011,USA)[11];Random assignment; senior nursing students	a high-fidelity simulation (n=24)	low-fidelity simulation: a static simulation (n=25)	written examination; megacode performance	No significant difference between high-fidelity simulation and low-fidelity simulation groups	Positive outcome: the high-fidelity simulation group outperformed the low-fidelity simulation group	Not evaluated
DeStephano et al. (2015, USA)[16]; Random assignment;2nd-4th year medical students	a high-fidelity simulation group: computer-controlled mannequin (n=47)	low-fidelity simulation group: an obstetrical abdominal-pelvic model (n=46)	performance of vaginal delivery manoeuvres; confidence to perform vaginal delivery manoeuvres	Not evaluated	No significant difference between high-fidelity simulation and low-fidelity simulation groups	students in the low-fidelity simulator group were significantly more confident in their ability than students in the high-fidelity simulator group did

Massoth et al. (2019,Germany)[4]; Random assignment; 4th-year medical students	a high-fidelity simulated Advanced Life Support training session (n=67)	a low-fidelity simulated Advanced Life Support training session (n=68)	pre- and post tests of theoretical knowledge; performance was recorded and rated	No significant difference between high-fidelity simulation and low-fidelity simulation groups	Low-fidelity simulation performs better than high-fidelity simulation in several subitems	Self-rated confidence was significantly overrated in the high-fidelity simulation than low-fidelity simulation groups
McCoy et al. (2019, USA)[18]; Random assignment; 4th-year medical students	a high-fidelity simulator (n=35)	a low-fidelity Resusci Anne cardiopulmonary resuscitation manikin (n=35)	performance in cardiopulmonary resuscitation skill	Not evaluated	Positive outcome: high-fidelity simulation is superior to low-fidelity simulation group	Not evaluated
Mills et al. (2016, Australia)[12]; Random assignment; 1st-year paramedicine students	high environmental fidelity simulations (LFenS) (n=19)	low environmental fidelity simulations (LFenS) (n=20)	psychological immersion and cognitive burden; performance	Not evaluated	Positive outcome:high-fidelity simulation performs better than low-fidelity simulation group	high-fidelity simulation creates significant additional cognitive burden
Mutlu et al. (2019, Turkey)[13]; Random assignment; 3rd-4th year nursing students	high-fidelity simulators (interactive patient simulators) (n=36)	low-fidelity simulators (computer and video) (n=35)	the Auscultation Skills Form; Descriptive Information Form	Positive outcome:high-fidelity simulators is more effective than low-fidelity simulators	Not evaluated	Not evaluated
Nimbalkar et al. (2015, Gujarat)[19]; Random assignment; 3rd-year medical students	SimNewB (an inter□ active high fidelity simulator) (n=50)	low fidelity Resusci® Baby Basic (n=51)	written test; Megacode assessment score	No significant difference between high-fidelity simulation and low-fidelity simulation groups	No significant difference between high-fidelity simulation and low-fidelity simulation groups	No significant difference between high-fidelity simulation and low-fidelity simulation groups
Tosterud et al. (2013, Norway)[14]; Random assignment; 1st-3rd year nursing students	High-fidelity patient simulator (n=29)	low-fidelity simulation group: Static mannequin (n=28)	Satisfaction and Self-Confidence	Not evaluated	Not evaluated	No significant difference between high-fidelity simulation and low-fidelity simulation groups
Urdiales et al. (2020, Brazil)[20]; Random assignment; 1st-2nd year medical students	a high-fidelity Megacode Kelly Laerdal® mannequin (n=30)	a low-fidelity model developed by the researcher (n=30)	multiple-choice test with 20 questions	No significant difference between high-fidelity simulation and low-fidelity simulation groups	Not evaluated	Not evaluated

Table 1: Descriptions and outcomes of included studies.

simulation and high-fidelity simulation groups [14,17,19]. One of these studies reported that students in the high-fidelity manikin simulator group recorded higher scores than students in the low-fidelity manikin simulator group [10]. One of these studies reported that students in the low-fidelity simulator group were significantly more confident in their ability than students in the high-fidelity simulator group [16]. One of these studies reported that self-rated confidence was significantly overrated in the high-fidelity simulation group compared with the low-fidelity simulation group [4]. One of these studies reported that high-fidelity simulation creates a significant additional cognitive burden [12].

Discussion

This meta-analysis and review provides data for evidence-based education by comprehensively analysing undergraduate medical education under different backgrounds and types of simulation. In this study, due to the different interventions used in each study and the different evaluation methods used for outcome indicators, it is difficult to determine which intervention is more effective. Although some results are positive, it seems that there was no significant difference between HFS and LFS in terms of students' theoretical knowledge, clinical skills or improved confidence.

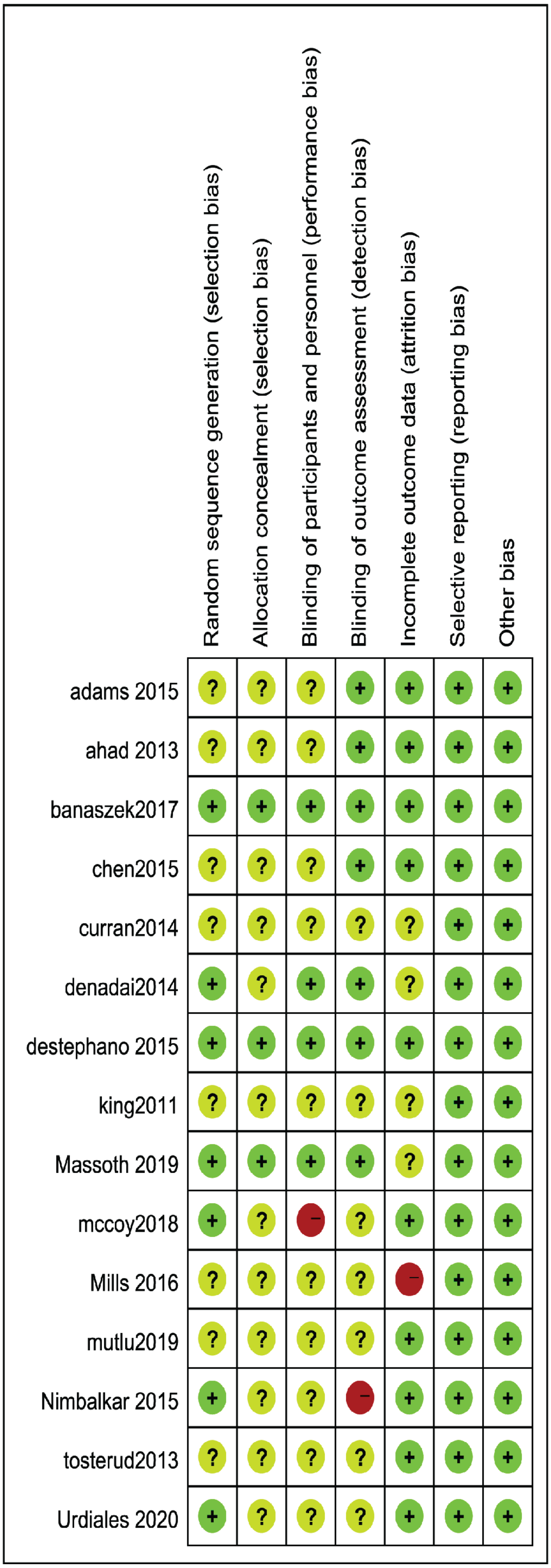

Figure 2: Risk assessment diagram of studies included in the meta-analysis.

Both high-fidelity and low-fidelity simulators can improve students' theoretical knowledge and clinical skills [19]. There is no difference in theoretical knowledge and clinical skills, and similar results have been reported in many studies [7,19,20]. These results may suggest that the teaching effect of LFS can be equivalent to that of HFS in medical undergraduate education. However, some studies have found that high-fidelity simulators are superior to low-fidelity simulators in improving students' clinical skills [11,13].

In terms of economy, the cost and price of high-fidelity simulators are much higher than those of low-fidelity simulators [21]. This leads to the high fidelity simulator expensive cost is contradictory in an unsuccessful performance in the simulation education of undergraduate students. Second, the majority of students from both groups had strong positive expectations of the value of HFS. Before the course, only the majority of the HFS group adhered to this belief, while many participants in the LFS group changed their views and did not consider LFS training to be inferior [18]. This suggested that LFS training did not discourage participants but rather made them more confident.

As the simulation level increases, the cognitive burden of inexperienced students also increases, and the complexity of the working environment will distract students' attention, leading to low learning efficiency and even lack of knowledge [22]. Some literature also suggests that students will feel pressured by high-fidelity simulators because of the highly simulated environment they create. However, students who have basic knowledge of clinical skills can refine their performance by entering the "deep" simulated environment of high-fidelity simulators [12]. It is completely feasible to conduct low-fiedlity simulations for students with little experience [20]. This has great educational value.

The limitations of this paper are as follows. First, the participants in our included studies were undergraduate medical students whose specific training and education levels may have influenced the outcomes in a way that is different from the way medical professionals are assessed. Second, the high heterogeneity of this study may be due to the heterogeneity of the intervention measures and measurement schemes across the included studies. This article includes only research published in English. Due to the different interventions used in each study and the different evaluation methods used for outcome indicators, it is difficult to determine which intervention is more effective by use of meta-analysis. Therefore, more clinical studies are needed to determine the relation between the fidelity of the simulator and medical undergraduate learning outcomes.

Conclusion

Due to the different interventions used in each study and the different evaluation methods used for outcome indicators, it is difficult to determine which intervention is more effective. According to the results of this study, there seems to be no positive relation between education outcomes and the fidelity of the simulator. This finding may be associated with the education level of our sample, and whether it is replicable in professional medical personnel needs further research. In terms of undergraduate medical education, HFS seems to not have high investment: high-fidelity simulator costs higher costs cannot be better performance in undergraduate medical simulation education, and the reasonableness of its use in medical undergraduate education is questionable. More clinical trials are needed to provide evidence.

Acknowledgement

We acknowledge support from the Clinical Skills Training Center, Wannan Medical College.

This work was supported by the Key Research and Development Program of Anhui Province (201904a07020034) and Funding of the "Peak" Training Program for Scientific Research of Yijishan Hospital, Wannan Medical College (GF2019G05). Anhui Provincial Quality Engineering Teaching Research Project (2019jyxm1068); Wannan Medical College Teaching Quality and teaching reform project key project (2018jyxm50).

Funding Statement

There is no funding.

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