High-fidelity simulation vs video-assisted teaching for early electrocardiography learning - Randomised controlled trial

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ABSTRACT

Introduction: Electrocardiography (ECG) interpretation is a vital yet challenging competency for preclinical medical students due to limited clinical exposure. While high-fidelity simulation teaching (HFST) offers immersive, experiential learning, video-assisted teaching (VAT) provides scalable, consistent instruction. Despite growing interest in both methods, comparative evidence remains limited. This study aimed to evaluate the effectiveness of HFST versus VAT in enhancing ECG knowledge and retention among preclinical students using a Multiple-Choice Question (MCQ) assessment for knowledge cognition.

Materials and Methods: It was a randomised controlled trial study where 136 first year undergraduate medical students were randomised into control (VAT) and intervention (HFST) groups. The intervention group received a 20-minute simulation session using SimMan, demonstrating ECG lead placement, interpretation, and basic management, followed by a 20-minute interactive discussion whereas the control group underwent a VAT session mirroring the HFST content with a 20-minute pre-recorded video followed by a 20-minute faculty-led discussion. MCQs were used to assess the acquisition and retention of knowledge, both as a pre-test (week 1) and a post-test (week 12). The outcomes were measured using the mean and standard deviation of the total scores of MCQ. Intragroup analyses were conducted using a dependent sample t-test, whereas intergroup analyses were performed using an independent samples t-test. ANCOVA was used to assess the difference in post-test MCQ scores among the groups after adjusting the Pre-test scores. The P-value was set at 0.05. "Institutional research trial registration number": RMC_NUIR_2024_21

Results: Both groups demonstrated significant enhancement in knowledge gain and retention from the pre-test to the post-test. The VAT group showed a greater mean score improvement compared to the HFST group. While the VAT group outperformed the HFST group in the post-test, this difference was not statistically significant. Adjusting for pre-test scores using ANCOVA further confirmed the non-significance of post-test score differences between the two groups. Two-way mixed ANOVA revealed no significant interaction between group and time point, indicating comparable patterns of knowledge gain across both teaching methods.

Conclusion: Both HFST and VAT significantly increased knowledge and retention among preclinical medical students. The VAT group showed a slightly higher knowledge gain than the HFST group, although the difference was statistically insignificant. The study demonstrated that both VAT and HFST were effective in mid-term knowledge acquisition and may offer a viable alternative for inclusion in undergraduate preclinical curricula.

KEYWORDS:
High-fidelity Simulation, simulation-based medical education, video-assisted learning, MCQ, RCT

INTRODUCTION

Knowledge of Electrocardiography (ECG) interpretation is an essential competency in medical education that remains a challenging topic for students across various healthcare professions. Accurate interpretation of ECG readings is not merely about memorizing patterns; it demands a deep understanding of how to situate these findings within relevant clinical contexts.[1] This presents a formidable challenge for preclinical medical students, who frequently lack sufficient exposure to real-life cases and practical experiences.[2]

Most medical schools have included ECG-related physiology and pathology in their course curricula, which start in the first year, with learning continuing into the clinical years. However, multiple studies have reported that students often lack the confidence and competence necessary to interpret ECGs during their formative training years accurately.[3,4] While senior medical students may demonstrate adequate proficiency in interpreting basic ECG parameters, they frequently struggle with recognizing complex patterns and emergencies.[5] Consequently, this early gap in training can undermine their confidence, hinder their performance, and foster the belief that mastering ECG-related concepts is an insurmountable task.[2]

In response to this problem, various instructional strategies have been contemplated to enhance ECG teaching. These include blended learning approaches that combine face-to-face instruction with online modules, standalone web-based tutorials and flipped classroom models incorporating team-

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based learning.[2,6-10] These techniques have been reported to enhance learning outcomes due to factors such as increased student autonomy, flexible access to resources, and better conceptual understanding with real-time scaffolding. Despite these innovations, there remains no consensus on the most effective instructional method, particularly concerning long-term retention and clinical applicability in the early preclinical year's perspective.

Simulation-based teaching has gained prominence as an innovative and immersive approach without exposing patients to the associated risks. It helps bridge the gap between theoretical learning and real-world clinical experience.[11] High-fidelity simulation (HFS), which utilizes computer-driven models to replicate clinical scenarios, is increasingly recognized for its ability to foster cognitive skills, clinical reasoning, teamwork, and professional behaviour.[12] It has also been shown to boost student satisfaction and engagement, particularly in settings with limited access to clinical sites or teaching faculty.[13] Furthermore, simulation may augment emotional investment, promoting memory retention, and is believed to prepare students more effectively for patient interactions.[14-16] Evidence supports the efficacy of HFS in delivering immediate knowledge gains and improving long-term retention. A study by Maddry et al. found that although lecture-based instruction was initially effective, students taught via simulation retained information better three months after the intervention.[17] Kashou et al. found web-based self-directed learning to be beneficial.[18] Whereas other RCTs involving flipped classrooms or algorithm-based instruction produced mixed outcomes, citing concerns over instructional clarity and learner adaptation.[19,20] These findings suggest the need for teaching methods tailored to both curricular goals and learner characteristics. Most existing literature focuses on blended or augmented teaching strategies rather than direct comparisons between simulation and standalone video methods. Additionally, recent findings emphasise the use of simulation to reinforce critical decision-making under realistic constraints, which is particularly valuable in ECG interpretation training.[21,22] Video-assisted teaching (VAT) has gained traction due to its scalability and adaptability, which also facilitate the consistent delivery of complex content and allow learners to control the pace of their education.[23] Despite the growing popularity of HFS, its application in ECG instruction for early-stage medical students remains underexplored, particularly through well-designed randomized controlled trials (RCTs). However, while HFS has become more widely used, RCTs directly comparing its efficacy with other methods in ECG education remain limited. Further high-quality evidence is required to validate its benefits and guide curriculum development.[24] In this context, our study aimed to assess the efficacy of high-fidelity simulation as compared to traditional video-assisted lectures in teaching ECG to preclinical medical students. The findings aimed to inform evidence-based curricular decisions and identify the most effective approaches for teaching complex diagnostic skills, such as ECG interpretation.

MATERIALS AND METHODS

Study Design

Randomized Controlled Trial (RCT) study with parallel groups and 1:1 allocation. Please see Figure 1 for the Flow Chart.

Recruitment and Eligibility Criteria

A total of 144 first year MBBS students in the institute (male and female) were recruited after obtaining their written informed consent. The students who declined consent were excluded from the study. The participants were between the ages of 18-21 years. Ultimately, 136 participants completed the study. The number of participants who dropped out of the study was eight (6.25%). The study was conducted between October 2024 and April 2025 (a period of seven months) in the Simulation Lab and Control Room [H.1.4] of Newcastle University Medicine, Malaysia.

Interventions

The participants who were offered VAT were designated as the control group (CG). The intervention group (IG) was provided with high-fidelity simulation teaching (HFST).
Description of Video Assisted Teaching (VAT) for the control group: It was based on a 20-minute pre-recorded video clip demonstrating a simulated case scenario that included ECG lead placements on the mannequin, interpretation of ECG findings, and basic management. It was taught by a faculty who was involved in the delivery of a preclinical curriculum for the MBBS programme at NUMed Malaysia. The video-assisted teaching was immediately followed by an interactive discussion session with the faculty for another 20 minutes.
Description of HFS-based teaching for the Intervention Group: A 20-minute facilitated simulation session identical to that of CG. It was demonstrated on SimMan by another faculty member who was involved in the delivery of a preclinical curriculum for the MBBS program at NUMed Malaysia. The hands-on training session was followed by an interactive discussion session for another 20 minutes.

Description of Hi-fidelity simulator: SimMan Hi-Fidelity Simulator (3G SN: 21247123132) was used for the simulation sessions. It is an advanced emergency care patient simulator designed for high-fidelity simulated scenarios, offering a fully immersive experience. Simulated complex medical cases can be created that enable learners to prepare for real-world situations. It helps learners practice critical skills, such as decision-making and team communication, for developing high-quality patient care.

Outcomes:

All participants appeared for the Pre-test and Post-test knowledge assessments in the first and twelfth weeks. Identical single best answer multiple choice questions (MCQ) were used in both the Pre-test and Post-test for assessing the gain and retention of knowledge.

The usefulness of HFST and VAT methods was assessed by noting the difference in the Pre-test and Post-test scores of the two groups. MCQs were constructed based on the learning outcomes of the interventions.

Sample Size

G* software and data from the pilot study were used for the calculation of the sample size.[25] The value of two independent means for continuous data was estimated by means of 80%

power and 5% type I error. A moderate effect size of 0.44 was accepted based on the pilot study. The sample size thus calculated was 128. 10% was added over it for allowance of dropouts.

Randomisation Process
A computer-generated random sequence method by utilising randomizer.org, was used to randomly assign the participants into control (VAT) and intervention (HFST) groups. A block size of two was applied. An independent member of the research team was involved in the enrolment process. The randomization process was assigned to a biostatistician who was not involved in delivering the interventions. While another member was involved in assigning the participants to their respective rooms for the delivery of the interventions. The outcome assessor and the biostatistician were blinded to the group allocation.

Data Collection
For each session, a cohort of 12 to 14 was recruited. Initially, a briefing was given to the participants regarding the learning outcomes, training course sessions, and the assessment protocol. All of them were informed about the modality of the teaching interventions, confidentiality, and the ethical issues involved. An introduction to the HFS SimMan was made for all participants in the simulation lab to inform them of its functionalities, including the handling of the equipment. They were assured that the training course was not part of the evaluation process for their first-year course curriculum. After the briefing session, all the participants appeared for the first knowledge assessment (Pre-test MCQ) for evaluation of their initial background knowledge about ECG physiology and ECG interpretations of common cardiac pathologies (myocardial ischemia, infarction, hypertrophy, cardiac arrhythmias, heart blocks) that had already been taught as part of the first-year course curriculum. The randomization process followed the Pre-test. Immediately after the briefing session, the participants were randomized into control (VAT) and intervention (HFST) groups. There were 6 to 7 participants in each group after the randomization process. The control group then participated in the VAT session, whereas the intervention group participated in a facilitated HFST session on SimMan. The total duration of both interventions (VAT and HFST) was 40 minutes. There were no provisions for additional teaching sessions for either the VAT or HFST groups during the course of the study. The facilitators involved in delivering the interventions were informed about the importance of maintaining uniformity in the teaching sessions to achieve optimal learning outcomes.

In the 12th week, both VAT and HFST groups appeared for the second knowledge assessment (Post-test MCQ) to assess their gain and retention of knowledge. The Post-test MCQ assessment was delayed, reducing recall bias and providing a better measure of knowledge retention.

Both the Pre-test and Post-test assessments consisted of 20 single-best-answer (A-type) multiple-choice questions (MCQs) to be completed within 20 minutes. The MCQs were designed in accordance with the guidelines of the National Board of Medical Examiners.[26] Each correct answer would receive one point, with no negative marking for incorrect responses. Based on the defined learning objectives, the MCQs were developed by six subject experts in the fields of Pathology, Physiology, Medicine, and Medical Education, all of whom were not part of the research team. The questions focused on ECG-related aspects of physiology, pathology, and interpretation. The MCQs were designed to assess knowledge comprehension, clinical reasoning, and application. Identical MCQs were used for both Pre-test and Post-test assessments. To minimize recall bias, the order of questions was adjusted between the Pre-test and Post-test assessments.

A pilot study involving 36 students was conducted to explore the time management, feasibility, acceptability, and validation of the multiple-choice questions (MCQs). This includes evaluating item difficulty using the difficulty index and item discrimination using the point bi-serial correlation. MCQs with a difficulty index between 20 and 80 and a bi-serial correlation of 0 to 0.14 were considered acceptable for this study. The Optical Mark Recognition (OMR) answer sheets were scanned and analysed using software provided by the Speedwell system (https://www.speedwellsoftware.com).

The students in the VAT group were provided with access to the same high-fidelity simulation sessions at the end of the course to ensure parity in their development of knowledge. Likewise, the HFST group was also given access to VAT at the end of the course. The students who had not consented to the research study were also provided with access to both teaching modalities.

Statistical Analysis
The data was analysed using IBM SPSS software (version 29). Descriptive analysis was used to describe the characteristics of the respondents, including frequency and percentage for categorical data, as well as the overall mean score of the knowledge assessments. An independent samples t-test was used to compare the mean scores of MCQs among the VAT and HFST groups, whereas a dependent samples t-test was carried out for intragroup comparisons of pre and post-knowledge assessments. The difference in post-test MCQ scores between the VAT and HFST groups was calculated using the principle of Analysis of Covariance (ANCOVA) with Pre-test MCQ scores as covariates. The effect size (partial eta squared) was calculated using ANCOVA to compare VAT and HFST Post-test MCQ scores. Cohen's dz was calculated for the intragroup comparison of Pre-test and Post-test MCQ scores. The difference in MCQ scores between the control and intervention groups over assessment time points was calculated using a two-way mixed ANOVA. All the statistical tests were two-sided, and the level of significance (p-value) was set at 0.05.

Institutional research trial registration number: RMC_NUIR_2024_21(12th July 2024)

Ethical registration number: 2900/49590 (27th September 2024)

RESULTS
A total of 136 preclinical medical students were included in the study, with equal allocation to VAT and HFST groups (Table I). The overall gender distribution showed a higher

Table I: Baseline demographic information of the participants

	Groups	Gender		Median Age (years)		Type of students		Total
		Male	Female	Local	International	Local	International	
Enrolled	VAT	28	44	19.1	20.3	36	36	144
	HFST	27	45			32	40	
Dropped out	VAT	3	1			2	2	8
	HFST	2	2			3	1	
Completed	VAT	25	43			34	34	136
	HFST	25	43			29	39	

Table II: Intragroup comparison of pre and post MCQ scores among intervention and control groups. (Dependent samples t-test)

Variable (groups)	n	Mean (SD)		Mean difference (95% CI)	t (df)	p-value	Dz
		Pre-test score	Post-test score				
Control (VAT)	68	8.40 (2.55)	9.65 (3.03)	1.25 (-1.96, -0.54)	-3.525 (67)	< 0.001*	0.428
Intervention (HFST)	68	8.28 (3.33)	9.19 (3.59)	0.91 (-1.73, -0.09)	-2.227 (67)	< 0.001*	0.270

* Significant
n: number of participants
SD: Standard Deviation
CI: Confidence Interval
Dz: Cohen's dz

Table III: Intergroup comparison of pre and post MCQ scores among intervention and control groups. (Independent samples t-test)

Variable (groups)	n	Mean (SD)		Mean difference (95% CI)	t (df)	p-value	Dz
		Control (VAT)	Intervention (HFST)				
Pre-test score	68	8.40 (2.55)	8.28 (3.33)	0.12 (-0.89, 1.12)	0.232 (125)	0.817	0.04
Post-test score	68	9.65 (3.03)	9.19 (3.59)	0.46 (-0.67, 1,58)	0.800 (134)	0.425	0.14

n: number of participants
SD: Standard Deviation
CI: Confidence Interval
Dz: Cohen's dz

Table IV: Intergroup comparison of pre and post MCQ scores among intervention and control groups with Pre-test MCQ scores as covariate (ANCOVA).

Variable (groups)	n	Post-test MCQ score		Mean difference	Observed Power[b]	p-value	Partial Eta Squared
		Mean[a]	Standard Error				
Control (VAT)	68	9.614	0.350	0.39	0.122	0.433	0.005
Intervention (HFST)	68	9.224	0.350				

a. Covariates appearing in the table were evaluated at the following values: Pretest Score = 8.3382.
b. Computed using alpha = 0.05

proportion of females (63.2%) compared to males (36.8%), with identical proportions observed in both study arms. In terms of nationality, the majority of participants were international students (53.7%), compared to Malaysians (46.3%). The HFST group comprised 57.3% international students compared to 42.7% local students, while the VAT group had an equal distribution of international and local students.

Table II illustrates within-group comparisons of Pre-test and Post-test scores. Overall, both groups exhibited a significantly higher gain and retention of knowledge. The VAT group showed greater improvement than the HFST group in terms of mean score difference. The effect size was moderate in the VAT group (Cohen's dz = 0.428). The effect size for the HFST group was small (Cohen's dz = 0.270).

Table III presents the comparison of knowledge gain and retention between the control and the intervention groups. At baseline, the mean score for the VAT group was slightly higher compared to the intervention group. However, this difference was not statistically significant (p = 0.817), indicating comparable baseline knowledge among the participants. In the post-test, the VAT group performed better than the HFST group; however, the difference remained statistically non-significant (p = 0.425). It suggested that neither instructional method (VAT and HFST) had yielded a superior outcome than the other in terms of post-intervention performance. The effect size was small in both groups.

The VAT group showed better performance than the HFST group in the Post-test knowledge assessment. However, after adjusting the pre-test MCQ scores as a covariate, the

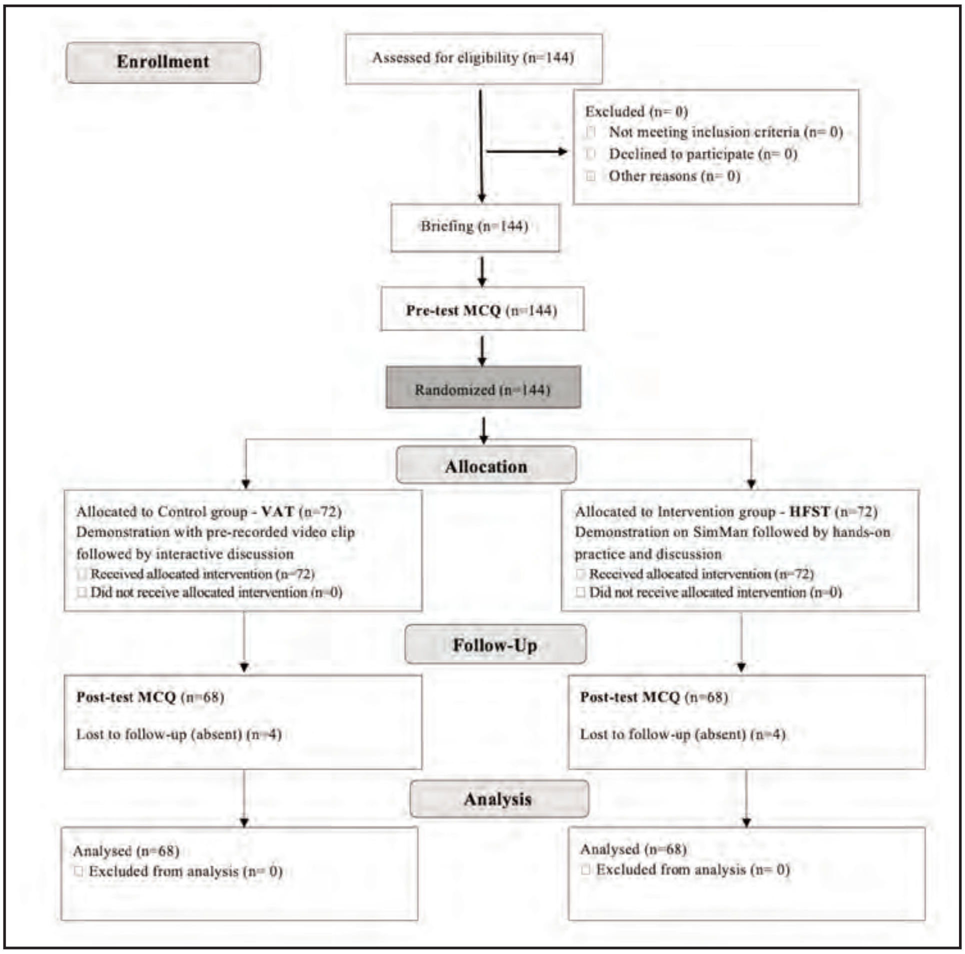

Fig. 1: Flowchart of participant recruitment, intervention, and results.

difference in post-test MCQ scores between the groups was statistically insignificant ($p = 0.433$). The effect size was minimal (See Table IV).

A two-way mixed ANOVA was conducted to evaluate differences in MCQ scores between the VAT and HFST groups across different assessment time points. There was no significant interaction between the type of intervention and time points on MCQ scores was found, indicating similar patterns of knowledge change in both groups. The assumption of homogeneity of variances was satisfied, as evidenced by Levene's test, which pointed no significant difference ($p = 0.410$).

The data of the study is available at https://doi.org/10.25405/data.ncl.27600783

DISCUSSION

Traditional teaching methods, such as didactic lectures and static visual aids, often struggle to provide the interactive and experiential learning crucial for mastering essential skills. Video-assisted teaching (VAT) uses multimedia for consistent and accessible instruction, allowing students to learn independently.[6] While VAT can improve short-term memory, it often fails to foster deep understanding and real-world application of ECG knowledge.[1] Additionally, passive learning methods may not effectively engage students or simulate the dynamic environments they will encounter in practice.[27] With the limitations of traditional methods, there's a shift toward active, learner-centered approaches like high-fidelity simulation teaching (HFST). This transformative approach offers immersive, hands-on experiences replicating real clinical scenarios. Research has demonstrated that these simulations significantly enhance clinical confidence and deepen understanding of complex concepts.[28] In this context, the study aimed to explore the efficacy of two different teaching modalities in the knowledge domain, specifically in mid-term retention of knowledge, based on the positive trends observed in the study's results. The importance of innovative teaching strategies in medical education is being explored worldwide, whereas previous analysis suggested such a combination could maximize learning efficiency and retention.[1,6]

Our study revealed better outcomes in terms of knowledge gain and retention in both teaching modalities. This corroborates the findings of a systematic study performed by Cheng et al., which demonstrated that simulation-based education not only enhances knowledge acquisition but also increases learner confidence, satisfaction, and long-term skill retention.[29] Recent studies have explored the impact of simulation on ECG education. For instance, Zheng et al. found that integrating high-fidelity simulation into cardiovascular physiology increased student engagement, response times, and understanding of ECG principles.[30] The participants who were exposed to HFS teaching scored higher in the Post-test knowledge assessment that reinforces the suitability of HFS inclusion in the preclinical course curriculum.[31]

Mixed learning approaches that combine traditional lectures with interactive elements have been shown to improve understanding and retention of ECG skills.[27] Asynchronous digital platforms with video modules and quizzes have proven to be as effective as conventional lectures for teaching ECG concepts.[32] These methods are associated with increased learner confidence and better retention of ECG skills.[1,6] For example, Viljoen et al. reported that blended learning improved competence and confidence in ECG among medical students compared to traditional methods.[2] Similarly, Olvet and Sadigh highlighted that asynchronous e-modules were as effective as lectures teaching ECG interpretation to first-year students.[6,27]

Conventional teaching modalities help enhance knowledge in some learners, but additional simulation teaching may support greater knowledge gain and overall satisfaction in preclinical medical education.[33] We compared two different teaching interventions that aligned with the findings of the above research studies. While both groups improved, the VAT group demonstrated a larger mean difference than the HFST group, with a higher level of statistical significance and a larger effect size. The VAT group performed better than the HFST group in both Pre-test and Post-test knowledge assessments, although the difference was statistically insignificant. This contradicted the findings of previous studies and the assumption that HFST is superior to VAT.[21,34-38] Our study also highlighted that VAT has a greater impact on knowledge acquisition, which also supported the findings of Alluri et al.[38] Studies directly comparing HFST and VAT were sparse, particularly in the domain of ECG education. Existing evidence suggests that while HFST may excel in skill acquisition and contextual learning, VAT is advantageous for reinforcing theoretical knowledge and enabling flexible, repeated access to material, leading to better outcomes.[39] In ECG instruction, video resources can standardize teaching across diverse student cohorts, ensuring all learners receive equivalent exposure to core concepts, and that may explain the better performance of the VAT group as compared to the HFST group.[2]

This study was able to effectively randomize and allocate students to further stringent the analysis on comparing the effectiveness of HFST and VAT through the MCQ test. There was a similar gender distribution in both the intervention and control groups, hence minimizing gender as the confounding variable in the comparison of the MCQ outcomes. Alongside, both groups had equal sample sizes, which strengthened the statistical power and validity of the results.

STUDY LIMITATIONS

Despite its robust design, this study acknowledged several limitations. First, the generalizability of the findings may be limited due to the single institution setting and small sample size, which could potentially underrepresent diverse student demographics. There is a possibility of selection bias due to the randomization in block size of two, where the allocation of the participants may become predictable. The likelihood of bias could be expected due to the different teaching faculty delivering the interventions in VAT and HFST. This might have influenced the delivery of the content due to variance in teaching styles, ultimately impacting the outcomes of the study. Additionally, the analysis did not control for the baseline academic performance prior to exposure to content or the learning style of students, which could potentially impact the results. Moreover, confounding variables such as discussions between students from different groups, recall memory, and preparation for the Post-test knowledge assessment could potentially influence the results. Further studies could expand on these limitations by including multi-centre studies, longer follow-ups, and additional outcome measures like clinical performance or cost-effectiveness.

CONCLUSION

HFST and VAT demonstrate a similar impact on enhancing the knowledge and retention of pre-clinical students. At baseline, both groups demonstrated equivalent levels of knowledge, with no statistically significant difference. Hence, validating the difference in performance measured later would be due to the teaching approaches rather than any existing gaps. Both HFST and VAT groups showed improvements in knowledge gain and retention. However, the post-intervention analysis showed that the VAT group had performed slightly better than the HFST group. This difference was not statistically significant, indicating that neither teaching method was significantly superior for mid-term knowledge acquisition nor retention. Both teaching approaches appeared to be equally effective in conveying the relevant content. Moreover, with the widespread use of HFST, VAT also demonstrated a higher efficacy as an educational approach for certain learning objectives. Further studies are necessary to compare the cost effectiveness and resource requirements of HFST and VAT in determining the potential benefits for practical implementation. Moreover, long-term outcomes and effectiveness of various teaching methods, adjusting for different variables to identify the most effective approaches in medical education also needs to be explored.

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DECLARATION OF INTEREST

The authors declare that they have not received any funding or benefits to conduct this study and have no conflicts of interest.

REFERENCES

1. Iqbal N, Kandasamy R, O J, R B, Jyothish K. Virtual reality simulation for the acquisition and retention of electrocardiogram interpretation skills: a randomized controlled trial among undergraduate medical students. Cureus 2024; 16(4): e62170.
2. Viljoen CA, Millar RS, Manning K, Burch VC. Effectiveness of blended learning versus lectures alone on ECG analysis and interpretation by medical students. BMC Med Educ 2020; 20(1): 488.
3. Jablonover RS, Lundberg E, Zhang Y, Stagnaro-Green A. Competency in electrocardiogram interpretation among graduating medical students. Teach Learn Med 2014; 26(3): 279-84.
4. Lever NA, Larsen PD, Dawes M, Wong A, Harding SA. Are our medical graduates in New Zealand safe and accurate in ECG interpretation? N Z Med J 2009; 122(1292): 9-15.
5. Kopeć G, Magoń W, Hołda M, Podolec P. Competency in ECG interpretation among medical students. Med Sci Monit 2015; 21: 3386-94.
6. Bazrgar A, Rahmanian M, Ghaedi A, Heidari A, Bazrafshan M, Amini M, et al. Face-to-face, online, or blended: which method is more effective in teaching electrocardiogram to medical students. BMC Med Educ 2023; 23(1): 566.
7. Bojsen SR, Räder SBEW, Holst AG, Kayser L, Ringsted C, Svendsen JH, et al. The acquisition and retention of ECG interpretation skills after a standardized web-based ECG tutorial—a randomised study. BMC Med Educ 2015; 15: 36.
8. Salem AM, Mohamed NMA, Masadeh A. The effectiveness of computer-based simulation on nursing students' electrocardiogram interpretation. Teach Learn Nurs 2023; 18(3): e9-12.
9. Mann AW, Cunningham J, Tumolo A, King C. Evaluating a blended learning model for medical student ECG teaching. South Med J 2023; 116(1): 57-61.
10. Calixte D, Haynes NA, Robert M, Edmond C, Yan LD, Raiti-Palazzolo K, et al. Online team-based electrocardiogram training in Haiti: evidence from the field. BMC Med Educ 2022; 22(1): 360.
11. Maran NJ, Glavin RJ. Medical errors: a common problem. BMJ 2001; 322(7285): 501.
12. Wright SW, Lindsell CJ, Hinckley WR, Williams A, Holland C, Lewis CH, et al. High fidelity medical simulation in the difficult environment of a helicopter: feasibility, self-efficacy and cost. BMC Med Educ 2006; 6: 49.
13. Schoenig AM, Sittner BJ, Todd MJ. Simulated clinical experience: nursing students' perceptions and the educators' role. Nurse Educ 2006; 31(6): 253-8.
14. Lammers RL. Simulation: the new teaching tool. Ann Emerg Med 2007; 49(4): 438-40.
15. Issenberg SB, McGaghie WC, Petrusa ER, Gordon DL, Scalese RJ. Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. Med Teach 2005; 27(1): 10-28.
16. MacDowall J. The assessment and treatment of the acutely ill patient–the role of the patient simulator as a teaching tool in the undergraduate programme. Med Teach 2006; 28(4): 326-9.
17. Maddry JK, Varney SM, Sessions D, Heard K, Thaxton RE, Ganem VJ, et al. A comparison of simulation-based education versus lecture-based instruction for toxicology training in emergency medicine residents. J Med Toxicol 2014; 10(4): 364-8.
18. Kashou AH, Noseworthy PA, Thomas TJ, Anavekar NS, Cullen MW, Angstman KB, et al. EDUCATE: An international, randomized controlled trial for teaching electrocardiography. Curr Probl Cardiol 2024; 49(3): 102409.
19. Wen H, Hong M, Chen F, Jiang X, Zhang R, Zeng J, et al. CRISP method with flipped classroom approach in ECG teaching of arrhythmia for trainee nurses: a randomized controlled study. BMC Med Educ 2022; 22: 850.
20. Rui Z, Lian-rui X, Rong-zheng Y, Jing Z, Xue-hong W, Chuan Z. Friend or foe? Flipped classroom for undergraduate electrocardiogram learning: a randomized controlled study. BMC Med Educ 2017; 17: 53.
21. Pal B, Chong SV, Thein AW, Tay AGM, Soe HHK, Pal S. A randomised controlled trial study on the effectiveness of high-fidelity simulation in enhancing skills among undergraduate medical students. Med J Malaysia 2024; 79(4): 421-8.
22. Reilly A, Spratt C. The perceptions of undergraduate student nurses of high-fidelity simulation-based learning: A case report from the University of Tasmania. Nurse Educ Today 2007; 27(6): 542-50.
23. Hew KF, Lo CK. Flipped classroom improves student learning in health professions education: a meta-analysis. BMC Med Educ 2018; 18(1): 38.
24. Doolen J, Mariani B, Atz T, Horsley TL, O'Rourke J, McAfee K, et al. High-Fidelity Simulation in Undergraduate Nursing Education: A Review of Simulation Reviews. Clin Simul Nurs 2016; 12(7): 290-302.
25. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007; 39(2): 175-91.
26. Case S, Swanson D. Constructing Written Test Questions for the Basic and Clinical Sciences. National Board of Examiners. National Board of Examiners; 2002.
27. Olvet DM, Sadigh K. Comparing the effectiveness of asynchronous e-modules and didactic lectures to teach electrocardiogram interpretation to first year US medical students. BMC Med Educ 2023; 23(1): 360.
28. Pinto AC, Soussi D, Qasim S, Dunin-Borkowska A, Rupasinghe T, Ubhi N, et al. Using animations of cardiac electrical activity to improve medical students' understanding of cardiac pathology and ECG traces. Future Healthc J 2023; 10(Suppl 3): 46-7.
29. Cheng A, Lockey A, Bhanji F, Lin Y, Hunt EA, Lang E. The use of high-fidelity manikins for advanced life support training—A systematic review and meta-analysis. Resuscitation 2015; 93: 142-9.
30. Zheng J, Lapu R, Khalid H. Integrating High-Fidelity Simulation into a Medical Cardiovascular Physiology Curriculum. Adv Med Educ Pract 2020; 11: 41-50.
31. Harris DM, Ryan K, Rabuck C. Using a high-fidelity patient simulator with first-year medical students to facilitate learning of cardiovascular function curves. Adv Physiol Educ 2012; 36(3): 213-9.
32. Gamo JA. Anatomy Education-Paradigm Shift from Passive to Active Learning-Effects on Student Engagement, Comprehension and Retention A Review of Literature from 2012 to 2022. FASEB J 2022; 36(S1).
33. Meyers L, Mahoney B, Schaffernocker T, Way D, Winfield S, Uribe A, et al. The effect of supplemental high Fidelity simulation training in medical students. BMC Med Educ 2020; 20(1): 421.
34. Pal B, Chong SV, Thein AW, Tay AG, Soe HH, Pal S. Is high-fidelity patient simulation-based teaching superior to video-assisted lecture-based teaching in enhancing knowledge and skills among undergraduate medical students? J Health Transl Med 2021; 24(1): 83-90.
35. Pal B, Thein AW, Chong SV, Tay AGM, Soe HHK, Pal S. A randomised control trial study on the efficacy of high-fidelity simulation in enhancing knowledge. Asia Pac Sch 2023; 8(3): 5-14.

36. Solymos O, O'Kelly P, Walshe CM. Pilot study comparing simulation-based and didactic lecture-based critical care teaching for final-year medical students. BMC Anesthesiol 2015; 15(1): 153.
37. La Cerra C, Dante A, Caponnetto V, Franconi I, Gaxhja E, Petrucci C, et al. Effects of high-fidelity simulation based on life-threatening clinical condition scenarios on learning outcomes of undergraduate and postgraduate nursing students: a systematic review and meta-analysis. BMJ Open 2019; 9(2): e025306.
38. Alluri RK, Tsing P, Lee E, Napolitano J. A randomized controlled trial of high-fidelity simulation versus lecture-based education in preclinical medical students. Med Teach 2016; 38(4): 404-9.
39. Toqan D, Ayed A, Khalaf IA, Alsadi M. Effect of High-Fidelity Simulation on Self-Satisfaction and Self-Confidence Among Nursing Students. SAGE Open Nurs 2023; 9.