Rationale, scope, and 20-year experience of vascular surgical training with lifelike pulsatile flow models

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Vascular surgical training currently has to cope with various challenges, including restrictions on work hours, significant reduction of open surgical training cases in many countries, an increasing diversity of open and endovascular procedures, and distinct expectations by trainees. Even more important, patients and the public no longer accept a "learning by doing" training philosophy that leaves the learning curve on the patient's side. The Vascular International (VI) Foundation and School aims to overcome these obstacles by training conventional vascular and endovascular techniques before they are applied on patients. To achieve largely realistic training conditions, lifelike pulsatile models with exchangeable synthetic arterial inlays were created to practice carotid endarterectomy and patch plasty, open abdominal aortic aneurysm surgery, and peripheral bypass surgery, as well as for endovascular procedures, including endovascular aneurysm repair, thoracic endovascular aortic repair, peripheral balloon dilatation, and stenting. All models are equipped with a small pressure pump inside to create pulsatile flow conditions with variable peak pressures of ~90 mm Hg. The VI course schedule consists of a series of 2-hour modules teaching different open or endovascular procedures step-by-step in a standardized fashion. Trainees practice in pairs with continuous supervision and intensive advice provided by highly experienced vascular surgical trainers (trainer-to-trainee ratio is 1:4). Several evaluations of these courses show that tutor-assisted training on lifelike models in an educational-centered and motivated environment is associated with a significant increase of general and specific vascular surgical technical competence within a short period of time. Future studies should evaluate whether these benefits positively influence the future learning curve of vascular surgical trainees and clarify to what extent sophisticated models are useful to assess the level of technical skills of vascular surgical residents at national or international board examinations. This article gives an overview of our experiences of >20 years of practical training of beginners and advanced vascular surgeons using lifelike pulsatile vascular surgical training models. (J Vasc Surg 2013;57:1422-8.)

In recent years, the wide field of patient safety has come under scrutiny in many countries. Many concerns have been raised along with this discussion, that, especially, surgeons are not prepared properly for their job. As in aviation and in virtually all other professions that are based on technical skills, the patients and the public no longer accept a "learning by doing" training philosophy that leaves the learning curve on the patient's side alone. Consequently, new training concepts are mandatory.[1-3]

Owing to a significant increase in vascular patients and tremendous progress in methods of open and endovascular surgical treatment in recent years, vascular surgery has evolved into an attractive surgical specialty.[4] This development is supported by substantial changes in curricula, for example, the 0-5 years scheme in the United States, and the foundation of vascular surgery as an independent specialty in many European countries.[5-7] However, vascular surgical training has to cope with significant challenges, such as work hour restrictions in Europe and the United States and—due to a dramatic increase of endovascular procedures—a significant reduction of open surgical cases suitable for training at many teaching hospitals, especially for open aortic surgery.[5,8-12] To overcome these obstacles, new training strategies and techniques focusing on simulation and close supervision have to be considered.[3,13-20]

CURRENT CONCEPTS OF ADULT LEARNING

The widely accepted theory of Fitts and Posner of motor skills acquisition is nicely transferable to vascular surgery because it discriminates among cognitive,

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associative, and autonomous stages.[21] Looking at the example of a leg bypass anastomosis, the first two steps can be achieved by using structured clinical training alone or combined with an intensive vascular training course. The third stage needs a repetitive performance of certain techniques, which supports the concept of deliberate practice by Ericcson.[22] He calculated that at least 10,000 hours of practice were required to acquire and maintain expert performance in a complex task, equaling ~8 hours per day of deliberate practice for 5 years.

Because simulation courses outside the hospital cannot substitute training and practice at home, they should clearly be able to support the cognitive and associative stages of motor skill acquisition, especially if training is performed by use of high-fidelity models. Sidhu et al[23] showed that realistic models are superior to simple plastic models. These authors randomized junior and senior residents to a 3-hour training session to perform a graft-to-arterial anastomosis on plastic models or a high-fidelity model (human cadaver arm, brachial artery). One week later, all participants performed a vascular anastomosis on a femoral artery on a live pig, where both junior and senior residents showed a significantly better skill transfer from the bench model to live animals when practicing on high-fidelity models.[23] As described below, this study strongly supports the philosophy of the Vascular International (VI) Foundation and School that training on largely realistic pulsatile models is superior to simple plastic models.

Besides the three stages of motor skills acquisition, the Dreyfus and Dreyfus framework is considered as a suitable model of individual professional development through a series of five levels: novice, advanced beginner, competent, proficient, and expert.[24,25] Mitchell and Arora[26] recently showed that this concept can also be nicely applied to vascular surgery. Again, vascular surgical simulation courses may be useful at almost every stage of an individual's professional development. This is more or less self-evident for medical students or residents in their first years but may also be applicable for competent or even proficient vascular surgeons if they aim to critically revise their own approaches and techniques or if they are interested in learning new techniques, such as, for example, the eversion technique for carotid endarterectomy (CEA). Residents who have nearly completed their training can also benefit significantly, especially when they are facing an assessment, such as the practical examination held by the Section and Board of Vascular Surgery of the Union of European Medical Specialists.[27]

According to Kneebone,[28] the following criteria are reasonable to judge simulation courses:

(*a*) Simulations should allow for sustained, deliberate practice within a safe environment, ensuring that recently acquired skills are consolidated within a defined curriculum which assures regular reinforcement;
(*b*) Simulations should provide access to expert tutors when appropriate, ensuring that such support fades when it is no longer needed;
(*c*) Simulations should map onto real-life clinical experience, ensuring that learning supports the experience gained within communities of actual practice; and
(*d*) Simulation-based learning environments should provide a supportive, motivational, and learner-centered milieu that is conducive to learning.

As described below, the courses presented by the VI Foundation and School meet these theoretic demands by offering a safe environment for deliberate practicing, continuous support by very experienced tutors, training on lifelike pulsatile models simulating close to real-world situations (including, for example, the management of leaking anastomoses), and a highly motivating and supportive faculty climate.

PRINCIPLES OF THE VI FOUNDATION AND SCHOOL

The main idea and mission of the VI Foundation and School are passion for vascular surgical education and shifting the learning curve from the patient to lifelike training models. With maximized patient safety as a priority, VI is aiming to constantly improve training in order to support safe and efficient open vascular and endovascular patient care.[29] Basic principles include a standardized technical skills training by use of 2-hour training modules, the use of lifelike vascular models with pulsatile flow, team building, and an ongoing scientific evaluation of the effectiveness of our courses.

Founded by surgeons for surgeons, VI has conducted >100 national and international courses at different sites, including annual meetings of the German Vascular Society (DGG), the European Society for Vascular Surgery (ESVS), and the Society for Vascular Surgery (SVS) in the United States, with >2500 participants from many Western and Eastern European countries, North and South America, and the Middle East since 1991.

Our basic courses address beginners in vascular surgery and many other surgical disciplines, including urology, gynecology, ear nose and throat, while the master classes are suitable for vascular surgical residents just before board examination or vascular surgeons who want to be retrained in complex open and endovascular techniques. For the past 3 years VI has also offered courses for vascular and endovascular nurses and team training for nurse and surgeons. Furthermore, for many years VI has organized an access course to lower leg arteries on cadavers at the University of Zurich Anatomical Institute, that addresses vascular, plastic, and trauma surgeons.

Models. To achieve largely realistic training conditions, lifelike models were created in 1991 and have been constantly improved for carotid, aortic, and peripheral bypass surgery as well as for endovascular procedures such as endovascular aneurysm repair, thoracic endovascular aortic repair, and peripheral balloon dilatation and stenting, respectively. Basic open surgical procedures, such as suture and basic anastomotic techniques, are trained in a box model in which vessel segments (calf aorta,

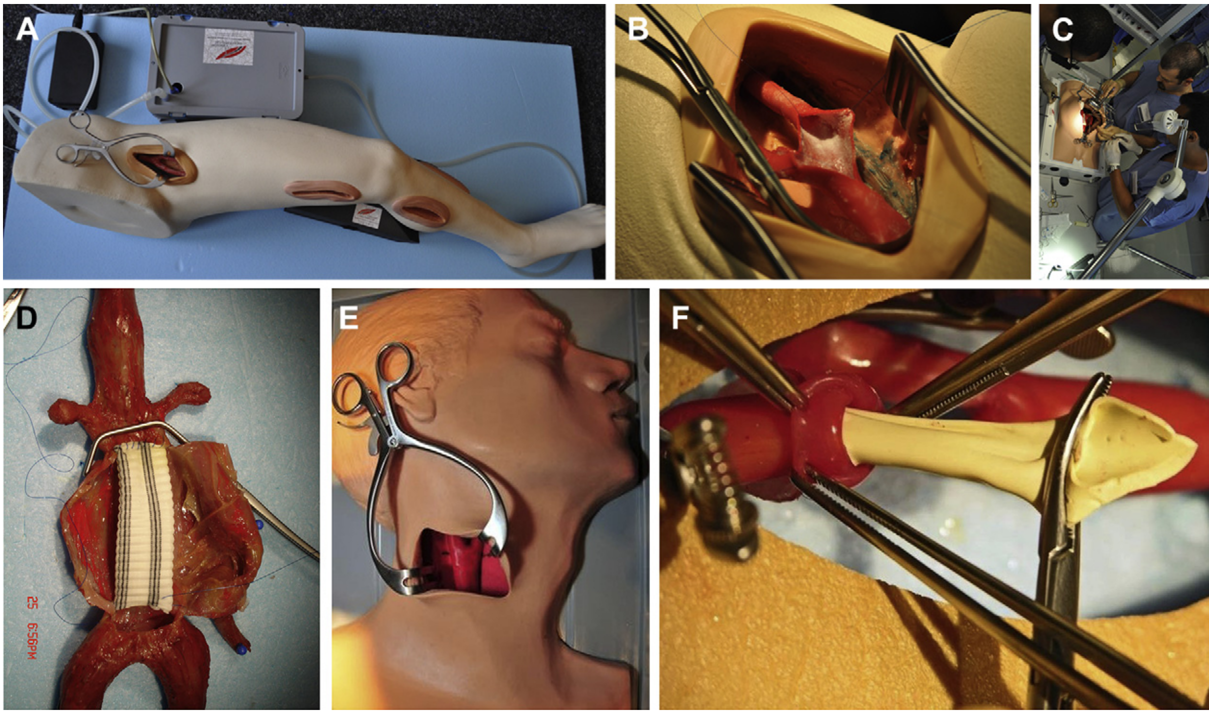

Fig 1. Pulsatile open surgical flow models designed and constructed by Vascular International (VI): **(A)** Leg model, **(B)** femoral inlay, **(C)** abdomen model, **(D)** aortic inlay, **(E)** neck model, and **(F)** carotid eversion technique.

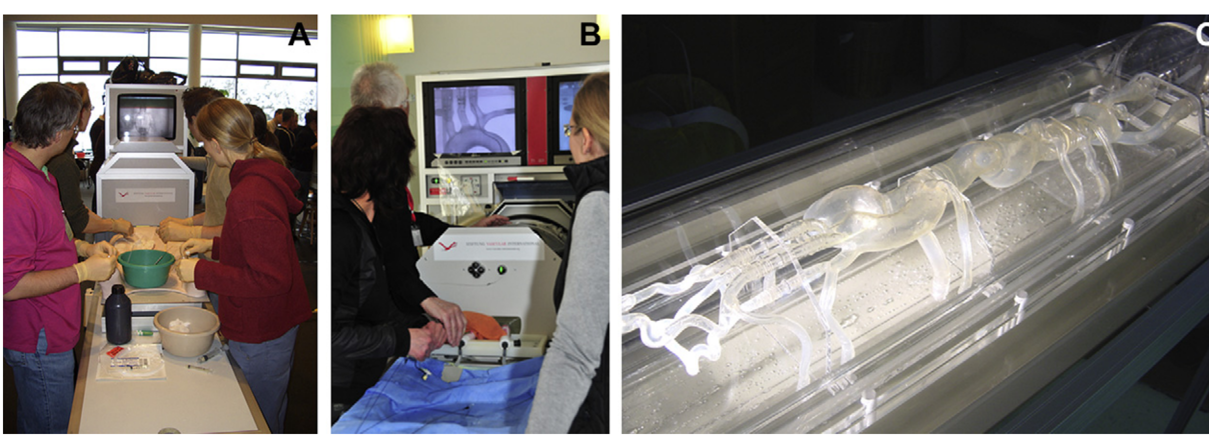

Fig 2. Pulsatile endovascular flow models designed and constructed by Vascular International (VI): **A,** Endovascular aneurysm repair (EVAR) model, **(B)** teaching carotid artery stenting, and **(C)** thoracoabdominal endovascular model for thoracic endovascular aortic repair (TEVAR)/EVAR.

veins, etc) are inserted. To simulate a realistic practical open and endovascular training situation, a wide range of synthetic arterial inlays have been designed for carotid stenosis, aortic aneurysms, and femoral bifurcation stenosis. These inlay models are exchangeable to guarantee that every trainee is able to perform the complete operation by himself or herself. The models are equipped with a small pump inside to create pulsatile-flow conditions with peak pressures of ~90 mm Hg within the inlays. The models have been constantly improved in usability, durability, and transportability and are individually available to equip training sites wherever needed, such as in hospitals, industry, or meetings. For lifelike endovascular procedures, a special contrast solution was developed to simulate visualization, navigation, and contrast angiography without the need for X-ray imaging (Figs 1 and 2). All models and inlays are commercially available (www.vascular-international.org).

Table I. The modular course system (each module lasts between 2 and 3 hours)

Group	*2- to 3-hour modules for open vascular surgery*	*Model*	*2- to 3-hour modules for endovascular surgery*	*Model*
1. Basics	a. Arteriotomy, suturing (single/running) b. Vein patchplasty in calf aorta c. Anastomosis between calf aorta and prosthetic grafts d. Anastomosis between calf aorta and vein segments	Vascular box (w/wo pressure)	e. Puncture of the CFA, sheath insertion, guidewire, catheter angiography f. Navigation with different guide wires and guiding catheters, cross-over-technique	Endotower
2. Peripheral	a. Femoral endarterectomy and transposition of the bifurcation b. Femoral endarterectomy and profundaplasty c. Femoropopliteal prosthetic bypass d. Femoropopliteal vein bypass e. Femorodistal bypass (vein, Linton-Patch, St.Mary's boot etc)	Leg model	f. PTA and stenting of an iliac stenosis g. PTA and stenting of femoro-popliteal lesions h. PTA and stenting of infragenual lesions i. Peripheral endoprosthetic grafting	Endotower (computer simulation)
3. Carotid	a. Carotid endarterectomy and patchplasty b. Carotid eversion endarterectomy and reinsertion c. Carotid interposition	Carotid model	d. Carotid stenting—easy access and morphology e. Carotid stenting—difficult access and advanced morphology	Endotower (computer simulation)
4. Abdominal aorta	a. AAA—tube interposition b. AAA—bifurcated grafting c. AAA—bifurcated grafting, reinsertion of the IMA and the internal iliac artery d. Juxtarenal AAA—tube interposition and renal bypass grafting	Abdominal model	e. AAA—EVAR with infrarenal fixation f. AAA—EVAR with suprarenal fixation g. AAA—EVAR with additional measures (iliac side branch, chimney technique)[a] h. Suprarenal AAA—fenestrated EVAR[a] i. Ruptured AAA—aorto-mono-iliac endografting[a]	Endotower (computer simulation)
5. Thoracic aorta	No open techniques	Currently no model	a. Thoracic aortic aneurysm - TEVAR with fixation below the left subclavian artery b. Thoracic aortic aneurysm (distal arch aneurysm—TEVAR with covering of the left subclavian artery	Endotower (computer simulation)

AAA, Abdominal aortic aneurysm; *CFA,* common femoral artery; *EVAR,* endovascular aneurysm repair; *IMA,* internal mesenteric artery; *PTA,* percutaneous transluminal angioplasty; *TEVAR,* thoracic endovascular aortic repair; *w/wo,* with and without.
[a]Modules 4g, 4h, 4i are currently under development.

Modular course system. VI offers a wide spectrum of courses, each tailored to meet different training levels. The basic courses are designed to train basic vascular and endovascular surgical techniques, whereas the master classes cover all aspects of peripheral bypass surgery, carotid surgery and carotid stenting, as well as open and endovascular aortic procedures. Absolute priority is given to practical training with step-by-step structured learning of open and endovascular procedures. To achieve a maximum training effect, the basic and advanced training courses consist of several 2- to 3-hour modules (Table I). Each module represents a complete open or endovascular procedure and follows an overall structure that includes the description of the target group, the educational objectives, and the sequence of the procedure (Table II). Besides the basic courses and master classes mentioned above, the modular system permits target-group oriented 1-, 2- or 3-day courses for different training levels of vascular specialists.

Practical training and course participants. Trainees practice in pairs on the open vascular surgical models and in trios on endovascular models, and with hands gloved, they use original instruments, material, and sutures. Each procedural step is demonstrated by the convenor at a separate table and transmitted to a video screen at every working place. The trainees must follow the sequence of the procedure as demonstrated by the convenor. Experienced tutors advise the trainees to follow those instructions very carefully. A ratio of usually one tutor to four trainees allows permanent supervision and assistance. The tutors assess the technical reconstruction at the end of each model and discuss with the trainees whether the educational objectives have been achieved. After the first procedure is completed, trainees change roles as principal surgeon.

Many key elements of vascular surgery, such as end-to-side-anastomosis, and the parachute technique, are also performed several times throughout the courses. During lunch

Table II. Overall structure of the Vascular International (*VI*) training modules

1.	Length of the module (usually 2 to 3 hours)
2	Target group (eg, resident surgeons in year 1 and 2, vascular surgeons, etc)
3	Educational objectives
4	Sequence of the procedure, usually divided in 5 to 10 steps
5	VI model and inlays to be used
6	Number of tutors (usually a relationship of one tutor to four trainees)
7	Graft and suture materials
8	Assessment of the reconstruction and the educational objectives (tutors and trainees)

and in the early afternoon, participants are also offered a supervised repetition of procedures or certain techniques.

The value of the VI philosophy of practicing on largely realistic pulsatile vascular models in a standardized way was confirmed by a very recent randomized trial during which 18 first-year surgical residents were taught technical aspects of a vascular anastomosis using femoral anastomosis simulation. One expert instructor taught a standardized anastomosis technique using the same method each time to one group for four sessions, while similar to current vascular training, four different expert instructors each taught one session to the other (traditional) group. The technical skill assessment as evaluated using objective structured assessment of technical skill (OSATS) performance metrics, clearly showed that standardized teaching leads to significantly higher mean overall technical and global skill scores. Furthermore, almost all of the trainees suggested a preference for a standardized approach.[30]

Theory. The practical training is supported by 1-hour theory sessions dealing with material science, surgical instruments, radiation protection, case discussions, including patient selection for open or endovascular intervention, complication management, and hemostasis, among others. Each trainee is also provided with a course-specific manual that explains each procedure in a stepwise fashion according to any given module. This supports the trainees to follow the training sequences not only during but also after the course if anyone wants to repeat the procedure.

EVALUATION OF PROCEDURES TRAINED BY VI

Besides feedback sessions and questionnaires before and after the course, several course elements have been evaluated systematically.

Vein patch plasty. Before and after a 2.5-day basic course in open vascular surgical techniques, 24 trainees were asked to perform a 5-cm-long vein patch plasty in a nonperfused calf aorta (running 5-0 suture polypropylene). Procedure time and the overall quality of the patch, scaled from 0 (catastrophic) to 10 (excellent), were measured. Two senior vascular surgeons independently performed all assessments. The results showed a significant reduction of procedure time from 19.8 ± 3 to 14.1 ± 2.2 minutes ($P < .001$), as well as a significant improvement of the overall quality of the vein patch, with a score of score 5.2 before the course and 6.2 at the end of the course ($P < .05$). These results were based on a very high interobserver correlation between the two surgical assessors ($r = 0.8849$).[31]

Open aortic repair. In another study, the performance of 15 trainees on an infrarenal aortic anastomosis model (18-mm polyester tube graft, polypropylene 3-0) was evaluated at the beginning and the end of a 3-day master class. Three experienced vascular surgeons assessed generic skills by use of OSATS and procedural skills with regard to overall technical quality and procedure time. Both assessments were measured on a scale from 8 to 40, with a score of ≥24 representing competence. In addition, a videotape of the trainees was used for blinded assessment. The results showed that generic skills increased significantly from OSATS scores of a median of 17.3 (range, 10.3-36.3) before the course to 26 (range, 12-33; $P = .006$) at the end of the course. Precourse scores for procedural skills were low (median, 17.3; range, 10-37) but improved to 25 (range, 13.3-32) at the end of the course ($P = .004$). Several operative components, such as front and back wall of the aortic anastomosis, needle and vessel handling, and corner stitches, and anastomotic apposition likewise improved significantly. Finally, trainees performed the aortic anastomosis significantly faster at the end of the course, with a median time of 23 minutes before the course and 18 minutes after the course.[32]

CEA and patch plasty. In a prospective observational cohort analysis with preinterventional and postinterventional measurements, 10 participants of a 3-day master class with a personal experience of <10 CEAs performed a conventional CEA with patch plasty on VI simulators. Primary end points were to assess any changes in the participants' surgical skills and in the technical quality of their completed carotid patches, documented by means of procedure-based assessment forms. Scores range from 1 (inadequate) to 5 (excellent). Again, a significant improvement in the surgical skills tasks was observed, with the mean score increase by 21.5% from 3.4 ± 0.9 to 4.2 ± 0.7 ($P < .001$). Furthermore, the mean score for the quality of the carotid patch increased by 27%, from 3.5 ± 0.9 to 4.5 ± 0.8 ($P < .01$).[33]

FUTURE DIRECTIONS

For the future, the translation of course-mediated skills into vascular surgical competence at the trainees' home hospitals needs to be assessed in studies with a longitudinal design. Evidence shows that the benefits of simulation courses and box trainers for laparoscopic, endourologic, and basic surgical techniques are related to an improved performance in the operating room.[34-38] Unfortunately, transfer data for vascular surgical training courses are sparse. Nonetheless, this kind of evidence is necessary to diminish existing doubts that vascular training courses do not have a significant positive effect on the vascular trainee's further learning curve and ability to acquire new skills. Just recently, external simulation courses were included in the surgical curriculum in Switzerland

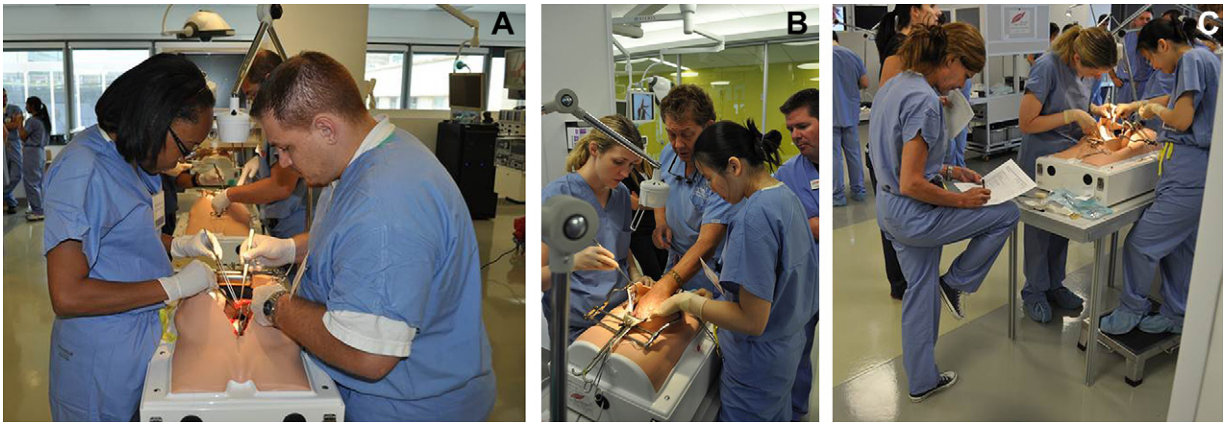

Fig 3. Assessment of an aortic reconstruction performed on an open surgical flow model designed and constructed by Vascular International (VI). **A,** Trainees perform open abdominal aortic aneurysm surgery. **B,** Assessment of the reconstruction and the educational objectives. **C,** Overall assessment of trainees in open abdominal aortic aneurysm surgery.

(J Schmidli, personal communication). Nonetheless, more data are needed to recommend an evidence-based implementation of simulation courses into national vascular surgical curricula.

The second major challenge in vascular surgical education is the assessment of technical skills at the end of the training period. Because the sheer number of procedures and years spent in a teaching hospital is no longer accepted as the only valid indicator for competence, a move from volume-based and time-based education to an expertise-based education is necessary.[1,39,40] Consequently, such a move would include an assessment of technical skills in the operating theater or on sophisticated training models.[41] According to Miller,[42] the assessment of clinical skills and competence can be identified in four stages: "knows" (indicating knowledge), "knows how" (indicating competence), "shows how" (level of competence assessment), and "does" (performance assessment). A transfer of this concept to vascular surgery is possible, for example, for the assessment of a trainee's competence to perform an aortic anastomosis and deal with leakage on a pulsatile lifelike model combined with a thorough discussion of access, choice of instruments, suture materials, and prosthetic grafts, among others (Fig 3). Today, practical examinations are in place only in a few countries. Using the example of the Union of European Medical Specialists examinations, trainees have to perform a tibial artery anastomosis, a saphenous junction ligation, and an endovascular access to the renal artery. Two independent experienced vascular surgeons perform the assessment using a scoring system for general and specific surgical skills. A sum score of at least 60% is mandatory to pass this part of the examination, and ~10% to 20% of all applicants fail every year. These young vascular surgeons are offered the chance to sit a repeat examination 6 or 12 months later.[27]

The future of vascular surgery depends on properly trained young surgeons. Meanwhile, it is internationally accepted that the frame conditions mentioned here demand a shift to novel training modalities.[1,5,18-20,43,44] All national vascular surgical societies should focus on that issue by creating nationwide structures for training, competence assessment, and credentialing. Unanimity should dominate to shift the vascular surgeon's learning curve from the patient to the training model.

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Conception and design: HE, JS, HS, AA
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REFERENCES

1. Reznick RK, MacRae H. Teaching surgical skills—changes in the wind. N Engl J Med 2006;355:2664-9.
2. Eidt JF. The aviation model of vascular surgery education. J Vasc Surg 2012;55:1801-9.
3. Pandey VA, Wolfe JH. Expanding the use of simulation in open vascular surgical training. J Vasc Surg 2012;56:847-52.
4. Schanzer A, Nahmias J, Korenda K, Eslami M, Arous E, Messina L. An increasing demand for integrated vascular residency training far outweighs the limited supply of positions. J Vasc Surg 2009;50:1513-8.
5. Bath J, Lawrence PF. Why we need open simulation to train surgeons in an era of work-hour restrictions. Vascular 2011;19:175-7.
6. Schmidli J, Dick F. Specialisation within vascular surgery. Eur J Vasc Endovasc Surg 2010;39:S15-21.

7. Kwolek CJ, Crawford RS. Training the next generation of vascular specialists: current status and future perspectives. J Endovasc Ther 2009;16(Suppl 1):142-52.
8. Lamont PM, Scott DJ. The impact of shortened training times on the discipline of vascular surgery in the United Kingdom. Am J Surg 2005;190:269-72.
9. Sachs T, Schermerhorn M, Pomposelli F, Cotterill P, O'Malley J, Landon B. Resident and fellow experiences after the introduction of endovascular aneurysm repair for abdominal aortic aneurysm. J Vasc Surg 2011;54:881-8.
10. Schanzer A, Steppacher R, Eslami M, Arous E, Messina L, Belkin M. Vascular surgery training trends from 2001-2007: a substantial increase in total procedure volume is driven by escalating endovascular procedure volume and stable open procedure volume. J Vasc Surg 2009;49:1339-44.
11. Grabo DJ, DiMuzio PJ, Kairys JC, McIlhenny SE, Crawford AG, Yeo CJ. Have endovascular procedures negatively impacted general surgery training? Ann Surg 2007;246:472-7; discussion: 477-80.
12. Nandivada P, Lagisetty KH, Giles K, Pomposelli FB, Chaikof EL, Schermerhorn ML, et al. The impact of endovascular procedures on fellowship training in lower extremity revascularization. J Vasc Surg 2012;55:1814-20.
13. Bismuth J, Donovan MA, O'Malley MK, El Sayed HF, Naoum JJ, Peden EK, et al. Incorporating simulation in vascular surgery education. J Vasc Surg 2010;52:1072-80.
14. Issenberg SB, McGaghie WC, Petrusa ER, Lee Gordon D, Scalese RJ. Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. Med Teach 2005;27:10-28.
15. McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. Effect of practice on standardised learning outcomes in simulation-based medical education. Med Educ 2006;40:792-7.
16. Seymour NE, Gallagher AG, Roman SA, O'Brien MK, Bansal VK, Andersen DK, et al. Virtual reality training improves operating room performance: results of a randomized, double-blinded study. Ann Surg 2002;236:458-63; discussion: 463-4.
17. Black SA, Harrison RH, Horrocks EJ, Pandey VA, Wolfe JH. Competence assessment of senior vascular trainees using a carotid endarterectomy bench model. Br J Surg 2007;94:1226-31.
18. Hupp T, Baltussen F, Böckler D, Debus ES, Diener H, Flessenkämper I, et al. [Model for advanced training to specialist in vascular surgery.] Gefässchirurgie 2010;15:603-10.
19. Flessenkämper I, Gussmann A, Berg P, Görtz H, Heider P, Heidrich M, et al. [Training in endovascular techniques with the private Academy for Research and Education of the German Society for Vascular Surgery.] Gefässchirurgie 2008;13:273-7.
20. Eckstein HH, Flessenkämper I, Görtz H. [Position paper of the German Society for Vascular Surgery and Vascular Medicine (DGG) Society for operative, endovascular and preventive vascular medicine on qualification for performance of endovascular interventions.] Gefässchirurgie 2010;15:236-49.
21. Fitts PM, Posner MI. Human performance. Belmont, CA: Brooks/Cole Publishing Co; 1967.
22. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. Acad Med 2004;79:S70-81.
23. Sidhu RS, Park J, Brydges R, MacRae HM, Dubrowski A. Laboratory-based vascular anastomosis training: a randomized controlled trial evaluating the effects of bench model fidelity and level of training on skill acquisition. J Vasc Surg 2007;45:343-9.
24. Dreyfus HL, Dreyfus SE. Mind over machine. New York: Free Press; 1988.
25. Dreyfus H. From novice to world discloser. Key note address presented at the Accreditation Council for Graduate Medical Education Design Conference on the Learning Environment. Chicago: Ill; September 9, 2006.
26. Mitchell EL, Arora S. How educational theory can inform the training and practice of vascular surgeons. J Vasc Surg 2012;56:530-7.
27. Union of European Medical Specialists (UEMS), Section and Board for Vascular Surgery. Available at: http://www.uemsvascular.com. Accessed May 27, 2012.
28. Kneebone R. Evaluating clinical simulations for learning procedural skills: a theory-based approach. Acad Med 2005;80:549-53.
29. Vascular International. Available at: www.vascular-international.org. Accessed May 27, 2012.
30. Bath J, Lawrence PF, Chandra A, O'Connell J, Uijtdehaage S, Jimenez JC, et al. Standardization is superior to traditional methods of teaching open vascular simulation. J Vasc Surg 2011;53:229-34; 235.e1-2; discussion: 234-5.
31. Wilhelm M, Klemm K, Assadian A, Schmidli J, Schumacher H, Merrelaar J, et al. [Improve your skills!: evaluation of a 2.5-day basic course in vascular surgery for surgical trainees.] Chirurg 2013;84:125-9.
32. Pandey VA, Black SA, Lazaris AM, Allenberg JR, Eckstein HH, Hagmuller GW, et al. Do workshops improve the technical skill of vascular surgical trainees? Eur J Vasc Endovasc Surg 2005;30:441-7.
33. Duschek N, Assadian A, Lamont PM, Klemm K, Schmidli J, Mendel H, et al. Simulator training on pulsatile vascular models significantly improves surgical skills and the quality of carotid patch plasty. J Vasc Surg 2013;57:1148-54.
34. Diesen DL, Erhunmwunsee L, Bennett KM, Ben-David K, Yurcisin B, Ceppa EP, et al. Effectiveness of laparoscopic computer simulator versus usage of box trainer for endoscopic surgery training of novices. J Surg Educ 2011;68:282-9.
35. Schout BM, Hendrikx AJ, Scheele F, Bemelmans BL, Scherpbier AJ. Validation and implementation of surgical simulators: a critical review of present, past, and future. Surg Endosc 2010;24:536-46.
36. Seymour NE. VR to OR: a review of the evidence that virtual reality simulation improves operating room performance. World J Surg 2008;32:132-8.
37. Wohaibi EM, Bush RW, Earle DB, Seymour NE. Surgical resident performance on a virtual reality simulator correlates with operating room performance. J Surg Res 2010;160:67-72.
38. Palter VN, Grantcharov T, Harvey A, Macrae HM. Ex vivo technical skills training transfers to the operating room and enhances cognitive learning: a randomized controlled trial. Ann Surg 2011;253:886-9.
39. Reznick R, Regehr G, MacRae H, Martin J, McCulloch W. Testing technical skill via an innovative "bench station" examination. Am J Surg 1997;173:226-30.
40. Beard JD. Assessment of surgical skills of trainees in the UK. Ann R Coll Surg Engl 2008;90:282-5.
41. Beard JD, Marriott J, Purdie H, Crossley J. Assessing the surgical skills of trainees in the operating theatre: a prospective observational study of the methodology. Health Technol Assess 2011;15:1-162; i-xxi.
42. Miller GE. The assessment of clinical skills, competence, performance. Acad Med 2004;65:S63-7.
43. Bath J, Lawrence PF. Twelve tips for developing and implementing an effective surgical simulation programme. Med Teach 2012;34:192-7.
44. Mitchell EL, Arora S, Moneta L. Ensuring vascular surgical training is on the right track. J Vasc Surg 2011;53:517-25.

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