

Biplane Imaging Versus Standard Transverse Single-Plane Imaging for Ultrasound-Guided Peripheral Intravenous Access: A Prospective Controlled Crossover Trial

OBJECTIVES: Obtaining peripheral IV access in critically ill patients is often challenging especially for novice providers. The availability of biplane imaging for ultrasound guided peripheral access has the potential to improve successful venous cannulation compared with standard plane imaging.

DESIGN: Single-center quasi-randomized (alternate allocation) crossover trial.

SETTING: Surgical ICU at the Massachusetts General Hospital.

SUBJECTS: Twenty surgical ICU nurses with no prior experience using ultrasound for peripheral IV were enrolled.

INTERVENTIONS: All participants viewed instructional videos on single-plane and biplane imaging for peripheral IV insertion. The participants were then quasi-randomly assigned to use either single-plane or biplane imaging for peripheral IV insertion using a phantom model. The time to catheter completion, successful lumen cannulation, and attempts in which the needle was observed to go through the back wall of the vessel were recorded for each of the three attempts. The following day the participants repeated the peripheral IV insertion with the alternate imaging modality.

MEASUREMENTS AND MAIN RESULTS: Biplane imaging compared with single-plane imaging was associated with a significantly greater overall success rate ($78.3\% \pm 22.4\%$ vs $41.7\% \pm 26\%$; $p < 0.001$), higher first-pass success rate ($80\% \pm 41\%$ vs $45\% \pm 51\%$; $p = 0.015$), faster cannulation times (27.8 ± 14.8 vs 36.6 ± 15.8 s; $p = 0.003$), and reduced frequency of backwall perforations (0.4 ± 0.7 vs 1.5 ± 0.8 ; $p < 0.001$).

CONCLUSIONS: This proof-of-principle study demonstrates that the biplane ultrasound imaging approach for vessel cannulation resulted in an overall faster, more successful, and safer peripheral IV access than the standard single-plane transverse approach when performed by novice ultrasound users.

KEY WORDS: biplane imaging; clinical trial; critical care ultrasound; multiple plane imaging; point-of-care ultrasound; vascular access; x-plane imaging

Obtaining peripheral IV (PIV) access in critically ill patients is often challenging even for experienced practitioners (1). For patients with difficult vascular access, ultrasound technology has become invaluable in facilitating successful vessel cannulation (2, 3). Two main strategies are used when attempting vascular access with ultrasound assistance, namely, the out-of-plane or transverse approach, and the in-plane or longitudinal approach, each of which has its own advantages and limitations (4, 5). The transverse approach that is the most common method requires users to “follow the needle tip” with their ultrasound probe, a technique that is not intuitive for many novice users

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and may require a significant learning curve. At the same time, there is a significant risk of posterior wall vessel perforation, which can, in turn, result in complications such as hematoma formation, guidewire breakage, or wire misplacement (6, 7). At the same time, the longitudinal approach requires the user to perfectly align and maintain the ultrasound beam in line with an often time, curved vessel while advancing the IV. This can be especially challenging in small caliber vessels (4, 8). Recently, biplane imaging (9) (also referred to as “X-plane imaging” [10, 11]), a modality that allows users to visualize both the transverse and longitudinal plane views simultaneously, has been incorporated into portable and affordable ultrasound devices that are now readily available to many users. We hypothesized that biplane imaging would improve the efficacy, efficiency, and safety of obtaining vascular access by novice ultrasound users. In this single-center prospective controlled crossover trial, we compared the efficacy, speed, accuracy, and safety of PIV access in an ultrasound phantom model using single-plane transverse imaging compared with biplane imaging by ICU nurses without any prior ultrasound experience.

METHODS AND MATERIALS

This single-center prospective controlled crossover trial was performed at the Massachusetts General Hospital after approval by the Institutional Review Board (Protocol 2020P003318). We enrolled a total of 20 ICU nurses with no prior ultrasound experience. Participants were eligible to participate if they had been practicing as an ICU nurse for at least 2 years and had at least 2 years of experience placing PIVs. Participants were excluded if they had prior hands-on experience with ultrasound. There were no restrictions based on age, race, sex, or ethnicity, and participants were obtained on a volunteer basis. Participants were enrolled via an e-mailed sign-up sheet that outlined the goal and procedures of the study, as well as consented at the time of the study.

Each participant was shown a training video on ultrasound-guided IV placement from the *New England Journal of Medicine* (4) in both the transverse and longitudinal (in-plane) planes to familiarize themselves with the ultrasound views used for the study. To familiarize the participants with biplane imaging, an additional video was shown, which demonstrated the simultaneous visualization of both the transverse and longitudinal ultrasound views (8).

Study participants were provided the Butterfly iQ+ probe (Butterfly Network, Guilford, CT) with the iPad Air with the Butterfly Network Ultrasound IPAD Application and used the ultrasound gel IV phantom model (YourDesign Medical Ultrasound Guided IV Trainer 3-Vessel Phantom, New York City, NY) for the evaluation. Each participant was given up to 2 minutes to familiarize themselves with the probe and the phantom model, as well as practice obtaining their assigned imaging approach view (biplane or single plane) prior to IV catheter placement attempt. The view was standardized to a gain of 70% and a depth of 4 cm. The participants were provided with three 20-gauge IV catheters for each imaging approach view.

The study participants were sequentially alternated between use of either the standard transverse single-plane or the biplane imaging approach for initial catheter placement on the first day, and then, the other imaging approach was used the following day (Fig. 1). Each attempt was video-recorded and timed, and participants were given up to 60 seconds (the maximum allotted time for video recordings on the Butterfly Network Ultrasound IPAD Application) to insert the catheter within the vessel of the ultrasound phantom.

When the participants believed that they had successfully placed the needle and catheter within the vessel

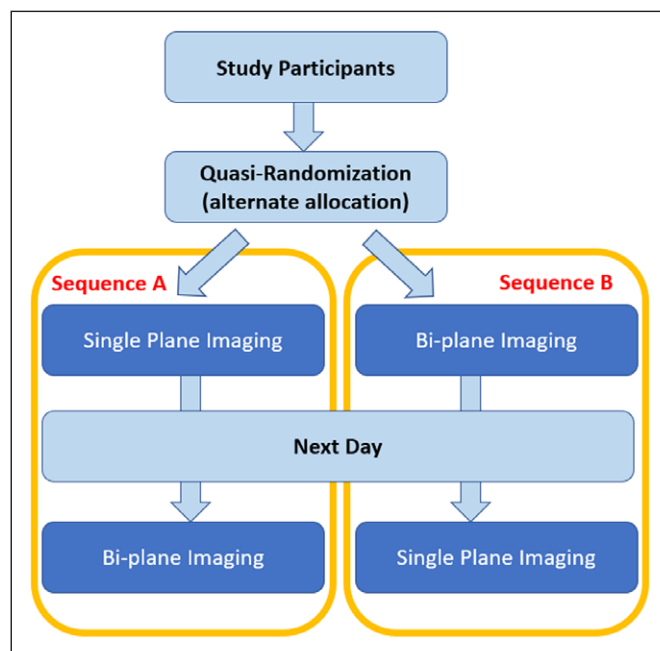


Figure 1. Study participants in this crossover trial were quasi-randomized by alternate allocation to either single-plane (sequence A) or biplane imaging (sequence B) for the first day of the study, followed by a switch to the opposite imaging modality for the next day of the study.

lumen, the timer was stopped, and the needle was removed from the catheter. A guidewire was then inserted into the catheter and advanced. If the wire was visualized within the vessel lumen (**Fig. 2A**), the catheter was determined to have been placed successfully within the vessel lumen. If the catheter was not able to be advanced, the catheter attempt was deemed to be unsuccessful (**Fig. 2B**).

Participants were given a total of three attempts for each of the imaging approaches. Time to catheter insertion, successful lumen cannulation, and attempts in which the needle was observed to go through the back wall of the vessel (**Fig. 2C**) were recorded for each of the three attempts for each imaging approach.

Based on preliminary data from the first three participants of the study, it was estimated that that at least 18 participants would be required to detect a 33% reduction in the primary outcome of the first-pass success

with 80% power and a type 1 error of 5%. Data in the article are expressed as mean \pm SD. The differences between means were assessed using the Student *t* test.

RESULTS

Biplane Imaging Improves Overall Success Rate

For the 20 ICU nurses without any prior ultrasound experience that were enrolled in the study and made a total of three attempts per imaging approach (standard transverse single plane or biplane), we found that all participants except for one had a higher overall success rate with biplane compared with the standard transverse single-plane imaging approach. The mean frequencies of success were $78.3\% \pm 22.4\%$ versus $41.7\% \pm 26\%$ ($p < 0.001$) for the biplane compared with the standard

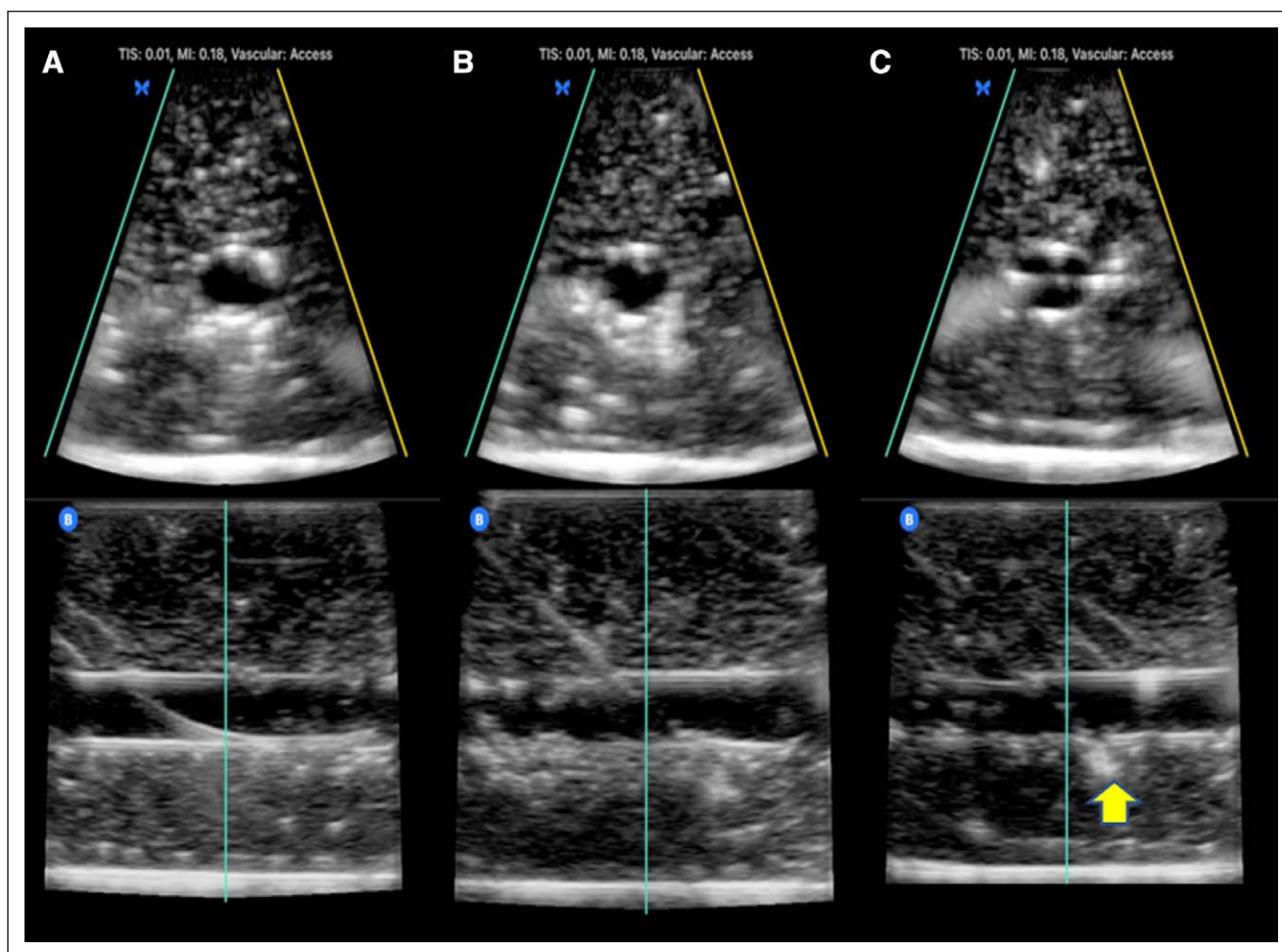


Figure 2. Biplane imaging to determine successful (**A**) and unsuccessful (**B**) catheter placement, and needle tip back walling of the vessel (**C**). Top and bottom panels show out-of plane and in-plane images, respectively. **A**, Guidewire inside vessel indicating successful catheter placement. **B**, Catheter not located within the vessel after catheter placement. **C**, Example where the needle tip (*yellow arrow*) was observed to go through the back wall of the vessel.

transverse single-plane imaging approaches (Fig. 3). The one participant who did not increase their overall success rate with biplane imaging had their frequency of success remain at 33% for each imaging approach.

Biplane Imaging Improves First-Pass Success Rate

Figure 4 shows that the first-pass success rate was substantially higher when using biplane imaging compared with the standard transverse single-plane imaging approach (80% ± 41% vs 45% ± 51%; *p* = 0.015).

Biplane Imaging Results in Faster Cannulation Attempts

Figure 5 shows that the time taken for each attempt was significantly less when using biplane imaging compared with the standard transverse single-plane imaging (27.8 ± 14.8s vs 36.6 ± 15.8s; *p* = 0.003).

Biplane Imaging Results in Less Posterior Wall Perforations

Figure 6 shows that the frequency of perforating the posterior wall of the vessel was significantly reduced when biplane imaging was used compared with the standard transverse single-plane imaging (0.4 ± 0.7% vs 1.5 ± 0.8%; *p* < 0.001).

DISCUSSION

Our study is the first to investigate the impact of biplane imaging compared with standard transverse single-plane imaging on efficacy, efficiency, and safety of PIV

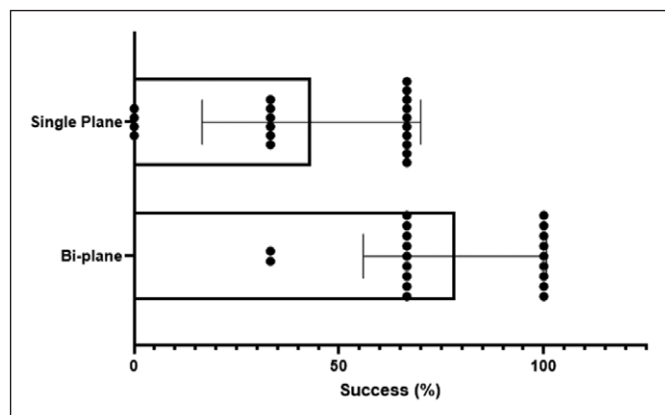


Figure 3. Comparative graph demonstrating the percent success rate with biplane and the standard transverse, single-plane imaging for each of the twenty participants (78.3 ± 22.4% vs 41.7% ± 26%; *p* < 0.001).

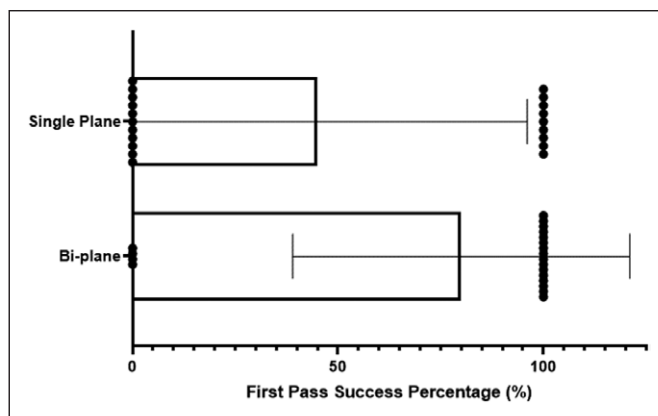


Figure 4. Comparative graph demonstrating the differences in the first-pass success percentage when utilizing the biplane ultrasound imaging modality compared with the standard transverse single-plane imaging (80% ± 41% vs 45% ± 51%; *p* = 0.015).

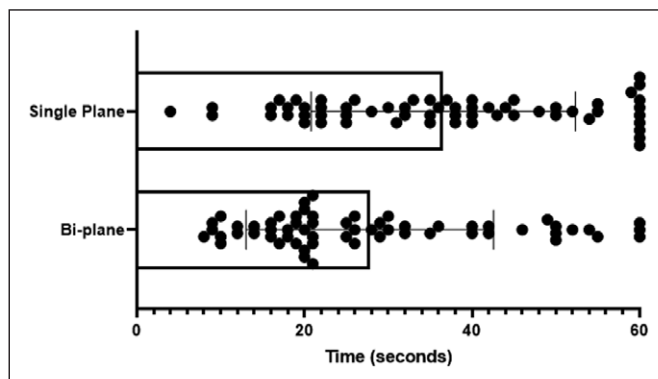


Figure 5. Comparative graph demonstrating the time in seconds taken for each attempt with the biplane imaging modality compared with the standard transverse single-plane imaging (27.8 ± 14.8 vs 36.6 ± 15.8s; *p* = 0.003).

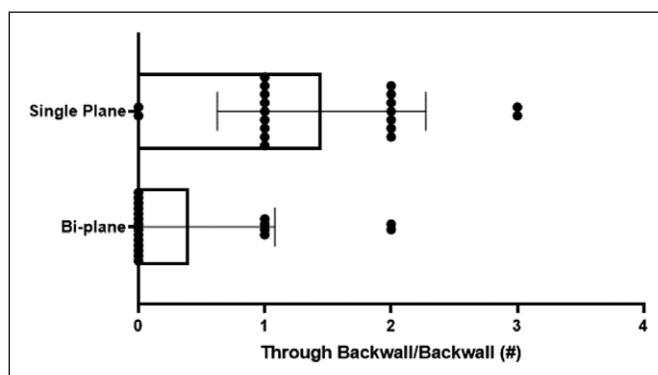


Figure 6. Comparative graph demonstrating the number of instances through which the posterior wall of the phantom vessel was perforated with the biplane imaging modality compared with the standard transverse single-plane imaging (0.4 ± 0.7 vs 1.5 ± 0.8; *p* < 0.001).

catheter insertion. We found that for novice ultrasound users, biplane imaging compared with the single-plane transverse approach improved all aspects of vessel cannulation including overall success rate, first-pass success, cannulation time, and reduced backwall perforations.

Our findings reflect the steep learning curve associated with the standard transverse single-plane imaging approach, which requires that the user follows the tip of the needle as it traverses through the tissue into the vessel lumen. This technique requires the user to move both the needle and the ultrasound probe simultaneously, which is not intuitive to many novice ultrasound users. Furthermore, imaging in just the single transverse plane does not allow the users to visualize the whole length of the needle entering the vessel but rather just a cross section of the needle, resulting in decreased efficacy, speed, accuracy, and safety.

In the past, point-of-care ultrasound technology for the purpose of vascular access and bedside cardiopulmonary evaluation was predominantly used by clinicians who had specialized training including cardiology, cardiac anesthesia, critical care, and emergency medicine, and was largely limited in many cases by factors such as accessibility, portability, and cost. The use of ultrasound technology has already improved procedural success and safety allowing for real-time visualization of invasive procedures. The advent of portable and affordable ultrasound devices now with biplane imaging capabilities should be expected to further improve upon the efficacy, efficiency, availability, and safety of venous access, especially for novice users in the clinical setting (12, 13) as was seen in our simulated proof-of-principle study. In more expert users' hands, we would expect biplane imaging to be valuable although likely less notable benefits in efficacy, efficiency, and safety given that they are already experienced in single-plane imaging. The use of biplane imaging to assist with central line placement will likely increase patient safety by reducing complications such as pneumothoraxes, carotid punctures, pseudoaneurysms, and local anesthetic systemic toxicity although formal evaluation is needed (14–16). Biplane imaging may be particularly helpful even in experienced ultrasound hands for scenarios such as cannulation for extracorporeal membrane oxygenation where cannula misplacements are not uncommon and can lead to major vascular injuries culminating in significant morbidity and mortality. Furthermore, biplane imaging may be useful in reducing complications

such as pneumothorax associated with subclavian central line placement, which have increased in popularity given guidelines and studies (17, 18) showing less central line-associated bloodstream infection rates compared with other sites. Furthermore, the incorporation of biplane imaging and teleguidance technologies (19) into handheld ultrasound machines is likely to decrease viral spread due to less cumbersome machinery that is easier to clean, which is critical during the coronavirus disease 2019 pandemic since they have less nooks and crannies compared with traditional ultrasound machines (20).

This proof-of-principle study has a number of limitations, most notably that this study was performed on a phantom model rather than on actual participants. The benefit of using a phantom model allowed us to standardize the vessel that was accessed in this study, which would be a confounding factor in a clinical vascular access study. In addition, although the participants in our article were nurses, our study is relevant to any individuals with IV placement experience without significant prior ultrasound experience rather than the scope of training (nurse or physician) of the individual. Alternate allocation ensured an equal number of participants would start with each imaging type, whereas imbalances could have occurred if random allocation had been used given the small sample size. In the clinical setting, vessels can be tortuous compared with the linear vessels of the phantom model. Biplane imaging is likely to be of particular benefit in this setting as it allows the ultrasound user to develop a better understanding of how the vessel travels. We propose that future investigations with the biplane imaging technology should involve vascular access by both novice and expert ultrasound users in actual participants who have a history of difficult vascular access.

CONCLUSIONS

This proof-of-principle study demonstrates biplane ultrasound imaging approach for vessel cannulation results in an overall faster, more successful, and safer lumen cannulation compared with the standard single-plane transverse approach when performed by novice ultrasound users.

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Drs. Convissar and Chang performed data collection and analysis; Drs. Convissar, Bittner, and Chang wrote and reviewed the article. Drs. Convissar and Chang had access to all data and assume responsibility for the submitted work.

Dr. Convissar received a Butterfly iQ+ for evaluation, which was used in this study. The remaining authors have disclosed that they do not have any potential conflicts of interest.

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