Eur J Vasc Endovasc Surg (2019) 58, 292—298

SYSTEMATIC REVIEW

The Impact of Operating Surgeon Experience, Supervised Trainee vs. Trained Surgeon, in Vascular Surgery Procedures: A Systematic Review and Meta-Analysis

Michael F. Bath [a], **Ayoola I. Awopetu** [a,b,*], **Philip W. Stather** [b], **Umar Sadat** [a,b], **Kevin Varty** [b], **Paul D. Hayes** [a,b]

[a] University Department of Surgery, University of Cambridge, Addenbrooke's Hospital, Cambridge, UK
[b] Cambridge Vascular Unit, Cambridge University Hospitals NHS Foundation Trust, Cambridge, UK

WHAT THIS PAPER ADDS
This review demonstrates that supervised trainees, with appropriate training and suitable experience, can perform surgical procedures in select vascular cases without any detriment to patient care. Developing and maintaining supported training programmes for vascular trainees to maximise their surgical exposure is essential, ensuring high standards of care for tomorrow's patients.

Objective: The operative caseload of a surgeon has a positive influence on post-operative outcomes. For surgical trainees to progress effectively, maximising operating room exposure is essential, vascular surgery being no exception. Our aim was to ascertain the impact of supervised trainee led vs. expert surgeon led procedures on post-operative outcomes, across three commonly performed vascular operations.
Methods: A literature search was undertaken using the MEDLINE, Web of Science, and Cochrane databases up to 1 January 2018. Studies reporting outcomes following major lower limb amputation, fistula formation, or carotid endarterectomy (CEA) that involved a direct comparison between supervised trainee and experts were included, with odds ratios (ORs) calculated. Primary outcomes varied depending on the specific procedure: amputations—rate of amputation revision within 30 days; fistula formation—primary patency; CEA—stroke rate at 30 days. Meta-analysis with the Mantel-Haenszel method was performed for each outcome.
Results: Sixteen studies were included in the final review. Overall, trainees accounted for a third of all procedures analysed ($n = 2\,421/7\,017$; 34.5%). Only one study was identified that described rates of amputation revision, precluding any further analysis. Four studies on fistula formation were included, showing no significant difference in outcomes between trainees and experts in primary patency (OR 1.68, 95% confidence interval [CI] 0.42—6.75). Nine studies were identified reporting post-CEA stroke rates, also demonstrating no difference between trainees and experts (OR 0.89, 95% CI 0.59—1.32).
Conclusion: In select cases, with appropriate training and suitable experience, supervised trainees can perform surgical procedures without any detriment to patient care. To ensure high standards for patients of the future, supported training programmes are essential for today's surgical trainees.

Keywords: Trainee, Training, Surgical outcomes, Vascular surgery
Article history: Received 1 November 2018, Accepted 15 March 2019, Available online 28 June 2019

INTRODUCTION

The variation in surgical outcomes between hospitals following inpatient surgery is well documented,[1] with those hospitals with a higher annual caseload demonstrating improved surgical outcomes across a variety of different specialties.[2] In recent years, the outcomes of individual surgeons in their own practice have come under increased scrutiny in an attempt to ensure safer practice, and, as a result, most surgical specialities now publicise their annual performance in the form of patient accessible clinical registries.[3] The volume of operations a surgeon performs has been shown to have a positive influence on post-operative outcomes,[4,5] and vascular surgery, being a specialty in its own right, is no exception.[6,7]

Surgical performance requires both technical and non-technical skills; hence, for trainees of any specialty to progress effectively, ensuring sufficient theatre time is often

* Corresponding author. Cambridge Vascular Unit, Cambridge University Hospitals NHS Foundation Trust, Cambridge CB2 0QQ, UK.
E-mail address: ayoola.awopetu@doctors.org.uk (Ayoola I. Awopetu).

https://doi.org/10.1016/j.ejvs.2019.03.029

favoured,[8] especially as many surgical training programmes move towards competency based curricula. It has been shown that patients who have their care managed by a trainee receive the exact same quality as any consultant led team;[9] in fact, there has been recent evidence to suggest improved post-operative outcomes from certain trainee led procedures.[10] However, such outcomes following trainee led vascular operations remain undetermined.

Trainees in vascular surgery are often required to have a training programme that fulfils the requirements of both open and endovascular experiences, achieving sufficient benchmarking to progress within this surgical speciality. Trainees assisting in carotid endarterectomies, albeit not performing them, have been shown not to confer any negative impact on peri-operative events,[11] while the outcomes for involvement in limb amputation and fistula formation remain less certain.[12–14] To ascertain the true impact of trainees leading vascular procedures, the aim was to perform a systematic review and meta-analysis to compare the surgical outcomes between trainees and experts (i.e., consultant/attending surgeons) across three commonly performed vascular operations.

METHODS

Inclusion criteria and definitions

The study was conducted in accordance to the standard Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[15] Studies reporting outcomes following major limb amputation, arteriovenous fistula (AVF) formation, or carotid endarterectomy (CEA), that involved a direct comparison between trainee and expert, were included.

Studies were limited to those in the English language and only studies published after 1980 were considered for analysis. Case reports, reviews, letters, abstracts, and conference proceedings were excluded, as were studies with fewer than 10 patients and studies not providing a direct comparison.

An expert was defined on a study by study basis, ideally either as a “Consultant” or “Attending Surgeon”. The definition of trainee was based pragmatically on the definition used within each study; additionally, only studies that included data on “supervised” trainees (when the expert was directly observing within the theatre environment) were included.

Primary and secondary outcomes varied depending on the specific procedure. (i) For amputations, the primary outcome was rate of amputation revision within 30 days, with secondary outcomes of operation time and compromised limb fitting. (ii) For AVF formation, the primary outcome was primary patency (defined as an AVF with long term haemodynamic patency without requiring intervention). The secondary outcomes were length of operating time and secondary patency (defined as an AVF with long term haemodynamic patency). (iii) For CEA, the primary outcome was stroke rate at 30 days, and secondary outcomes were operation time, 30 day all cause mortality, and rate of cranial nerve (CN) palsies.

Search criteria

A literature search was undertaken using MEDLINE, Web of Science, and the Cochrane Library, with grey literature search results subsequently added using the Open Grey database. Searches included all articles up to 1 January 2019 and any duplicates were removed. The search was performed independently by two of the authors (MFB and AIA), with any discrepancies resolved by discussion and consensus. The search terms used can be seen in Appendix S1 (see Supplementary Material).

Articles of potential interest were then reviewed in full and those selected were included in the study. Additional studies that were not included in the database search were identified through searching the reference lists of retained articles. The quality of the studies was assessed using the Newcastle–Ottawa Scale;[16] a score of $\geq$5/8 was deemed sufficient for study inclusion.

Statistical analysis

Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated for each included study, and a p value $< .05$ was considered statistically significant. A Mantel–Haenszel statistical method was performed, calculating an overall OR for each outcome: an OR $>$ 1.00 inferred a worse outcome for the experimental group (i.e., the trainee group) vs. the control group (i.e., the expert group), while an OR $<$ 1.00 inferred a better outcome. Where the 95% CI includes the value of 1.00, statistical significance was not inferred.

Given the high heterogeneity from the methodology of the studies, from differences in study setting, definitions used, differences in surgical techniques, and study quality, a random effects model was used. Heterogeneity was quantified using I^2 statistic, representing the percentage of the total variation across studies in estimated effects due to heterogeneity (rather than to chance). In addition, the effect of removal of one study each time on the OR was also assessed to identify the impact of individual studies on pooled effect size, for each of the primary outcomes.

All statistical analysis was performed using Review Manager (RevMan) Version 5.3 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, 2014).

RESULTS

After duplicate removal, 8 696 studies were screened for the systematic review (Fig. 1). Sixteen studies were included in the final review, two of them covering amputations, five of them AVF formation, and the remaining nine CEA (Table 1). All included studies were observational, including seven that were prospective in nature. Overall, trainees accounted for a third of all procedures analysed (n = 2 421/7 017; 34.5%).

The definition of an expert was most commonly defined as either a consultant or attending surgeon. The definition of a trainee was more variable, ranging from early residency to near completion of surgical training. None of the studies presented separate data according to grade of trainee, precluding further sub-analysis. One study was excluded

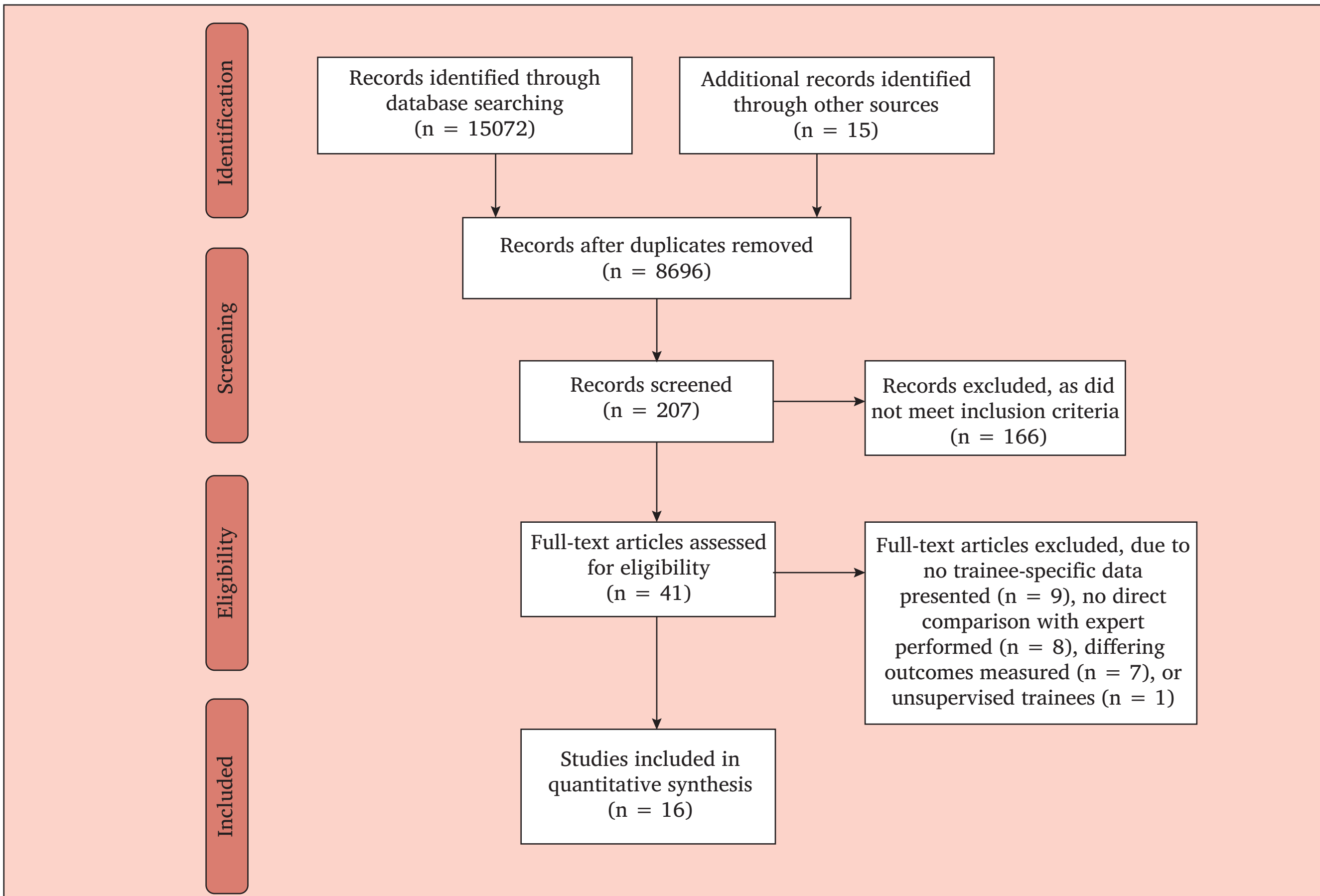

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart of study selection.

from the analysis because trainees were reported as being unsupervised.[17]

The effect of removal of individual studies on the pooled OR for the primary outcomes of the AVF and CEA studies, respectively, showed no difference in outcomes (an insufficient number of studies were identified covering amputation, precluding any similar analysis).

Amputation

Only one study was identified that compared trainees and experts in their rate of amputation revision following initial amputation,[18] reporting rates of 6.8% ($n = 3/44$) and 4.4% ($n = 4/90$), respectively (Table 2).

For the secondary outcome of limb fitting, another study was identified for analysis;[12] however, no difference in the rate of compromised limb fitting following amputation between trainees and experts was identified (OR 1.50, 95% CI 0.30—7.57) (Fig. S1; see Supplementary Material). No identified study compared the operating times between trainees and experts.

AVF formation

Four studies looked at primary patency,[19—22] totalling 962 patients (Table 3). No significant difference was identified in AVF primary patency rates (OR 0.84, 95% CI 0.43—1.66) (Fig. 2).

Four studies were identified for secondary patency outcomes,[19,20,22,23] also demonstrating no significant difference between trainees and experts (OR 0.97, 95% CI 0.60—1.57) (Fig. S2; see Supplementary Material). Only one study commented on mean operating times,[21] reporting a significantly longer time for trainees.

Carotid endarterectomy

A total of nine studies were identified that provided data on stroke rates following CEA,[24—32] totalling 5 716 patients (Table 4). No difference was identified between trainees and experts in stroke rates (OR 0.89, 95% CI 0.59—1.32) (Fig. 3).

Six studies looked at 30 day mortality outcomes,[25—29,31] which did not show any significant difference (OR 0.73, 95% CI 0.29—1.81) (Fig. S3; see Supplementary Material). Post-operative CN palsy rates did not show any significant differences between trainees and experts (OR 0.90, 95% CI 0.49—1.66) (Fig. S4; see Supplementary Material) from the five studies available.[24,25,27,28,32] Three studies also made reference to operating times,[25,27,32] demonstrating trainees overall taking longer than the experts ($p < .001$).

Table 1. Characteristics of the studies included in the final meta-analysis

Authors	Study period	Location	Procedure	*n*	Study design	Quality score (out of 8)
Cosgrove[18]	1992–96	Plymouth, UK	Amputation	260	Retrospective single centre	6
White[12]	1989–94	Leicester, UK	Amputation	62	Retrospective multicentre	7
Fassiadis[19]	2002–05	London, UK	AVF	195	Retrospective single centre	7
Gundevia[20]	2001–04	Birmingham, UK	AVF	170	Retrospective single centre	8
McGrogan[23]	2009	Birmingham, UK	AVF	143	Prospective	8
Regus[21]	2012–16	Erlangen, Germany	AVF	159	Retrospective single centre	8
Weale[22]	1998–2001	Bristol, UK	AVF	438	Retrospective single centre	8
Bradbury[24]	1975–91	Edinburgh, UK	CEA	219	Prospective	5
Cacioppa[25]	2005–15	Bologna, Italy	CEA	1 379	Retrospective single centre	6
Pai[26]	1995–99	Oxford, UK	CEA	240	Prospective	5
Krupski[32]	1980–83	San Francisco, USA	CEA	200	Not defined	7
Lutz[27]	1995–2004	Dessau, Germany	CEA	1 379	Retrospective multicentre	8
Metzger[28]	2002–11	Salzburg, Austria	CEA	816	Prospective	8
Naylor[29]	1996	Leicester, UK	CEA	151	Prospective	8
Ricco[30]	1995–2009	Poitiers, France	CEA	1 179	Prospective	7
Rijbroek[31]	1995–2000	Amsterdam, Netherlands	CEA	200	Retrospective single centre	8

Note. AVF = arteriovenous fistula, CEA = carotid endarterectomy.

DISCUSSION

This systematic review and meta-analysis found no differences in the post-operative outcomes between trainee surgeons and trained surgeons, across three commonly performed vascular procedures. With experts probably operating on the potentially more challenging cases, the similarities observed in the clinical outcomes will probably have been influenced by an unadjusted case mix. However, it remains that in select cases, with appropriate training and suitable experience, supervised surgical trainees can perform operative procedures without any detriment to patient care.

Studies have previously documented a potential link between high volume surgeons leading to improved outcomes within vascular surgery.[6,7] The drive towards consultant led surgical services across many countries has resulted in a reduction in the time available for trainees to reach competencies. For new generations of vascular surgeons to develop and provide optimal care to their future patients, within an environment of open teaching and training, obtaining sufficient case numbers of supervised operations is essential. Other groups have drawn similar conclusions, that with no detriment to clinical outcomes, trainees should have operative exposure maximised in suitably structured and supported training programmes.[10,27]

Surgical exposure for trainees

With increasing difficulties in obtaining sufficient operating time, technological resources, such as simulation training, virtual reality software, and smartphone apps, are increasingly allowing trainees to develop their surgical skills outside of the theatre environment,[33,34] in theory making procedures safer when being performed. Trainees can prepare for procedures at their own pace and optimise their hands on exposure. However, such technologies can only go so far in training; while many intra-operative non-technical aspects of development, such as cognitive and interpersonal skills, can be developed in simulation scenarios,[35,36] it is the complementary effects of merging simulation with patient exposure that ensures such skills are most effective. Neglecting the non-technical aspects of training can reduce a surgeon's performance and increase errors;[37] hence, obtaining sufficient training within the theatre environment is essential.[38]

The operations chosen for this analysis represented procedures that require varying degrees of expertise, those that a trainee surgeon would experience as they progress in their clinical career. They represent a mix of elective and emergency operations, with studies included from across the world, representing the complete spectrum of trainee surgical procedures. While preliminary searches for trainee involvement in aneurysm repair and infra-inguinal bypass

Table 2. Summary of amputation outcome studies.

Author	*n*		Amputation revision rate		Compromised limb fitting	
	Trainee	Expert	Trainee	Expert	Trainee	Expert
Cosgrove et al.[18]	44	90	3 (6.8%)	4 (4.4%)	8 (18.2)	22 (24.4)
White et al.[12]	30	32	–	–	12 (40.0)	5 (15.6)

Note. Data are *n* (%).

Table 3. Summary of fistula outcome studies

Author	n		Primary patency		Mean ± SD operation time (min)		Secondary patency	
	Trainee	Expert	Trainee	Expert	Trainee	Expert	Trainee	Expert
Fassiadis et al.[19]	42	153	31 (73.8)	122 (79.7)	–	–	34 (81.0)	142 (92.8)
Gundevia et al.[20]	109	61	63 (57.8)	28 (45.9)	–	–	72 (66.1)	31 (60.8)
McGrogan et al.[23]	50	93	–	–	–	–	22 (44.0)	37 (39.8)
Regus et al.[21]	85	74	4 (4.6)	14 (18.9)	54 ± 13	34 ± 7	–	–
Weale et al.[22]	136	302	27 (19.9)	52 (17.2)	–	–	28 (20.6)	55 (18.2)

Note. Data are *n* (%) unless otherwise specified. SD = standard deviation.

Study or Subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight	Odds Ratio M-H, Random, 95% CI
Fassiadis N, 2007	31	42	122	153	24.4%	0.72 (0.32, 1.58)
Gundevia Z, 2008	63	109	28	61	27.8%	1.61 (0.86, 3.03)
Regus S, 2017	4	85	14	74	17.6%	0.21 (0.07, 0.68)
Weale AR, 2004	27	136	52	302	30.2%	1.19 (0.71, 2.00)
Total (95% CI)		**372**		**590**	**100.0%**	**0.84 (0.43, 1.66)**
Total events	125		216			

Heterogeneity. $Tau^2 = 0.32$; $Chi^2 = 10.24$, df = 3 (P = 0.02); $I^2 = 71\%$
Test for overall effect: Z = 0.49 (P = 0.62)

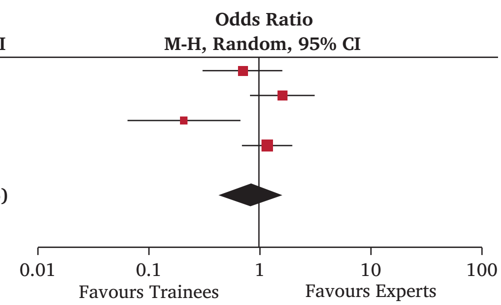

Figure 2. Forest plot of primary patency following arteriovenous fistula formation. *Note.* CI = confidence interval; M-H = Mantel Haenszel odds ratio.

surgery were also performed, no such suitable comparative studies were identified. Nonetheless, the results demonstrate that across all the post-operative domains collected for the selected procedures, supervised trainees perform equally well compared with their expert colleagues, albeit at the expense of an apparent increased operative duration.

The low event rates observed in the included studies across the chosen primary outcomes makes the likelihood of type II errors quite high in this study; however, the rates of complications from amputation, AVF, and CEA were similar to those reported in the general literature.[39–41] Indeed, the UK National Vascular Registry reports a post-CEA stroke rate of 1.7%,[42] nearly equivalent to the combined rate of 2.1% from all the included studies. Of note, in one of the larger studies identified in the analysis,[25] including >1 000 patients undergoing CEA, while trainees may have had prolonged operative times, they demonstrated equivalent outcomes to their more experienced colleagues, notwithstanding the operative technical difficulty potentially influencing these outcomes.

There are ever increasing criteria that trainees are required to meet, both clinically and non-clinically, in order to progress in their careers. Trainees often assist in procedures, which has been shown to be at no detriment to the patient;[11] however, this has less benefit to both technical and non-technical skills progression, compared

Table 4. Summary of carotid endarterectomy outcome studies

Author	N		Stroke rate		Mean ± SD operation times (min)		30 day mortality		Cranial nerve palsy rates	
	Trainee	Expert	Trainee	Expert	Trainee	Expert	Trainee	Expert	Trainee	Expert
Bradbury et al.[24]	92	127	7 (7.6)	9 (7.1)	–	–	–	–	14 (15.2)	18 (14.2)
Cacioppa et al.[25]	199	1 180	1 (0.5)	14 (1.2)	104 ± 1.9	99 ± 1.0	0 (0)	6 (0.5)	18 (9.0)	92 (7.8)
Pai et al.[26]	140	100	6 (4.3)	8 (8.0)	–	–	2 (1.4)	2 (2.0)	–	–
Krupski et al.[32]	100	100	1 (1.0)	2 (2.0)	164.0 ± 45.1	102.3 ± 30.3	–	–	8 (8.0)	23 (23.0)
Lutz et al.[27]	475	904	15 (3.2)	28 (3.1)	121.3 ± 30.1	101.9 ± 26.9	2 (0.4)	8 (0.9)	58 (12.2)	59 (6.5)
Metzger et al.[28]	353	463	4 (1.1)	5 (1.1)	–	–	1 (0.3)	1 (0.2)	55 (15.6)	71 (15.3)
Naylor et al.[29]	82	69	2 (2.4)	0 (0)	–	–	1 (1.2)	0 (0)	–	–
Ricco et al.[30]	367	812	4 (1.1)	11 (1.4)	–	–	–	–	–	–
Rijbroek et al.[31]	117	36	3 (2.6)	1 (2.8)	–	–	3 (2.6)	1 (2.8)	–	–

Note. Data are *n* (%) unless otherwise specified. SD = standard deviation.

Study or Subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight	Odds Ratio M-H, Random, 95% CI
Bradbury AW, 1997	7	92	9	127	15.1%	1.08 (0.39, 3.01)
Cacioppa LM, 2018	1	199	14	1180	3.8%	0.42 (0.06, 3.22)
Krupski WC, 1985	1	100	2	100	2.7%	0.49 (0.04, 5.55)
Lutz HJ, 2009	15	475	28	904	39.2%	1.02 (0.54, 1.93)
Metzger P, 2014	4	353	5	463	9.1%	1.05 (0.28, 3.94)
Naylor AR, 1998	2	82	0	69	1.7%	4.32 (0.20, 91.45)
Pai M, 2002	6	140	8	100	13.4%	0.51 (0.17, 1.53)
Ricco J, 2011	4	367	11	812	12.0%	0.80 (0.25, 2.54)
Rijbroek A, 2003	3	117	1	36	3.0%	0.92 (0.09, 9.14)
Total (95% CI)		**1925**		**3791**	**100.0%**	**0.89 (0.59, 1.32)**
Total events	43		78			

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 3.15$, df = 8 (P = 0.92); $I^2 = 0\%$

Test for overall effect: Z = 0.60 (P = 0.55)

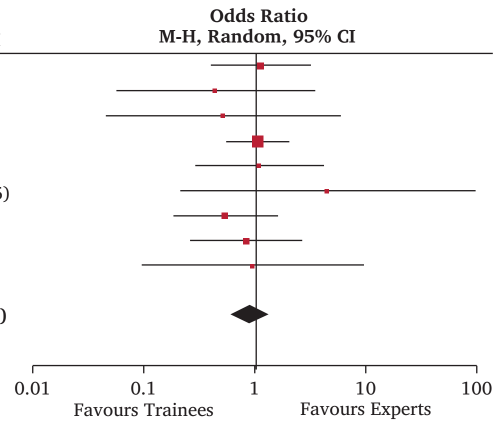

Figure 3. Forest plot of stroke rate following carotid endarterectomy. *Note.* CI = confidence interval; M-H = Mantel Haenszel odds ratio.

with leading the procedure itself. Indeed, neglecting the non-technical aspects of training can reduce a surgeon's performance and increase errors.[43] The present study demonstrates that trainees are safe in performing selected supervised procedures; in order to train and progress successfully, such opportunities should be maximised through supported and safe training programmes.

There was large heterogeneity in the definitions of the outcomes from the studies included within the meta-analysis, which was partially accounted for by use of random effects models; however, the many other differences between the studies could not be completely corrected for, therefore limiting the conclusions that can be drawn. Many studies did not specify subtypes for the individual procedures, such as the type of amputation performed (e.g., below knee vs. above knee), which limits further potential conclusions suggesting suitable procedures for trainees. It was not possible to stratify specific data relative to trainee grade, nor to trainee specialisation, as many studies did not include such data, precluding any further subgroup analysis. The probable increased complexity of expert led vs. trainee led cases introduces a significant selection bias, which has been considered in the conclusions drawn. Similar results may not be produced if a prospective randomised study were performed; ongoing direct trainee supervision in appropriate cases remains paramount.

CONCLUSION

In select cases, supervised surgical trainees have similar outcomes to experts in performing vascular operations, with no detriment to patient care. To ensure high standards for patients in the future, supported training programmes and maximised surgical exposure is needed for today's surgical trainees.

CONFLICT OF INTEREST

None.

FUNDING

None.

APPENDIX A. SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ejvs.2019.03.029.

REFERENCES

1 Ghaferi AA, Birkmeyer JD, Dimick JB. Variation in hospital mortality associated with inpatient surgery. *N Engl J Med* 2009;**361**:1368–75.
2 Birkmeyer JD, Siewers AE, Finlayson EVA, Stukel TA, Lucas FL, Batista I, et al. Hospital volume and surgical mortality in the United States. *N Engl J Med* 2002;**346**:1128–37.
3 Stey AM, Russell MM, Ko CY, Sacks GD, Dawes AJ, Gibbons MM. Clinical registries and quality measurement in surgery: a systematic review. *Surgery* 2015;**157**:381–95.
4 Halm EA, Lee C, Chassin MR. Is volume related to outcome in health care? A systematic review and methodologic critique of the literature. *Ann Intern Med* 2002;**137**:511–20.
5 Birkmeyer JD, Stukel TA, Siewers AE, Goodney PP, Wennberg DE, Lucas FL. Surgeon volume and operative mortality in the United States. *N Engl J Med* 2003;**349**:2117–27.
6 Mao J, Goodney P, Cronenwett J, Sedrakyan A. Association of very low-volume practice with vascular surgery outcomes in newyork. *JAMA Surg* 2017;**152**:759–66.
7 Cowan JA, Dimick JB, Thompson BG, Stanley JC, Upchurch GR. Surgeon volume as an indicator of outcomes after carotid endarterectomy: an effect independent of specialty practice and hospital volume. *J Am Coll Surg* 2002;**195**:814–21.
8 Harries RL, Rashid M, Smitham P, Vesey A, McGregor R, Scheeres K, et al. What shape do UK trainees want their training to be? Results of a cross-sectional study. *BMJ Open* 2016;**6**.
9 van der Leeuw RM, Lombarts KMJMH, Arah OA, Heineman MJ. A systematic review of the effects of residency training on patient outcomes. *BMC Med* 2012;**10**:65.
10 Kelly M, Bhangu A, Singh P, Fitzgerald JEF, Tekkis PP. Systematic review and meta-analysis of trainee- versus expert surgeon-performed colorectal resection. *Br J Surg* 2014;**101**:750–9.
11 Reeves JG, Kasirajan K, Veeraswamy RK, Ricotta JJ, Salam AA, Dodson TF, et al. Characterization of resident surgeon participation during carotid endarterectomy and impact on perioperative outcomes. *J Vasc Surg* 2012;**55**:268–73.
12 White SA, Thompson MM, Zickerman AM, Broomhead P,

Critchley P, Barrie WW, et al. Lower limb amputation and grade of surgeon. *Br J Surg* 1997;**84**:509–11.
13 Prischl FC, Kirchgatterer A, Brandstätter E, Wallner M, Baldinger C, Roithinger FX, et al. Parameters of prognostic relevance to the patency of vascular access in hemodialysis patients. *J Am Soc Nephrol* 1995;**6**:1613–8.
14 O'Hare AM, Dudley RA, Hynes DM, McCulloch CE, Navarro D, Colin P, et al. Impact of surgeon and surgical center characteristics on choice of permanent vascular access. *Kidney Int* 2003;**64**:681–9.
15 PRISMA. Preferred Reporting Items for Systematic Reviews and Meta-Analyses. Available at: http://www.prisma-statement.org (accessed 10 April 2019).
16 Wells GA, Shea B, O'Connell D, Peterson J, Welch V, Losos M, Tugwell P. The Newcastle–Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Available at: http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp (accessed 10 April 2019).
17 Barnes R, Smith GE, Chetter IC. A prospective observational study to assess the impact of operator seniority on outcome following arteriovenous fistula formation. *J Vasc Access* 2015;**16**:372–6.
18 Cosgrove CM, Thornberry DJ, Wilkins DC, Ashley S. Surgical experience and supervision may influence the quality of lower limb amputation. *Ann R Coll Surg Engl* 2002;**84**:344–7.
19 Fassiadis N, Morsy M, Siva M, Marsh JE, Makanjuola AD, Chemla ES. Does the surgeon's experience impact on radiocephalic fistula patency rates? *Semin Dial* 2007;**20**:455–7.
20 Gundevia Z, Whalley H, Ferring M, Claridge M, Smith S, Wilmink T. Effect of operating surgeon on outcome of arteriovenous fistula formation. *Eur J Vasc Endovasc Surg* 2008;**35**:614–8.
21 Regus S, Almási-Sperling V, Rother U, Meyer A, Lang W. Surgeon experience affects outcome of forearm arteriovenous fistulae more than outcomes of upper-arm fistulae. *J Vasc Access* 2017;**18**:120–5.
22 Weale A, Barwell J, Chant H, Lear P, Mitchell D. The impact of training on outcomes in primary vascular access surgery. *Ann R Coll Surg Engl* 2004;**86**:275–80.
23 McGrogan DG, Maxwell AP, Inston NG, Krishnan H, Field M. Preserving arteriovenous fistula outcomes during surgical training. *J Vasc Access* 2014;**15**:474–80.
24 Bradbury A, Brittenden J, Murie J, Jenkins A, Ruckley C. Supervised training in carotid endarterectomy is safe. *Br J Surg* 1997;**84**:1708–10.
25 Cacioppa LM, Pini R, Longhi M, Vacirca A, Gallitto E, Faggioli G, et al. The value of carotid endarterectomy as a learning tool for trainees. *Ann Vasc Surg* 2018;**47**:195–9.
26 Pai M, Handa A, Hands L, Collin J. Adequate vascular training opportunities can be provided without compromising patient care. *Eur J Vasc Endovasc Surg* 2002;**23**:524–7.
27 Lutz HJ, Michael R, Gahl B, Savolainen H. Is carotid endarterectomy a trainee operation? *World J Surg* 2009;**33**:242–5.
28 Metzger P, Aspalter M, Guggenbichler S, Dabernig W, Linni K, Butturini E, et al. Case numbers in carotid surgery training can be accomplished and are not associated with an inferior outcome. Results of a university based tertiary care center study. *Eur Surg* 2014;**46**:239–43.
29 Naylor AR, Thompson MM, Varty K, Sayers RD, London NJM, Bell PRF. Provision of training in carotid surgery does not compromise patient safety. *Br J Surg* 1998;**85**:939–42.
30 Ricco JB, Régnault De La Mothe G, Fujita S, Page O, Valagier A, Marchand C. Impact of routine completion angiography on the results of primary carotid endarterectomy: a prospective study in a teaching hospital. *Eur J Vasc Endovasc Surg* 2011;**41**:579–88.
31 Rijbroek A, Wisselink W, Rauwerda JA. The impact of training in unselected patients on mortality and morbidity in carotid endarterectomy in a vascular training center and the recommendations of the European Board of Surgery Qualification in Vascular Surgery. *Eur J Vasc Endovasc Surg* 2003;**26**:256–61.
32 Krupski WC, Effeney DJ, Goldstone J, Deuel M, Webb RL, Etheredge SN, et al. Carotid endarterectomy in a metropolitan community: comparison of results from three institutions. *Surgery* 1985;**98**:492.
33 Malas T, Al-Atassi T, Brandys T, Naik V, Lapierre H, Lam B. Impact of visualization on simulation training for vascular anastomosis. *J Thorac Cardiovasc Surg* 2018;**155**:1686–93.
34 Mughal NA, Atkins ER, Morrow D, Al-Jundi W. Smartphone learning as an adjunct to vascular teaching – a pilot project. *BMC Med Educ* 2018;**18**.
35 Desender L, Van Herzeele I, Lachat M, Duchateau J, Bicknell C, Teijink J, et al. A multicentre trial of patient specific rehearsal prior to EVAR: impact on procedural planning and team performance. *Eur J Vasc Endovasc Surg* 2017;**53**:354–61.
36 Desender LM, Van Herzeele I, Lachat ML, Rancic Z, Duchateau J, Rudarakanchana N, et al. Patient-specific rehearsal before EVAR influence on technical and nontechnical operative performance. A randomized controlled trial. *Ann Surg* 2016;**264**:703–9.
37 Greenberg C, Walle K Vande. Intraoperative non-technical skills: a critical target for improving surgical outcomes. *BMJ Qual Saf* 2018:2727.
38 Yurko YY, Scerbo MW, Prabhu AS, Acker CE, Stefanidis D. Higher mental workload is associated with poorer laparoscopic performance as measured by the NASA-TLX tool. *Simul Healthc* 2010;**5**:267–71.
39 Faglia E, Clerici G, Clerissi J, Gabrielli L, Losa S, Mantero M, et al. Early and five-year amputation and survival rate of diabetic patients with critical limb ischemia: data of a cohort study of 564 patients. *Eur J Vasc Endovasc Surg* 2006;**32**:484–90.
40 Schinstock CA, Albright RC, Williams AW, Dillon JJ, Bergstralh EJ, Jenson BM, et al. Outcomes of arteriovenous fistula creation after the fistula first initiative. *Clin J Am Soc Nephrol* 2011;**6**:1996–2002.
41 The SPACE Collaborative Group. 30 day results from the SPACE trial of stent-protected angioplasty versus carotid endarterectomy in symptomatic patients: a randomised non-inferiority trial. *Lancet* 2006;**368**:1239–47.
42 National Vascular Registry. *2018 Annual report*. 2018. Available at: https://www.vsqip.org.uk/content/uploads/2018/12/2018-NVR-Annual-Report.pdf. [Accessed 10 April 2019].
43 Lear R, Riga C, Godfrey AD, Falaschetti E, Cheshire NJ, Van Herzeele I, et al. Multicentre observational study of surgical system failures in aortic procedures and their effect on patient outcomes. *Br J Surg* 2016;**103**:1467–75.