Carotid Endarterectomy Surgical Simulation Model Using a Bovine Placenta Vessel

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BACKGROUND: Carotid endarterectomy (CEA) is a common, well-developed surgical procedure. Although surgical simulation is gaining in importance for residency training, CEA practice opportunities for surgical residents are limited.

OBJECTIVE: To describe a new haptic CEA model.

METHODS: Six bovine placentas were used to create the model. Each placenta provided about 6 large arterial and venous bifurcations. In total, 36 large-vessel bifurcations were dissected and prepared for the CEA simulation. Bovine placenta vessels were arranged to simulate the common carotid artery (CCA), internal carotid artery (ICA), and external carotid artery (ECA). The diameters and wall thicknesses were measured and compared with human CCA, ICA, and ECA parameters.

RESULTS: All bovine placentas provided vessels suitable for modeling carotid artery bifurcations and CEA training. Mean ± SD diameters of simulated CCAs, ECAs, and ICAs were 11.2 ± 1.8, 4.3 ± 0.5, and 9.8 ± 3.0 mm, respectively, from nondilated veins and 8.7 ± 1.4, 4.4 ± 1.3, and 7.2 ± 1.7 mm, respectively, from nondilated arteries. Mean vessel wall thicknesses were 2.0 ± 0.6 mm for arteries and 1.4 ± 0.5 mm for veins. Placental vessel tissue had dimensions and handling characteristics similar to those of human carotid arteries. The CEA procedure and its subtasks, including vessel-tissue preparation and surgical skills performance, could be reproduced with high fidelity.

CONCLUSION: A bovine placenta training model for CEA is inexpensive and readily available and closely resembles human carotid arteries. The model can provide a convenient and valuable simulation and practice addition for vascular surgery training.

KEY WORDS: Bovine, Carotid artery, Endarterectomy, Placenta, Simulation, Training

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Stroke is the fourth leading cause of death in the United States[1] and the second major cause of death around the world.[2] Carotid endarterectomy (CEA) is a surgical procedure that is commonly performed by multiple subspecialists, with proven benefits for stroke prevention in appropriately selected patients.[3]

The novice doctor in residency or fellowship training currently faces a learning paradox. Complications occurring during the learning curve are becoming less tolerated, and the demands of supervision have increased, which has resulted in fewer opportunities for surgical trainees to hone their skills on living patients.[4]

ABBREVIATIONS: CCA, common carotid artery; **CEA,** carotid endarterectomy; **ECA,** external carotid artery; **ICA,** internal carotid artery

For many years, surgical skill was acquired only by performing actual procedures. Increasingly, trainees' early exposure is gained in the form of simulation models. With increased demand for the best possible outcomes in every patient, limitations on training experiences imposed by working-hour restrictions, and medicolegal concerns, simulation is a logical and practical method to bridge novices' development as they attain competence.[5]

The best known methods for surrogate surgical training are to use animals, human cadavers, silicone, and virtual models.[6] The validation and importance of vascular surgery practice on models are evidenced by the many residency program directors who have discussed a minimal training curriculum as part of the requirements for board certification.[7] The human placenta has been described by our group as an attractive model for neurosurgical and interventional neuroradiology training (in press). The use of a bovine placenta has not previously been described as a surgical training model.

Although models inherently have advantages and disadvantages, the objective of this study is to describe the appeal of the bovine placenta as a useful, inexpensive, widely available model that is able to simulate carotid artery surgery with high fidelity.

METHODS

Six bovine placentas were collected from a farm and taken to Barrow Neurological Institute. The placentas were refrigerated at 4°C to 8°C in a plastic bag for about a week and then discarded. All placentas were similar in size (approximately 1.5 m in total length and 40 cm in width) and in general vessel anatomy (ie, having a pair of umbilical arteries and a pair of umbilical veins with multiple branches). We found that the placentas should be cleaned and the bifurcations dissected as soon as possible to avoid deterioration of the specimen. Removing the allantoic membrane to expose the vessels did not seem to influence the deterioration of the placenta as a whole but allowed a cleaner biological training substrate for the surgeon. Freezing the placentas led to loss of the normal vessel elasticity and thus to an unsuitable model.

The largest bovine placenta vessels were chosen by direct vision and dissected from the placental allantoic membrane (Figure 1A and 1B). Multiple large vascular bifurcations resembling the common carotid artery (CCA), internal carotid artery (ICA), and external carotid artery (ECA) were identified in all placentas and isolated (Figure 1C). A total of 22 arterial and 14 venous bifurcations were used.

Vessel diameters and wall thicknesses were measured with a caliper to compare them with measurements for the human CCAs, ICAs, and ECAs in a patient population (mean age, 68 ± 8 years) with severe (>80% diameter reduction) carotid bifurcation occlusive disease after completion of the CEA, closing of the arteriotomy, and re-establishment of flow.[8] In bovine placenta, measurements were taken before and after vessel dilation, which was performed by inflating the cannulated vessel with normal saline injected from a 60-mL syringe (Figure 1D). Comparisons were done with the Mann-Whitney *U* test with Statistica 8.0 software (StatSoft, Inc). Values are presented as mean ± SD. *P* values $<.05$ were considered statistically significant.

The arterial Y shape was dissected from the bovine placenta. Opening the bovine placenta membrane is reminiscent of opening the carotid sheath in humans. Each end of the respective vessel was connected to an intravenous line to simulate anterograde and retrograde flow (Figure 1E). Normal saline was used to inflate the vessels, but any fluid should suffice.

CEA was simulated on the bifurcation segments of the bovine placenta vessels. Pen-dot markings were made over the simulated ICA and CCA to guide the incision (Figure 2A). After sequential vessel clamping under microscopic guidance, an arteriotomy was made with a number 11 blade (Figure 2B). The vessel lumen was carefully observed. With the aid of a surgical dissector, a blood clot (a simulated atherosclerotic plaque) was removed from the vessel intima layer (Figure 2C). The vessel was closed starting at either end with a 6-0 Prolene suture (Figure 2D). Next, the clamps were temporarily released to allow flow from the CCA simulated vessel and back flow from the ICA and ECA simulated vessels before the final closing suture was placed (Figure 2E). After the last suture, high-pressure flow was created using the normal saline intravenous line with

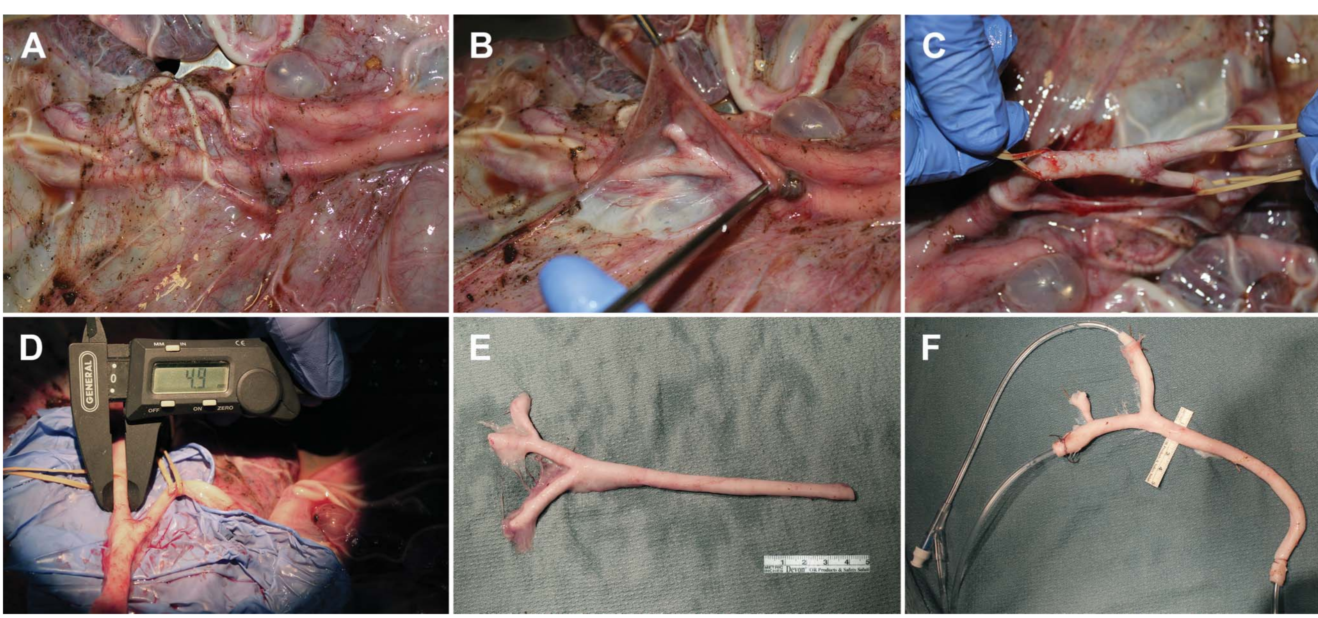

FIGURE 1. *Preparation of bovine placenta vessels.* **A**, *gross view of vessels in the allantoic membrane.* **B**, *identification and dissection of simulated common carotid artery, internal carotid artery, and external carotid artery.* **C**, *vessels are completely dissected from the debris and taken on rubber ligatures.* **D**, *measurement of the vessel diameter.* **E**, *dissected bifurcation.* **F**, *simulated flow into the carotid bifurcation model using intravenous tubes. Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*

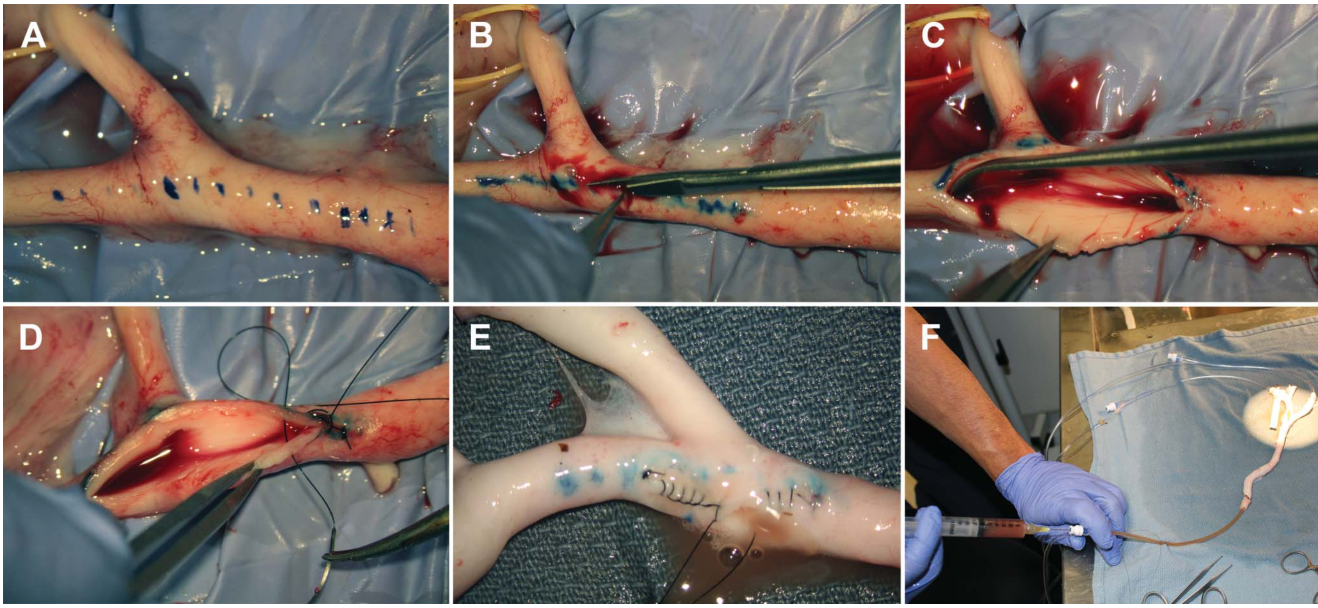

FIGURE 2. *Carotid endarterectomy simulation.* **A**, *marking the incision.* **B**, *opening the artery with scissors.* **C**, *removing the intra-arterial mass with a blunt dissector.* **D**, *closing the artery.* **E**, *flow and backflow simulation to wash out potential clots before final suture.* **F**, *checking the consistency of the suture line with high-pressure infusion. Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*

a pressure manometer to simulate arterial blood flow restoration; this tested the patency of the "carotid" suture line (Figure 2F).

RESULTS

From a total of 6 bovine placentas, 36 vessel bifurcations were prepared to simulate human carotid bifurcations. The mean vessel diameters for the simulated CCAs, ECAs, and ICAs were 11.2 ± 1.8, 4.3 ± 0.5, and 9.8 ± 3.0 mm, respectively, from nondilated bovine placenta veins and 8.7 ± 1.4, 4.4 ± 1.3, and 7.2 ± 1.7 mm, respectively, from nondilated bovine placenta arteries. The mean vessel wall thicknesses were 2.4 ± 0.6, 2.4 ± 0.4, and 1.6 ± 0.3 mm for bovine placenta arteries simulating CCAs, ICAs, and ECAs and 1.7 ± 0.6, 1.6 ± 0.6, and 1.1 ± 0.2 mm for nondilated veins simulating CCAs, ICAs, and ECAs (Figure 3).

Nondilated bovine placenta vein wall thickness was similar to that of human CCAs and ECAs; however, the thickness was statistically significant different for ICAs at 1.5 ± 0.5 vs 0.8 ± 0.3 mm, respectively ($P = .02$), although these means were different by only 0.7 mm (Figure 3). Nondilated bovine placenta veins had a diameter significantly different from that of human CCAs ($P = .02$) and ECAs ($P = .04$) at the level of the bifurcation and not significantly different from that of human ICA ($P = .06$). Although these differences are statistically significant, absolute differences between means are <2.3 mm. If $P < .01$ were taken as a lower level of statistical significance, then the observed differences in diameters between nondilated and dilated veins and human carotid arteries would be statistically insignificant. In general, except for bovine placenta dilated veins and dilated placenta artery for ICAs, the standard deviations of bovine placenta vessel diameters and human carotid arteries overlapped. The difference between the means of dilated placenta artery and human ICA diameter was 3.5 mm, which is practically acceptable for simulation purposes.

All bovine placenta bifurcations were suitable for performing the CEA simulation exercises. Individual subtasks were evaluated as surgical steps in carotid surgery to give the novice surgeon a master training experience for the whole procedure.

DISCUSSION

The utility and importance of vascular simulation methods for residents and fellows have been discussed previously.[9-11] The general consensus is that current training models accelerate the learning process and aid in mastery of the technique in a risk-free environment, and some have suggested that a minimum training curriculum for vascular surgeons in North America should exist.[7]

The bovine placenta CEA simulation model reproduces critical technical steps (ie, hand and instrument maneuvers) of the surgical procedure that are encountered in carotid arteries with high fidelity. At this time, however, the model does not include training on diseased vessels. It also has the advantages of being inexpensive and easily available. Although our hospital center is within a major metropolitan area, there are many dairy farms easily accessible within and outside the city limits. Within 60 km of our medical center, there are 37 dairy farms. The potential for biological risk

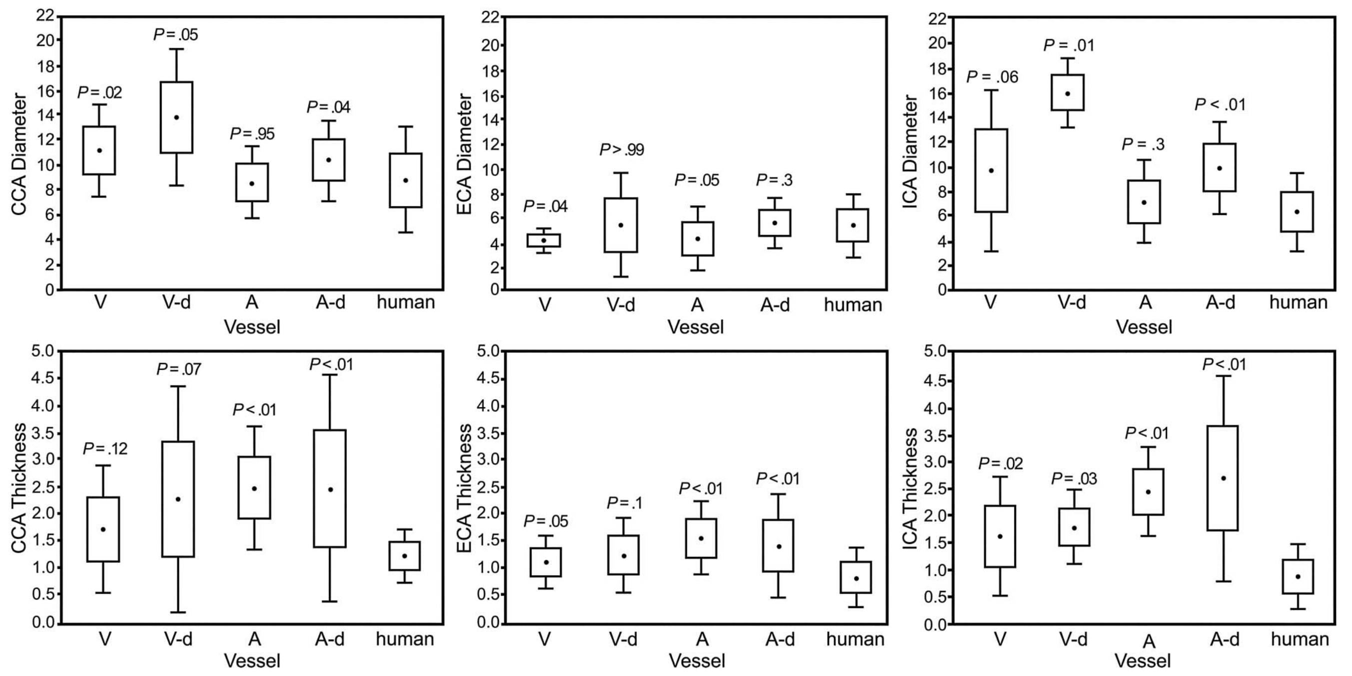

FIGURE 3. *Comparison of human common carotid artery (CCA), external carotid artery (ECA), internal carotid artery (ICA), and bovine placenta (BP) vessel diameters and wall thickness (in mm). Human CCA, ECA, and ICA diameters and wall thicknesses at the end of diastole are from Kamenskiy et al.[8] P values are presented as a comparison of the parameter with the corresponding human carotid artery. Small dot shows the mean; box, standard deviation; and whiskers, 1.96 × SD. A, BP artery; A-d, dilated BP artery; V, BP vein; V-d, dilated BP vein. Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*

and infection is minimized by strict adherence to routine biological contamination precautions and is believed to be no greater than that associated with any other tissue, including tissue from humans. We do not believe that any additional infrastructure besides that already available in a simple surgical laboratory is needed to work with the bovine placenta model.

CEA surgery is a relatively common surgical procedure that requires a high degree of technical skill to be performed precisely and efficiently.[12] A high degree of surgical proficiency and a low complication rate are needed to make the surgery beneficial to the candidate patient population.[13] If the duration of carotid artery clamping surpasses the tolerated time allowed by the relatively reduced contralateral blood flow perfusing the ipsilateral cerebral hemisphere, it may result in a stroke, with the potential for permanent neurological deficit. The bovine placenta CEA simulation model was developed to duplicate all the steps of the CEA, excluding neck dissection, and to promote reduced clamp time. The only technical difference in the bovine placenta model is that the thickness of the bovine placenta vessel wall is greater than that of the human carotid artery. This can make the arteriotomy and vessel suturing more difficult. However, a simulation model that is more difficult than the actual surgery may actually represent a training advantage.

Traditionally, synthetic models made of silicone and rubber have been used for carotid artery surgery training.[14] Synthetic models have the advantage of eliminating the biological contamination risk, but they do not provide the same degree of fidelity. Simulating blood flow, recreating arterial systemic pressure, and producing backflow can all be done in both synthetic and biological models.

Live animal models have been used previously in vascular surgery training.[15] They are excellent models but have important limitations. These models require more supporting infrastructure; they are substantially more expensive; and there are ethical concerns associated with live animal use and sacrifice that make these models increasingly unattractive for many training centers. Obtaining bovine placentas from a local cattle or dairy farm has minimal ethical issues without significant financial expenditure.

An optimal strategy for CEA training using the bovine placenta model is for the novice surgeon to watch a live patient CEA case video and then reproduce the procedure step by step.[9,10] The trainee can verify his or her own technique by comparing it with the video before and after each step. A variety of optional steps can be tried such as patching vs no patching, placement of a temporary shunt, and application of tacking sutures to deal with an intimal flap.

Inherent limitations of this model include the absence of relevant surrounding anatomy such as jugular vein, vagus nerve, and hypoglossal nerves that require preservation and the absence of surgical steps in diseased vessels such as atherosclerotic plaque dissection, arterial clamping, and arteriotomy closure. Competency, proficiency, and dexterity with the surgical procedures in real vessels that are of similar gauge and tissue characteristics certainly provide an increased level of confidence and success. Other working or instrument environment restrictions can be added to the model to challenge the surgeon. These can include forcing the surgeon to perform tasks within a limited time period or even placing barriers around the placenta vessel area that might simulate a narrowly angled incision or corridor, vessel clamps on rotated arteries, or other scenarios that may replicate accessing a high bifurcation situation. Removal of small intimal flaps after plaque detachment is also a critical step in CEA, but it cannot be well addressed by the placenta model. The described model is certainly adequate for initial training by residents and medical students, but it does not include work on diseased vessels, which may be of more interest and profit for experienced and advanced trainees.

The bovine placenta CEA model requires validation to prove that its teaching objectives are being met and to determine its efficacy as a training model for improving actual surgical performance. Establishing a minimum cerebrovascular surgery training curriculum with this kind of simulation model is an interesting and important topic. This model is used as a support for the residents' training curriculum in our neurosurgical center to increase their manual dexterity and familiarity with CEA. If a training center has the facility to offer different kinds of models, prospective studies can help determine the appropriate use of each simulator for the specific subtask until the whole task is mastered. Although CEA metrics are described and we consider them of great value for self-assessment and intermediate performance assessment,[16] at this time, we have not implicated such metrics to assess CEA performance on our model. It is becoming clear that neurosurgical training will need to better establish competency thresholds for procedures such as CEA.

CONCLUSION

Because surgery is facing a teaching paradigm modification, the development and validation of different training models are well justified. A CEA simulation model using bovine placentas is an excellent model with high fidelity that is inexpensive and readily available.

Disclosure

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