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Blue-Blood Pig Thorax Model Increases Residents' Confidence in Internal Mammary Dissection

Kirsten A. Gunderson, MD[1] Weifeng Zeng, MD[1] Zeeda H. Nkana, BS[1] Kasey Leigh Matabele Wood, BS[1] Sarah M. Lyon, MD[1] Nicholas J. Albano, MD[1] Samuel O. Poore, MD, PhD[1]

[1] Division of Plastic Surgery, University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin

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Address for correspondence Samuel O. Poore MD, PhD, Division of Plastic Surgery, University of Wisconsin School of Medicine and Public Health, 600 Highland Avenue, CSC G5/347, Madison, WI 53792 (e-mail: poore@surgery.wisc.edu).

Abstract

Background Preparation of the recipient vessels is a crucial step in autologous breast reconstruction, with limited opportunity for resident training intraoperatively. The Blue-Blood–infused porcine chest wall—a cadaveric pig thorax embedded in a mannequin shell, connected to a saline perfusion system—is a novel, cost-effective ($55) simulator of internal mammary artery (IMA) dissection and anastomosis intended to improve resident's comfort, safety, and expertise with all steps of this procedure. The purpose of this study was to assess the effect of the use of this chest wall model on resident's confidence in performing dissection and anastomosis of the IMA, as well as obtain resident's and faculty's perspectives on model realism and utility.

Methods Plastic surgery residents and microsurgery faculty at the University of Wisconsin were invited to participate. One expert microsurgeon led individual training sessions and performed as the microsurgical assistant. Participants anonymously completed surveys prior to and immediately following their training session to assess their change in confidence performing the procedure, as well as their perception of model realism and utility as a formal microsurgical training tool on a five-point scale.

Results Every participant saw improvement in confidence after their training session in a minimum of one of seven key procedural steps identified. Of participants who had experience with this procedure in humans, the majority rated model anatomy and performance of key procedural steps as “very” or “extremely” realistic as compared with humans. 100% of participants believed practice with this model would improve residents' ability to perform this operation in the operating room and 100% of participants would recommend this model be incorporated into the microsurgical training curriculum.

Conclusion The Blue-Blood porcine chest wall simulator increases trainee confidence in performing key steps of IMA dissection and anastomosis and is perceived as valuable to residents and faculty alike.

Keywords
- microsurgery
- surgical simulation
- surgical education
- autologous reconstruction

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Consistent, frequent, and intensive practice is essential in the refinement and mastery of microsurgical skills.[1] In an effort to meet the educational needs of surgical residents, microsurgical training models—which allow the novice surgical trainee to practice microsurgical skills in a laboratory setting that is both low stakes and realistic—have been developed.[2] Studies have shown that repetitious practice on such models over a long period of time is a highly effective means by which surgical residents may overcome the steep learning curve associated with microsurgery.[1,3] It is no surprise, then, that laboratory simulations have become an indispensable component of microsurgical training.[1,2,4]

Live animal models are considered the gold standard for simulated microsurgical training; however, their use is limited by high costs and associated ethical concerns.[5] The use of cadaveric animal tissue—most commonly chicken, rat, and porcine—presents an alternative that is cost-effective, acceptably realistic, and shown to improve resident's competence.[6–10] However, without investigation, it is difficult to discern a microsurgical training model's ability to contribute positively toward resident's education. Consequently, it is essential to evaluate a given model for fidelity and impact prior to its incorporation into a training curriculum.[11]

We recently described the creation of the Blue-Blood porcine chest wall as a realistic and affordable means of simulating internal mammary artery (IMA) and internal mammary vein (IMV) preparation and anastomosis.[12] This procedure is extremely important for residents in plastic and reconstructive surgery to learn as it is a key step in autologous breast reconstruction. This operation (e.g., deep inferior epigastric perforator [DIEP] flaps) typically relies on the use of the IMA and IMV as the recipient vessels.[13–16] The preparation of the IMA and IMV is a crucial step in autologous breast reconstruction, as failure to perform it correctly may result in patient injury,[17] complication, or flap failure.[18,19] Thus, the Blue-Blood porcine chest wall model was developed with the intention of improving resident's comfort and expertise in this critical surgical procedure prior to performing the operation on humans.

The aim of the present study was to assess the effect of training with the Blue-Blood porcine chest wall on trainee confidence in performing dissection and anastomosis of the IMA and IMV, as well as obtain resident's and faculty's perspectives on the realism and utility of this model.

Methods

This study was reviewed by the University of Wisconsin Institutional Review Board (IRB) and determined to be exempt. As such, a formal information sheet approved by the University of Wisconsin IRB was provided to all individuals invited to participate, who then had the option to accept or decline participation. Participants could withdraw at any point during the study.

Setting and Study Population

Postgraduate year (PGY)3, PGY4, PGY5, and PGY6 plastic surgery residents and microsurgery faculty from the Division of Plastic Surgery at the University of Wisconsin were invited to participate. PGY1 and PGY2 residents were excluded as use of the simulator is most beneficial to residents with a strong grasp of basic microsurgery techniques and some experience in the operating room (OR) during cases of breast reconstruction via microvascular free tissue transfer.

Level of training was recorded for each participant. Subjective, anchored experience with this procedure in humans was additionally documented for each participant and categorized as follows: none, minimal, some, moderate, considerable, or extensive.

The Blue-Blood porcine chest wall model was assembled as previously described, as demonstrated in ►**Fig. 1**.[12] All training sessions were conducted at the University of Wisconsin Microsurgical Training Center housed in the laboratory of the senior author (S.O.P.). One expert microsurgeon (W.Z.) led individual training sessions and performed as the microsurgical assistant. During training sessions, participants were guided through dissection of the chest wall, preparation of the internal mammary vessels, and vessel anastomoses, as demonstrated in ►**Video 1**.

Video 1

Blue-Blood pig thorax simulator for internal mammary vessel dissection. Narrated video captured through a surgical microscope showing a resident's training session on the novel Blue-Blood pig thorax simulator. (Reprinted with permission from Zeng W, Gunderson KA, Sanchez RJ, et al. The Blue-Blood porcine chest wall: a novel microsurgery training simulator for internal mammary vessel dissection and anastomosis. J Reconstr Microsurg 2020.) Online content including video sequences viewable at: https://www.thieme-connect.com/products/ejournals/html/10.1055/a-2057-0766.

Data Sources

Participants anonymously completed a survey immediately prior to and immediately following the training session to assess change in participant confidence, model fidelity, and perceived model utility. We utilized an eight-question survey with a five-point rating scale to assess change in resident's confidence in performing seven key procedural steps in humans, as well as the procedure as a whole (►**Table 1**), with a response of 1 corresponding to "not at all confident" and 5 corresponding to "extremely confident." The post-training survey also assessed model fidelity with regard to the anatomy of the model (►**Table 2**) and performing each surgical step on the model as compared with humans (►**Table 3**).

Finally, participants were asked questions regarding model utility. Participants were asked if they believe practice with this model would improve residents' ability to perform this operation in the OR, if they would recommend that this model be incorporated into the plastic surgery residency microsurgical training curriculum and, if so, at what training

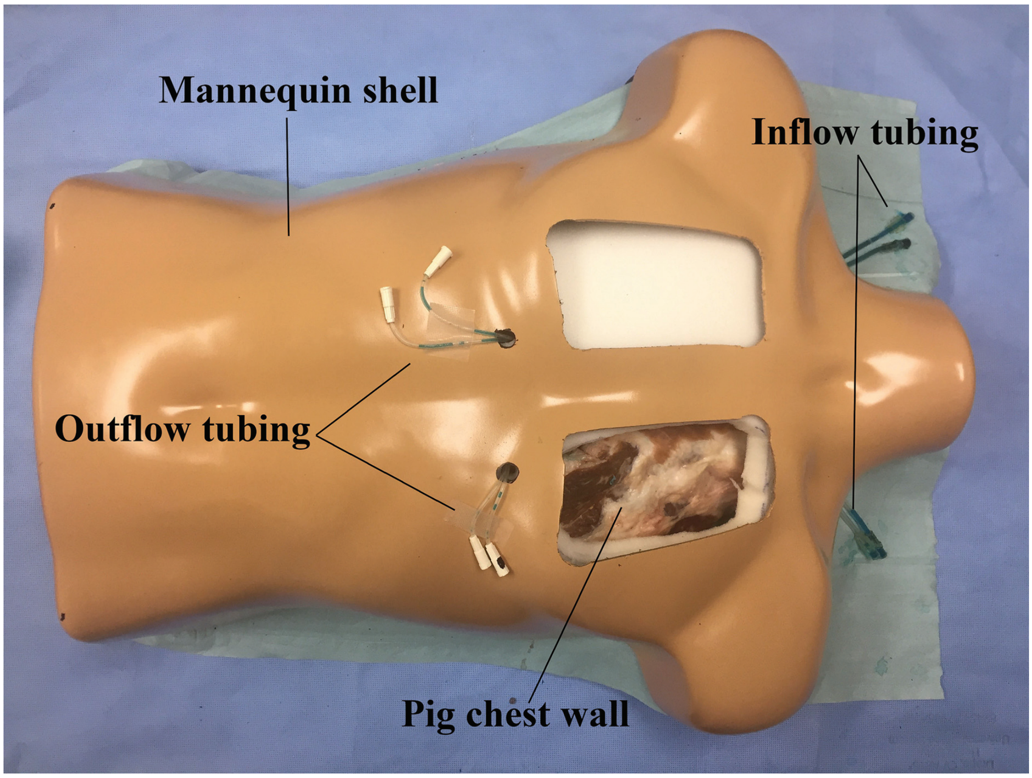

Fig. 1 Fully assembled Blue-Blood internal mammary artery training model. (Reprinted with permission from Zeng W, Gunderson KA, Sanchez RJ, et al. The Blue-Blood porcine chest wall: a novel microsurgery training simulator for internal mammary vessel dissection and anastomosis. J Reconstr Microsurg 2021;37(04):353–356.)

Table 1 Participant's confidence survey

Surgical steps	Not at all	Slightly	Moderately	Very	Extremely
Dissection down to rib	○	○	○	○	○
Incision and elevation of the perichondrium	○	○	○	○	○
Excision of rib	○	○	○	○	○
Identification of vessels	○	○	○	○	○
End-to-end anastomosis	○	○	○	○	○
Use of venous coupler	○	○	○	○	○
Evaluation of anastomosis	○	○	○	○	○
Overall surgical procedure	○	○	○	○	○

Note: Participants were asked to rate how confident they are performing each part of the procedure in humans independently both before and after their training session.

Table 2 Anatomic fidelity survey

Anatomic feature	Not at all	Slightly	Moderately	Very	Extremely
Overall anatomy	○	○	○	○	○
Vessel depth	○	○	○	○	○
Vessel thickness	○	○	○	○	○
Vessel consistency/behavior	○	○	○	○	○
Rib anatomy	○	○	○	○	○
Perichondrium anatomy	○	○	○	○	○

Note: Participants were asked to mark how realistic they felt the anatomy was in this model compared with humans.

Table 3 Surgical fidelity survey

Surgical step	Not at all	Slightly	Moderately	Very	Extremely
Dissection down to rib	○	○	○	○	○
Incision and elevation of the perichondrium	○	○	○	○	○
Excision of rib	○	○	○	○	○
Identification of vessels	○	○	○	○	○
End-to-end anastomosis	○	○	○	○	○
Use of venous coupler	○	○	○	○	○
Evaluation of anastomosis	○	○	○	○	○
Overall surgical procedure	○	○	○	○	○

Note: Participants were asked to mark how realistic they felt each surgical step was in this model compared with humans.

level they felt it would be most beneficial. A free text section was provided for additional comments regarding the model and training experience. Time to completion of each training session was also documented.

Statistical Analysis

Descriptive statistics were calculated to characterize the participants' responses to the general survey information (i.e., PGY level and amount of experience). Next, microsurgical competency survey results were analyzed. The Shapiro–Wilk normality test was utilized to confirm that the data were not normally distributed. Subsequently, a paired two-sample Wilcoxon's tests were conducted to assess if microsurgical competency survey results demonstrated a statistically significant change in confidence among participants prior to and after completing the IMA activity. These survey results were then visualized via generation of paired data point boxplots.

To assess how level of surgical training influenced participants' confidence, one-way ANOVA tests were used to determine if there was a relationship between level of surgical training (resident vs. attending) and difference in survey responses prior to and after the IMA activity. The one-way ANOVA test was again utilized to quantify the association between level of surgical training and time used to complete the IMA training activity. Finally, descriptive statistics were conducted to evaluate participants' perception of realism of the IMA training model.

Results

A total of 17 participants, including 12 residents and 5 faculty members, participated in this study, with previous experience preparing the IMA in humans ranging from "none" to "extensive." Breakdown of participant training level and previous experience can be visualized in ►**Figs. 2** and **3**, respectively.

Self-Assessed Confidence

After training with the Blue-Blood IMA model, participants had significantly increased comfort and confidence in performing six of the seven key procedural steps identified (►**Table 4**). Additionally, participants were significantly more confident in their ability to perform the procedure as a whole after the training session, with a pretraining average confidence rating of 2.94 out of 5 and a posttraining average

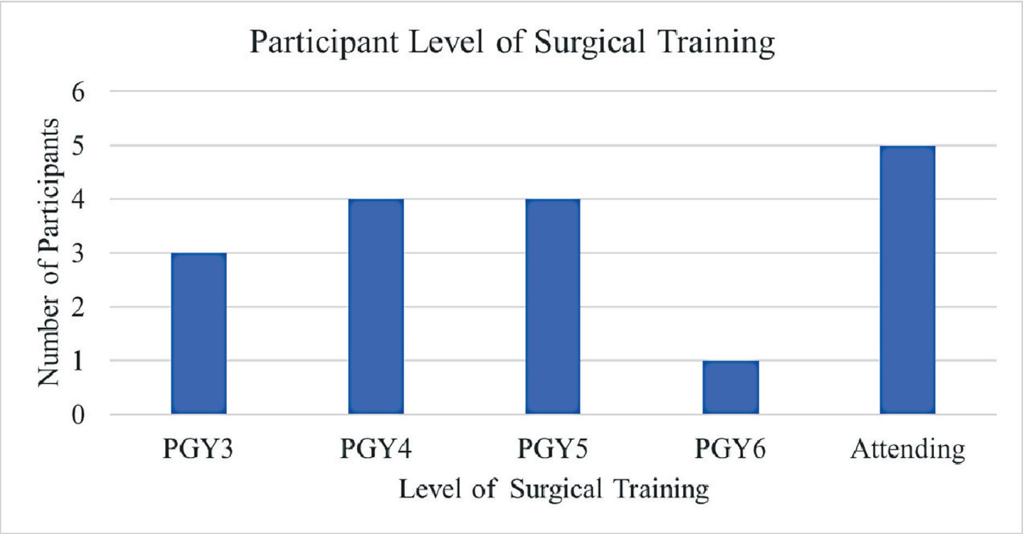

Fig. 2 Number of participants in study by level of surgical training.

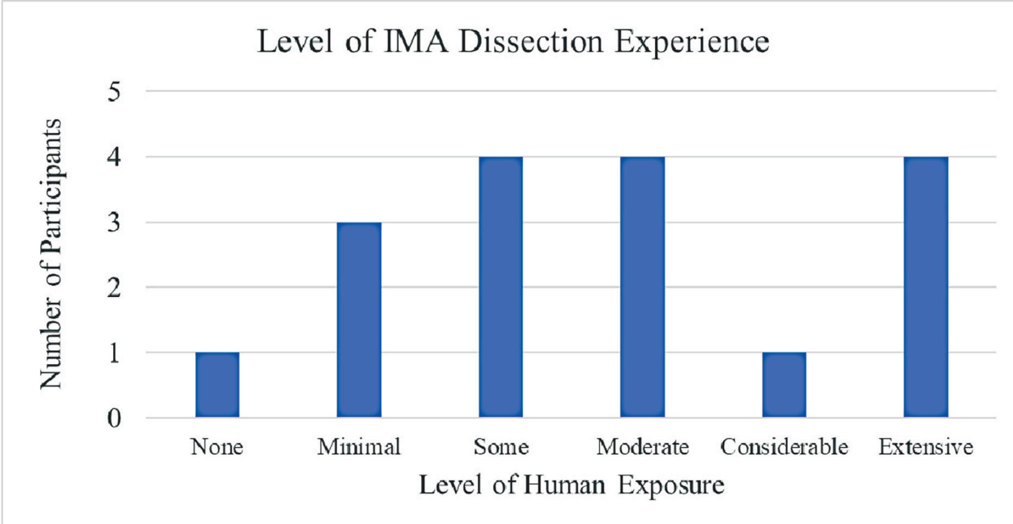

Fig. 3 Number of participants in study by level of experience performing procedure in humans. None = no experience. Minimal = observation only. Some = acting as first assist. Moderate = acting as primary surgeon with minimal supervision. Considerable = comfortable with all aspects of the procedure, not regularly performed in my practice. Extensive = perform this operation regularly in my practice.

Table 4 Participant's confidence pre- versus posttraining with model

Procedural step	Pre-survey Mean ± SD (range)	Post-survey Mean ± SD (range)	*p*-Value
Dissection to rib	3.24 ± 1.62 (1–5)	3.82 ± 1.13 (1–5)	0.03125[a]
Elevation of perichondrium	3.35 ± 1.54 (1–5)	3.76 ± 1.25 (1–5)	0.02627[a]
Excision of rib	3.00 ± 1.70 (1–5)	3.59 ± 1.28 (1–5)	0.06789
Identify vessels	3.12 ± 1.50 (1–5)	3.71 ± 1.10 (1–5)	0.01922[a]
End-to-end anastomosis	3.29 ± 1.31 (1–5)	3.76 ± 1.20 (1–5)	0.005962[a]
Venous coupler	3.24 ± 1.39 (1–5)	3.75 ± 1.24 (1–5)	0.03054[a]
Evaluation of anastomosis	3.29 ± 1.40 (1–5)	3.76 ± 1.20 (1–5)	0.01471[a]
Overall surgical procedure	2.94 ± 1.52 (1–5)	3.47 ± 1.23 (1–5)	0.008334[a]

Notes: Participant's perceptions of confidence levels of performing each surgical step in humans before versus after training session. 1 = not at all, 2 = slightly, 3 = moderately, 4 = very, 5 = extremely. Significance indicated by superscript "a."

confidence rating of 3.47 out of 5 ($p = 0.008$). Change in confidence performing the procedure can be visualized in ►**Fig. 4**. Notably, every participant reported improvement in confidence in at least one of the seven key procedural steps identified. When stratified by trainee type (resident vs. faculty), there was a significant difference in the amount of change in confidence following the training session, with residents reporting a significantly greater change in confidence in four of the seven procedural steps and the procedure as a whole (►**Table 5**).

Fig. 4 Boxplot of participant's confidence in performing overall procedure pre- versus posttraining with the Blue-Blood chest wall model. Gray lines show individual participant change in responses.

Model Fidelity

Overall model fidelity, with regard to the anatomy of the model and performance of each surgical step, was evaluated by each participant. On average, participants felt the surgical steps and anatomy were "moderately" to "extremely" realistic (►**Table 6**). Of participants with at least "moderate" experience with this procedure in humans (13 participants), the majority (10 participants) rated model anatomy and performance of key procedural steps as "very" or "extremely" realistic as compared with humans. In the category of anatomic fidelity, vessel depth and performance of

Table 5 Resident versus faculty change in confidence after training session

	Difference in pre-survey and post-survey responses Mean ± SD (range)		
Procedural step	**Resident ($n = 12$)**	**Faculty ($n = 5$)**	***p*-Value**
Dissection to rib	0.917 ± 0.900 (0–2)	−0.2 ± 0.447 (−1 to 0)	0.004196[a]
Elevation of perichondrium	0.583 ± 0.669 (0–2)	0 ± 0 (0–0)	0.0116[a]
Excision of rib	0.833 ± 1.19 (−2 to 2)	0 ± 0 (0–0)	0.03407[a]
Identify vessels	0.833 ± 0.835 (0–2)	0 ± 0 (0–0)	0.005354[a]
End to end anastomosis	0.583 ± 0.515 (0–1)	0.2 ± 0.447 (0–1)	0.1596
Venous coupler	0.636 ± 0.809 (0–2)	0.2 ± 0.447 (0–1)	0.1896
Evaluation of anastomosis	0.583 ± 0.669 (0–2)	0.2 ± 0.447 (0–1)	0.1944
Overall surgical procedure	0.75 ± 0.622 (0–2)	0 ± 0 (0–0)	0.001537[a]

Notes: Comparison of change in confidence before and after training session between residents and faculty. Significance indicated by superscript "a."

Table 6 Model fidelity evaluation

Fidelity category	Answer (scale: 1–5) Mean ± SD (range)
Anatomic fidelity	
Overall anatomy	3.65 ± 0.61 (3–5)
Vessel depth	3.94 ± 0.83 (2–5)
Vessel thickness	3.76 ± 0.66 (3–5)
Vessel consistency	3.88 ± 0.86 (2–5)
Rib anatomy	3.06 ± 0.77 (2–4)
Perichondria anatomy	3.56 ± 1.03 (1–5)
Surgical fidelity	
Dissection of rib	3.47 ± 0.51 (3–4)
Perichondrium	3.41 ± 0.87 (2–5)
Excision of rib	3.76 ± 0.75 (2–5)
Identify vessels	4.11 ± 0.93 (2–5)
End to end anastomosis	4.24 ± 0.75 (3–5)
Venous coupler	4.09 ± 0.94 (2–5)
Evaluation of anastomosis	4.29 ± 0.69 (3–5)
Overall surgical procedure	3.88 ± 0.60 (3–5)

Notes: Descriptive statistics to evaluate participants' survey responses pertaining to how realistic the IMA training model is. 1 = not at all, 2 = slightly, 3 = moderately, 4 = very, 5 = extremely.

Table 7 Benefit of model based on level of training

Level of training	Number of responses
Medical student	0
PGY1	2
PGY2	4
PGY3	12
PGY4	12
PGY5	9
PGY6	5
PGY7	0
Faculty	1

Note: Level of training at which utilization of IMA model and training session is perceived to be most beneficial.

anastomoses were perceived as the model's strongest features; however, participants noticed differences in rib and perichondrium anatomy, describing these structures as wider and flatter in comparison to human anatomy.

Model Utility

Perception of model utility was remarkably positive. One hundred percent of participants believed practice with this model would improve residents' ability to perform this procedure in the OR. One hundred percent of participants also stated they would recommend this model be incorporated into the existing microsurgical training curriculum. Most participants believed that utilization of this model in the training curriculum would be most beneficial during the PGY3 and PGY4 years (►**Table 7**).

Time to Completion

We found that differences in time to completion of the training session based on level of surgical training did not reach significance (►**Table 8**); however, a trend demonstrating a decrease in time to completion was noted as level of surgical training increased (►**Fig. 5**). On average, residents required more time to complete the training model than faculty (40.5 ± 10.7 minutes vs. 31.5 ± 10.0 minutes).

Discussion

Preparation of the IMA and IMV as recipient vessels is a critical step of breast reconstruction via microsurgical free tissue transfer that plastic surgery residents must master. In this study, we have demonstrated that not only is the Blue-Blood porcine chest wall simulator highly realistic, but also that training with the model improves resident's comfort and confidence in performing the steps of this procedure after just one session. Expert faculty and residents alike agree integration of this model into existing microsurgical training curriculum would be beneficial.

The traditional model for surgical training revolved around an apprenticeship model, with the aim of providing trainees hands-on learning in a setting that fostered autonomy.[2,20,21] Many surgical training programs have transitioned from the

Table 8 Time to completion by level of training

	n	Number of minutes used to complete anastomosis Mean ± SD (range)	*p*-Value
Level of training			0.0724
PGY3	3	45.0 ± 14.8 (30.4–60)	
PGY4	4	40.9 ± 13.9 (22–52.6)	
PGY5	4	37.8 ± 6.59 (31.9–47.1)	
PGY6	1	36.9 ± NA (NA)	
Faculty	5	31.5 ± 10.0 (20.5–40.6)	
Overall			
	Resident (n = 12)	**Faculty (n = 5)**	**p-Value**
Minutes used to complete IMA training activity Mean ± SD (range)	40.5 ± 10.7 (22.00–60.00)	31.5 ± 10.0 (20.5–40.6)	0.1345

Note: Amount of time required to complete the IMA model training session across discrete levels of surgical training.

apprenticeship model to a paradigm that emphasizes core competencies and formalized assessments.[21] Resultantly, surgical training models have been popularized as they increase the efficiency with which trainees may acquire critical surgical skills.[22–24] This finding underscores the potential of the Blue-Blood porcine chest wall simulator to provide a highly productive learning experience for surgical trainees.

Ziolkowski et al recently published a pilot study of a novel, fully synthetic, DIEP flap IMA anastomosis surgical simulator.[25] This model focused on providing authentic simulation of chest excursion that occurs during natural breathing of a patient while completing the surgical anastomosis of this procedure. The authors demonstrated residents had an increase in confidence performing anastomoses after practice on the simulator, highlighting the importance of surgical simulation in the acquisition of the specific skills of insetting a DIEP flap and improving confidence prior to the operating theater. The Blue-Blood simulator similarly identified increased resident's confidence in performing these skills. Our model also carries the additional advantages of improved vessel fidelity by use of cadaveric tissue, real-time feedback with the Blue-Blood perfusion system, and the ability to improve acquisition of other steps involved in the preparation of the vessels in addition to the anastomosis, all provided at a much lower cost—$55 versus >$13,000 for physical materials.

The findings herein identify an increase in confidence on the part of the resident trainees with use of this model. While there is no doubt the most realistic training occurs in the OR, this can be a high stress environment for both the trainee and the faculty surgeon when it comes to performing critical portions of procedures for the first time, particularly with faculty–trainee pairing that may be new to each other. Implementation of a surgical training model may provide a platform for the trainees to refine their skills until deemed suitable for transition to the OR under preceptor supervision.[2,26,27] Eventually, this simulation training has the potential to not only bring more opportunity and autonomy for the residents but also improve the safety and health of patients undergoing free flap breast reconstruction.

An additional benefit was identified in this study on the part of the faculty. In discussion with participating attendings, multiple faculty members stated that existence of the model made them more confident in residents' abilities to perform this portion of the procedure in the OR. In turn, they stated that they would be more likely to allow them to perform it in the OR in the future after having practiced with this model, highlighting the value that this model can bring to a trainee's education.

Furthermore, the study herein highlighted the realism of the model with regard to anatomy. Importantly, the similar anatomical configuration of the porcine chest wall makes this a suitable model for multiple methods of IMA and IMV dissection. As our institution employs the non–rib-sparing technique, in this study, the seven key procedural steps evaluated were those of the non–rib-sparing technique. Though not evaluated in this study, this model may easily be used for other methods of IMA and IMV dissection, including rib-sparing techniques.[12,28,29] Rib-sparing techniques have become more popular recently, and some series have demonstrated a decreased complication profile than non–rib-sparing techniques.[30] This technique is seen by some as more technically challenging, requiring creation of anastomoses in a more confined area. Use of this model for

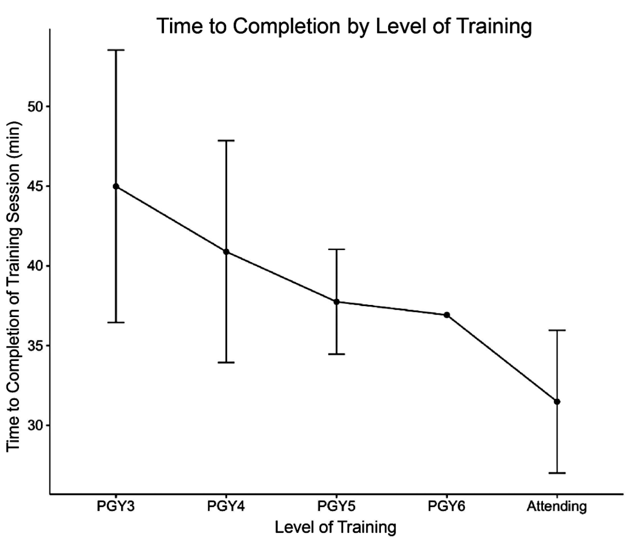

Fig. 5 Line graph with error bars illustrating the mean time used to complete the IMA model training session for each level of surgical training.

practice of this technique prior to the OR would likely be beneficial for residents, just as it was found to be for the non–rib-sparing technique in this study.

Importantly, the focus of this study was to assess change in resident's confidence in performing IMA and IMV dissection and anastomosis after training with the model, with the goal of improving trainee's confidence and safety in performing this procedure in the OR. The purpose of this study was not for the creation of a resident assessment tool. As such, at its current level of evaluation, we recommend this model as an adjunct training tool for a comprehensive microsurgical curriculum, and not as an assessment tool for resident's competency. With the push toward competency-based education and training in plastic and reconstructive surgery, valid, objective assessment of resident's performance is necessary. Further investigation is required for this model to create a formal assessment tool for microsurgical and plastic surgery education.

There are several limitations to this study. This study was conducted at a single institution with a robust microsurgical curriculum; thus, the generalizability for which level of trainee this model is most beneficial for may differ at other institutions. Results may be different in our small cohort than across different institutions where there is variation in clinical exposure, variation in clinical volume, and who may have an entirely different surgical and microsurgical training curriculum. As we have implemented our microsurgery curriculum earlier in resident's training over the years, as is true for many programs across the nation, it is apparent residents are gaining technical skills at earlier stages in their training. In the future, this model may prove beneficial as part of a resident's microsurgical training curriculum even earlier in residency than the PGY3 level, which was the cutoff utilized in this study. Additionally, this study only assessed resident's confidence change immediately after one training session with the simulator. Further research is necessary to determine the long-term impact on resident's confidence and how repeated use of the model affects training outcomes. Furthermore, as mentioned earlier, the present study utilized self-reported participant's confidence to assess the validity of the Blue-Blood porcine chest wall simulator, which has been used to assess previous surgical training models[31–33]; however, self-reported confidence is limited in its generalizability in that it is not standardized. Future investigations into the validity of the Blue-Blood porcine chest wall simulator might implement methods of evaluation that are more standardized and objective. Finally, the low cost for the creation of this model ($55) accounts for physical materials required for assembly only, as described previously.[12] The cost of this model is low in the setting of an institution with an existing simulation laboratory with dedicated laboratory microscope and microsurgical training staff, as well as donated cadaveric specimens. Cost of creating and maintaining a space such as this would be much greater than $55. However, it is our belief that this model in isolation would also be appropriate for training under loupe magnification and would only require the additional purchase of a basic microsurgical instrument set.

Conclusion

The Blue-Blood porcine chest wall model is a novel simulator for resident's training of IMA and IMV preparation and anastomosis. Training with this simulator increases trainee's confidence in performing key surgical steps of the procedure after one training session. The model is perceived as highly authentic and valuable to resident's education by both residents and faculty and will be formally integrated into our institutional microsurgery training curriculum.

Conflict of Interest
None declared.

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