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The effects of virtual reality-based bronchoscopy simulator on learning outcomes of medical trainees: A systematic review

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Abstract

Background and Aims: Conventional medical training routes of bronchoscopy may decrease patients' comfort and increase procedure-related morbidity. Virtual reality (VR)-based bronchoscopy is a beneficial and safe solution for teaching trainees. The aim of this systematic review was to study the effectiveness of VR-based bronchoscopy simulators on the learning outcomes of medical trainees.

Methods: Well-known sources (i.e., Scopus, ISI Web of Science, and Medline via PubMed) were systematically searched using Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines on December, 2021. Peer-reviewed English papers that used VR-based simulation for bronchoscopy training were included. The articles that were studying other technologies, or those that were unrelated to the topic, were excluded. The risk of bias was assessed using the Joanna Briggs Institute checklists for quasi-experimental studies and randomized controlled trials (RCTs).

Results: Out of 343 studies, 8 of them met our inclusion criteria. An appropriate control group and statistical analysis were the most common and unavoidable sources of bias in included non-RCTs, and lack of blinding in participants was the most common source of bias in RCTs. The included studies evaluated learning outcomes regarding dexterity ($N = 5$), speed ($N = 3$), the accuracy of procedures ($N = 1$), and the need for verbal assistance ($N = 1$). Based on the results, 100% (5/5) and 66% (2/3) of studies showed that the use of VR-based simulation on the learning outcomes of medical trainees led to improvement in manual ability (i.e., dexterity) and swiftness of execution (i.e., speed in performance), respectively. Additionally, improving the accuracy of subjects' performance, and reducing the need for verbal guidance and physical assistance was reported in studies that evaluated these variables.

Conclusion: VR bronchoscopy simulator as a training method for teaching medical trainees, especially for novices has the potential to improve medical trainees' performance and reduce complications. Further studies are needed to evaluate the positive effects of VR-based simulation on the learning outcomes of medical trainees.

KEYWORDS
bronchoscopy, learning, simulator, systematic review, virtual reality

1 | INTRODUCTION

Bronchoscopy is a method for exploration of the changes in trachea and bronchi.[1] It is also an important skill in the specialties of anesthesia, medical emergencies, pulmonology, and pharyngeal surgery.[2–4] Traditional bronchoscopy training is an apprenticeship model based on direct skill training by an expert.[5] In this process, the trainee starts from observation and gradually becomes experienced by doing the procedure.[6] Gaining manual skills over time by practicing on patients has disadvantages such as ethical problems which endanger patients' safety. Accordantly, developing alternative methods to the traditional bronchoscopy training model such as the use of mannequins and bronchoscopy simulators is demanded.[7]

Simulation in medical sciences is progressing almost in line with the advances in technologies such as virtual reality (VR). VR is computerized method to create a similar environment to the real condition which allows the user to interact with it. 3D printing along with VR which are two wings of simulation proponents, are expanding day by day in the field of clinical students education.[8–10] Simulation-based learning has multiple advantages such as ensuring patient safety and providing a safe environment for the learners to achieve the desired skill.[11–13]

Researchers have recommended using this method as a complementary method in bronchoscopy training.[14] Multiple studies showed that VR simulation in bronchoscopy training can reduce the number of errors during the operation, improves the performance of trainees, and raise the level of competence and ability of the individual.[15–17] On the other hand, some studies have shown that the use of simulators is not more effective than other methods,[18] or even less effective.[19]

Given the changes in simulator-related technologies, including VR, and due to the lack of a comprehensive outcome about the effectiveness of VR, our aim in this systematic review is to examine the effectiveness of VR bronchoscopy on learning outcomes in medical trainees including residents and fellowship students based on the most recent literature.

2 | METHODS

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[20]

2.1 | Search and selection

Our team searched Scopus, ISI Web of Science, and Medline via PubMed databases with the following keywords: ("Virtual Reality" [Mesh] OR [Virtual Realit*]) AND ("Bronchoscopy" [Mesh] OR Bronchoscop*) in fall 2021. The search results were imported into the reference manager software and after removing the duplicated studies, two independent researchers assess the eligibility of the search results in two title/abstract and full-text stages. In the case of disagreements, the authors resolved them by discussion, and if a consensus was not reached, the other author, who is an expert in this field, helped them to resolve it.

2.2 | Eligibility criteria

The PICO (population, interventions, comparisons, and outcomes) of this systematic review is as follow:

- Population: medical trainees.
- Intervention: immersive VR-based bronchoscopy simulation.
- Comparison: any comparison mentioned in the studies.
- Outcome: learning outcomes.

All of the studies that investigated the effect of VR bronchoscopy stimulators on medical learners, were included in this study. Other types of simulations, non-English studies, conference abstracts, review articles, case reports, letters, comments, opinion articles, and finally studies without access to the full text were excluded.

2.3 | Data extraction and quality assessment

Two independent researchers extracted the data using an electronic table in Microsoft excel. Data include the name of the first author of the study, publication year, design of the study, sample size (trainee number) and their education levels, the comparison group (if existed), VR system and procedure, and any reported outcome representing the proficiency of learners. Quality assessment was conducted using the Joanna Briggs Institute checklist for quasi-experimental studies and randomized controlled trials (RCTs), by two independent researchers.

3 | RESULTS

3.1 | Search results and selection process

Out of 343 studies found in the primary search, we selected 8 studies that evaluated the efficacy of VR-based bronchoscopy simulators in the educational processes. The details of the selection process are presented in Figure 1 and a summary of included studies is presented in Table 1.

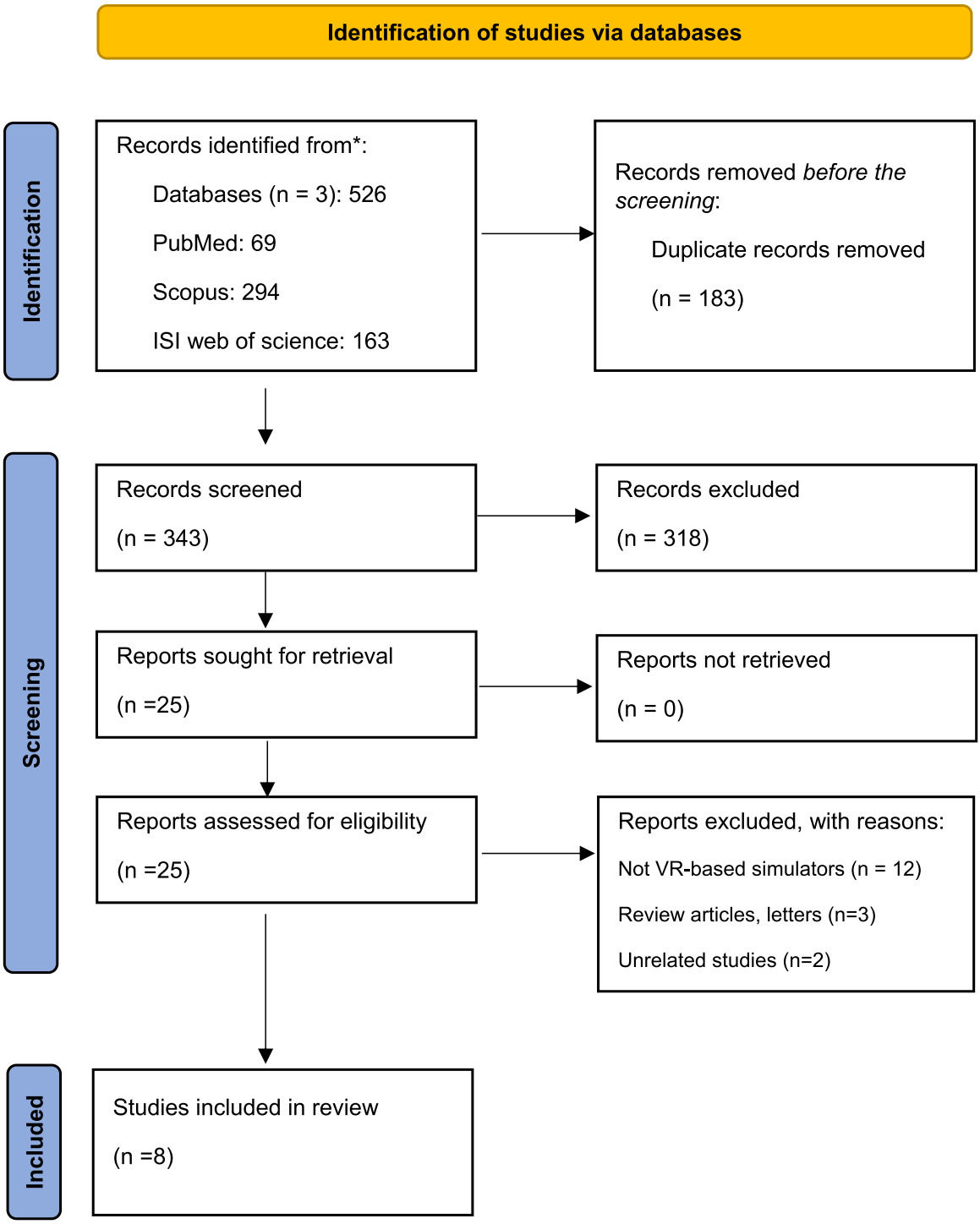

FIGURE 1 PRISMA 2020 flow diagram for new systematic reviews. PRISMA, preferred reporting items for systematic reviews and meta-analyses; VR, virtual reality.

3.2 | Risk of bias

The results of RoB assessment is presented in Tables 2 and 3. Appropriate control group and statistical analysis were the most common source of bias in included non-RCTs, while in RCTs, lack of blinding in participants was the most common and nature source of bias in our included studies.

3.3 | Dexterity

Dexterity was assessed using different methods in studies such as measuring the contacts with bronchial wall per minute of bronchoscopy, number of scope collisions, percentage of visualized segments, bronchial anatomy knowledge, bronchoscope navigational skills, total bronchoscopy skills and tasks assessment

TABLE 1 Summary of the included studies.

Author	Study design	Number of trainees and education levels	Comparison groups	VR procedure	Conclusion
Colt et al.[7]	Pre–post	5 novices	4 skilled physicians	4 h of group instruction and 4 h of individual unsupervised practice	When the simulator was used, the number of wall collisions was reduced, as well more airway sections were explored. The bronchoscopists participating in this study confirmed this promotion in the control group
Ost et al.[21]	RCT	11 novices 8 intermediates 9 experts	None	AccuTouch flexible bronchoscopy simulator (Immersion Medical, Gaithersburg, MD)	After 20 sessions of training with the simulator the skill level of participants was enhanced by speed, percentage of segments visualized, and collisions
Moorthy et al.[22]	Pre–post	9 novices without experience 9 experienced (200–1000) bronchoscopists	None	Bronchoscopic simulator: HT Medical Systems, Gaithersburg, MD, USA/ Flexible bronchoscope/ 7–10 training sessions for novice group/2 training sessions for EB	When the simulator was used, the number of wall collisions was reduced, as well more airway sections were explored. The bronchoscopists participating in this study confirmed this promotion in the control group
Blum et al.[23]	RCT	Rresidents with no bronchoscopy training ($n = 5$), trained residents after bronchoscopy simulator training ($n = 5$) Experienced residents with previous bronchoscopy experience ($n = 3$)	None	The bronchoscopy simulator includes a computer with a monitor, software, and a realistic proxy bronchoscope (connected to the computer). The amount of time spent with the simulator averaged 60 min	The group using the simulator needed less verbal guidance and physical assistance than the control group. Although the overall time of bronchoscopy was not significantly different for all three groups of intervention, control, and expert, the simulation group performed bronchoscopy more accurately
Rowe et al.[24]	RCT	20 pediatric residents 12 simulator group 8 control group	2-week rotation pediatric residents	The simulator consists of a proxy flexible bronchoscope, a robotic interface device, a computer with a monitor, and simulation software. Total time on the simulator (min): 39	The performance of residents in the simulator group had markedly improved after the simulator session. They concluded that this bronchoscopy simulator was an effective tool for teaching residents
Krogh et al.[17]	RCT	20 third-year medical students 10 intervention group 10 control group	None	The portable OrsimTM bronchoscopy simulator (Airway Simulation Limited, Auckland, New Zealand) Spent an average of 71 min training	The results of the evaluation with a bronchoscopy quality score showed that; the intervention group played significantly a better role than the control group
Gopal et al.[3]	Pre–post	Twenty-five first-year (53.2%), 16 second-year (34.0%), 1 third-year (2.1%), and 5 fourth-year (10.6%) medical students	None	The EndoVR endoscopy simulator (CAE Healthcare, Montreal, Quebec, Canada)	The EndoVR bronchoscopy simulator was found to be a useful procedure for trainees and led to an improvement in their skills and knowledge
Jiang et al.[25]	Pre–post	Forty-six anesthesia residents in two groups of training on fiberoptic bronchoscopy manipulation $n = 23$ High-fidelity mannequin: $n = 23$	None	Group VR performed fiberoptic manipulation from mouth to carina 25 times, whereas group manipulation participants did the same on the mannequin	The results of the comparison between the two groups demonstrated that, in terms of teaching, VR seemed to be superior to a mannequin

Abbreviations: RCT, randomized controlled trials; VR, virtual reality.

tool score, a validated five-point global rating scale and economy of performance (percentage/time). In terms of evaluating the dexterity, all five studies that had assessed the subjects' performance (with different methods), pre- and post-training indicated that the use of VR in different groups could be advantageous and positive effect.[3,7,17,22,24]

TABLE 2 Risk of bias, using checklist for quasi-experimental studies (non-randomized experimental studies).

Study	1	2	3	4	5	6	7	8	9
Colt et al.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Moorthy et al.	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Gopal et al	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	No
Jiang et al.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No

1. Is it clear in the study what is the cause' and what is the "effect" (i.e., there is no confusion about which variable comes first)?
2. Were the participants included in any comparisons similar?
3. Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest
4. Was there a control group?
5. Were there multiple measurements of the outcome both pre and post the intervention/exposure?
6. Was follow-up complete and if not, were differences between groups in terms of their follow-up adequately described and analyzed?
7. Were the outcomes of participants included in any comparisons measured in the same way?
8. Were outcomes measured in a reliable way?
9. Was appropriate statistical analysis used?

3.3.1 | Speed

Four studies have assessed the time, pre- and post-training with VR. Among three studies, two of them indicated a better speed in performance of trainees with VR.[21,24] The analysis of Jiang et al. study didn't show a specific difference in terms of speed, after training with VRS.[25]

3.3.2 | Accuracy

Among the included studies, Colt et al.[7] had assessed the trainees' accuracy of bronchoscopy performance, before and after training with VRS, by evaluating the missed segments. The results showed that there was a significant difference in terms of accuracy after the training sessions with VRS in subjects' performance.

3.4 | Need for verbal guidance

In Blum et al.'s study,[23] the results showed that the group using the simulator needed less verbal guidance and physical assistance than the control group.

None of the studies reported the negative effect of VR-based bronchoscopy simulators on the learning outcomes of medical trainees.

4 | DISCUSSION

This review evaluated the effects of VR bronchoscopy simulator training on learning outcomes and the results showed that overall, using VR-based bronchoscopy as a training procedure is potentially

TABLE 3 Risk of bias using checklist for randomized controlled trials.

Study	1	2	3	4	5	6	7	8	9	10	11	12	13
Ost et al.	UC	Yes	Yes	N/A	N/A	No	No	Yes	Yes	Yes	Yes	UC	UC
Blum et al.	Yes	UC	Yes	N/A	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	UC
Rowe et al.	Yes	UC	Yes	N/A	N/A	Yes	Yes	Yes	Yes	Yes	Yes	UC	UC
Krogh et al.	Yes	Yes	Yes	N/A	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

1. Was true randomization used for assignment of participants to treatment groups?
2. Was allocation to treatment groups concealed?
3. Were treatment groups similar at the baseline?
4. Were participants blind to treatment assignment?
5. Were those delivering treatment blind to treatment assignment?
6. Were outcomes assessors blind to treatment assignment?
7. Were treatment groups treated identically other than the intervention of interest?
8. Was follow-up complete and if not, were differences between groups in terms of their follow-up adequately described and analyzed?
9. Were participants analyzed in the groups to which they were randomized?
10. Were outcomes measured in the same way for treatment groups?
11. Were outcomes measured in a reliable way?
12. Was appropriate statistical analysis used?
13. Was the trial design appropriate, and any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?

beneficial in improving trainees' skills. The included studies had assessed the effectiveness of VR in different aspects such as speed of bronchoscopy, dexterity, accuracy, and the number of times the trainees asked for help.

The results of the studies which had evaluated the efficacy and usefulness of VRS, demonstrates advantageous manifestations of training with it. According to scholarly literature, VR is a conceptual framework used to simulate real-life environments, occurrences, and entities, thereby allowing users to interact with them.[26] VR bronchoscopy provides a simulation of real-life phenomena such as vocal cord closure, respiratory movements, airway secretions, and cough. Therefore, practicing with a simulator may decrease the failures that might happen during bronchoscopy by providing an unlimited time to practice on a model, rather than experience on real patients.[27]

Three out of five included studies, reported VR-based bronchoscopy stimulation as an advantageous method in improving the participants' dexterity. The role of VR-based simulation in assessing the dexterity and skill level of learners was discussed in previous studies. Twenty novice bronchoscopists and 10 expert bronchoscopists were enrolled in Chen et al.'s[28] study. The results of the analysis showed that the parameters of operating time, percentage of bronchi reviewed, percentage of recurrent bronchi entered, percentage of pathologies identified, and the number of wall collisions were capable of determining the skill level of the bronchoscopist. Also, dexterity was evaluated from the sight of participants; regarding the users' feedback, Gopal et al.'s[3] demonstrated that the most frequent demand of post-training students was having more one-on-one practicing time with an expert. Although the presence of a tutor might have affected the results of the study, a guided practicing procedure seemed to be useful for initial learners and it would decrease their anxiety level as well as their possible inaccuracy.

In terms of speed, although many studies have approved the positive effect of VR bronchoscopy on novice bronchoscopists' skills, the duration of training time differed from minutes to several sessions in various studies; therefore, an exact duration of training sessions is needed to be determined to achieve a comprehensive conclusion. Moreover, most of the included studies have assessed the impact of VR on a short-term follow-up, due to time limitations. Organizing a long-term follow-up with a standard interval would provide more insight into the assessment of the effect of VR simulation training on the true level of skill retention. A recent investigation conducted by Samuelson and colleagues indicated that the use of a bronchoscopy simulator for 5 min before the actual procedure had a significant and favorable impact on both the duration and quality of the bronchoscopy compared to not using a simulator.[29] There have been reports of patients' satisfaction treated by physicians who have used simulators in the training process,[30,31] so performing this learning method can help increase patients' acquiescence.

In addition to training, the simulator can be useful for measuring trainees' skills to qualify their knowledge and readiness for performing bronchoscopy procedures on patients. Thus bronchoscopy simulation may play an important role in educating not only pulmonary physicians but also other healthcare providers such as nurses, intensive care personnel, and respiratory therapists.[21] Casso et al. study is testing the anatomical and procedural accuracy of a VR bronchoscopy simulator using experts' opinions and a scoring system. Although it was mentioned that the experts agreed on the potential of the simulator being a good educational tool, the authors didn't test the effect of the simulator on students' level of understanding. Therefore, the evaluation of the VR-based bronchoscopy should be considered by the researchers in their studies.[32]

The results of Jiang et al.[25] study in which novice anesthesia residents (with no experience of bronchoscopy) were enrolled to compare the effect of training with VR and mannequin showed that, although training with VRS seemed to be efficient, VR was inferior to mannequin simulation in terms of costs. They noted that VR cannot be widely used in developing countries such as China where cost remains an important factor in many situations which may be a limit in the widespread use of this method. Mahmood et al.,[5] also have identified some disadvantages of this method, which include mismanaging pathologic findings, extended time for training, and lack of continuity of training. Acquiring competence in intensive procedures such as bronchoscopy needs manual and technical skills as well as the capability to work quickly and gently, and these abilities procure by practicing whether on awake or sedated patients or models, mannequins, or simulators.

One of the limitations of our study was the limited number of papers. The other limitation of our study was the heterogeneity of the evaluation methods that were performed to compare the intervention groups and control groups of studies. In addition, the timing of training sessions differed in included studies, and the subjects that were enrolled in studies differed in terms of spatiality, education level, and experience, which prevented us from conducting a meta-analysis.

5 | CONCLUSION

As a conclusion, in this systematic review, we found out that, overall, training with VR bronchoscopy simulator is a profitable method for medical trainees and especially for novices. Using VR bronchoscopy as a training method will improve medical trainees' performance and reduce the number of errors.

AUTHOR CONTRIBUTIONS

Mahmud Bejani: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing—original draft; writing—review and editing. **Ali Taghizadieh**: Conceptualization; Data curation; formal analysis; funding acquisition; investigation; validation. **Taha Samad-Soltani**: Conceptualization; data curation; methodology; resources; software. **Afsoon Asadzadeh**: Conceptualization; Methodology; resources; visualization; writing—original draft; writing—review and editing. **Peyman Rezaei-Hachesu**: Conceptualization; data curation; formal analysis;

funding acquisition; project administration; resources; software; validation; visualization; writing—original draft; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All authors have read and approved the final version of the manuscript. Peyman Rezaei-Hachesu had full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

ETHICS STATEMENT

The study is a part of a PhD thesis approved by the Tabriz University of Medical Sciences Ethics Committee (Number: IR.TBZME-D.REC.1399.501). Informed consent was not applicable to our study.

TRANSPARENCY STATEMENT

The lead author Peyman Rezaei-Hachesu affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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