

QI and EBP

Development of Ultrasound-Guided Peripheral Vascular Access Education for the Nurse Anesthetist: A Quality Improvement Project

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Background

Ultrasound-guided peripheral vascular access was rarely used by Certified Registered Nurse Anesthetists (CRNA) within a large academic hospital since the use of ultrasound had not been common practice among CRNAs.

Objective

The purpose of this quality improvement project was to develop an educational intervention to increase the use of ultrasound for peripheral vascular access among CRNAs by 20% while also improving their knowledge, comfort, and confidence in using the technology.

Design

A pre-intervention survey revealed limited use of ultrasound for peripheral vascular access by practicing CRNAs, despite benefits of enhanced patient care demonstrated in the literature. The educational intervention included a virtual learning module, hands-on simulated training, and pre- and post-intervention knowledge assessments to measure CRNAs' skills in ultrasound-guided techniques.

Results

Post-intervention results demonstrated a 64% increase in ultrasound use, with the average monthly rate of individual usage rising from 2.1 to 3.4 times. Additionally, participants' knowledge scores improved from 52% to 82%, and they reported increased confidence with performing ultrasound-guided vascular access procedures.

Conclusion

While certain barriers, like lack of access to ultrasound machines and time constraints persisted after the intervention, this education effectively addressed individual knowledge and skill gaps. This quality improvement project underscores the value of structured educational programs in advancing the use of ultrasound technology in healthcare. This highlights the importance of ongoing training and education to sustain and improve CRNAs' knowledge and skills.

INTRODUCTION

Ultrasonography is used by anesthesia providers for various procedures, from ultrasound-guided regional nerve blocks to point-of-care ultrasound. At our large midwestern academic hospital, ultrasonography has been underutilized by Certified Registered Nurse Anesthetists (CRNA) since most ultrasound procedures fall under the physician scope of practice at this institution. On January 30th, 2021, the Council on Accreditation of Nurse Anesthesia Educational

Programs required ultrasound guided vascular access (USGVA) education be incorporated into nurse anesthesia program curriculum. The knowledge and skills nurse anesthesia students have developed in USGVA from their formal education prompted greater interest among the CRNAs of our institution to gain the education and experience needed to become proficient at this valuable skill. A prior survey at our institution revealed 52% of current CRNAs never received USGVA training during their formal anesthesia education and 64% never received USGVA training after their formal anesthesia education. The education and/

or training CRNAs did report receiving was reported to be self-taught or peer guided. To succeed in ultrasound-guided procedures, proper education and experience are essential for CRNAs, particularly when encountering patients with difficult intravascular access.

This quality improvement (QI) project aimed to enhance ultrasound use for arterial and venous peripheral vascular procedures through the development and implementation of an online education module and hands-on simulation-based training. The primary aim was to increase the use of USGVA by 20% from baseline, with secondary aims of increasing knowledge, comfort, and confidence of CRNAs performing USGVA procedures.

BACKGROUND

Obtaining reliable intravascular access is a fundamental skill for CRNAs. Venous cannulation is essential for administering medications, fluids, and blood products and arterial cannulation is often required for continuous arterial blood pressure monitoring and laboratory testing.¹⁻⁴ Traditionally, CRNAs identify target vessels using landmark techniques, relying on presumed anatomical location, surface anatomy, and manual palpation.^{1,3-16} Difficult intravascular access is associated with extremes of chronological age, obesity, diabetes, intravenous drug use, end-stage renal disease, vascular pathology, hypovolemia, and hypotension among other factors.^{1-4,6-11,17} Difficult intravascular access often leads to multiple attempts, decreased patient comfort and satisfaction, increased need for central venous access, and treatment delays.^{1,2,5-8,11,16}

Real-time ultrasound guidance enhances the likelihood of successful cannulation on the first attempt.^{2-4,16-22} Ultrasound guidance is also associated with shorter time to successful cannulation, greater patient satisfaction, and fewer complications.^{4,5,7,11,13,14,17,19,20,22} This demonstrates why ultrasound is now the standard of practice for central venous access, given the complications that may occur without it.^{5,6,10-12,14} By providing real-time, 2-dimensional imaging of anatomical structures, ultrasound offers a more objective assessment than traditional methods of palpation and direct visualization.¹⁴ Ultrasound enables the CRNA to assess suitable vascular targets through visualizing anatomical variations such as changes in vessel size, bifurcations, thromboses, calcifications, as well as vessel's relation to neighboring structures such as nerves and other vasculature.^{12,14,21,23} Given the rise in obesity in the United States, the demand for ultrasound guidance in identifying deeper vessels has become necessary.^{7,11,12} Many institutions recommend that only qualified personnel with adequate ultrasound training use ultrasound guidance for peripheral vascular access procedures.^{4,6,11} For hands-on procedures like USGVA, providers are encouraged to complete sufficient training, including didactic instruction, simulation-based practice, supervised skill performance in the clinical setting, and performance evaluations.^{4,6,11,19}

Previous studies on USGVA education have incorporated didactic education coupled with hands-on competency assessments to demonstrate proficiency.^{6,11,16,19-21} For in-

stance, Bhargava et al⁶ studied a group of nurses performing first and second attempt peripheral intravenous (PIV) cannulation on pediatric patients using traditional landmark techniques. After completing a 1 hour didactic session and hands-on training in ultrasound-guided PIV access, the nurses achieved statistically significant improvements in PIV success rates with an increase from 47.3% to 85.9% for first attempts and 54% to 92.2% for second attempts.⁶

Competency thresholds varied among studies. For example, Adhikari et al⁹ deemed learners to be competent once they demonstrated successful cannulation on a simulation model, while Anderson et al⁸ measured competence after at least 9 successful cannulations post-education.⁶ Note that when introducing a new technique, practice and experience are necessary to achieve competence. Ultrasound-guided vascular procedures require fine motor skills and precise hand-eye coordination to guide the needle tip into a vessel which can be challenging for novice practitioners that are not familiar with ultrasound.¹¹

METHODOLOGY

This QI project was deemed exempt from Institutional Review Board approval and supported by the anesthesia department's clinical practice committee. The primary goal was to increase ultrasound use by CRNAs for peripheral vascular access procedures, with secondary goals of enhancing ultrasound knowledge, comfort, and confidence in USGVA.

STEP ONE: NEEDS ASSESSMENT

A needs assessment survey was distributed via the internal Research Electronic Data Capture (REDCap) system to all CRNAs within a large, midwestern academic hospital and was completed by 50% of CRNA staff. CRNAs who reported difficult intravascular access (1-2 times/month: 52%; 3-5 times/month: 26%; 5 or more times/month: 18%) rarely chose to utilize ultrasound (never: 39%; 1-2 times: 38%; 3-5 times: 11%; 5 or more times: 11%). Eighty-five percent of the CRNAs who completed the survey agreed or strongly agreed that proficiency in USGVA is a necessary skill of CRNAs, however 58% felt they did not have the training or experience necessary to perform USGVA independently. Ninety percent of the CRNAs indicated interest in formal ultrasound education and hands-on training for USGVA.

STEP TWO: ONLINE MODULE DEVELOPMENT

The use of ultrasound for any procedure requires knowledge of ultrasound technology, sonoanatomy, ultrasound transducer orientation, and proper body ergonomics. An online module was created with the help of institution-supported medical photographers, medical animation specialists, and instructional designers specializing in education. The module was divided into 4 lessons and took approximately 60 minutes to complete.

The first lesson covered ultrasound technology and physics. An interactive video provided an overview of ultra-

sound frequency, soundwave reflection, and attenuation artifact affecting soundwave transmission. The 3 most common ultrasound transducers, linear, curvilinear, and phased array, were discussed including ultrasound frequency, ultrasound wave distribution, and common uses for each transducer. The high frequency linear transducer was designated as the preferred ultrasound transducer for USGVA, since it provides the best resolution of small structures less than 6 centimeters in depth.

The second lesson focused on vascular anatomy, including the most common venous and arterial anatomical structures within the upper extremity. Examples of the expected sonoanatomy and anatomical relationships of veins, arteries, and nerves, and the echogenic differences between these structures were also provided. Anatomical knowledge of arteries and veins is crucial for the CRNA to identify the specific target vessels in a systematic and timely manner. It is equally important for the CRNA to know the location of surrounding structures to prevent iatrogenic complications during vascular access procedures.

The third lesson covered ultrasound machine preparation. The lesson provided interactive images on machine set up allowing the participant to practice adding patient information, choosing the appropriate linear transducer, and positioning the ultrasound machine to allow proper ergonomics for the provider. The last portion of this lesson included a video on proper sterile sheath application of the transducer.

The final lesson included instructions on how to orient the transducer to the ultrasound screen and how to scan the target vessel and surrounding anatomy. Once the vessel was identified, the learner was instructed to optimize image resolution by adjusting gain and depth and demonstrate proper transducer mechanics to center the vessel on the ultrasound screen. Lastly, while holding the ultrasound transducer with the nondominant hand and catheter/needle with the dominant hand, 2 styles of dynamic out-of-plane techniques were demonstrated via videos.

For shallow vessels (< 0.5 cm deep), the tilting technique was demonstrated starting with the transducer tilted toward the insertion site to visualize the needle tip prior to vessel puncture. Once the needle tip is identified as a hyperechoic dot on the ultrasound screen, the transducer is tilted away from the insertion site to follow the needle tip into the vessel. For deeper vessels (> 0.5 cm deep), the sliding technique was demonstrated starting with the transducer perpendicular to the skin. Once the needle tip is identified, the transducer is slid away from the insertion site, stopping when the needle tip is no longer identified on the ultrasound screen. The needle is then advanced until it reappears, and this sliding process is repeated until the needle tip is guided into the vessel. The final portion of this lesson demonstrated how to save an image for proper electronic medical record documentation.

Included in the education module was a pre- and post-education test to measure knowledge acquisition. The questions for the pre- and post-test were the same. To measure the change in participant knowledge, the pre-test answers were not released. Once the learner completed the

online module and post-test, the questions and answers were shared with the learner for review.

STEP THREE: HANDS-ON SIMULATION-BASED TRAINING DEVELOPMENT

Three simulation stations were created to measure the learner's understanding of the educational material and allow an opportunity for hands-on practice. The first station included anatomical identification of specific structures of the upper extremity via ultrasound. Each CRNA was asked to identify various veins, arteries, and nerves on a human volunteer including: the cephalic vein of the forearm, the basilic vein of the upper arm, the radial artery at the wrist, the ulnar nerve at the wrist, the brachial artery at the cubital fossa, and the median nerve at the cubital fossa. The other 2 stations measured the learner's ultrasound technique when cannulating arterial and venous structures on gel models using the dynamic short-axis, out-of-plane technique. Participants had the choice of using either the tilting or sliding technique for each station. The hands-on training allowed participants to practice these techniques on artificial models under instructor guidance before utilizing these techniques in clinical practice. Participants used institution-provided ultrasound machines and a linear transducer for each station.

STEP FOUR: IMPLEMENTATION

To support statistical significance, a sample size of 30 volunteers was deemed sufficient as a participant group. Given the possibility of some CRNAs not completing portions of the project, the goal for the initial group of CRNA participants was 50 volunteers. Seventy-nine CRNAs replied to an email invitation volunteering to participate in the project. Fifty CRNAs were randomly selected using a random draw generator, representing all 10 specialty practice areas. Of the 50 volunteers invited to participate, 39 completed every aspect of the project including pre- and post-surveys, the educational module, and in-person simulation training.

Prior to assigning the online education, a survey was sent to the study group via REDCap to assess their current estimated use of USGVA over the span of 1 month, confidence in their knowledge of ultrasound, comfort with using the technology, and any barriers encountered to the use of USGVA. Once the survey was complete, they were assigned the online module and were asked to complete the module including the pre- and post-tests within 2 weeks. The hands-on simulation-based training was held on 2 separate days and CRNAs used their personal time to participate. This training was conducted within a large conference room setting where 3 stations were set up for each skill. Each volunteer spent 30 minutes completing the 3 stations and received 1:1 observation and instruction. Three months after participants completed the education, a post-survey was sent via REDCap to again assess their current estimated use of USGVA over 1 month's time, confidence in their knowledge of ultrasound, and comfort with using the technology. Existing barriers to the use of ultrasound were also evaluated.

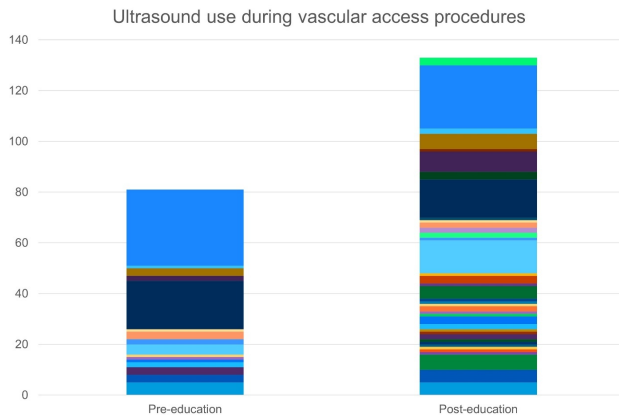


Figure 1. Ultrasound Use During Vascular Access Procedures

Each color represents a single participant's self-reported ultrasound use pre- and post-education.

RESULTS

Study data was analyzed using BlueSky Statistics® software and was solely the work of the authors. The primary aim of increasing the use of ultrasound by 20% from baseline was exceeded with a pre-education combined estimated use of 81 times and a post-education estimated use of 133 times. This is a 64% increase in use (see [Figure 1](#)).

Pre- and post-survey results were analyzed using the Wilcoxon paired-sample test. A p-value of < 0.05 was used to determine statistical significance. Results from the secondary aims revealed a statistically significant improvement in how each CRNA perceived their comfort ($p = 0.0004$) (see [Figure 2](#)), knowledge ($p = 0.008$) (see [Figure 3](#)), and confidence ($p = 0.0003$) (see [Figure 4](#)) using ultrasound technology.

Barriers preventing volunteers from utilizing ultrasound changed from pre- to post-intervention. Before the education, participants reported more internal barriers such as lack of skill, knowledge, and training. Following the education, less internal barriers were reported but external barriers remained, such as ultrasound availability, lack of time before a case, and current work culture (see [Figure 5](#)).

Post-education results show a large decrease in education related reasons (blue colors) such as lack of skill, lack of knowledge, and time needed to train.

Participant knowledge was also assessed within the online module with 10 questions pre- and 10 questions immediately post-completion of the module. The McNemar's test was used to compare the pre- and post-tests and a p-value of < 0.05 indicated statistical significance. All questions revealed an improvement in knowledge with 6 of the questions showing a statistically significant difference (see [Table 1](#)).

DISCUSSION

This QI project addressed the need for ultrasound education as identified through barriers by CRNA participants.

This project adds to current literature on the successful use of a structured online learning module enhanced by hands-on simulation-based training. This project led to increased use of ultrasound by CRNAs through increased knowledge, comfort, and confidence. This project also decreased individual barriers through education and training.

Much of the literature detailing educational projects like this one focused on first attempt success rates as a primary goal.^{2-4,16-22} This QI project did not compare first attempt success rates using traditional methods versus ultrasound guidance. As previously discussed, outcomes among novice practitioners using ultrasound may not show increased first attempt success or decreased time to cannulation due to the steep learning curve necessary to become proficient in USGVA.¹¹ This may deter those who are already successful with traditional vascular access methods to trial USGVA considering they may initially struggle.

It was difficult finding time, space, and support during the work week to complete the hands-on training. Allowing the hands-on practice to occur within a reasonable amount of time following the education, CRNA participants used personal time on 1 of 2 days to complete the hands-on simulation-based training within the project's pre-determined timeline.

Through pre- and post-surveys, CRNAs self-reported their use of ultrasound over 1 month's time. The authors are aware that this data is subjective and there is potential for bias considering no true measurement was used. Having participants estimate their use was the only feasible measurement option as the electronic medical record is not routinely used to document ultrasound use and the CRNA population is too large to incorporate observation-based measurement in a project of this caliber.

In a busy, constantly changing healthcare environment, CRNA retention was challenging. Throughout the project's many phases, CRNAs retired, changed departments, and ended employment altogether. Many other volunteers completed only a portion of the project with some completing no portions at all. Because of this, the participant group was not as robust as initially planned but still exceeded the minimum sample size as determined by the a priori analysis. Various methods were employed to keep participants active and involved including frequent in-person and email communication and providing treats during simulation-based training sessions.

Other barriers to ultrasound use were identified through the project's pre- and post-surveys and offer opportunities for future QI work. These include items such as lack of access to an ultrasound machine, lack of time before the case, conflict with other specialties or groups when choosing to use ultrasound, and current work culture. These barriers are unique to this institution and may differ when compared to barriers at other institutions. A thorough identification of barriers should be performed if this project were to be duplicated at an outside institution. Limitations to this project include the inability to measure any level of CRNA competence in USGVA which would require a formal measuring tool and supervision by a designated evaluator during clinical performance when using USGVA.

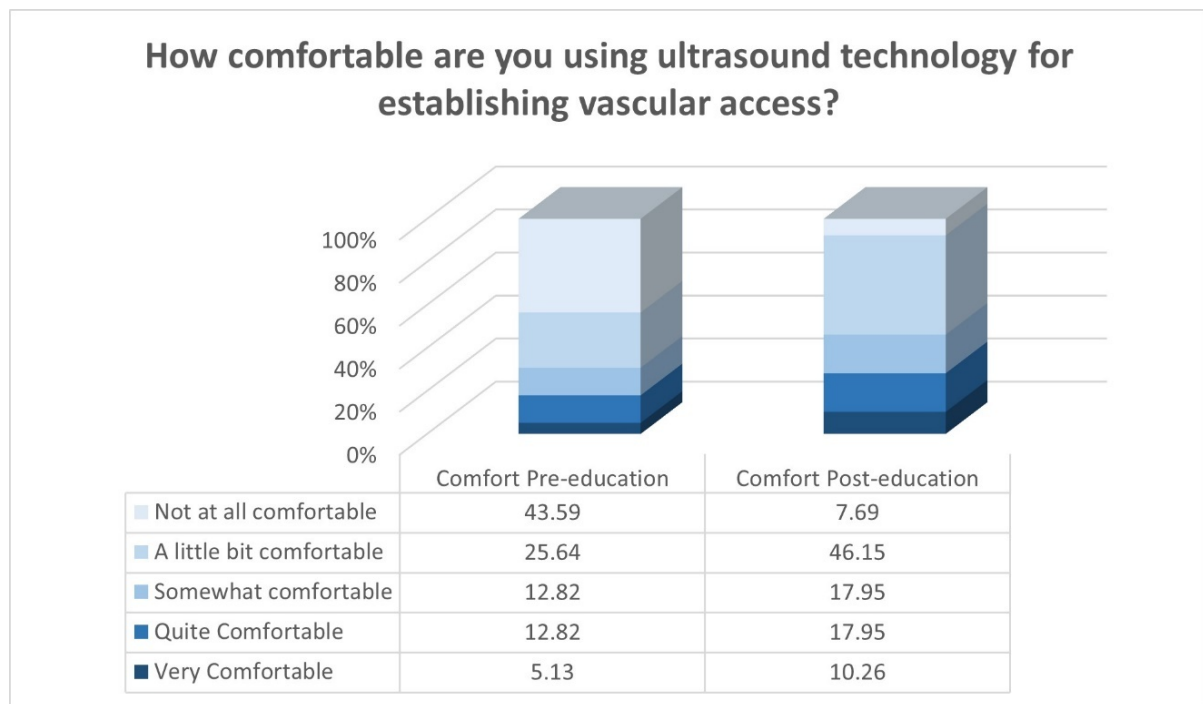


Figure 2. CRNA Comfort Using USGVA

Wilcoxon paired-sample test revealed a statistically significant increase in CRNA comfort using USGVA ($p = 0.0004$).

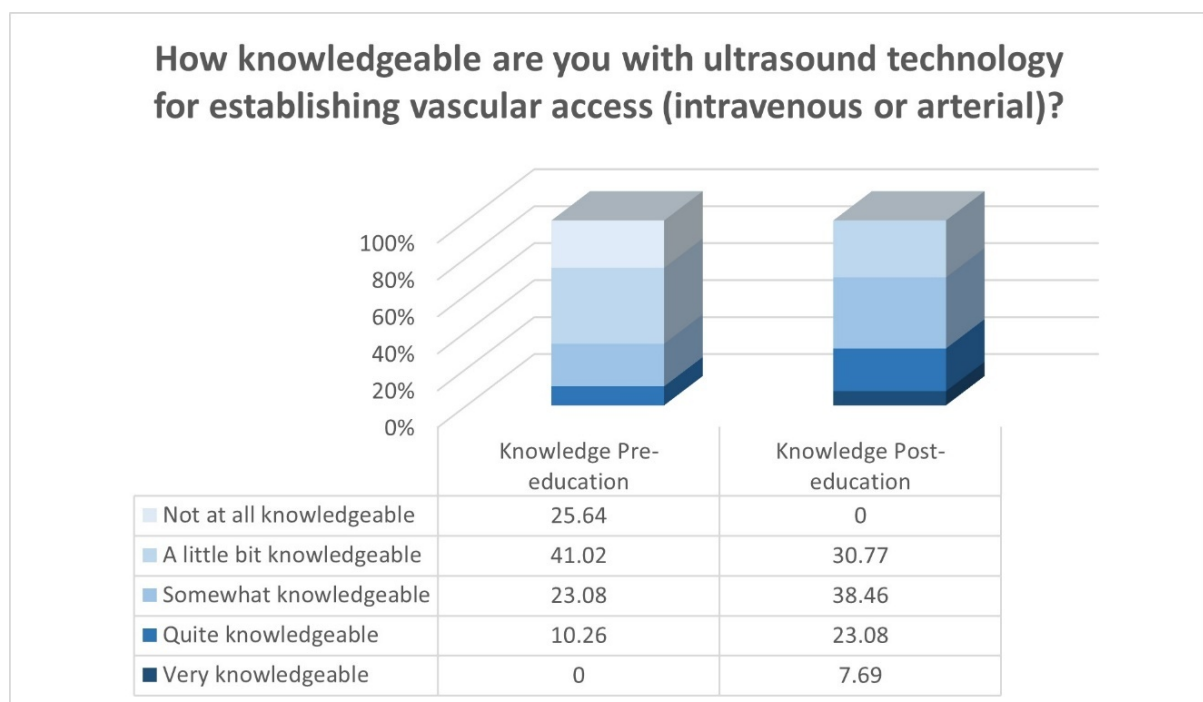


Figure 3. CRNA Knowledge Using USGVA

Wilcoxon paired-sample test revealed a statistically significant increase in CRNA knowledge of ultrasound technology for USGVA ($p = 0.008$).

CONCLUSION

Through the implementation of a structured ultrasound education program, we aimed to assess the impact on participants' utilization with a primary objective of increasing ultrasound use by 20%. At 6 months following the formal-

ized education, the participants' use had increased to 64%. Pre- and post-education test results revealed significant improvements in participants' ultrasound knowledge. Furthermore, participants reported increased comfort and confidence after receiving the training. Findings highlight the efficacy of a structured ultrasound education program in

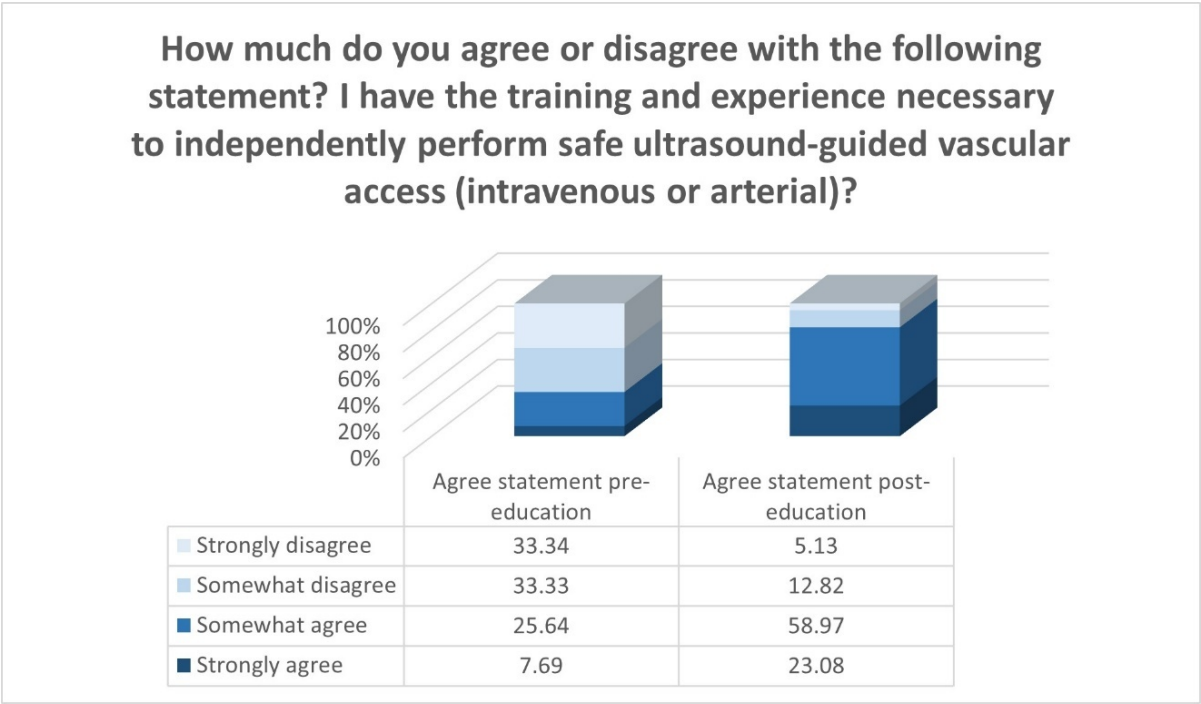


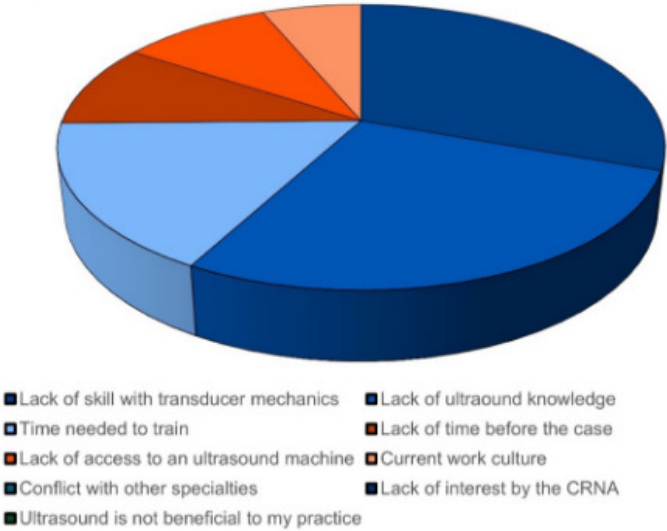
Figure 4. CRNA Confidence When Performing USGVA

Wilcoxon paired-sample test revealed a statistically significant increase in CRNA confidence when performing USGVA ($p = 0.0003$).

enhancing both utilization rates and participants’ knowledge and skills. These results emphasize the importance of continuous education and training in healthcare settings to improve patient care outcomes and staff satisfaction.

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Reasons participants did not use ultrasound for peripheral vascular access procedures - Pre-education



Reasons participants did not use ultrasound for peripheral vascular access procedures - Post-education

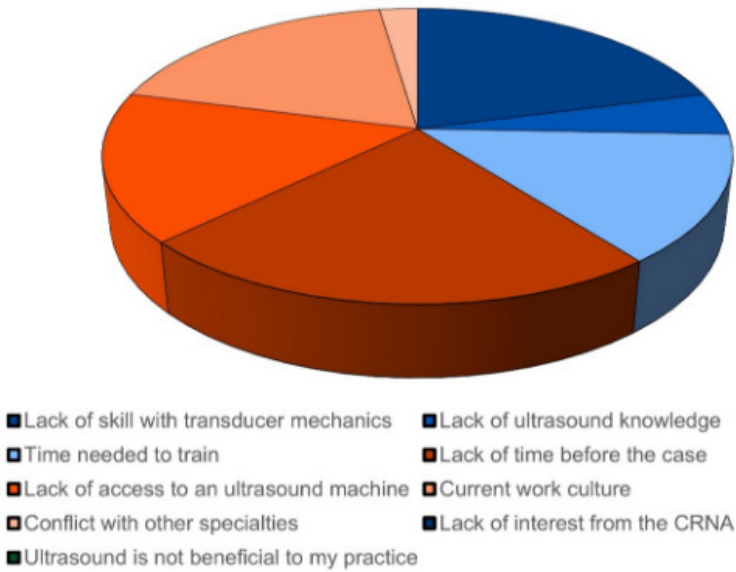


Figure 5. Barriers Hindering the Use of Ultrasound for Vascular Access Procedures

Questions	Pre-education (n=39) Correct	Post-education (n=39) Correct	p-value
Q1	20 (51%)	36 (92%)	0.0001
Q2	9 (23%)	30 (77%)	< 0.0001
Q3	22 (56%)	32 (82%)	0.0063
Q4	17 (44%)	25 (64%)	0.0963
Q5	33 (82%)	35 (90%)	0.4531
Q6	29 (74%)	39 (100%)	< 0.0001
Q7	16 (41%)	34 (87%)	< 0.0001
Q8	10 (26%)	32 (82%)	< 0.0001
Q9	14 (36%)	20 (51%)	0.1460
Q10	33 (85%)	37 (95%)	0.2891
Total number correct	203 (52%)	320 (82%)	< 0.001
Means: Pretest 5.2 w/ SD of 1.9 Means: Posttest 8.2 w/ SD of 1.5			

Table 1. McNemar's Test



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REFERENCES

1. Briggs CV, Smith-Steinert R, Bakis M. Continuing education for the Certified Registered Nurse Anesthetist: ultrasound-guided peripheral intravenous access. *J Contin Educ Nurs*. 2021;52(10):489-492. doi:[10.3928/00220124-20210913-09](https://doi.org/10.3928/00220124-20210913-09)
2. Bahl A, Pandurangadu AV, Tucker J, Bagan M. A randomized controlled trial assessing the use of ultrasound for nurse-performed IV placement in difficult access ED patients. *Am J Emerg Med*. 2016;34(10):1950-1954. doi:[10.1016/j.ajem.2016.06.098](https://doi.org/10.1016/j.ajem.2016.06.098)
3. Panebianco NL, Fredette JM, Szyld D, Sagalyn EB, Pines JM, Dean AJ. What you see (sonographically) is what you get: vein and patient characteristics associated with successful ultrasound-guided peripheral intravenous placement in patients with difficult access. *Acad Emerg Med*. 2009;16(12):1298-1303. doi:[10.1111/j.1553-2712.2009.00520.x](https://doi.org/10.1111/j.1553-2712.2009.00520.x)
4. Pitman JS, Buscemi M, Funk EM, Weaver S, Thompson JA, Falyar C. Incorporating evidence-based ultrasound-guided vascular access (USGVA) standards into the nurse anesthetist armamentarium: a quality improvement project. *J Perianesth Nurs*. 2023;38(4):564-571. doi:[10.1016/j.jopan.2022.11.014](https://doi.org/10.1016/j.jopan.2022.11.014)
5. van Loon FHJ, Buise MP, Claassen JJF, Dierick-van Daele ATM, Bouwman ARA. Comparison of ultrasound guidance with palpation and direct visualisation for peripheral vein cannulation in adult patients: a systematic review and meta-analysis. *Br J Anaesth*. 2018;121(2):358-366. doi:[10.1016/j.bja.2018.04.047](https://doi.org/10.1016/j.bja.2018.04.047)
6. Bhargava V, Su E, Haileselassie B, Davis D, Steffen KM. Ultrasound education improves safety for peripheral intravenous catheter insertion in critically ill children. *Pediatr Res*. 2022;91(5):1057-1063. doi:[10.1038/s41390-021-01568-6](https://doi.org/10.1038/s41390-021-01568-6)
7. Laksonen RP Jr, Gasiewicz NK. Implementing a program for ultrasound-guided peripheral venous access: training, policy and procedure development, protocol use, competency, and skill tracking. *Nurs Clin North Am*. 2015;50(4):771-785. doi:[10.1016/j.cnur.2015.07.010](https://doi.org/10.1016/j.cnur.2015.07.010)
8. Anderson AP, Taroc AM, Wang X, Beardsley E, Solari P, Klein EJ. Ultrasound guided peripheral IV placement: an observational study of the learning curve in pediatric patients. *J Vasc Access*. 2022;23(2):250-256. doi:[10.1177/1129729820987958](https://doi.org/10.1177/1129729820987958)
9. Adhikari S, Schmier C, Marx J. Focused simulation training: emergency department nurses' confidence and comfort level in performing ultrasound-guided vascular access. *J Vasc Access*. 2015;16(6):515-520. doi:[10.5301/jva.5000436](https://doi.org/10.5301/jva.5000436)
10. Bortman J, Mahmood F, Mitchell J, et al. Ultrasound-guided intravenous line placement course for Certified Registered Nurse Anesthetists: a necessary next step. *AANA J*. 2019;87(4):269-275.
11. Bullington PW, Reed JR, Owens DL, Rothers JL, Peek GJ, Herring C. Improving healthcare professionals' ultrasound-guided peripheral vascular access ability utilizing self-assembled ultrasound phantoms: a prospective, observational quality improvement project. *J Vasc Access*. Published online May 27, 2024. doi:[10.1177/11297298241254633](https://doi.org/10.1177/11297298241254633)
12. Weiner MM, Geldard P, Mittnacht AJ. Ultrasound-guided vascular access: a comprehensive review. *J Cardiothorac Vasc Anesth*. 2013;27(2):345-360. doi:[10.1053/j.jvca.2012.07.007](https://doi.org/10.1053/j.jvca.2012.07.007)
13. Maecken T, Grau T. Ultrasound imaging in vascular access. *Crit Care Med*. 2007;35(5 Suppl):S178-S185. doi:[10.1097/01.CCM.0000260629.86351.A5](https://doi.org/10.1097/01.CCM.0000260629.86351.A5)
14. Lamperti M, Bodenham AR, Pittiruti M, et al. International evidence-based recommendations on ultrasound-guided vascular access. *Intensive Care Med*. 2012;38(7):1105-1117. doi:[10.1007/s00134-012-2597-x](https://doi.org/10.1007/s00134-012-2597-x)
15. Avelar AF, Peterlini MA, da Luz Gonçalves Pedreira M. Ultrasonography-guided peripheral intravenous access in children: a randomized controlled trial. *J Infus Nurs*. 2015;38(5):320-327. doi:[10.1097/NAN.0000000000000126](https://doi.org/10.1097/NAN.0000000000000126)
16. McCarthy ML, Shokoohi H, Boniface KS, et al. Ultrasonography versus landmark for peripheral intravenous cannulation: a randomized controlled trial. *Ann Emerg Med*. 2016;68(1):10-18. doi:[10.1016/j.annemergmed.2015.09.009](https://doi.org/10.1016/j.annemergmed.2015.09.009)
17. Doniger SJ, Ishimine P, Fox JC, Kanegaye JT. Randomized controlled trial of ultrasound-guided peripheral intravenous catheter placement versus traditional techniques in difficult-access pediatric patients. *Pediatr Emerg Care*. 2009;25(3):154-159. doi:[10.1097/PEC.0b013e31819a8946](https://doi.org/10.1097/PEC.0b013e31819a8946)

18. Bouaziz H, Zetlaoui PJ, Pierre S, et al. Guidelines on the use of ultrasound guidance for vascular access. *Anaesth Crit Care Pain Med*. 2015;34(1):65-69. doi:[10.1016/j.accpm.2015.01.004](https://doi.org/10.1016/j.accpm.2015.01.004)
19. Kaganovskaya M, Wuerz L. Development of an educational program using ultrasonography in vascular access for nurse practitioner students. *Br J Nurs*. 2021;30(2):S34-S42. doi:[10.12968/bjon.2021.30.2.S34](https://doi.org/10.12968/bjon.2021.30.2.S34)
20. Kantor DB, Su E, Milliren CE, Conlon TW. Ultrasound guidance and other determinants of successful peripheral artery catheterization in critically ill children. *Pediatr Crit Care Med*. 2016;17(12):1124-1130. doi:[10.1097/PCC.0000000000000936](https://doi.org/10.1097/PCC.0000000000000936)
21. Millington SJ, Hendin A, Shiloh AL, Koenig S. Better with ultrasound: peripheral intravenous catheter insertion. *Chest*. 2020;157(2):369-375. doi:[10.1016/j.chest.2019.04.139](https://doi.org/10.1016/j.chest.2019.04.139)
22. Otani T, Morikawa Y, Hayakawa I, et al. Ultrasound-guided peripheral intravenous access placement for children in the emergency department. *Eur J Pediatr*. 2018;177(10):1443-1449. doi:[10.1007/s00431-018-3201-3](https://doi.org/10.1007/s00431-018-3201-3)
23. Troianos CA, Hartman GS, Glas KE, et al. Special articles: Guidelines for performing ultrasound guided vascular cannulation: recommendations of the American Society of Echocardiography and the Society Of Cardiovascular Anesthesiologists. *Anesth Analg*. 2012;114(1):46-72. doi:[10.1213/ANE.0b013e3182407cd8](https://doi.org/10.1213/ANE.0b013e3182407cd8)