

Development of a pulsatile, tissue-based, versatile vascular surgery simulation laboratory for resident training

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ABSTRACT

Simulation in surgery is becoming an important component of surgical education. Training on bench top models has been demonstrated to improve technical skills. The objective of our project was to create a vascular surgery simulation model. The simulation model consists of a platform, artificial blood reservoir, artificial blood, inflow and outflow limbs, electric motor, battery, pulse generator, and cryopreserved vessel. Three different vascular surgery simulation stations were created: carotid endarterectomy with shunting and patch angioplasty, arterial bypass, and arteriovenous graft formation. A scientific study involving surgical residents will need to be undertaken to determine whether this simulator has intermodal transferability. (*J Vasc Surg Cases and Innovative Techniques* 2017;3:209-13.)

Since the establishment of the Accreditation Council for Graduate Medical Education residency duty hour restrictions, there have been reports of reductions in the operative experience of residents training in general surgery.¹ These external pressures have placed surgery residency programs in challenging positions, specifically in terms of advancing technical skills through practice. In response to the growing recognition of an inadequate uniformity at which to measure proficiency in technical skills, there has been a prevailing interest in supplementation of skills through simulation training. Seymour et al² and Grantcharov et al³ each demonstrated, independently, in randomized trials that residents without previous training on laparoscopic simulators make more operative errors compared with residents afforded previous training on laparoscopic simulators, suggesting an evidence-based benefit to investment in surgical simulation. The Society of American Gastrointestinal and Endoscopic Surgeons developed the Fundamentals of Laparoscopic Surgery program, an evidence-based, scientifically sound surgical education program that entails a skills and cognitive component for training in basic laparoscopic surgery and provides a yardstick to objectively document technical and cognitive competency in the basics of laparoscopic surgery. The success of the

Fundamentals of Laparoscopic Surgery program has resulted in its becoming a training requirement by the American Board of Surgery before graduation of general surgery residents. The U.S. Department of Health and Human Services Agency for Healthcare Research and Quality supports simulation as an instrument to potentially improve practitioners' acquisition of skills with a goal aimed at improving patient safety and provides funding for multiple different simulation-based projects.⁴ As is evident by the adoption of multiple well-recognized organizations that are leaders in medical education, simulation can be considered to play an important role in surgical training.

Surgical simulation in vascular surgery is becoming an increasingly important component of a comprehensive education in vascular surgery. Studies have demonstrated that technical skills in vascular surgery can improve with the implementation of open simulation training.^{5,6} Robinson et al⁷ demonstrated in a randomized trial that with dedicated faculty instruction, resident performance improves in an open, simulated abdominal aortic aneurysm repair. Duschek et al⁶ demonstrated a statistically significant improvement in technical skills of 10 participants on a pulsatile, lifelike carotid endarterectomy with Dacron patch simulator. Training courses such as the UMass Vascular Skills and Simulation Course and the Cardiovascular Fellow's Bootcamp of the DeBakey Institute for Cardiovascular Education and Training have been developed and involve intricate vascular surgery simulators for complex skill training.^{8,9}

The objective of our project was to create a vascular surgery simulation model that had the characteristics of being safe, realistic, reproducible, and versatile and provided tactical feedback for an optimal experience for technical skill acquisition. To accomplish this, we designed a pulsatile, human tissue-based vascular surgery simulator capable of a variety of operative procedures that could potentially be used by surgery residents in an attempt to acquire technical skills.

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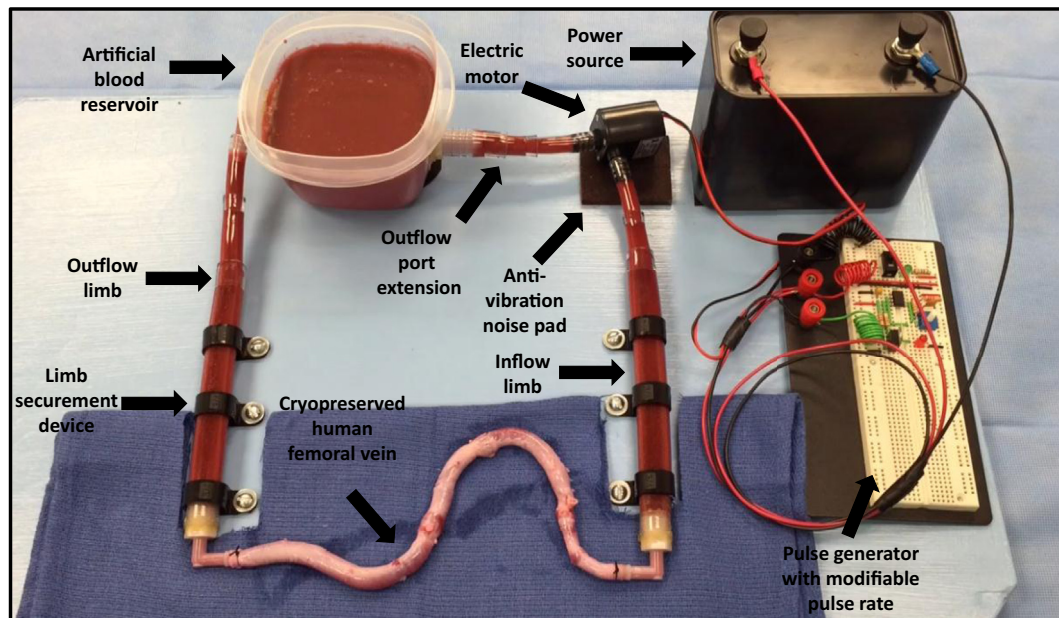


Fig 1. Vascular surgery simulation model with labeled components.

SIMULATOR DEVELOPMENT

A platform was constructed using a 60.5-cm long, 37-cm wide, and 1-cm thick piece of plywood. Inflow and outflow limbs were created using a combination of 0.64-cm inner diameter (ID), 90-degree nylon male hose barb elbows, epoxy plastic binder, and vinyl tubing (Watts, North Andover, Mass). Limbs were attached to the platform with securement devices created using cable clamps, screws, and washers. An artificial blood reservoir was made using a combination of a 473-mL plastic container; 0.64-cm ID, 90-degree nylon male hose barb elbow; 1.27-cm ID, nylon male hose barb adaptor; and port extension limb. An outflow port extension limb was created using a 4-cm segment of 1.59-cm outer diameter (OD), 1.27-cm ID vinyl tubing; 4-cm segment of 1.27-cm OD, 0.95-cm ID vinyl tubing; and 6-cm segment of 0.95-cm OD, 0.64-cm vinyl tubing.

A 4.8 W power consumption, 12 V DC rating, 240 L/h static flow rate electric water pump was used to create blood flow. A pulse generator with a modifiable pulse rate, consisting of a circuit board, integrated circuits, resistors, capacitors, wires, diodes, transistors, light-emitting diode, switch, and amplifier, was created by Jaime De La Ree, PhD, in his electrical engineering laboratory at Virginia Polytechnic Institute and State University. A 1.18-kg, 12 V, screw terminal battery was used as the power source. Each end of a ~9-mm ID, ~25-cm-long cryopreserved human femoral vein was fit over the 0.64-cm ID, 90-degree nylon male hose barb elbow of each of the inflow and outflow limbs (Fig 1).

An arteriovenous graft simulator was developed by creating another platform with all the associated components in an identical fashion with a few differences,

including modification of the artificial blood reservoir, creation of an accessory limb, and another approximately 10-cm segment of cryopreserved human saphenous vein graft placed in parallel with the arterial conduit. A bovine carotid artery was used as the arteriovenous graft. Artificial blood was made using a combination of water, corn starch, cocoa, and red food coloring (Table).

The simulation laboratory was able to be constructed into three different vascular surgery simulation stations: carotid endarterectomy with shunting and patch angioplasty (Fig 2), arterial bypass (Fig 3), and arteriovenous graft formation (Fig 4). Each simulation station was performed by the investigator and videotaped (Video). The Doppler flow of each simulation station were recorded using WavePad version 6.42 (NCH Software, Greenwood Village, Colo).

DISCUSSION

Work hour limitations, consistently evolving technologies, multifaceted physician responsibilities, and the highest focus on patient outcomes have stimulated the development of new training models in health care. Cook et al¹⁰ evaluated 609 studies involving 35,226 health care trainees and concluded that simulation training was reliably associated with improvement in multiple outcome measures, including technical skills. Simulation training with bench top models has also been demonstrated to result in transfer of skills to the operating room.¹¹ The Accreditation Council for Graduate Medical Education promotes and endorses simulation training in its ability to enable performance assessments in lifelike scenarios.

Table. Components of vascular surgery simulator

Component	Material details	Manufacturer/vendor	Distributor	Dimensions	Estimated cost (U.S. \$)
Platform	Plywood(TopChoice), sandpaper (3M), waterproof paint (Valspar, light blue, ~500 mL), cable clamps (Gardner Bender, black, 1.91 cm), screws, washers, antivibration motor pad (softtouch); pack of brown, self-adhesive, square felt pads used as furniture leg protectors, cut to 5.5 (L) × 5 (W) cm	TopChoice, 3M, Valspar, Gardner Bender, softtouch	Lowe's	60.5 (L) × 37 (W) × 1 (H) cm	30.00
Electric motor	4.8 W power consumption, 12 V DC rating, 400 mA max current, 240 L/h static flow rate, 3M static lift; life span, >30,000 hours; weight, 0.065 kg; OD, 8.6 mm; ID, 5.4 mm	Andoer	Amazon	5.2 × 4.6 × 5.5 cm	9.00
Pulse generator	Circuit board, integrated circuit, resistors, capacitors, wires, diodes, transistor, light-emitting diode, switch, amplifier	Jaime De La Ree, PhD	Multiple	18 (L) × 10 (W) × 1 (H) cm	10.00
Power source	1.18-kg, 12 V, screw terminal, mercury- and cadmium-free battery	Rayovac	Amazon	13.5 (L) × 7 (W) × 11 (H) cm	15.00
Artificial blood	Water, corn starch (Maizena 0.40 kg pack), cocoa (Hershey's cocoa special dark 0.23 kg container), red food coloring (McCormick)	Maizena, Hershey, McCormick	Kroger	500 mL	10.00
Artificial blood reservoir	0.45 kg plastic container (Rubbermaid); 0.64-cm ID, 90-degree nylon male hose barb elbow and 1.27-cm ID, nylon male hose barb adaptor (BrassCraft); epoxy plastic binder (Loctite); vinyl tubing: combination of 4 cm (1.59-cm OD, 1.27-cm ID), 4 cm (1.27-cm OD, 0.95-cm ID), 6 cm (0.95-cm OD, 0.64-in ID) (Watts)	Rubbermaid, BrassCraft, Loctite, Watts	Target	11 (L) × 11 (W) × 8 (H) cm	10.00
Inflow limb	One 0.64-cm ID, 90-degree nylon male hose barb elbow (BrassCraft); epoxy plastic binder (Loctite); vinyl tubing: combination of 16 cm (1.59-cm OD, 1.27-cm ID), 8.5 cm (1.27-cm OD, 0.95-cm ID), 8.5 cm (0.95-cm OD, 1.27-cm ID) (Watts)	BrassCraft, Loctite, Watts	Lowe's	30.5 (L) cm	10.00
Outflow limb	One 0.64-cm ID, 90-degree nylon male hose barb elbow (BrassCraft); epoxy plastic binder (Loctite); vinyl tubing: combination of 18 cm (1.59-cm OD, 1.27-cm ID), 9 cm (1.27-cm OD, 0.95-cm ID), 5.5 cm (0.95-cm OD, 0.64-cm ID) (Watts)	BrassCraft, Loctite, Watts	Lowe's	29.8 (L) cm	10.00
Arteriovenous graft accessory limb	Three 0.64-cm ID, 90-degree nylon male hose barb elbow (BrassCraft); epoxy plastic binder (Loctite); vinyl tubing, two components: first, 11 cm (1.59-cm OD, 1.27-cm ID); second, 9 cm (0.95-cm OD, 0.64-cm ID) (Watts)	BrassCraft, Loctite, Watts	Lowe's	First piece, 15 (L) cm; second piece, 9 cm	6.00
Human vessel	Cryopreserved human femoral vein and saphenous vein	CryoLife	Cryolife	~3-9 mm (ID) × ~15-25 cm (L)	N/A (donated)
Arteriovenous graft	Bovine carotid artery graft	Artegraft	Artegraft	~7 mm (ID) × ~10 cm (L)	N/A (donated)
Carotid patch	Porcine small intestinal submucosa extracellular matrix	CorMatrix	CorMatrix	2 cm (W) × 10 cm (L)	N/A (donated)

H, Height; ID, inner diameter; L, length; N/A, not applicable; OD, outer diameter; W, width.

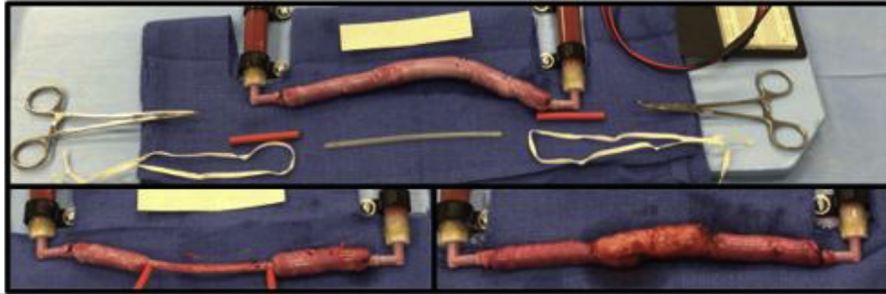


Fig 2. Carotid endarterectomy with shunting and patch angioplasty simulation station.



Fig 3. Arterial bypass simulation station.

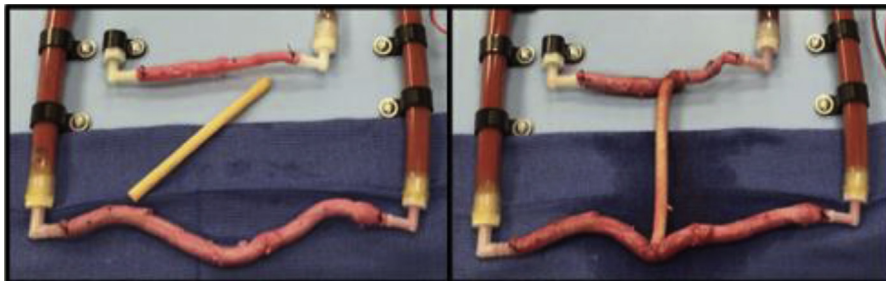


Fig 4. Arteriovenous graft simulation station.

A vascular surgery simulator with high fidelity, compared with one with low fidelity, has been shown to have a statistically significant difference in technical performance.⁵ Eckstein et al¹² suggested from their >20-year experience with pulsatile, lifelike vascular surgery simulation models that vascular surgery skill competence should be assessed with training models. Our simulator has the advantages of a simple bench top model in that it is relatively inexpensive to produce, carries negligible potential harm to the operator, and is transportable. It also has the ability to capture data in terms of procedural blood loss, quality of the anastomosis, and tissue handling. The simulation model could potentially be used to practice end-to-end anastomosis, end-to-side anastomosis, shunting, patch angioplasty, and vessel cannulation. This simulation model will also potentially allow the trainee to practice multiple different, complex, multistep operations as displayed in Figs 1-3 consisting of a carotid endarterectomy with patch angioplasty, arterial bypass, and arteriovenous fistula.

CONCLUSIONS

Considering the accumulating evidence of the effectiveness of surgical simulation and the growing interest in development of uniform, objective instruments to evaluate technical skills, high-fidelity surgical simulators are a potential fruitful investment to supplement formal surgical education. Our vascular surgery simulation model represents an innovative technique in the surgery simulation arena as a supplement to intraoperative skill acquisition. Further study will need to be undertaken with residents in surgical training to determine whether this simulator translates into statistically significant improvement in vascular surgery skills and understanding of operative sequence.

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