ORIGINAL RESEARCH

Comparison of Ultrasound-Guided Central Venous Catheter Placement Techniques Using an Easily Made Simulator Model

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Conflicts of interest/funding: This study has received no financial support. The authors declare that they have no conflict of interest.

Keywords: central venous catheter; simulation; technique; ultrasound; vascular access

Abbreviations:
CVC: central venous catheter
ED: emergency department
EM: Emergency Medicine
IQR: interquartile range
US: ultrasound

Received: November 2, 2020
Revised: January 5, 2021
Accepted: January 14, 2021

doi:10.1017/S1049023X21000303

Abstract

Objectives: Central venous catheter (CVC) placement is an important procedure which is frequently performed in the emergency department (ED) and can cause serious complications. The aim of this study is to introduce a simulation-based tissue model for ultrasound (US)-guided central venous access practices and to compare the effectiveness of static and dynamic US techniques through this model.

Methods: This was a prospective study on US-guided CVC placement techniques simulated with a chicken tissue model. This model is based on the principle of placing two cylindrical balloons filled with colored water (red for arterial and blue for venous) between a raw chicken breast and wrapping the formed structure with plastic wrap. The study was conducted in an academic tertiary care hospital with Emergency Medicine (EM) residents who have received basic US training, including vascular access procedures. All participants performed simulated CVC placement procedures with both static and dynamic US techniques. At the end of the study, the practitioners were asked to rate usefulness of these techniques between one and ten (one was the lowest and ten was the highest score).

Results: A total of 32 EM residents were included in the study. Their median age was 29 (IQR = 27 - 31) years and 72% of them were male. Their median duration in ED was 19 (IQR = 12 - 34) months. According to the results of simulated CVC placement procedures, there was no significant difference between the static and dynamic US techniques in terms of puncture numbers, procedure durations, and success rates. However, according to the usefulness scores given by the practitioners, the dynamic US technique was found to be more useful ($P < .001$).

Conclusions: The chicken tissue model is a convenient tool for simulating US-guided CVC placement procedures. The dynamic US technique is considered to be more useful in this field than the static technique, but the results of practitioner-dependent practices may not always support this generalization.

Idil H, Kilic TY. Comparison of ultrasound-guided central venous catheter placement techniques using an easily made simulator model. ***Prehosp Disaster Med.*** **2021;36(3):301–305.**

Introduction

Vascular cannulation is frequently required in emergency department (ED) patients for both blood sampling and medical treatment. Although peripheral vascular access is often sufficient, central venous catheter (CVC) placement may also be required. These procedures, depending on patient characteristics and practitioner experience, pose a significant risk of complications such as bleeding, hematoma, pneumothorax, local irritation, and infection.[1,2]

In recent years, with the widespread use of bedside ultrasound (US) in EDs, central vascular cannulation has become an easier and more comfortable procedure. Compared with the traditional blind method, using US before or during vascular cannulation reduces the first-attempt failure and complication rate.[2,3] The US-guided vascular access procedures can be performed using static or dynamic techniques. The static method is based on the determination and marking of the proper puncture point with the help of US. In the dynamic method, puncture is performed with the guidance of US during the process.[3]

Clinicians responsible for CVC insertion need to practice sufficiently with appropriate simulators before practicing on patients. In the training process for vascular access procedures, simulation models prepared with organic materials such as pork belly and chicken breast can be used, as well as commercially available mannequins which are relatively expensive and do not have human tissue characteristics.[4,5] Simulators allow repeated practice of US-guided vascular access without risk to patients.

The aim of this study is to introduce a simulation-based tissue model that can be easily made from chicken breast and cylindrical balloons for US-guided central venous access practices in the ED and to compare the effectiveness of static and dynamic US techniques through this model.

Material and Methods

Study Design

This was a prospective study on the usefulness of US-guided CVC placement techniques simulated with a chicken tissue model. The study was carried out in the ED of a tertiary care hospital with an Emergency Medicine (EM) residency program in March 2020. Institutional review board approval was obtained prior to initiation of the study.

Participants

The study was conducted with EM residents who have received two days of basic US training, including vascular access procedures. All participants were verbally informed about the study, but no additional training on US practice was provided. The age, gender, duration in ED, number of previous CVC insertions, and number of US-guided procedures for each participant were recorded. These data were obtained from interventional transaction records of residents.

Tissue Model

The tissue model used to simulate CVC placement procedures in the study can be constructed from chicken breast and other readily available materials within 10 minutes, with minimal effort and low cost. This model is mainly based on the principle of placing two cylindrical balloons filled with colored water (which can be prepared with food coloring: red for arterial and blue for venous) between the raw chicken breast tissue and tightly wrapping the formed structure with plastic wrap (Figure 1).

During US-guided interventions, the vascular simulation is displayed in a transverse plane with a linear probe (Figure 1E). In order to verify the position of the guide wire while inserting the CVC, practitioners must also be familiar with the longitudinal view of the vessels (Figure 1H). Also, in this model, images of the pulsatility of the arteries can be obtained by rhythmically squeezing and releasing the simulated vessel from one end using the colored Doppler US mode (Figure 1F).

In order to prevent deterioration of US image quality, care should be taken not to leave air on the contact surface between the plastic wrap and the chicken breast tissue. Also, inadvertently injecting air into the soft tissue or into the balloons, or not re-injecting the aspirated liquid into the simulated vein reduces US image quality. Therefore, the model should be checked before each application and renewed if necessary.

Implementation of Procedures

After verbal consent, the participants were randomized into two equal groups (Group A and Group B) to work with the static or dynamic US technique first. In the second part of the study, it was planned that each group of practitioners would use the other technique. Thus, the aim was to prevent bias and for all participants to experience both US techniques (Figure 2).

The sonographic examination was performed with a 7.5-10MHz linear probe (Mindray M9; Color Diagnostic Ultrasound System; Shenzhen, China). The practitioners were asked to view the simulated vessels with US in the transverse plane and puncture with a 5mL syringe from the balloon on the left side of the screen with the blue-colored liquid inside. Puncture from the simulated vein, with up to three attempts in two minutes, was considered a successful cannulation.

At the end of the study, all practitioners were asked to rate "usefulness of the static and dynamic US techniques" between one and ten (one was the lowest and ten was the highest score). For each participant, the number of punctures, the duration of the procedures, whether the procedures were successful, and the usefulness scores indicated by the practitioner were recorded on the study forms.

Statistical Analysis

All analyses were performed using IBM SPSS 22.0 (IBM Corp.; Armonk, New York USA). Categorical variables are presented as number of observations and percentages and were compared with the McNemartest. Quantitative variables are presented using median, interquartile range (IQR; 25% - 75%), minimum (min), and maximum (max) values and were compared with the Wilcoxon Signed Ranks test. All tests were two sided and P values $<.05$ were considered statistically significant.

Ethics Committee Approval

The study was approved by Ethics Committee of the University of Health Sciences Tepecik Training and Research Hospital, Izmir, Turkey (Approval Number: 2019/18–15, Date: 26.12.2019) and all study procedures were performed in accordance with the Declaration of Helsinki.

Results

There was a total of 37 EM residents at the academic center where the study was conducted, and five of them were not included in the study as they had not yet received basic US education. One-half of the 32 participants included in the study worked with the static technique first and the second-half worked with the dynamic technique first. Once the first part of the study was completed, each group of practitioners then used the other method (Figure 2). Thus, all participants performed simulated vascular intervention procedures with both US-guided static and dynamic techniques.

Baseline Characteristics

Demographic characteristics of participants are presented in Table 1. A total of 32 EM residents were included in the study. The median age of the participants was 29 (IQR = 27 - 31) years and 72% of them were male. Their median duration in ED was 19 months (IQR = 12 - 34; min = 7; max = 41). The median number of CVC placements of the residents was 10 (IQR = 7 - 15; min = 4; max = 35) with US having been used in approximately one-quarter of these procedures.

Evaluation of US Techniques

At the end of the study, the results of simulated CVC placement procedures with static and dynamic US techniques were compared (Table 2). There was no significant difference between the two techniques in terms of puncture numbers, procedure durations, and success rates. In US-guided CVC practices, one attempt with the dynamic method and three attempts with the static method failed. A statistically significant difference was found between the static and dynamic US techniques in terms of the usefulness scores given by the practitioners ($P < .001$).

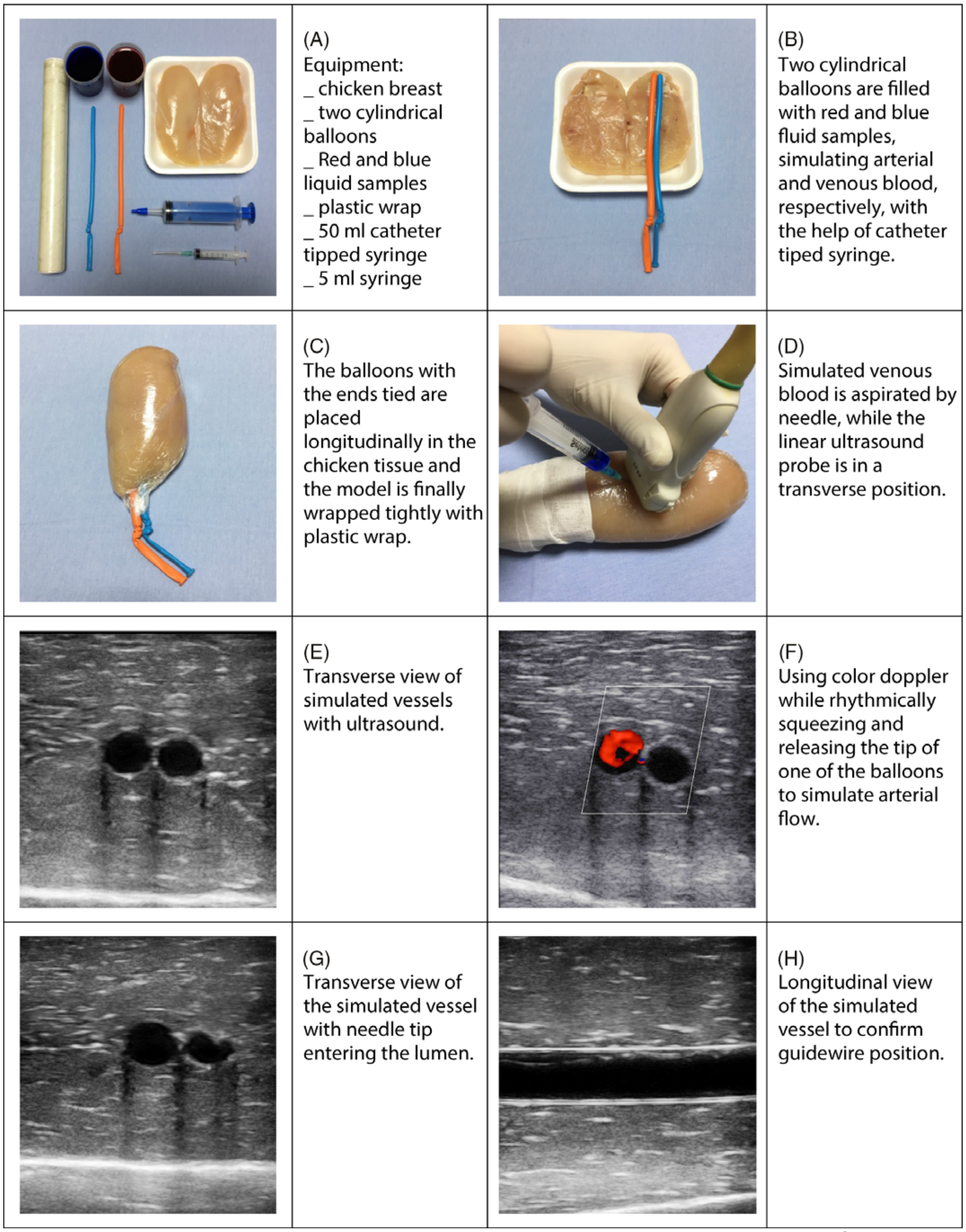

Figure 1. Images of the Chicken Tissue Model Designed to Simulate Central Venous Catheter Placement Procedures.

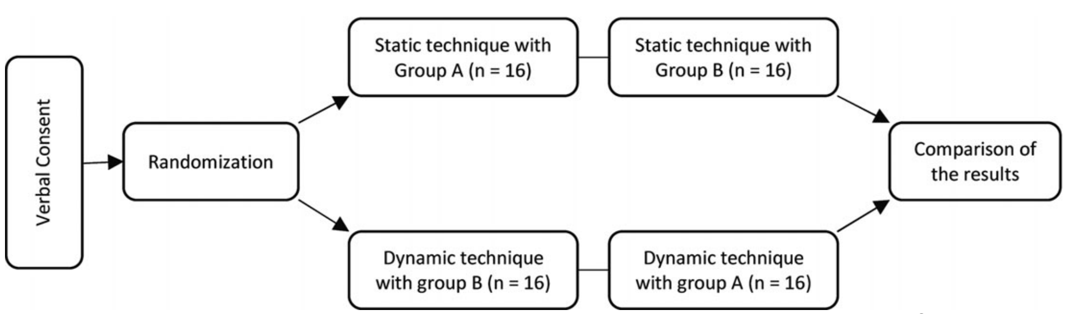

Figure 2. Flow Diagram.

https://doi.org/10.1017/S1049023X21000303 Published online by Cambridge University Press

Gender	
Male	23 (72%)
Female	9 (28%)
Age	29 (27 - 31)
Duration in ED (months)	19 (12 - 34)
Total Number of CVC Insertion	10 (7 - 15)
Number of US-Guided Procedures	3 (2 - 5)

Table 1. Baseline Characteristics of the Participants
Note: Results were presented as number (%) or median (IQR; 25% - 75%) depending on the variable type.
Abbreviations: CVC, central venous catheter; ED, emergency department; IQR, interquartile range; US, ultrasound.

Parameters	Static Technique	Dynamic Technique	P Value
Number of Punctures (1 to 3)	1.5 (1 - 2)	1 (1 - 2)	.243
Procedure Duration (< 120 second)	24 (14 - 56)	22 (14 - 78)	.799
Usefulness Score (1 to 10 points)	6 (5 - 8)	9 (8 - 10)	.001
Application Success	29 (91%)	31 (97%)	.625

Table 2. Comparison of US-Guided Central Venous Catheter Placement Techniques
Note: The practitioners were asked to rate "usefulness of both ultrasound techniques" on a 10-point scale (1 lowest and 10 highest). Results were presented as number (%) or median (IQR; 25% - 75%) depending on the variable type.
Abbreviations: IQR, interquartile range; US, ultrasound.

Discussion

Central vascular cannulation is frequently required in ED patients. Performing CVC placement under US guidance has positive consequences, especially in difficult vascular access situations.[3,6] In most of the studies in this area, real-time US-guided vascular access with the dynamic method was found to be more effective than the static method based on the principle of finding and marking the appropriate puncture point with the help of US.[7,8] In the present study, accordingly, the practitioners scored the dynamic technique much higher in terms of usefulness than the static technique. However, in the simulated CVC placement procedures performed with the chicken tissue model, there was no statistically significant difference between the two techniques in terms of puncture numbers, application duration, and intervention success.

Many of the practitioners in the study stated that they will use the dynamic technique instead of the static technique in CVC placement procedures that they perform in real patients in the future. Only five (16%) of the participants found the static technique more useful, and two (6%) scored both techniques equally. It was observed that these practitioners had difficulty in using both hands simultaneously while working with the dynamic method and achieved success in a shorter time with the static method. To the authors' knowledge, this is the first study among EM residents validating the effectiveness of dynamic and static US techniques using an animal tissue model for simulated central vascular access practices.

Training for US-guided vascular access is provided in many medical specialty programs, and various educational materials are used for this purpose. According to the limited literature in this field, animal tissue models were found to be more useful than the commercially available and relatively expensive mannequins. These models were shown to be superior in terms of similarity to human tissue characteristics, imaging quality, easy accessibility, cost-effectiveness, and overall effectiveness as a teaching tool.[9,10] Consistent with these results, the chicken breast model used in this study was found to be very useful for US-guided CVC placement practices.

Limitations

The main limitations of the study are that it is single-centered and has a relatively small number of practitioners. The previous experience of the practitioners may have affected the results somewhat, but the order of using both US techniques has been organized to minimize this limitation. Although the standardized tissue model used in the study is suitable for CVC placement practices, it is possible to obtain different results in a similar study with human subjects.

Conclusions

The chicken breast tissue model is a convenient tool that can be used in the teaching processes of US-guided CVC placement procedures. Therefore, the promotion and further development of this model should be encouraged. Clinicians often find the dynamic US technique more useful for central vascular access procedures than the static technique, but the results of practitioner-dependent practices may not always support this generalization.

Author Contribution

Idil H: Concept and design, formal analysis, data collection, visualization, and writing - original draft. Kilic TY: Concept and design, methodology, data collection, supervision, and writing - review and editing.

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