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The Virtual Reality Technology Effects and Features in Cardiology Interventions Training: A Scoping Review

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Abstract

Background: Virtual Reality (VR) as an emerging and developing technology has received much attention in healthcare and trained different medical groups. Implementing specialized training in cardiac surgery is one of the riskiest and most sensitive issues related to clinical training. Studies have been conducted to train cardiac residents using this technology. This study aimed to identify the effects and features of VR technology in cardiology interventions training.

Methods: This scoping review was conducted in 2021 by searching PubMed, Scopus, and Web of Sciences scientific databases by combining the related keywords. A data extraction form was used for data gathering. Data analyses were done through the content analysis method, and results were reported based on the study objectives.

Results: 21 studies were included; from the 777 articles found in the initial searches, seven (33.33%) were RCT studies. VR-based education studies in cardiology interventions have grown significantly in recent years. The main effects of applying VR include improved user attitude and satisfaction, improved performance after VR training, and improved training and learning. Input devices include tracking devices, point input devices, and controllers. Output devices were three main categories include graphics audios and haptic.

Conclusion: The use of new technologies, especially VR, can improve the efficiency of medical training in clinical settings. It recommends that this technology train the necessary skills for heart surgery in cardiac residents before performing real surgery to reduce the potential risks and medical errors.

Keywords: Virtual Reality, Cardiology, Medical Training

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Introduction

In medical education with a traditional approach, living patients should be used to strengthen the skills of specialists in various clinical fields (1, 2). At the same time, educational and medical centers will be responsible for providing optimal treatment for patients and ensuring their safety and well-being (3). These conflicting needs pose a

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↑What is "already known" in this topic:
Various studies have been conducted in teaching cardiovascular interventions based on virtual reality in recent years, and different results have been obtained. Identifying the features and effects of these interventions in various studies and explaining the existing challenges and gaps can increase the effectiveness of these interventions.

→What this article adds:
The features of VR for training cariological intervention were include VR modeling tools, simulation platform, input device, and output device. The main effects of applying VR were include improved user attitude and satisfaction, improved performance after VR training, and improved training and learning.

moral challenge in medical education, widely recognized (4). Also, traditional teaching methods in medical universities do not provide the power to analyze, prioritize and organize emerging knowledge required for critical and creative thinking and practical learning. In medical education, professors must constantly confront students with various issues and situations and force them to challenge themselves mentally (5). Thus, medical education has led in charge to consider the use of alternative methods; therefore, new technologies such as virtual reality (VR) have been widely used in recent years (6).

As an emerging and expanding educational technology in medical education, VR is highly regarded and used in the education of various medical groups (1). This technology simulates the world around the computer and communication through the receiver (7). VR is a computer-based technology that creates a simulated and three-dimensional environment that allows the patient to perform thousands of exercises without time and space constraints and harm the patient (8).

VR is a hybrid interface (human-machine), which combines various technologies such as computer graphics, image processing, pattern recognition, artificial intelligence, networking, and audio systems to produce computer simulations and interactions (9). This technology gives the user the feeling of being in an actual condition through various sensory feedback such as Visual, auditory, and tactile (10-12).

Medical errors have always been a significant issue. One of the most important ways to reduce medical errors is to increase students' practical training and increase the quality of education. While empowering medical students, VR technology can minimize the stress and mood of this group and cover the inherent disadvantages of traditional medical education (13). VR technology will provide a unique visualization for students that is not possible in traditional classrooms (14). The advantages of this technology include high safety, flexibility, and proper interaction with learners, which has increased their interest and interaction, ultimately improved the quality of education, and has led to appropriate responses to problems such as language differences (15).

Implementing specialized training in various fields of cardiac is one of the riskiest and most sensitive issues related to clinical activity (16). Therefore, studies have been conducted to train cardiac residents using VR technology. Many studies have emphasized using this technology in medical education, especially in cardiology interventional education (17-20).

In their study, Alfalah et al. compared the heart's anatomy using VR with traditional methods. They showed that VR had improved the quality of heart anatomy to learners and the high level of satisfaction with this method of education (21). In their study, Abiri et al. Used a VR-based simulator to simulate the morphological changes of the heart and emphasized that the tool used could be a high-resolution tool for teaching basic and clinical sciences (22). Another study by Aeckersberg et al. found that simulated VR-based training increased motivation for novice trainees. In general, low-loyalty simulation has the potential to be useful for novice trainees, but the potential risks of simulation training need to be further assessed (23).

With the increase in studies and growth of VR in cardiologists and residents' education, the variety of tools and methods used in this field, the need to study features of these technologies felt more than ever. Scientific studies on the technologies used can help researchers and officials make more appropriate decisions in using VR. This study aimed to identify the effects and features of VR technology in cardiology interventions training in a review.

Methods

Search Strategy and data sources

This study is a scoping review done in 2021 based on scoping review and systematic review guidelines (24, 25). The scoping review has three main parts: Population, Context, and Concept (PCC) (26). Therefore, it was formulated based on the scoping review parts.

The searches have been done in PubMed, Scopus, and ISI Web of Sciences scientific databases to find related studies by applying associated keywords (Table 1). Also, searches are limited to English-language articles conducted in the last ten years to review the most significant changes made during this period.

Inclusion criteria

All original articles about VR technology in cardiology interventions training in different medical students, especially cardiologists, were included. The purpose of the intervention term was invasive and non-invasive surgeries and heart procedures.

Exclusion criteria

Other article types such as reviews, short communications, letters, commentaries, and case reports were excluded from the study. Articles that were not about applying VR to cardiology interventions training were excluded. Articles in other languages except English excluded from the study. Also, articles about different training methods in cardiology interventions, such as traditional methods or multimedia educational products, were excluded. The studies that do not implement the VR program for cardiology intervention training were excluded.

Table 1. Search strategy of the study

Limitations	English full-text article, During 2012-2021
#1	"virtual reality" OR "augmented reality" OR "virtual realities" OR "VR" OR "mixed reality" OR "augmented realities" OR "mixed realities" OR "computer simulate"
#2	"cardiology" OR "heart physician" OR "cardiologist" OR "heart surgery"
Search	#1 And #2

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Data gathering
Two authors collected data independently (at the same time), and the inconsistency has been forwarded to the next author. Data gathering was done using a data extraction form in Excel (Microsoft Office 2019). The data extraction table includes four parts: article bibliography information, methodological information, features and effects, and other study results.

Data analyses
We used the content analyses approach to analyze the data, and the results were reported based on the study objectives.

Results
Of the 777 articles found in the initial search, finally, 21 studies were included in the study based on the inclusion and exclusion criteria (Fig. 1).

The general information of selected studies showed in Table 2. Based on this table, cardiac catheterization, angiography, and interventions for Congenital Heart Disease patients were the most popular intervention.

According to Figure 2, the number of conducted studies increased in the last three years, including 2019 (3 studies), 2020 (3 studies), and 2021 (6 studies); 58% of conducted studies were in these years.

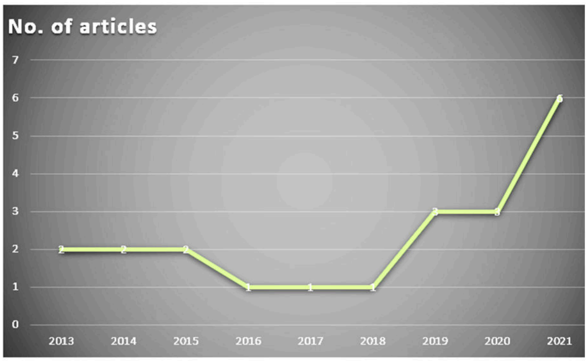

Fig. 2. Study trends based on year of publication

The results showed that the conducted articles were in 11 countries. The USA has five studies (23.81%), China with three studies (14.29%), and Canada with three studies (14.29%) have the most conducted studies.

Based on Table 3, the observational studies were more than interventional studies. Comparative studies (cross-sectional) were the most study type in observational studies.

Table 4 shows the technical features of the VR system in the studies based on software and tools information.

Based on Table 5, the effects of VR-based training on cardiology interventions have three main themes and 18

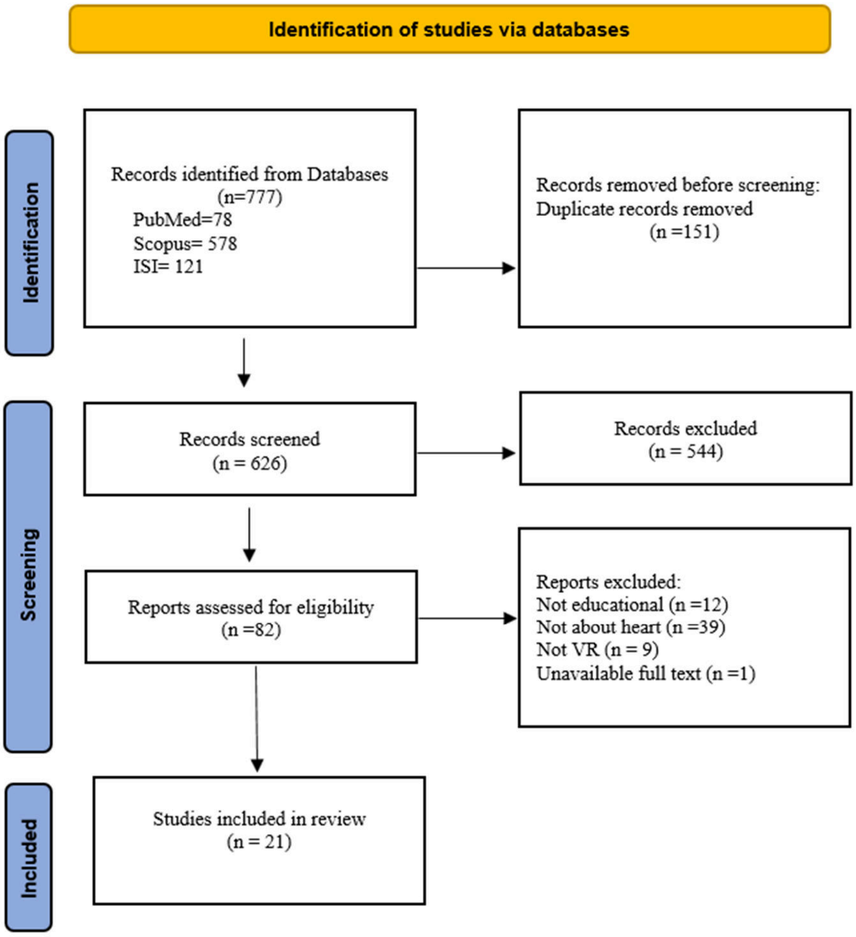

Fig. 1. Study selection steps (27)

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Table 2. The features of the selected studies

Authors, Year, Country	Aim	Education topic	Study participants	Data analyses	Main results
Aeckersberg 2019 Germany (23)	The relevance of low-fidelity virtual reality simulators compared with other learning models	Basic endovascular skills	50 Medical students	Nonparametric tests	The simulation system used was useful for students, but the risks of simulation should also be considered in the study.
Andersen 2021 Denmark (28)	Evaluating the effect of VR education on a course (peripheral venous cannulation)	Peripheral venous cannulation	19 Medical students	Fisher exact tests	Using VR along with regular training can improve catheterization learning. There was no difference in the time of surgery between the two groups. Suggest further studies
Balian 2019 USA (29)	Feasibility of AR cardiopulmonary resuscitation education	Cardiopulmonary resuscitation	51 HCP	Quantitative and qualitative analysis	Satisfied with the system, helpful for training, willing to use the application Further studies in this area are suggested.
Chang 2021 Taiwan (30)	The effect of using VR on knowledge related to atrial fibrillation	Atrial fibrillation	20 residents	Descriptive statistics	Achieve the purpose of a paperless environment
Galvez 2020 USA (31)	Using VR to teach peripheral and lateral circulation of the heart to medical students	Peripheral and lateral circulation of the heart	32 medical students	Quantitative and qualitative	Recommended for use in similar studies. The high willingness of participants to use this technology. The results of the study also suggest many guidelines for the use of virtual reality.
Guo 2018 China (32)	Evaluate the performance of interventional surgeries using a virtual reality simulator	Endovascular interventional surgery	Surgeons	Analytical statistics	The simulation method used provides the real needs of residents for endovascular interventional surgery.
Bagai 2012 Canada (33)	Investigating the effect of VR on cardiac catheterization skills	Cardiac catheterization	27 residents	Linear regression	Less skilled residents have more learning to perform catheterization than more skilled residents.
Fierros 2021 Mexico (34)	Designing a mobile-based virtual reality software to teach Cardiopulmonary Resuscitation Techniques	Cardiopulmonary Resuscitation	-	Multifactorial ANOVA, multifactorial analysis of variance	Training with this system increases users' skills.
Isaranuwatchai 2014 Canada (35)	Evaluation of the cost-effectiveness of using a VR simulator in intravenous catheterization training	Intravenous catheterization	45 medical students	Benefit regression model to identify the most cost-effective training program via paired comparisons	The progressive program had the highest cost. However, the high-fidelity program had the highest running costs. The progressive training program was the most cost-effective
Jaskiewicz 2020 Poland (36)	Use of VR in the quality of pressure on the chest during cardiac arrest	Chest massage during heart attacks	113 medical students	Quantitative analysis using PHStat software	Future studies should focus on finding the most effective way to combine VR with traditional skills training in the CPR curriculum.
Jensen 2016 Sweden (37)	explore if proficiency-based training in coronary angiography (CA) simulator	Angiography	Sixteen senior cardiology residents	Analytical statistics	In real life, the VR-trained group had shorter fluoroscopy and total procedure times than the controls
Kim 2020 USA (38)	Development and evaluation of the usability of VR system in Congenital Heart Disease	Congenital Heart Disease	22 medical trainees	Independent T-test and ANOVA.	Immersion is an important feature of displaying medical images for diagnostic accuracy in joint discussions.
Lau 2021 Australia (39)	Comparison of the clinical value of VR compared to 3D Printing in Congenital Heart Disease	Congenital Heart Disease	35 medical practitioners	Descriptive and analytical statistics	Twenty-one participants (72%) showed that VR and 3DPHM offer more benefits than conventional medical imaging. This study concludes similar clinical value of VR and 3DPHM in CHD, although more research is needed for more cardiologists to comment on the usefulness of these tools.
Li 2021 China (40)	Design and Evaluation of Personalized Percutaneous Coronary Intervention Surgery Simulation System	Percutaneous Coronary Intervention Surgery	16 cardiologists and 20 intervention trainees	Analytical statistics	The results confirm that the simulation system can provide a better user experience and is a good platform for training and practicing PCI surgery.
Popovic 2019 France (41)	Training in Coronary Angiography by VR	Coronary Angiography	12 cardiology residents	Mann Whitney U test when unpaired and the Wilcoxon signed-rank test when paired	Virtual reality can be used as a skill assessment tool. Provides a safe environment for specialist training and leads to a coherent and standardized learning plan.

Sub-themes.

Applying VR in cardiology intervention training has some challenges. Based on Table 6, these challenges are classified into seven categories.

Table 2. Continued

Authors, Year, Country	Aim	Education topic	Study participants	Data analyses	Main results
Ralston 2021 USA (42)	training in the pediatric cardiac intensive care unit for the first time	Pediatric cardiac care	6 participants	Descriptive statistics	Further studies are indicated as this is a preliminary study.
Valdis 2015 Canada (43)	Validation of a Novel Virtual Reality Training Curriculum for Robotic Cardiac Surgery	Robotic Cardiac Surgery	20 surgical trainees	Kruskal-Wallis analysis of variance and Mann-Whitney U analysis	Further evaluation of this curriculum is needed for its widespread implementation in surgical education
Vallurupalli 2013 USA (44)	Using AR to improve education and patient outcomes in a cardiology fellowship program	Cardiology fellowship program	Cardiology fellows	-	Medical institutions should work on policies to use such technologies to enhance medical care without compromising patient privacy. Training program managers can record their trainees' skills as a way to ensure pre-graduation competency.
Voelker 2015 Germany (45)	The effect of simulation-based training on coronary artery interventions	Coronary artery interventions	Eighteen cardiology fellows	Kruskal–Wallis test, Mann–Whitey U-test	The level of performance of the cardiologist in coronary artery interventions is improved using VR. Further research is needed to assess the impact on clinical outcomes.
Zhou 2014 China (46)	Cardiovascular-interventional-surgery virtual training platform	Cardiovascular-interventional-surgery	Cardiologist	Translation test (a) and rotation test	More studies will be done in the future. Carry out studies to validate the present study.
Talbot 2017 France (47)	Interactive training system for interventional electrocardiology procedures	Interventional electrocardiology procedures	Cardiologist	-	According to a heart arrhythmia scenario, they demonstrate the ability of the user-guided simulator to move through the catheter into the arteries and cavities of the heart and reproduce an erosive technique including extracellular potential measurements, endocardial surface reconstruction, and electrophysiological mapping.

Table 3. Study type of selected articles

Study type		Number of studies	%
Interventional		7	33.33
Observational	Feasibility study	3	66.67
	Prospective	1	
	Cohort	1	
	Comparative (cross-sectional)	5	
	Developmental	4	

Discussion

The use of technological advances such as VR seems to be essential for the training of physicians and medical students. By creating a near-realistic environment for practical training for cardiac residents, VR allows residents with little experience to gain enough experience in the background and make fewer errors in the realm of intervention and patient intervention. Specialized clinical training has high sensitivities and is directly related to human lives. One of the challenges in educating medical students is their attitude and satisfaction. Based on the results of the study, it found that the attitude and satisfaction of trainers of cardiac interventions using VR increased, and they showed a greater desire to learn (23, 30, 31).

All studies were conducted in developed countries. It suggested that other countries, including countries with serious challenges in medical education and developing countries, use these tools to improve teaching and increase the effectiveness of medical education, especially for teaching heart interventions, use VR-based tools. Using countries' experiences that have used information technology can influence future projects' success (48).

It examined the type of studies conducted in cardiac intervention training using VR. It found that a small percentage of the studies were performed as interventional. Given the role of intervention studies in evidence-based decision-making, it suggested that more intervention studies be conducted on the use of VR to teach cardiology interventions to ensure its positive effects on resident education.

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Table 4. The technical features of the VR system in the selected studies

VR Modeling Tools		Simulation Open-source Framework Architecture (SOFA) in an XML (32,47)
		3D data (32)
		3D modeling (34)
		3D-human model (36)
		MENTICE VIST (Vascular Intervention Simulation Trainer) (33)
		GIMIAS (an open-source framework providing image visualization, manipulation, and annotation) (47)
		4D-Image based model of the heart (47)
		GPU implementation (47)
Simulation platform		iOS app (23)
		Android platform (34)
		Computer-based system (35, 46)
		Smartphone, tablet, or personal computer (44)
Input device	Tracking device	A tablet-based program with Wireless connection (23)
		A head-mounted device with 2 controllers, using tip tracking (28)
		CPR recording manikin integrated with a head-mounted commercial AR device (Microsoft Hololens, Microsoft, Redmond WA) (29)
		Computers running the VR version of Organon and Vive headsets (31)
		The virtual catheterization is rendered with a real-time frame rate of 75 FPS with a single high-performance instrument (46)
		HX711 integrated circuit block, an analog-digital converter that, together with the sen-1045 sensor, measures the force applied to a mannequin or substitute (34)
		Live video stream from the glass (44)
	Point input device	Interactions through buttons and physical movements during the simulation (34)
	Controller	ANGIO Mentor simulator allows C arm movement, contrast injection, and fluoroscopic imaging, and displays direct cardiovascular monitoring (23, 45)
		Image detector angle and projection, and zoom features like in a real catheterization laboratory (33)
		Nodemcu ESP32 microcontroller (34)
		Arm simulator and SimMan (35)
Output device	Visual	Simulator monitor (23)
		Tablet monitor (28)
		Instructor feedback in a monitor (31)
		Display some results in screen (33)
		Virtual reality lenses (34)
		Video and script (35)
		Virtual operation scene, a CT image and a virtual ECG monitor developed to simulate the realistic virtual operation environment (46)
	Audios	Hololens device, in the form of a heartbeat at 110 bpm, was audible to the subject as a guide (29)
	Haptic	Phantom (28)
		Modified instruments are inserted through the access port using a haptic interface device (coronary catheters, guidewires, inject contrast dye, and perform diagnostic) (34)
		Was implemented for HTC Vive (HTC, Taoyuan, Taiwan) and Noitom Hi5 VR Glove (36)
		Decoupled haptic device (45)

Table 5. The effects of VR in cardiology interventions training

Theme	Sub-theme	References
Improve user attitude and satisfaction	Increase interest,	(23)
	Self-efficacy	(30)
	Increase satisfaction	(30)
	Enjoy learning	(31)
Improve performance after training with VR	Higher practical skills	(23)
	Improving angiography skills by cardiologist residents	(37, 41)
	Angiography error reduction	(37, 41)
	Improve catheterization skills	(41)
	Improvements in CPR	(36)
	Reduce catheterization time in the real environment	(41)
	Improving the accuracy of surgical interventions	(46)
Improve training and learning	Increased the learning efficacy	(28)
	Positive impact on education,	(29)
	Useful educational tool	(29)
	Increase knowledge of residents	(30)
	Facilitate the learning of pediatric cardiac interventions	(42)
	Improving the efficiency and quality of learning in robotic heart surgery	(43)
	Improve training to run a heart fellowship program	(44)

A review of the trend shows that studies based on training in cardiac interventions using VR have grown significantly in recent years, which could be due to many reasons, including this increase. Studies have been done to realize the importance and role of this technology in cardiac intervention education. On the other hand, the outbreak of the COVID-19 and the closure of some face-to-face training (49), the emphasis on virtual training and reducing direct contact between people, and cutting the transmission chain can also be reasons for increasing the tendency to use VR to train heart interventions. Therefore, using this technology in critical situations like COVID-19

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Table 6. The disadvantages of VR in cardiology training

Row	Disadvantages	References
1	There was no significant performance improvement in practical skills	(23)
2	Further, assess the risks of VR-based education	(23)
3	Extra VR equipment placed on the trainee's body may make chest tightness more difficult.	(36)
4	If the use of VR before training is not common, it may have adverse effects on the depth of massage and Full Chest Relaxation (FCR).	(36)
5	Limitations of realism in some mechanical aspects in VR	(42)
6	Flexibility, accuracy, and inadequate response of the mechanical system of VR	(46)
7	Uncertainty in generalizing the results and proposing to conduct other studies	(45, 46, 48-50)

can be a good alternative.

The study results showed that cardiac catheterization and angiography were the most emphasized in educating VR technology (33, 37, 41, 45). Due to the high sensitivity of cardiac catheterization and angiography and the high risk of performing these interventions in novice physicians or cardiovascular residents, the use of VR for adequate training and education before entering the hospital and inpatient wards is a good option.

The assessments conducted in the study showed that VR implementation time to perform cardiac interventions for residents is very sensitive and should be performed for residents who are at the beginning of the training path and have not performed the relevant intervention for actual patients. If this point is observed, it can expect that training efficiency will increase (44). If VR is added to the training of cardiac residents to perform cardiac interventions, this training should be performed by them before performing actual interventions.

Studies in this field have shown that a large part of the studies on the use of VR to train medical groups in the anatomy of various body organs (50). It suggested that due to the heart organ's nature, VR should be used more in teaching anatomical positions, especially the heart, especially for students of general medicine and other medical and paramedical departments.

The results showed that different platforms such as iOS, Android, computer-based systems, and in some cases, a combination of different media (23, 34, 44, 46) were used to design and use VR. The expansion of VR tools with the ability to run on various platforms has provided the ground for more implementation of this technology in medical education. However, for the widespread implementation of this technology in medical education, in addition to technical aspects, other factors such as economic and cultural factors should be considered. It suggested that more studies should be done in this field.

Many studies have spoken cautiously about the widespread use of VR, emphasizing further studies in this area. In their research, Aeckersberg et al. pointed to the need to assess the risks of VR-based training in basic endovascular skills training (23). Other important issues in many studies in the field have been the limited sample and low chance of generalizing the study results. This is why many studies have suggested further studies in this area.

Another issue with VR-based medical education is the degree to which it is realistic and provides conditions similar to reality in VR tools (46). It is necessary to ensure the level of realism of these tools and how close they are to reality and should be done more studies and experiments on the development of these tools.

Conclusion

The use of VR can improve the efficiency of medical training in clinical settings. Thus, it is recommended to use this technology to train the necessary skills for heart surgery in cardiac residents before performing real surgery to reduce the potential risks and medical errors. Although it can be cost-effective to implement VR -based programs for specialized medical training, one can hope for the cost-effectiveness of this type of training, in the long run, to reduce medical errors in the future. Due to the high risk of cardiac interventions being very sensitive, it needs a high level of clinical skills. If VR improves the skills of performing cardiac interventions by physicians and residents, it can be said that VR will be a cost-effective method. Therefore, it's suggested that medical schools and specialized heart training hospitals set up VR -based cardiac intervention training laboratories to test these methods.

In general, teaching cardiology interventions using VR cannot substitute for conventional methods of teaching residents and other medical students in this field. It is a supportive tool and can be a reliable training before entering the ward and bedside the patient. Under no circumstances should the actual training time be reduced due to VR use.

It is recommended that more studies be conducted about the feasibility of VR in cardiological intervention training. Extensive studies and comparisons of the effect of education using VR with existing educational methods are other recommendations that medical universities can use.

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Conflict of Interests

The authors declare that they have no competing interests.

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