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Novel Simulation Model That Realizes Arterial and Venous Blood Flow for Ultrasound-Guided Central Venous Catheter Insertion in Children

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This work involved human subjects or animals in its research. Approval of all ethical and experimental procedures and protocols was granted by IRB of Seoul National University Hospital under Approval No. 1802-068-922.

ABSTRACT **Objective**: We developed and validated a realistic simulation model for ultrasound-guided central venous catheter insertion in children that is easy to build and inexpensive and can automatically reproduce arterial and venous blood flow. **Methods**: The simulation model was constructed with a chicken breast, two DWP-385 water pumps, two types of tubes and a controller. An elastic rubber tourniquet and a silicone tube were connected to each water pump, which generated different continuous flows mimicking those of the pediatric internal carotid artery and internal jugular vein, respectively. Both tubes were inserted into a piece of chicken breast and connected to the controller. Then, we provided a simulation program of ultrasound-guided central venous catheter insertion using our novel model to resident emergency medicine physicians. We also collected data on their knowledge and confidence levels regarding the procedure before and after the simulation via questionnaires utilizing a 5-point Likert scale. **Results**: The flow patterns of the artery and vein were well demonstrated with our model. A total of 11 resident physicians were enrolled. The knowledge and confidence regarding the discrimination of arteries and veins were significantly improved after training with our simulation model (p-value $<$ 0.01). The subjective similarity and usefulness of our model also scored high on the questionnaire (median: 4; interquartile range in both categories: 4-5). **Conclusion**: Our novel simulation model is useful and realistic for ultrasound-guided central venous catheter insertion training. **Clinical impact:** This controlled motor system can be applied to many simulation models of artery and vein circulation.

INDEX TERMS Central venous catheter, child, Doppler, ultrasonography, simulation training, education.

I. INTRODUCTION

Central venous catheters (CVCs) play an important role in the initial treatment of critically ill patients. Several guidelines and review articles have proposed the use of ultrasound (US) in the placement of CVCs to increase the success rate and reduce the complication rate [1]–[3]. Additionally, real-time US guidance for CVC placement has been effective in pediatric patients. The success rate with the US guidance method has been shown to be higher than that with the anatomical landmark-guided method, and US-guided CVC placement has also been reported to be helpful to nonexpert or resident physicians [4], [5].

Simulation-based training for US-guided CVC access has been shown to improve CVC insertion skills for nonskilled physicians [6]–[8]. Several phantom models using whole chicken, ballistic gelatin, pork belly and chicken breast for the simulation of CVC insertion have been proposed that are inexpensive and easy to make [9]–[14]. To differentiate arteries from veins in the simulation, some models adopt different sizes and materials between the two vessels, and some models enable manually squeezing vessels to mimic arterial pulsation. A few commercial models are currently available; however, they are expensive and do not provide realistic arterial and venous blood flow. Therefore, we aimed to create a novel phantom model that is easy to build and inexpensive and can generate realistic arterial and venous blood flow for US-guided CVC insertion.

II. METHODS

A. STUDY DESIGN AND POPULATION

This was a prospective simulation study to develop and validate the effectiveness of a novel phantom model of US-guided CVC insertion. This study was performed in a pediatric emergency department (PED) of an urban tertiary teaching hospital with an annual census of approximately 20,000.

Residents in the emergency department of the hospital who volunteered to participate after informed consent were enrolled. The residents in our hospital rarely obtain experience with CVC insertions in pediatric patients because these are usually performed by specialists in pediatric emergency medicine. This study was approved by the institutional review board of our hospital (on April 24, 2018; IRB No. 1802-068-922).

B. CHARACTERISTICS AND PHYSIOLOGICAL FLOW CURVES OF THE INTERNAL CAROTID ARTERY (ICA) AND INTERNAL JUGULAR VEIN (IJV) IN CHILDREN

The internal diameter of the IJV is relatively larger than that of the ICA in children as measured on US. For example, in patients aged 1 month to 2 years, the median internal diameters of the IJV and ICA are reportedly 8.9 mm and 4.3 mm, respectively [15]. In addition, the reported mean intima-media thickness of the ICA in children measured by B-mode US is 0.56 mm [16].

The flow of the ICA consists of a low-resistance systolic wave with continuous diastolic flow. The flow of the IJV consists of a, S, v and D waves, which result from right atrial pressure changes (Fig. 1A, 1B) [17]. In the systolic stage (S), intraatrial pressure decreases and the flow rate increases. When the right atrium is overfilled (o), intraatrial pressure increases and the flow rate decreases. In the diastolic stage (D), the tricuspid valve opens and the intraatrial pressure decreases, increasing the flow rate. During atrial systole (a), intraatrial pressure increases, and the flow rate decreases.

C. FABRICATION OF THE PHANTOM MODEL

The phantom model consisted of a piece of chicken breast, a rubber tourniquet mimicking the ICA (inner diameter: 4 mm; outer diameter: 6 mm; thickness: 1 mm), a silicone tube simulating the IJV (inner diameter: 6 mm; outer diameter: 7.5 mm; thickness: 0.75 mm), two silicone tubes for circulating water, two water pumps, a 1.5 L water bottle as a water reservoir, and a controller (Fig. 2).

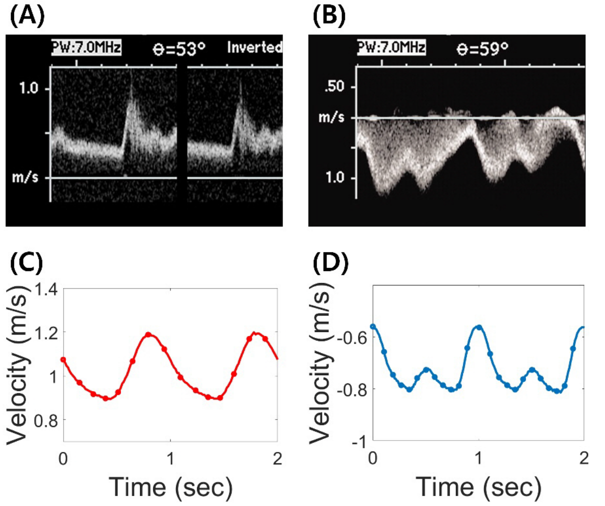

FIGURE 1. Spectral wave form from pediatric internal carotid artery (A) and internal jugular vein (B) in the reference article* and flow velocity of the arterial circuit (C) and venous circuit (D) generated by our simulation model. *"© 2008 Radiographics. Reprinted, with permission, from G. B. Chavhan, D. A. Parra, A. Mann, and O. M. Navarro, Radiographics, vol. 28, no. 3, pp. 691-706 (2008) [17]".

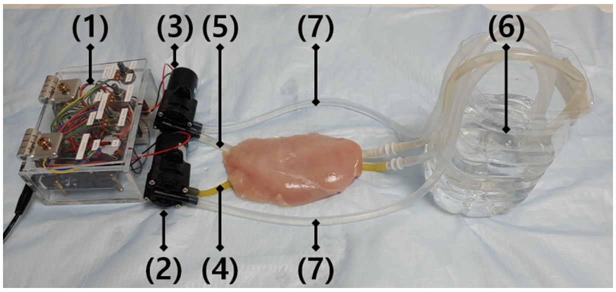

FIGURE 2. The components of the flow tissue phantom model for vascular access: (1) controller; (2) water pump for generating arterial flow; (3) water pump for generating venous flow; (4) rubber tube for the arterial vessel; (5) silicone tube for the venous vessel; (6) bottle of mineral water for the reservoir; and (7) two circulating tubes for returning water to the reservoir.

A water pump (DWP-385 12 V, Robotmart, Seoul, Republic of Korea) was used to generate the ICA and IJV flow. The maximum flow rate of the pump was 1.35 L/min, and the average speed in the rubber tube was 1.79 m/s. These parameters were sufficient for simulating ICA and IJV flow [17]. The pump worked by displacing the fluid with helical gears, which allowed the instantaneous speed to be easily adjusted, making it suitable for imitating pulsatile flow. The circuits for the ICA and IJV were separate, and the pumps were independently controlled to demonstrate apparently different flows of the ICA and IJV. The flow of the ICA was demonstrated as high velocity systolic flow followed by continuous diastolic flow, while that of the IJV was demonstrated as relatively continuous flow with low velocity waves. Water passed through the simulated ICA or IJV inside the chicken breast and returned to the reservoir through the individual circulating tubes.

The controller consisted of an Arduino UNO microprocessor (Adafruit, New York, USA) and a TB6612 motor driver

(Adafruit, New York, USA). The Arduino UNO transmits signals to the TB6612 as programmed, and the TB6612 supplies the voltage to the pump according to the signal. The flow rates of the two pumps and the frequency of the ICA pump were controlled by pulse width modulation (PWM) by adjusting three dials on the controller. The ICA and IJV flow were implemented similarly to the shape in the reference figure from the study by Chavhan *et al.* [17].

D. PERFORMANCE EVALUATION

The ability of the ICA and IJV pumps to control the flow rate and pulse rate were evaluated. To verify the ability of the pump to implement flow, the flow rates were measured using a rotor flowmeter (YM-401A, HanjinData, Gyeonggi-do, Republic of Korea). The maximum rate of the ICA pump was changed to 1.05, 1.15 and 1.30 L/min, which becomes 1.4, 1.55 and 1.7 m/s, respectively, when converted to velocity. The maximum rate of the IJV pump was changed to 1.1, 1.2 and 1.35 L/min, which becomes 0.65, 0.73 and 0.80 m/s, respectively, when converted to velocity. To confirm the ability to implement pulses, the flow rates were measured while changing the pulse frequency to 0.9, 1.0 and 1.1 Hz. The sampling rate was 1000 Hz, and the moving average was performed on 19 samples.

E. SIMULATION PROTOCOL

A piece of chicken breast (300 g, 110 mm × 50 mm) was used to simulate the tissue surrounding the ICA and IJV. The phantom model was used in several simulation sessions; each time, the chicken breast and rubber and silicone tubes were changed. Prior to the simulation, brief lectures on vessel identification and approach techniques were provided to all participants. The following five steps of the procedure were emphasized: 1) simultaneously visualize two vessels (ICA and IJV) and discriminate between them with the probe compression method; 2) use the Doppler image and confirm the different flow patterns of the artery and vein; 3) attempt to cannulate the IJV on a dynamic short axis approach using the following-the-tip method; 4) attempt to cannulate the IJV on a dynamic long axis approach; and 5) confirm venous cannulation with US.

The simulation of CVC insertion with our model was performed using a US machine (Z. one SmartCart; ZONARE Medical Systems, Inc, Mountain View, Calif). The simulation was performed in a private room until enough skill was acquired, and the authors provided real-time feedback if needed. Pre- and post-simulation questionnaires were collected regarding knowledge of and confidence in US-guided CVC insertion.

F. DATA COLLECTION AND OUTCOMES

The training level of the participants was recorded. In addition, data regarding experience with US-guided CVC insertion in adult and pediatric patients prior to this study were also collected.

The primary outcomes were improvements in knowledge and the confidence level regarding US-guided CVC insertion. Secondary outcomes included the subjective similarity of the phantom model with real patients and the usefulness of the phantom model. All outcomes were analyzed from pre- and post-simulation questionnaires utlizing a 5-point Likert scale.

G. SAMPLE SIZE ESTIMATION

We assumed that the knowledge and confidence level would increase by 1 point on a 5-point Likert scale after simulation training. At a power of 0.9 and a significance level of 0.05, the required sample size was 9 participants, and a sample size of 11 participants was determined to account for a dropout rate of 20% [18].

H. STATISTICAL ANALYSIS

The data were analyzed using Stata Ver. 14 for Windows (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP). Descriptive data are presented as medians with interquartile ranges (IQRs). Categorical data are presented as numbers (%). The Wilcoxon signed-rank test was used to compare outcomes on pre- and post-simulation questionnaires. A p-value of 0.05 was considered statistically significant.

III. RESULTS

A. PERFORMANCE OF THE NOVEL MODEL

For the ICA, the pulsatile flow caused by cardiac movements was well implemented (Fig. 1C). In the systolic stage, the flow increased sharply and then dropped rapidly. In the diastolic stage, the forward flow continued at approximately half the peak systolic velocity (PSV). The model yielded a PSV of 50-170 cm/s, an end-diastolic velocity of 30-130 cm/s, and a resistive index of 0.26-0.50, similar to the values reported in a study by Chavhan *et al.* [17].

For the IJV, a tangled flow pattern caused by cardiac movements was well implemented (Fig. 1D). The model yielded the S, v, D and waves reported in the study by Chavhan *et al.* [17]. The results of the flow rate control and frequency control performance evaluation are shown in Supplementary Figure 1. Similar curve shapes were apparent, but with different flow rates and frequencies.

B. EFFECTIVENESS OF SIMULATION WITH THE NOVEL MODEL

From June 2018 to October 2018, eleven residents of the emergency department were enrolled in this study. The training level of the participants was relatively well distributed from 1 to 4 years. Eight (72.7%) residents had experience with more than 10 US-guided CVC insertions in adults, but only one (9.1%) had experience with US-guided CVC insertions in children (Table 1).

This model operated perfectly in every simulation session, which made it possible to distinguish arteries and

TABLE 1. Demographics of study participants.

CHARACTERISTICS	N (%)
Years of resident training	
1	2 (18.18%)
2	3 (27.27%)
3	3 (27.27%)
4	3 (27.27%)
Previous experience with US-guided CVC insertion in adults	
0	2 (18.18%)
1–9	1 (9.09%)
10–49	4 (36.36%)
≥50	4 (36.36%)
Previous experience with US-guided CVC insertion in children	
0	10 (90.91%)
1–9	1 (9.09%)
10–49	0
≥50	0

US = ultrasound, CVC = central venous catheter

TABLE 2. Improvement in knowledge and confidence of the trainees on a 5-point likert scale after the simulation with our model.

Category	Before	After	p-value
Knowledge of			
Probe compression method	3 [2–4]	4 [3–5]	0.006
Doppler image discrimination	3 [2–3]	4 [3–5]	0.003
Following-the-tip method	3 [1–3]	4 [3–5]	0.004
Long axis approach	2 [1–3]	4 [3–5]	0.004
Overall	3 [1.5–3]	4 [3–5]	<0.001
Confidence of			
Probe compression method	3 [2–4]	4 [3–5]	0.003
Doppler image discrimination	3 [2–4]	4 [3–5]	0.008
Following-the-tip method	2 [1–3]	4 [3–4]	0.003
Long axis approach	2 [1–3]	4 [3–4]	0.004
Overall	3 [1–3]	4 [3–4.5]	<0.001

veins through simple ultrasonography and Doppler scans (Videos 1 and 2).

The participants' knowledge about the probe compression method, Doppler image discrimination, following-the-tip method and long axis approach significantly improved after the simulation training (5-point Likert scale overall score: from 3 [IQR 2-4] to 4 [IQR 3-5]; $p < 0.001$). The confidence of participants in the probe compression method, Doppler image discrimination, following-the-tip method and long axis approach also significantly improved after the simulation training (5-point Likert scale overall score: from 3 [IQR 1-3] to 4 [IQR 3-4.5]; $p < 0.001$) (Table 2). The scores for the subjective reality and usefulness of vessel discrimination of our phantom model were also very good (4 [IQR 4-5] and 4 [IQR 4-5], respectively).

IV. DISCUSSION

We developed a novel phantom model for US-guided CVC insertions into the IJV of children. This model could generate water flow similar to the blood flow of the ICA and IJV, which is useful for discriminating arteries and veins with Doppler images.

The use of real-time two-dimensional US when accessing CVCs is widely accepted as an important method for reducing complication rates [1]–[5]. In addition, one systematic review demonstrated that the use of Doppler US increased the success rate at the first attempt [19]. Doppler US is also helpful in identifying the anatomy, thrombosis and stenosis of the vein, especially in patients with previous CVC insertions [20], [21]. Therefore, the adoption of Doppler image training in the CVC phantom model is an important change. Previous studies have demonstrated that simulation training for medical devices is effective and useful for nonskilled personnel [22]–[26]. Similarly, the participants in this study expressed that the training with our model was helpful and realistic.

Our model is cheaper than the commercialized models and can be used semi-permanently with changes in the chicken breast, rubber tube and silicone tube within several minutes. Furthermore, the model can generate much more realistic arterial and venous flow and mimics the characteristics of the ICA and IJV in terms of size, thickness and elasticity. A few commercial products are already available for the training of CVC insertion (Table 3). However, models that can automatically generate arterial and venous flow are much more expensive, thus limiting the simulation. Moreover, these models are less realistic, as they are not based on clinical data of arterial and venous blood flow in children.

In addition, the model is easy to build. Among the items that were readily available, we chose a rubber tourniquet to mimic the ICA. The characteristics of rubber tourniquets are quite similar to those of ICAs, and although tourniquets are thicker, this is not a problem because the ICA is not supposed to be punctured. In contrast, we purchased silicone tubes, which are larger than rubber tourniquets and easy to puncture, to simulate IJVs relatively accurately. DWP-385R was selected as the pump based on the consideration of price and performance. The maximum flow rate and pressure head value were sufficient for demonstrating arterial and venous flow. The achievement of arterial and venous flow using the same kind of pump with a control modification is another strong point of this study. The controller, which consisted of the Arduino UNO and TB6612 motor drivers, can be easily set up with a shared program. The whole process and the method for setting up the controller have been well described and are accessible on the internet. The controller can be implemented simply by downloading and installing it, and the designs can be shared (S2∼4); they can be easily and inexpensively manufactured when they are requested from the nearest manufacturing plant. The manufacturing process is simple enough for use in children's education [27], and the model can also be produced by commissioning a manufacturing plant. In addition, the price of each part is low, so the model can be manufactured at low cost (Table 4). We believe that the fabrication of our model can be widely used.

There are some limitations to this study. First, the outcomes of this study were collected via a questionnaire with a subjective Likert scale. The participants were not blinded to the purpose of this study. There can be bias in positive or negative directions when answering questionnaires. Second, this study did not assess the usefulness when accessing CVCs in actual pediatric patients after training. However, we believe our new model is helpful for nonexpert physicians in real situations.

TABLE 3. Market research for ultrasound-guided central venous catheter insertion simulator.

Product	Blue Phantom Regional Anesthesia and Ultrasound Central Line Training Model	Central Line Training System
Company	CAE, Inc.	SynDaver, Inc.
Price (U.S. dollars)	7,000	4,440
Dimensions (L x W x H)	13 in x 7 in x 16 in (330 mm x 178 mm x 406 mm)	18 in x 18 in x 8 in (457 mm x 457 mm x 203 mm)
Weight	8 lbs. (3.6 kg)	20 lbs (9.1 kg)
Pumping system	Hand bulb and pump system	Pump system

TABLE 4. Materials and costs for fabrication of a phantom model.

Materials	Cost (U.S. dollars)
Rubber tube	1.00
Silicone tube * 3	0.60
Water pump for ICA	11.00
Water pump for IJV	11.00
Arduino UNO	25.00
TB6612 motor driver	6.00
Chicken breast	1.50
Total cost	56.10

V. CONCLUSION

We developed a new phantom model for CVC insertion in children that automatically generates arterial and venous blood flow. This model is realistic, easy to build and inexpensive. Therefore, the model can help educate nonexpert physicians regarding real-time CVC insertion in children and the discrimination of arteries and veins. We believe our model can be applied to many phantom models that implement arterial and venous circulation.

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REFERENCES

[1] B. Saugel, T. W. L. Scheeren, and J.-L. Teboul, "Ultrasound-guided central venous catheter placement: A structured review and recommendations for clinical practice," *Crit. Care*, vol. 21, no. 1, p. 225, Aug. 2017.

[2] American College of Surgeons. *Revised Statement on Recommendations for use of Real-Time Ultrasound Guidance for Placement of Central Venous Catheters*. Accessed: May 1, 2020. [Online]. Available: https://www.facs.org/about-acs/statements/60-real-time-ultrasound

[3] M. Lamperti *et al.*, "International evidence-based recommendations on ultrasound-guided vascular access," *Intensive Care Med.*, vol. 38, no. 7, pp. 1105–1117, Jul. 2012.

[4] C. S. Lau and R. S. Chamberlain, "Ultrasound-guided central venous catheter placement increases success rates in pediatric patients: A meta-analysis," *Pediatric Res.*, vol. 80, no. 2, pp. 178–184, Aug. 2016.

[5] E. J. Yang, H. S. Ha, Y. H. Kong, and S. J. Kim, "Ultrasound-guided internal jugular vein catheterization in critically ill pediatric patients," *Korean J. Pediatrics*, vol. 58, no. 4, pp. 41–136, Apr. 2015.

[6] A. L. Madenci, C. V. Solis, and M. A. de Moya, "Central venous access by trainees: A systematic review and meta-analysis of the use of simulation to improve success rate on patients," *Simul. Healthcare*, vol. 9, no. 1, pp. 7–14, Feb. 2014.

[7] M. A. Corvetto, J. C. Pedemonte, D. Varas, C. Fuentes, and F. R. Altermatt, "Simulation-based training program with deliberate practice for ultrasound-guided jugular central venous catheter placement," *Acta Anaesthesiologica Scandinavica*, vol. 61, no. 9, pp. 1184–1191, Oct. 2017.

[8] S. M. Thomas, W. Burch, S. E. Kuehnle, R. G. Flood, A. J. Scalzo, and J. M. Gerard, "Simulation training for pediatric residents on central venous catheter placement: A pilot study," *Pediatric Crit. Care Med.*, vol. 14, no. 9, pp. e416–e423, Nov. 2013.

[9] M. J. Ault, B. T. Rosen, and B. Ault, "The use of tissue models for vascular access training. Phase I of the procedural patient safety initiative," *J. Gen. Internal Med.*, vol. 21, no. 5, pp. 514–517, May 2006.

[10] D. S. Morrow and J. Broder, "Cost-effective, reusable, leak-resistant ultrasound-guided vascular access trainer," *J. Emergency Med.*, vol. 49, no. 3, pp. 313–317, Sep. 2015.

[11] J. C. Rippey, P. Blanco, and P. J. Carr, "An affordable and easily constructed model for training in ultrasound-guided vascular access," *J. Vascular Access*, vol. 16, no. 5, pp. 422–427, Sep./Oct. 2015.

[12] J. Sanchez-de-Toledo and I. Villaverde, "Advanced low-cost ultrasound-guided vascular access simulation: The chicken breast model," *Pediatric Emergency Care*, vol. 33, no. 9, pp. e43–e45, Sep. 2017.

[13] H. Baddoo, R. Djagbletey, and C. Owoo, "A simple tissue model for practicing ultrasound guided vascular cannulation," *Ghana Med. J.*, vol. 48, no. 1, pp. 47–49, Mar. 2014.

[14] I. Chang *et al.*, "Educational effectiveness of an easily made new simulator model for ultrasound-guided vascular access and foreign body management procedures on pediatric patients," *Pediatric Emergency Care*, vol. 35, pp. 407–411, Feb. 2018.

[15] E. P. S. Neto, S. Grousson, F. Duflo, F. Tahon, C. Mottolese, and F. Dailler, "Ultrasonographic anatomic variations of the major veins in paediatric patients," *British J. Anaesthesia*, vol. 112, no. 5, pp. 879–884, May 2014.

[16] R. El Jalbout *et al.*, "Carotid artery intima-media thickness measurement in children with normal and increased body mass index: A comparison of three techniques," *Pediatric Radiol.*, vol. 48, no. 8, pp. 1073–1079, Aug. 2018.

[17] G. B. Chavhan, D. A. Parra, A. Mann, and O. M. Navarro, "Normal Doppler spectral waveforms of major pediatric vessels: Specific patterns," *Radiographics*, vol. 28, no. 3, pp. 691–706, May 2008.

[18] F. Faul, E. Erdfelder, A. G. Lang, and A. Buchner, "G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences," *Behav. Res. Methods*, vol. 39, no. 2, pp. 175–191, May 2007.

[19] P. Brass, M. Hellmich, L. Kolodziej, G. Schick, and A. F. Smith, "Ultrasound guidance versus anatomical landmarks for internal jugular vein catheterization," *Cochrane Database Systematic Rev.*, vol. 1, Jan. 2015, Art. no. CD006962.

[20] A. S. McIntyre, R. A. Levison, S. Wood, R. K. Phillips, and J. E. Lennard-Jones, "Duplex Doppler ultrasound identifies veins suitable for insertion of central feeding catheters," *J. Parenteral Enteral Nutrition*, vol. 16, no. 3, pp. 264–267, May-Jun. 1992.

[21] H. Gupta *et al.*, "Evaluation of pediatric oncology patients with previous multiple central catheters for vascular access: Is Doppler ultrasound needed?" *Pediatric Blood Cancer*, vol. 48, no. 5, pp. 527–531, May 2007.

[22] S. Drost, N. Alam, J. G. Houston, and D. Newport, "Review of experimental modelling in vascular access for hemodialysis," *Cardiovascular Eng. Technol.*, vol. 8, no. 3, pp. 330–341, Sep. 2017.

[23] S. Farsoni, L. Astolfi, M. Bonfe, S. Spadaro, and C. A. Volta, "A versatile ultrasound simulation system for education and training in high-fidelity emergency scenarios," *IEEE J. Transl. Eng. Health Med.*, vol. 5, pp. 1–9, Jan. 2017, Art. no. 1800109.

[24] B. Siassi, M. Ebrahimi, S. Noori, S. Sheng, D. Ghosh, and I. Seri, "Virtual neonatal echocardiographic training system (VNETS): An echocardiographic simulator for training basic transthoracic echocardiography skills in neonates and infants," *IEEE J. Transl. Eng. Health Med.*, vol. 6, pp. 1–7, Nov. 2018, Art. no. 4700113.

[25] N. C. Hanumara *et al.*, "Classroom to clinic: Merging education and research to efficiently prototype medical devices," *IEEE J. Transl. Eng. Health Med.*, vol. 1, Jul. 2013, Art. no. 4700107.

[26] C. Wang *et al.*, "Development of a novel massage platform for medical training," *Technol. Health Care*, vol. 28, pp. 89–101, Jun. 2020.

[27] P. Plaza *et al.*, "Arduino as an educational tool to introduce robotics," in *Proc. IEEE Int. Conf. Teaching, Assessment, Learn. Eng. (TALE)*, Wollongong, NSW, Australia, Dec. 2018, pp. 1–8.