Original Article

Enhancing the Central Venous Catheterization Competency of Medical Students through a Specialized Team and an Interactive Response System: A pre–post study

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Abstract

Background: Central venous catheterization (CVC) is a critical clinical procedure. To avoid complications, possessing good knowledge regarding the CVC care bundle and skills for the proper insertion and maintenance of CVC are important.

Objectives: To evaluate the effectiveness of an educational intervention and the use of an interactive response system in enhancing the CVC bundle care and insertion skills of medical students undergoing critical care medicine training.

Materials and Methods: Sixth-year medical students (equivalent to fourth-year students in the United States) engaged in didactic lessons, interactive demonstrations, and simulator training facilitated by a CVC team comprising three thoracic and two vascular surgeons (all with a minimum 5 years of experience in central venous access) during their intensive care unit (ICU) rotation. Self-reported knowledge and confidence levels were assessed using pre-and posttests administered through the Zuvio App, an interactive response system.

Results: A total of 60 students underwent the educational intervention, of which 54 completed the pretest and 40 completed the posttest. In the posttest, significant improvement was found in the CVC bundle care competency and understanding ($P = 0.002$), preprocedural preparation ($P = 0.002$), insertion procedures ($P = 0.004$), complications ($P = 0.003$), and insertion depth decisions ($P = 0.001$). Staff and students reported that assessment and interaction via the Zuvio App were valuable, practical, and feasible in a clinical setting, providing trainees with an individual competency portfolio of receiving precise medical education.

Conclusions: Integrating the training provided by a specialized team with an interactive response system enhanced the knowledge and competency level in CVC insertion among medical students in this study.

Keywords: Central venous catheterization, clinical competency, competency-based education, critical care, interactive response system, medical student, skill acquisition

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INTRODUCTION

Central venous catheterization (CVC) is a crucial skill for physicians working in the departments of surgery, critical care, anesthesiology, and emergency medicine, as most central venous catheters are inserted in the intensive care unit (ICU). However, CVC-related complications affect about 15% of the patients.[1] In particular, central venous catheter-associated bloodstream infection (CVC-BSI) has been demonstrated to significantly elevate the risk of mortality,[2] indicating healthcare professionals' need to possess a high level of knowledge regarding the CVC care bundle and of practice skills for the proper insertion and maintenance of CVC.

Studies have suggested that formal instruction and skills training are critical for patient safety because they increase clinical competence and reduce the length of hospital stay, healthcare costs, and surgical mortality.[3,4] Traditional medical learning, often summarized as "see one, do one, teach one," remains valid but can be enhanced.[3] By incorporating diverse learning principles, dedicated mentors, and advanced technology, trainees can improve their surgical skills. This evolution should occur in an environment that prioritizes patient safety.[3,5] Early clinical exposure can enhance competencies, but challenges in its implementation highlight the need for alternatives.

Simulation-based clinical exposure is a viable alternative in resource-constrained settings.[6] Although the benefits of simulation training may improve proficiency in CVC placement, in previous studies, many residents have reported a lack of confidence in performing this invasive procedure.[7-9] To circumvent this issue, in October 2021, we had launched a Central Venous Catheter Access Team (CVC Team) with the mission of "education as the primary focus, with execution as a supplementary aspect" in critical care.[10] The CVC Team, comprising three thoracic and two vascular surgeons with a minimum 5 years of experience in central venous access, taught CVC to trainees, including medical students, to improve the quality of CVC-BSI management. Medical students received CVC bundle care teaching and simulation training at the beginning of the educational intervention. The project yielded positive outcomes, resulting in a reduction in CVC-BSI rates to 3.5% in our institution.[10] However, the high clinical demands and diverse clinical schedules may limit the utility of this traditional lecture-room format.

Research indicates that self-assessment of competence is pivotal in competency-based medical education (CBME) and should be fostered to facilitate lifelong learning.[11] Immediate feedback is an excellent way to increase students' involvement in learning and improving academic achievement. An interactive response system (IRS) provides a solution to challenges faced by instructors, offering opportunities for interactive activities. Many studies have highlighted that the IRS can promote active participation and motivate student learning.[12] This study aimed to determine if educational intervention from a dedicated CVC Team along with the use of an interactive response system helps enhance the knowledge and competency of medical students undergoing critical care medicine training.

MATERIALS AND METHODS

Study design, setting, and participants

This pre–post evaluation study included sixth-year medical students and was conducted between August 2022 to July 2023. The study was conducted in the Tri-Service General Hospital, which is one of Taiwan's largest tertiary medical centers, distinguished for its well-established ICU in northern Taiwan.

In Taiwan, the medical school curriculum has been shortened from 7 to 6 years, following the recommendations of Taiwan's Taskforce of Medical School Curriculum Reform.[13] At the study site, the sixth year covers clinical clerkships in major clinical specialties of surgery, internal medicine, emergency/critical medicine, pediatrics, and obstetrics and gynecology.

Ethical approval for this study was obtained from the Institutional Review Board of Tri-Service General Hospital, Taipei, Taiwan. Written informed consent was obtained from all participants.

Procedures

This integrated program allowed students to interact with the CVC Team through teaching for CVC insertion bundle care, indications, potential complications, and control measures of punctures through a simulator training model (CAE Blue Phantom, BPH 660-HP, CAE Healthcare Inc., Florida, USA). Our training program consisted of intensive teaching sessions lasting 2 hours. The students were divided into two teams, with each team attending two 1-hour training sessions. During these sessions, we implemented a small-group instructional format, with at least three students per group, to ensure personalized attention and effective learning. Furthermore, each student participated in at least two practical hands-on sessions using mannikins to simulate real-life scenarios and enhance their procedural skills.

Students' self-evaluation questionnaire on competency was implemented using the interactive Zuvio App to facilitate effective documentation and meaningful feedback in learning and teaching [Figure 1]. While various IRS tools exist, such as the GoodX system,[14] we used the Zuvio app because it is supported on personal iOS and Android mobile devices. The leader of the CVC Team (Y.M.T., who had >5 years of experience with CVC insertion procedures) designed the questionnaire in collaboration with experts in medical education, clinical practice, and assessment. The questionnaire comprised 10 questions in the central-line care bundle assessment and 8 in the competency assessment.

Students completed this questionnaire before CVC training (pretest) via Zuvio. Then, the supervisor illustrated the CVC procedure using landmark-guided techniques for internal jugular vein cannulation.[15] After the initial session and under a supervisor's guidance, one-on-one sessions were designed to provide individualized learning experiences. Each student received at least two hands-on sessions on mannikins. Subsequently, students again completed the same questionnaire (posttest) on Zuvio. However, due to constraints such as patient availability, ethical considerations, and the need to ensure a controlled learning environment, students mostly observed procedures or practiced in a supervised setting, with actual patients being limited to only some of the students. This approach ensures that each student receives focused instruction and feedback tailored to their educational needs and the practical realities of the ICU setting.

Outcome measures

Each participant independently completed the pre/posttest on the components of the care bundle and an assessment of CVC insertion using an 8-item tool with rating rubrics referring to CVC insertion performance and competency assessment scores. The Zuvio IRS assessment was used to improve student engagement and feedback during the two hands-on CVC insertion experience on mannikins. The correct placement of the CVC was confirmed by puncturing the internal jugular vein, which was filled with blue fluid in the mannikins, and completing the entire procedure, indicating successful cannulation of the vein. The assessment gauged their confidence levels in performing CVC skills, ranging from 1 (not confident) to 5 (highly confident).

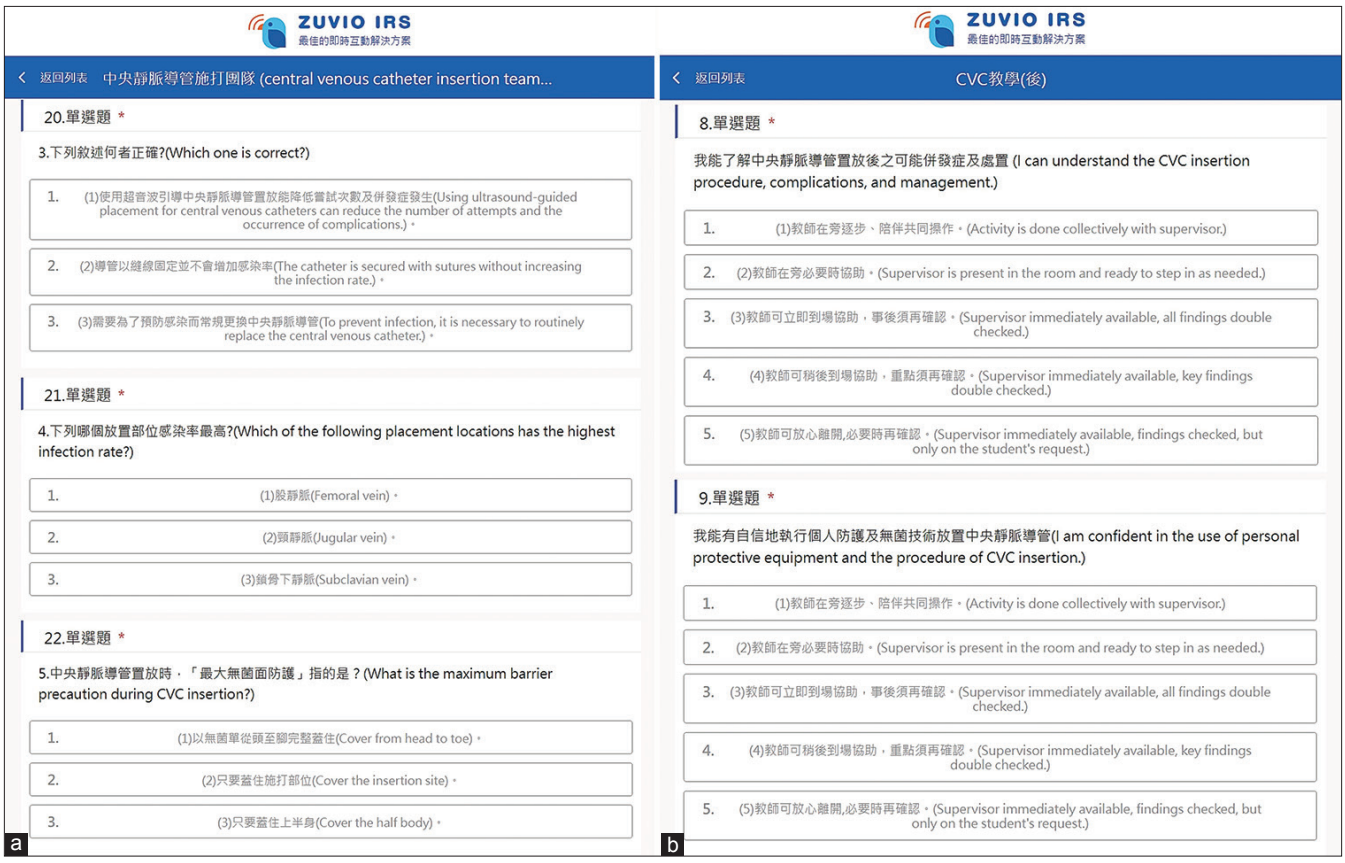

Figure 1: Examples of students logging into the Zuvio Interactive Response System. (a) Students can answer the pretest/posttest and fill in the questionnaire. (b) Teachers and trainees can both directly evaluate their competence and provide personalized feedback

Data analysis

Means and standard deviations were used to summarize continuous data, whereas numerical values and percentages were used for categorical data. Pretest and posttest results were expressed as the correct rate (%), and comparison was performed using unpaired *t*-test. Mann–Whitney *U* tests were used to compare continuous data between the pre- and post-CVC Team intervention groups. A two-tailed *P*- value of <0.05 was considered statistically significant. The statistical analysis was conducted using SPSS version 22 (SPSS Inc, Chicago, IL, USA). A biostatistician provided expertise in data analysis to ensure the accuracy and validity of the statistical findings.

RESULTS

A total of 60 sixth-year medical students completed rotations in the ICU as part of educational interventions covering knowledge, skills, and professional attitudes, of which most were male (n = 49; 81.7%). All students had access to Zuvio for pre-/posttests, questions, responses, and questionnaires. The pretest was completed by 54 students, whereas the posttest was completed by 40 students. The comprehensive CVC education and evaluation framework holistically integrated clinical case discussions, bundle care principles, procedural skills, infection control measures, teamwork dynamics, and postprocedural care considerations. This approach ensured that the students achieved a well-rounded and practical understanding of CVC-related practices.

To determine the students' learning efficiency, pretest and posttest results were expressed as percentage of correct answers on a scale of 0–100 (pretest or posttest/total). Between the two tests, students demonstrated significant improvement in items related to knowledge of care bundle (P = 0.003), common complications (P = 0.044), appropriate timing for replacing sterile dressings (P = 0.044), and CVC-BSI-induced complications (P = 0.044). On the posttest, students exhibited enhanced accuracy in the optimal site for CVC insertion (from 92.6% in the pretest to 100% in the posttest), implementation of maximal barrier precautions (from 90.7% to 95%), understanding of the CVC-BSI definition (from 51.9% to 57.5%), and the recommended timing for catheter replacement if aseptic technique (from 61.1% to 62.5%). However, these improvements were not statistically significant [Table 1].

Using the Zuvio IRS app, students completed a self-assessment of assumed competency in CVC insertion and a questionnaire for each supervisor they worked with. The mean self-assessed proficiency in CVC placement showed statistically significant improvement across knowledge of CVC bundle care, preprocedural preparation, insertion procedures, complications, and understanding of how to decide the insertion depth in CVC [Table 2]. The combination of the expertise of a specialized access team and the user-friendly features of the interactive app delivered guided, formative feedback. Engaging in clinical case discussions and hands-on teaching enhanced students' eagerness to acquire knowledge and develop skills, likely improving their work performance. Table 3 summarizes and presents the students' feedback. Trainees affirmed that the assessment and interaction facilitated by the app were valuable, practical, and feasible for evaluating trainees in a clinical setting. This approach not only provided trainees with a personalized competency portfolio but also supported precise medical education.

DISCUSSION

CVC insertion is a critical procedure requiring precision and expertise to prevent complications. In clinical practice, many patients may experience pain, stress, and catheter-related bloodstream infections owing to challenging venous access.[16] The initial objective of the established CVC Team was to improve patient safety and reduce the incidence of CVC-BSI.[10] However, we observed a deficiency in our trainees' confidence regarding the care-bundle that was taught to students, in their procedural skills, and their ability to address potential issues. The contributing factor could be their infrequent exposure to this invasive procedure from clerkship through residency training. The potential solution to this problem was to increase hands-on practice in a clinical setting. However, medical students face limited opportunities to perform CVCs on patients. In the ICU, patients considered at risk of developing complications are not eligible for students to perform the procedure.

Enhancing hands-on clinical experience in the ICU poses challenges. An alternative approach is simulation training.[17] Pre-procedural ultrasound evaluation effectively identifies the optimal site for catheter insertion by providing a detailed visualization of the anatomy and patency of the veins. This crucial step assists in selecting the most suitable catheter size and type, thereby significantly reducing the risk of complications such as accidental arterial puncture or venous thrombosis. It also enhances the likelihood of successful catheter placement. Post-procedure, the placement of the catheter tip is typically confirmed using a chest X-ray. This method is routinely taught to trainees to ensure accurate positioning and avoid subsequent complications. Although practicing on manikins lacks the diversity found

Table 1: Central-line care bundle assessment

Item	Survey questions	Pretest correct rate (%)	Posttest correct rate (%)	*P*
1	What does the term "care bundle" refer to in the context of healthcare?	81.5	100.0	0.003**
2	What are the common complications associated with placement of a central venous catheter?	92.6	100.0	0.044*
3	What is the rationale for use of ultrasound-guided central venous catheter placement?	88.9	90.0	1.000
4	What is the best site for insertion of a central venous catheter in critically ill patients?	92.6	100.0	0.083
5	What is the maximum-barrier precaution during CVC insertion?	90.7	95.0	0.325
6	What is the definition of central-line-associated bloodstream infection?	51.9	57.5	0.571
7	If uncertainty about the aseptic technique arises during CVC placement due to an emergency situation, when should the catheter be removed and reinserted?	61.1	62.5	0.535
8	What is the appropriate time for replacement of sterile dressing?	88.9	100.0	0.044*
9	What are CVC-BSI-induced complications?	90.7	100.0	0.044*
10	What is the risk factor for CVC-BSIs?	66.7	85.0	0.046*

*$P<0.05$, **$P<0.01$. CVC-BSI – Central venous catheter-related bloodstream infection

Table 2: Median values of self-reported competency assessment

Item	Competency	Preintervention (median score)	Postintervention (median score)	*P*
1	Indication and documentation	3.04	3.95	0.006*
2	Perioperative medication management (pain medicine and sedation)	2.85	3.84	0.002*
3	Anatomy of the cardiovascular system, thorax, and neck	2.72	3.79	<0.001**
4	Evaluation and signs of correct positioning of the CVC	2.89	3.92	0.001*
5	Knowledge of "care bundle"	2.89	3.87	0.002*
6	CVC insertion procedure and complications, including frequency of occurrence	2.85	3.82	0.003*
7	Confidence in personal protective equipment use and in performing CVC insertion procedures	2.87	3.82	0.004*
8	Confidence in the use of ultrasound to identify the artery and vein	2.81	3.92	<0.001**

*$P<0.01$, **$P<0.001$. CVC – Central venous catheterization

Table 3: Feedback responses from all learners

Positive	Comments
Accessibility	There was a live person present to teach
	It is easy to access the Zuvio platform using a mobile phone
Interactivity	Teacher was present onsite
	Instant feedback
Promotion of active participation	One-on-one education was great
	We could watch the instructor perform the task
Self-assessment	We were able to ask questions
	I could determine my level of understanding about the topics
Promotion of deep learning	Lots of fun
	We could physically touch the equipment
Others	Real-world experience with patient contact and patient types
	The patient may have greater safety with a higher success rate of venipuncture
Negative	I was not familiar with the app
	I wanted more time and cases to practice
	Using three-dimensional graphics, such as primal pictures or complete anatomy would enhance our knowledge of anatomy

in actual patients, it still could improve students' dexterity. Furthermore, assessing knowledge of the CVC care bundle in alignment with recommended practices can enable an understanding of learning effectiveness and identification of areas that may require reinforcement in future education.

Utilizing a team approach for CVC insertion has been found to enhance the first-time success rate and has historically been linked to a reduction in complications.[18,19] In the current study, the teaching staff adopted the interactive Zuvio IRS for educational interventions, optimizing the learning value throughout the assessment program. The extensive knowledge and expertise of the specialized team supervisors, along with interactive feedback, provided invaluable experience for teaching and evaluation. Skills training may be challenging owing to work hour restrictions, which may raise concerns about fulfilling healthcare demands and delivering effective medical services. Nonetheless, our model ensured that students practice under the guidance of experienced instructors, accelerating the acquisition of CVC skills. Sequential learning in compliance with bundle care protocols, CVC insertion procedures, followed by integration into seamless performance, can enhance the learning process. Hands-on simulation-based training ensures medical students with essential skills for disease management and core competencies. The model incorporates intensive, targeted training sessions designed to maximize skill acquisition within constrained time frames.

CBME aims to cultivate proficient healthcare professionals through the targeted development of specific competencies. By emphasizing these skills, it seeks to bridge the gap between medical education and real-world patient care, ultimately enhancing the quality of healthcare delivery. The approach also prioritizes learner-centered education, adapting the learning process to individual needs and

fostering active, self-directed learning with continuous assessment and feedback.[20] The current study used self-reported competency statements, as they are crucial for clinical skills development. They offer valuable insights into students' perceptions and confidence levels in performing specific skills. While objective assessments such as multiple-choice questions evaluate theoretical knowledge, self-reported statements capture subjective experiences, aiding educators in identifying areas needing additional support. This holistic approach enhances overall clinical skills development.

Zuvio is a straightforward IRS platform accessible through the web or by scanning the provided QR code, enabling immediate assessment and interactive feedback. Participants in our study expressed the highest appreciation for the effectiveness of Zuvio IRS in facilitating learning, closely followed by a positive perception of the discussion function. Our findings underscore that students found the IRS app to be easy to navigate and operate, with an exceptionally high satisfaction level after the intervention, scoring 9.79/10. All trainers understand the "what," "why," and "how" of each step in their actions.[21] We effectively used interactive technology to enable students to self-assess their confidence in procedural training [Video 1].

The findings of this study demonstrated that integration of training by a specialized team with interactive technology enabled students to assess their knowledge and competence in CVC insertion. Although students learn about anatomy during their time in medical school, the demanding nature of hospital settings underscores the need for ongoing reinforcement of their anatomical knowledge. In the future, hospitals and medical schools should recognize the importance of simulations and hands-on training. Refresher courses, workshops, and updated exercises could enhance anatomical knowledge, refine technical skills, and improve confidence for trainees and medical students. By fostering a culture of continuous learning and emphasizing practical experience, the preparedness of medical professionals can be enhanced, which in turn would improve patient outcomes.

CONCLUSIONS

This study found that educational intervention that was implemented by a specialized team along with the use of an interactive technology enhanced medical students' knowledge and confidence regarding CVC insertion. This indicates that combining theoretical education with practical simulations, hands-on experiences, and mentorship can empower medical professionals to navigate challenging situations with greater competence and confidence, which would eventually improve patient care.

Ethical considerations

Ethical approval for this study was obtained from the Institutional Review Board of Tri-Service General Hospital, Taipei, Taiwan (Ref. no.: A202205157; date: October 2, 2022). All methods were carried out in accordance with relevant guidelines and regulations, including the Declaration of Helsinki, 2013. Written informed consent was obtained from all participants.

Peer review

This article was peer-reviewed by two independent and anonymous reviewers.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author contributions

Conceptualization: Y-M.T. and G-S.H.; Methodology: F-C.L. and Y-W.C.; Data collection: Y-M.T. and S-Y.L.; Data analysis: Y-M.T. and C-S.L.; Writing–original draft preparation: Y-M.T.; Writing – review and editing: Y-M.T. and C-S.L.; Supervision: Y-M.T. and G-S.H.

All authors have read and agreed to the published version of the manuscript.

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Conflicts of interest

There are no conflicts of interest.

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