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A comparison of homemade vascular access ultrasound phantom models for peripheral intravenous catheter insertion

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Abstract

Background: Ultrasound (U/S) guided peripheral IV catheter (PIV) placement is often needed after unsuccessful traditional IV attempts. Commercial U/S PIV training phantoms are expensive and difficult to alter. Non-commercial phantoms have been described; however, there has been no comparison of these models. The primary objectives of this study were to compare the echogenic and haptic properties of various non-commercial phantoms. Secondary objectives were to characterize the cost and ease of making the phantoms.

Methods: This prospective observational study trialed six unique phantom models: Amini Ballistics; Morrow Ballistics; University of California San Diego (UCSD) gelatin; Rippey Chicken; Nolting Spam; and Johnson Tofu. Total cost and creation time were noted. Emergency Ultrasound Fellowship trained physicians performed U/S guided PIV placement on each model to evaluate their resemblance to human tissue haptic and echogenicity properties, utility for training, and comparability to commercial phantoms (Likert scale 1–5; higher performance = 5).

Results: The Rippey model scored highest for each primary objective with an aggregate score of 4.8/5. UCSD ranked second and Nolting last for all primary objectives, with aggregate scores 3.7/5 and 1.3/5 respectively. Cost of production ranged from $4.39 (Johnson) to $29.76 (UCSD). Creation times ranged from 10 min (Johnson) to 120 min (UCSD).

Conclusion: In our study the Rippey model performed best and offered a mid-level cost and creation time. Non-commercial U/S phantoms may represent cost-effective and useful PIV practice tools. Future studies should investigate the utility of these phantoms in teaching U/S guided PIV to novices and compare non-commercial to commercial phantoms.

Keywords

Techniques & procedures, interventional radiology, intensive care, new devices, nursing

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Introduction

Peripheral intravenous (PIV) catheters are the most frequently placed devices for patient care in hospitals.[1] PIV insertion is required for many critical patient situations including shock, hemorrhage, or infection.[2] It has been estimated that 8% to 23% of patients in the Emergency Department will require ultrasound guidance to insert a PIV. This equates to between 12 and 34.5 million PIV line placements that will require ultrasound guided insertion every year in the United States.[3] The incorrect placement of a PIV can lead to extravasation, infiltration, phlebitis, cellulitis, arterial puncture, and critical delay in medical care.[4] Given the prevalence and importance of ultrasound

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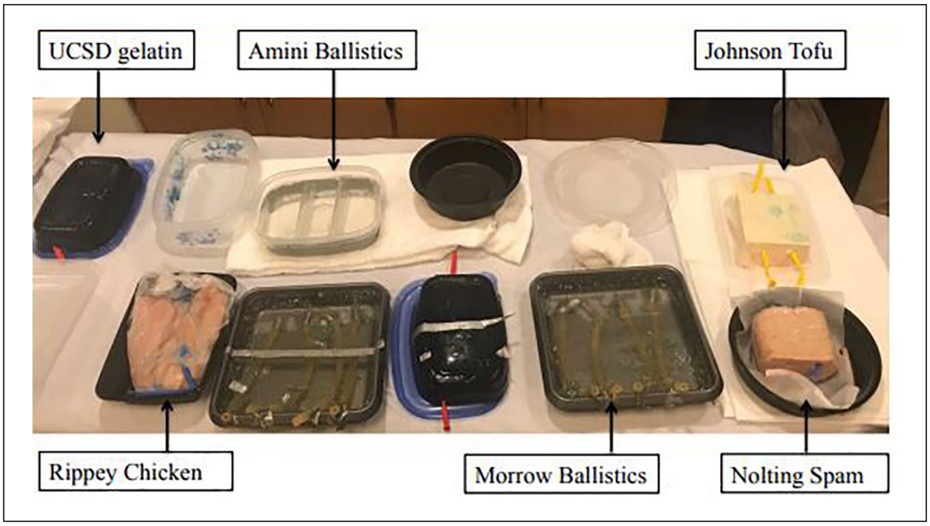

Figure 1. All homemade phantom models prior to analysis.

guided PIV insertion, it is vital that healthcare providers receive adequate training. Vascular access "phantom" models are commonly used to teach and train practitioners on this procedure.

Commercially available phantoms exist but are expensive, difficult to alter, and degrade with use.[5] Various non-commercial vascular access phantoms have been described in the published literature and online videos and blogs. Different materials and techniques have been suggested for making these non-commercial phantoms, including meat based products, other food products, gelatin, agar, and ballistics gel.[6–11] There has been no comparison of these non-commercial ultrasound guided vascular access phantoms. The primary objectives of this study are to compare the echogenic resemblance and haptic similarity of various non-commercial phantoms to ultrasound guided PIV placement on human patients. Secondary objectives were to characterize the cost, ease of making the phantoms, and their reusability.

Methods

This simulation based prospective observational study assessed homemade ultrasound vascular access phantom models that were constructed using recipes described in the published literature, educational blogs, and do-it-yourself online instructional videos. Using Pubmed search tools and homemade phantom creation literature databases, six models were identified for this study. These models were chosen to represent a variety of material types. The six models were: Amini Ballistics; Morrow Ballistics; University of California San Diego (UCSD) Gelatin; Rippey Chicken; Nolting Spam; and Johnson Tofu.[6–11] The models were constructed the day before testing. Each model was constructed according to directions from their source paper or tutorial (Figure 1). Each model contained two to four simulated vessels. Each model had areas demarcated to ensure each participant used a non-punctured entry point for testing.

The authors created a scoring rubric to assess data on the model creation process. Parameters such as total cost, ease of material acquisition, and time for creation (including active time in which creator must be present and passive time in which creator need not be present or is waiting) were measured (Table 1).

The protocol was approved by the Institutional Review Board at Thomas Jefferson University. All participants provided written informed consent for study participation. Six Emergency Ultrasound fellowship trained Emergency Medicine physicians who were deemed skilled practitioners in teaching and performing ultrasound guided PIV participated in this study. Each participant performed ultrasound guided PIV placement on each of the models to evaluate their utility as an educational tool. The participants were instructed to use an out-of-plane transverse scan technique in order to visualize the simulated vessel. 20 gauge 1.88 in (48×1.1 mm) catheter needles were used for this simulated procedure. The participants were allowed to adjust the ultrasound machine settings to optimize visualization of the needle and simulated vessels. Figure 2 demonstrates representative short axis images of the six gel models. Each participant completed a post-procedure scoring rubric intended to allow for quantitative assessments of model resemblance to human tissue haptic and echogenicity properties, utility for training, and comparability to commercial phantoms. The rubric was created based on previous literature and Emergency Ultrasound faculty consensus on the important characteristics of phantom models. The rubric consisted of eleven questions answers via 5-point Likert scale with high numbers denoting better

Table 1. Results of the phantom creation scoring rubric.

	Morrow Ballistics	Amini Ballistics	UCSD Gelatin	Johnson Tofu	Rippey Chicken	Nolting Spam
What was the amount of time needed to actively construct this phantom from start to finish?	20 min	45 min	120 min	10 min	15 min	15 min
What was the total amount of time needed to construct this phantom, including both active construction and passive time (i.e. freezing, refrigeration, oven)?	150 min	90 min	12 h	10 min	15 min	15 min
What was the complexity of making this phantom model, with (1) being not very complex and (5) being very complex?	3	3	4	1	1	4
Are the materials needed to create this phantom are all easily accessible at local stores or online, with (1) being very accessible and (5) being not very accessible?	3	3	2	1	1	1
What was the total cost of materials needed to create this phantom (per phantom)?	$27.11	$26.40	$29.76	$4.39	$16.87	$5.00
Are the appliances needed to create this phantom are all easily accessible in most households or can be easily bought in local stores?	Yes	Yes	Yes	Yes	Yes	Yes
This phantom requires special storage conditions (i.e. refrigerator, freezer, etc.):	No	No	Yes	Yes	Yes	Yes
This phantom requires special handling considerations:	No	No	No	No	Yes	No

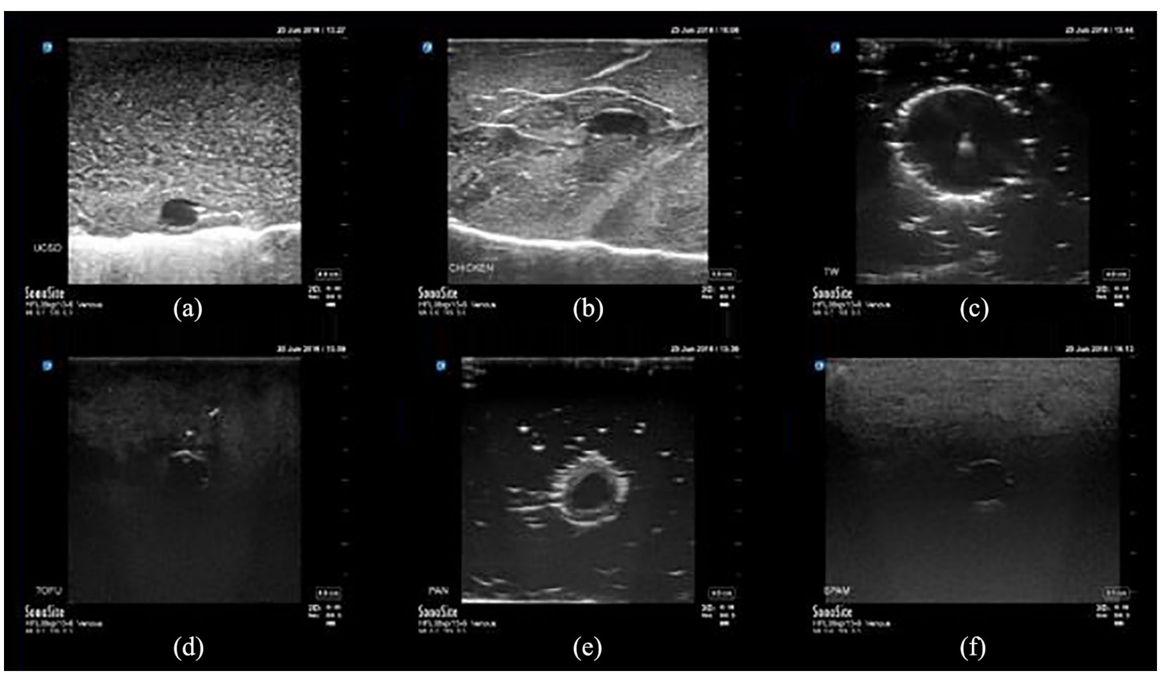

Figure 2. Ultrasound images of homemade phantoms: (a) UCSD Gelatin, (b) Rippey Chicken, (c) Amini Ballistics, (d) Johnson Tofu, (e) Morrow Ballistics, (f) Nolting Spam.

rating. This was repeated by each participant for all six phantom models. Lastly, the participants were allowed and encouraged to comment on specific features they found important for each model.

In the next phase of the study, the models were repeatedly punctured with a single catheter needle. Each phantom was assessed for track marks and degradation using ultrasound after each puncture and the process was repeated until the phantom was deemed unsuitable for novice training due to deterioration of the model. The number of needle insertions tolerated by each model was recorded and used as a proxy to estimate the training life expectancy of each model. Descriptive statistics were calculated.

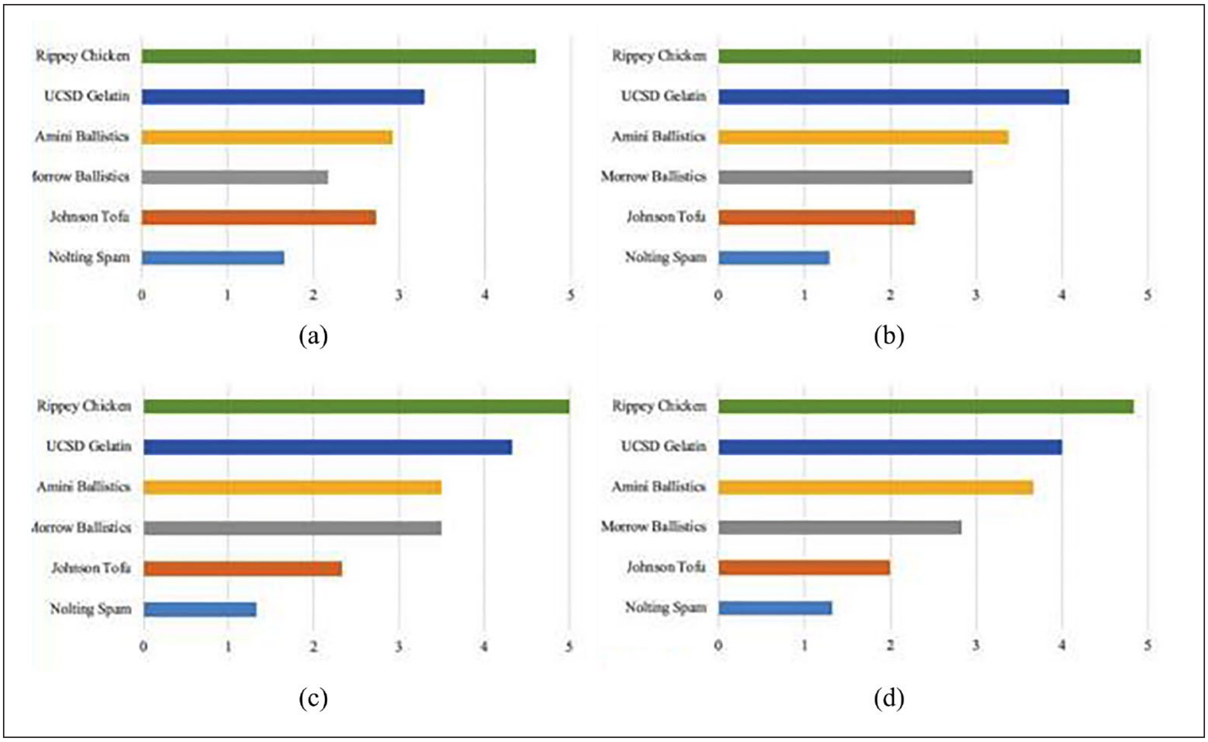

Figure 3. Categorical scores for each phantom based on question responses above are visually represented as (a) Aggregate scores across questions assessing phantom haptics. (b) Aggregate scores across questions assessing phantom echogenicity properties. (c) Utility for USIV practice insertion. (d) Comparability to commercial phantoms.

Results

The six phantom models were successfully created according to their published recipes. Cost of model creation ranged from \$4.39 for the Johnson Tofu model to \$29.76 for UCSD Gelatin model (Table 1). The time to construct each model ranged from 10 min for Johnson Tofu to 12 h (10 h passive; 2 h active) for UCSD Gelatin. The food based models (Rippey Chicken, Johnson Tofu, UCSD Gelatin, and Nolting Spam) all required special storage conditions or handling requiring use within established food safety regulations (i.e. expiration date and temperature regulations). All models except the ballistic based models were refrigerated overnight. The ballistics models notably did not require special handling.

The materials required to create the six phantom models could be found at local grocery, retail, and hardware stores. The one exception was the ballistics gel that was used to create both the Morrow Ballistics and Amini Ballistics models, which was ordered online from a ballistics gel supplier.

Scoring results from all six participants on the six phantom models were included in the data analysis. The Rippey Chicken model scored highest overall for the primary study objectives: haptic similarity 4.6/5, echogenic resemblance 4.9/5, teaching utility 5/5, and commercial comparability 4.8/5 (Figure 3). The aggregate means for all data points for each phantom were calculated (Figure 4). Overall, the Rippey Chicken model scored highest (4.8/5), followed by the UCSD Gelatin (3.7/5), Amini Ballistics (3.2/5), Morrow Ballistics (2.6/5), Johnson Tofu (2.5/5), and Nolting Spam (1.5/5). Participant comments about each model were collected. An overview of these comments is displayed in Table 2.

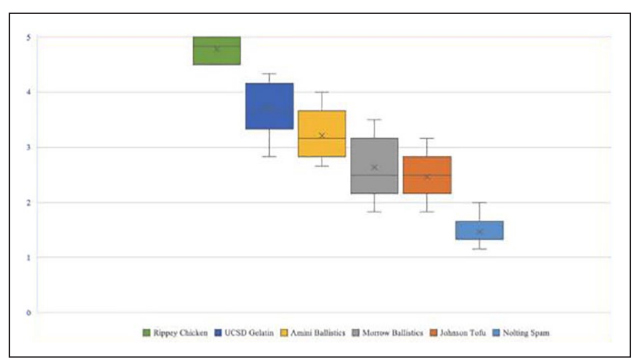

Figure 4. Aggregate score for all phantoms across all questions. Each box and whisker set represents the average Likert-scale values for that specific phantom for every question asked. X = mean value; Boxes range 2nd–3rd quartiles; Whiskers represent full range of values.

The Rippey Chicken, UCSD Gelatin, Morrow Ballistics, and Amini Ballistics were each pierced 25 times without

Table 2. Participant comments made about each of the models.

Amini Ballistics	Commercial comparability: "PVC pipe was too large for IV target practice and too close to the gel surface. The gel was too firm compared to human tissue."
Johnson Tofu	Soft tissue echogenicity: "Could not slide the probe, as it dug into [the] model." Ultrasound artifacts: "Air artifact. Very poor visualization" Vessel echogenicity: "Very poor visualization" Commercial comparability: "The worst." "Multiple areas of air artifact. Very poor visualization of the vessel on this particular model. Would be useful for simulating air in soft tissue/abscess/necrotizing fasciitis."
Morrow Ballistics	Haptic feedback of phantom soft tissue: "Too firm, too much resistance." Haptic feedback when puncturing the vessel: "Too much resistance." Haptic feedback when advancing the catheter within the vessel: "Too much resistance." Commercial comparability: "Very dense/firm texture, tubing for simulated vessels was too thick for easy IV catheterization."
Nolting Spam	Soft tissue echogenicity: "Poor tissue interface." Simulated vessel echogenicity: "very poorly visualized vessels" Commercial comparability: "Very poor visibility of balloon in the spam. Beyond piercing the spam, the needle was very difficult to visualize." "Worse than tofu."
Rippey Chicken	Commercial comparability: "Great model. The tissue and fascial planes were very clear." "The best."
UCSD Gelatin	(No comments)

noticeable degradation of image quality. The Johnson Tofu model showed loss of image quality and model degradation before 20 pierces. The Nolting Spam model showed substantial enough degradation at the initial survey evaluation that it did not proceed to further reusability testing as it had already been deemed unsuitable for novice training.

Discussion

Standardized clinical simulations result in greatly improved ultrasound guided catheter insertion skills, knowledge, and confidence, yet barriers to implementing ultrasound education are an issue in many clinical settings.[12] In a survey of 82 curricular administrators at United States Doctor of Medicine (MD)-granting medical schools, a lack of financial support was cited as one of the most significant barriers to implementing ultrasound education at the undergraduate medical education level.[13]

Commercial grade ultrasound phantoms are expensive and while reusable, their cost may pose a barrier to organizing simulation training. The Blue Phantom (CAE Healthcare, Sarasota, FL) 2 Vessel Ultrasound Training Block currently lists at $449.00.[14] According to the manufacturer website this phantom allows for repeated use "thousands of times without requiring replacement". In contrast, the homemade two vessel models tested in this study ranged in cost from $4.39 (Johnson Tofu) up to $29.76 (UCSD Gelatin model) While the Johnson Tofu model showed loss of image quality and model degradation in under 20 pierces, the Rippey Chicken, UCSD Gelatin, Morrow Ballistics, and Amini Ballistics models each survived 25 piercings without significant degradation. Similar to the Blue Phantom and its long shelf life, the UCSD Gelatin, Morrow Ballistics, and Amini Ballistics models also offer long shelf lives. Additionally, the Morrow Ballistics and Amini Ballistics models can be deconstructed and remade at minimal additional cost to prolong their usability. In contrast, the Johnson Tofu, Nolting Spam, and Rippey Chicken models have very limited lifespans. No homemade model required more than 2 h of active creation time, with most requiring 45 min or less.

Depending on training needs, use of non-commercial ultrasound PIV training models may make vascular access ultrasound teaching more attainable without funding posing a barrier. For example, if a large training session were planned for a single day or consecutive days, then it would be far more economic to create multiple homemade phantoms with chosen qualities to best suit the needs of the learners rather than purchasing multiple commercial phantoms.

Significant disparities exist between models in terms of their overall teaching utility and reusability. Consistent with the findings in this study, meat-based phantom models have been described to provide more realistic tissue feedback and background echogenicity properties when compared to non-meat based phantoms.[9] The chicken breast model, described by Rippey et al., consistently scored higher than other models in this study (4.8/5 aggregate score). In addition to scoring highest on every primary outcome, the Rippey Chicken model had mid-level scores for secondary outcomes pertaining to creation time and creation cost and survived the maximum piercings trialed in this study without image or model degradation. Important weaknesses of meat-based models include shorter shelf lives and the risk of transmission of pathogens from uncooked meat.[9] These models may also be off putting to some users due to smell and texture.

The UCSD Gelatin model, in contrast to the Rippey Chicken model, can be stored at lower temperatures for at least 2 weeks and has no risk of transmission of pathogens. Though the weaknesses intrinsic to the Rippey Chicken model are avoided, this comes with decreased haptic feedback (3.9/5 vs 4.7/5) and echogenicity properties (3.7/5 vs 4.8/5), a higher monetary cost ($29.76 vs $16.87 for the Rippey Chicken model), and a longer creation time (2 h + overnight cooling vs 15 min total for the Rippey Chicken model). Although both Morrow Ballistics and Amini Ballistics models scored on average lower than both the Rippey Chicken model and the UCSD Gelatin model (2.6/5 for the Morrow Ballistics and 3.2/5 for the Amini Ballistics model), they can be stored indefinitely without any special storage conditions and can theoretically be used for years without replacement. However, due to the specific ballistics gelatin used for both these models, their cost exceeds that of any of the other models tested ($27.11 for the Morrow model and $26.40 for the Amini Ballistics model). Although the Johnson tofu and Nolting Spam models both require special storage conditions and scored the lowest on average, they are the cheapest and easiest to make which may be attractive in certain instances, such as quickly setting up training programs; however, they were noted to be overall poor quality training models for novices.

This study is limited by the prospective observational methodology. The primary limitation is that the models were tested by skilled practitioners while phantom models are typically used for teaching a new skill. Testing these models directly on clinicians who do not yet have this procedural skill may lead to more robust and generalizable results for training purposes. Model longevity over time was indirectly measured via repeated needle punctures on the same day, which were quantified as a proxy measurement for reusability over time. Along these lines, the Likert scale scoring rubric questions were representative of the initial use of newly constructed phantoms, removing variables such as deterioration and handling issues. Although the chicken phantom scored highest in our study, the gelatin phantom could have potentially scored higher if longevity were represented in our primary objectives. The unblinded nature of the study introduced a further limitation as the participants were both aware of which models they and other participants were trialing, which could lead to bias in feedback. This study did not directly compare non-commercial to commercial phantoms, something which may be considered for future studies.

Homemade phantom models represent an easily accessible, cost-effective, useful and thus important tool in ultrasound education. As such, studying and vetting different models is important to enhance educational opportunities and clinical outcomes. The findings in this study represent the first formal head-to-head comparison of many unique homemade phantom models in the setting of ultrasound guided PIV insertion.

Authors contributions

A.A. conceived of the presented question and supervised the project. The protocol was designed by L.S., Z.R., S.Z., L.H., R.L., K.K., and A.A. Phantom models were created by L.S., Z.R., S.K., L.H., K.K., K.G., R.K., and A.A. Phantom models were tested by A.A., Z.R., K.G., R.K., D.M. and S.K. Data was compiled and analyzed by S.Z. and L.H. L.S. led manuscript writing. All authors provided feedback and guidance throughout the process of protocol development, data acquisition, and manuscript writing.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical approval/patient consent

This protocol was approved by the institutional IRB at Thomas Jefferson University. All participants provided written informed consent.

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References

1. Zingg W and Pittet D. Peripheral venous catheters: an under-evaluated problem. *Int J Antimicrob Agents* 2009; 34(Suppl 4): S38–S42.
2. Alexandrou E, Ray-Barruel G, Carr PJ, et al. Use of short peripheral intravenous catheters: characteristics, management, and outcomes worldwide. *J Hosp Med*; 13. Epub ahead of print 30 May 2018. DOI: 10.12788/jhm.3039.
3. Gottlieb M, Sundaram T, Holladay D, et al. Ultrasound-guided peripheral intravenous line placement: a narrative review of evidence-based best practices. *West J Emerg Med* 2017; 18: 1047–1054.
4. Duran-Gehring P, Bryant L, Reynolds JA, et al. Ultrasound-guided peripheral intravenous catheter training results in physician-level success for emergency department technicians. *J Ultrasound Med* 2016; 35: 2343–2352.
5. Makeeva V, Gullett JP, Dowla S, et al. Evaluation of homemade ballistic gelatin phantoms as a low-cost alternative to commercial-gade phantoms in medical education. *Med Sci Educ* 2016; 26(3): 307–316.

6. Amini R. A novel and inexpensive ballistic gel phantom for ultrasound training. *World J Emerg Med* 2015; 6(3): 225.
7. Morrow DS and Broder J. Cost-effective, reusable, leak-resistant ultrasound-guided vascular access trainer. *J Emerg Med* 2015; 49(3): 313–317.
8. UCSD Ultrasound. How to: DIY ultrasound guided peripheral IV phantom – UCSD ultrasound, http://emultrasound.sdsc.edu/index.php/2017/12/07/usgpiv-phantom/ (2017, accessed 18 June 2019).
9. Rippey JCR, Blanco P and Carr PJ. An affordable and easily constructed model for training in ultrasound-guided vascular access. *J Vasc Access* 2015; 16(5): 422–427.
10. Johnson G. How to make & practice with an ultrasound phantom for IVs, lines, abscess, https://www.youtube.com/watch?v=I-Wqu6Tp8U4&feature=youtu.be (2016, accessed 3 October 2019).
11. Nolting L, Hunt P, Cook T, et al. An inexpensive and easy ultrasound phantom: a novel use for SPAM. *J Ultrasound Med* 2016; 35(4): 819–822.
12. Spencer TR and Bardin-Spencer AJ. Pre- and post-review of a standardized ultrasound-guided central venous catheterization curriculum evaluating procedural skills acquisition and clinician confidence. *J Vasc Access* 2019; 21(4): 440–448.
13. Bahner DP, Goldman E, Way D, et al. The state of ultrasound education in U.S. medical schools: results of a national survey. *Acad Med J Assoc Am Med Coll*. 2014; 89(12): 1681–1686.
14. CAE Healthcare. Branched 2-vessel ultrasound training model for vascular access ultrasound training, http://www.bluephantom.com/product/Branched-2-Vessel-Ultrasound-Training-Block-Model.aspx?cid=436 (accessed 3 October 2019).