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Similar long-term outcomes for venous, bovine pericardial, and polyester patches for primary carotid endarterectomy

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Abstract

Background: Currently, the type of patch used for carotid endarterectomy closure depends on the preference of the operating surgeon. Various materials are available, including autologous venous patches, bovine pericardial patches (BPP), and synthetic patches. The purpose of this study was to compare the long-term outcomes.

Methods: All patients who underwent primary carotid endarterectomy with patch angioplasty using a venous, bovine, or polyester patch between 2010 and 2020 at two high-volume medical centers were included in this retrospective analysis on largely prospectively collected data. Study endpoints included long-term ipsilateral transient ischemic attack or cerebrovascular accident, restenosis, reintervention, and all-cause mortality. Cox proportional hazard models were fitted to assess the effect of patch type to each outcome.

Results: In total, 1481 CEAs were performed with a follow-up of 32 (13–65) months. Venous patch was used in 309 patients (20.9%), BPP in 1000 patients (67.5%), and polyester patch in 172 patients (11.6%). A preoperative symptomatic carotid artery stenosis of >50% was observed in 91.9% ($n = 284$) of the patients who received a venous patch, 92.1% ($n = 921$) of the patients who received BPP, and 90.7% ($n = 156$) of the patients who received a polyester patch ($p = 0.799$). Only in selected patients with an asymptomatic stenosis of >70% surgery was considered. Multivariable analyses showed no significant differences between the three patch types regarding long-term outcomes after adjusting for confounders.

Conclusions: In patients undergoing primary carotid endarterectomy, the use of venous, bovine pericardial, or polyester patches seems equally safe and durable in terms of comparability in long-term outcomes.

KEYWORDS

bovine pericardial patch, carotid endarterectomy, patch angioplasty, polyester, venous patch

1 | INTRODUCTION

Stroke is a major cause of death and disability and 10%–15% of all strokes are caused by thromboembolism from a previously asymptomatic significant stenotic lesion of the internal carotid artery.[1,2] Carotid endarterectomy (CEA) may be used to decrease the risk of major stroke in symptomatic and asymptomatic patients. CEA with standard or selective patch angioplasty may reduce the risk of perioperative occlusion and long-term restenosis and is therefore recommended over standard primary closure.[1,3] Various materials are currently available for patch angioplasty, including autologous vein, synthetic materials (e.g., polyester or PTFE), or biological xenografts (e.g., bovine pericardial patch [BPP]). However, no specific recommendations are available regarding which patch type to use.

Currently, the choice depends on the preference of the operating surgeon.[1] Autologous venous patches (e.g., the great saphenous vein) show good results, with easy handling characteristics and resistance to infection.[4] However, a suitable vein is not always available. Furthermore, harvesting the vein prolongs intervention time and it carries the risk of developing wound complications at the harvesting site.[3,5] An advantage of using "off the shelf" patches such as synthetic or xenograft patches, is that the vein is left intact for future coronary or peripheral bypass surgery. However, synthetic materials have other disadvantages, such as a higher infection risk and more thrombogenicity compared to autologous vein material.[6] A meta-analysis that included CEA with either venous or synthetic patches showed similar outcomes for both patches in terms of reducing the risk of stroke, death, and restenosis during the perioperative period and long-term follow-up.[6] However, this study included only one randomized controlled trial comparing BPP ($n = 51$) to synthetic patches ($n = 44$) with a follow-up until 1 year, and redo CEA was not described as an exclusion criterion. Another group conducted a network meta-analysis and found that patching with BPP or PTFE was associated with a lower rate of adverse outcomes compared to other techniques such as autologous vein and Dacron patching.[7] Our recent single center study compared BPP and polyester patches in 416 patients. Both patch types showed comparable safety and durability.[8] These comparable results were confirmed by a recently published registry-based study ($n = 413$ BPP and $n = 3921$ polyester).[9] However, no venous patches were included in both studies.

Because there is still no recommendation on which patch to use in the guidelines and because of a shorter follow-up of previously published studies, the aim of this multicenter study was to compare short- and long-term outcomes of primary CEA using autologous venous, BPP, and polyester patches. Furthermore, this study serves as external validation of previously published studies.[9,10]

2 | MATERIAL AND METHODS

All consecutive patients who underwent primary CEA with patch angioplasty using venous patch, BPP, or polyester between January 2010 and December 2020 at the University Medical Center Utrecht (UMCU) or the University Medical Center Groningen (UMCG) were included in this study. In 2010, BPP was introduced as a patch option at the UMCU and five years later, in 2015, it was introduced at the UMCG. In both centers BPP surpassed the other materials as the most used patch. Patients who underwent redo carotid surgery, or CEA with primary closure or patch angioplasty using materials, were excluded.

The Medical Ethical Institutional Review boards of both centers granted dispensation for the study from the Medical Research Involving Human Subjects Act (WMO) obligation in accordance with Dutch law on patient-based medical research obligations (registration numbers UMCU 2022/896 and UMCG 2021/493). Patient data were processed and electronically stored in agreement with the Declaration of Helsinki: Ethical Principles for medical research involving human subjects.[11] Data were stored and analyzed anonymously. UMCU-data were retrieved from an ongoing prospective study: the Athero-Express Biobank (AE) study. An outline of the objectives of the AE has been published previously.[12] Data from UMCG-patients were collected retrospectively from the electronic patient file and were found using intervention codes.[8]

2.1 | Patient characteristics

Patient characteristics included age at time of CEA, sex (assigned at birth: male/female), body mass index (BMI), and tobacco use (current use or $\leq$ 1 year of abstinence). The following comorbidities were collected according to the Society for Vascular Surgery system (class 0–3; positive if score $\geq$1) in accordance with the Ad Hoc Committee on Reporting Standards: hypertension, hyperlipidemia, and diabetes mellitus.[13,14] Furthermore, the history of coronary artery disease (CAD) was based on the presence of angina pectoris, myocardial infarction, percutaneous coronary interventions, and/or coronary artery bypass grafting.

Carotid stenosis was defined as "symptomatic" if an internal carotid artery stenosis of >50% was present, in addition to one or more of the following preoperative ipsilateral symptoms in the past 6 months: ocular symptoms (amaurosis fugax), transient ischemic attack (TIA), or cerebrovascular accident (CVA). If none of these events occurred in the past 6 months, the carotid stenosis was labeled "asymptomatic"[1,15] Data on pre-operative antiplatelet therapy and the use of anti-coagulation were collected. The following peak systolic velocities (PSV) cut-off values were used to grade the pre- and post-operative internal carotid artery ipsilateral stenosis: <125 cm/s for <50% stenosis, ≥125 cm/s for 50%–69% stenosis, ≥230 cm/s for 70%–99% stenosis (but not near occlusion).[16] Contralateral occlusion (confirmed with duplex ultrasound) was also noted. Indications for surgery were based on the European Society for Vascular Surgery (ESVS) guidelines.[1] In general, patients with a symptomatic stenosis of 50%–99% underwent CEA with patch angioplasty. Only in selected patients (i.e., average surgical risk patients with characteristics that may be associated with an increased risk of late stroke) with an asymptomatic stenosis of >70% surgery was considered.[1] Especially in cases with contralateral occlusion, progressive ipsilateral stenotic disease, in men younger than 75 years of age.[1]

2.2 | Technical aspects

Technical aspects of the procedure have been published previously.[17] If patients were not already on anticoagulation therapy, they received antiplatelet therapy. Furthermore, they received a statin. Pre-operatively, 2 g of cefazolin intravenous was given. All patients were operated under general anesthesia. Five-thousand IU heparin intravenous was administered before the carotid artery was clamped. Electroencephalography (EEG) and transcranial Doppler (TCD) were used to monitor patients during surgery. A shunt was utilized on indication depending on EEG and TCD changes. The longitudinal carotid arteriotomy was closed using a patch containing autologous vein (distal great saphenous vein), BPP (XenoSure Biologic Vascular Patch; LeMaitre, USA or Vascu-Guard Peripheral Vascular Patch; Baxter), or polyester (Hemagard Carotid Patch; Getinge). The choice of patch material was based on the preference of the surgeon. There were no indications to prefer one patch over another. Protamine was given in a standard fashion but only on indication. Antiplatelet (monotherapy) or anti-coagulation therapy was prescribed post-operatively. Patients underwent standard surveillance duplex ultrasound examination at 3 months, 1 year, and yearly thereafter.

2.3 | Short-term adverse events

Short-term adverse events (within 30 days), including mortality, TIA or CVA, CAD, restenosis, wound infection (including infection of the cervical wound and the harvesting site in case of a venous patch), cranial nerve palsy (CNP), and cervical hematoma (SVS class 1–3 were scored positive and re-explorations were noted) were collected.[15]

2.4 | Outcomes

The primary outcome was ipsilateral TIA or CVA (i.e., diagnosed by a neurologist based on clinical presentation and cerebral imaging) during follow-up. Secondary outcomes were ipsilateral restenosis of >50% (defined as PSV-threshold >213 cm/s),[1] ipsilateral re-intervention (i.e., management of access site complications and management of postoperative stroke),[15] and all-cause mortality. Graft infection was defined following the Management of Aortic Graft Infection group (MAGIC) criteria, with the presence of at least one major and one minor criterium from another category.[18]

2.5 | Statistical analysis

Continuous data were described as mean and standard deviation (SD) or median and interquartile range (IQR), depending on the distribution. Distribution was checked visually and using the Shapiro–Wilk test. One-way ANOVA was used to compare normally distributed variables and Kruskal–Wallis was used to compare variables with a skewed distribution. Kaplan–Meier survival curves were used to visualize the effect of each patch type on the outcomes. Both uni- and multivariable Cox proportional hazard models were fitted to assess the effect of patch type to each outcome during follow-up. Multivariable Cox regression models were fitted using a stepwise backward elimination approach. Variables with a univariable p-value of <0.10 were eligible to be confounders for the multivariable model. A variable was considered a confounder if the regression coefficient of the intervention changed ≥10%. All models consisted of an estimated regression coefficient (β) with a corresponding hazard ratio (HR) and 95% confidence interval (CI). The Cox regression model assumptions were tested and fulfilled. $p < 0.05$ was considered the threshold of statistical significance. p-values were adjusted for multiple testing using the Bonferroni correction. Statistical analyses were performed in R, version 4.0.5 (R Foundation for Statistical Computing), using the survival, survminer-, and ggplot2-packages.

3 | RESULTS

In total, 1481 patients who underwent primary CEA with patch angioplasty were included in this study. Three hundred nine (20.9%) patients received a venous patch, 1000 (67.5%) patients received a BPP, and 172 (11.6%) patients received a polyester patch.

In both centers, after introduction of BPP, mainly BPP was used instead of venous or polyester patches. Baseline characteristics, divided per patch type and symptom status, are shown in Table 1. Patients with a venous patch had a mean age of 67.4 ± 9.5 years, those with a BPP were 70.4 ± 8.8 years, and those with a polyester patch were 71.5 ± 9.0 years. Patients with a venous patch were more often male (76.4%), compared to BPP (68.9%) and polyester (67.4%) ($p = 0.027$). Tobacco use ($p = 0.002$), hypertension ($p = 0.039$), diabetes mellitus ($p < 0.001$), and CAD ($p = 0.002$) differed significantly between the three intervention groups.

Distribution of preoperative ipsilateral symptomatology was significantly different between patch types ($p = 0.002$). Patients with a venous patch or polyester patch presented with a CVA most often (40.8% and 45.3%, respectively), while most patients with a BPP presented with a TIA (36.6%). Furthermore, the use of anticoagulation was significantly lower in the venous patch group (8.1%), compared to BPP (11.6%) and polyester (16.9%; $p = 0.017$). A significant difference was found in ipsilateral stenosis grades between the three groups. Seventy-nine percent of patients with a polyester patch had a severe stenosis (70%–99%) compared to 83.5% and 86.8% of patients with venous and BPP grafts, respectively. No significant differences in intra-operative characteristics were found between the patches (Table 2).

3.1 | Short-term adverse events (<30 days)

In the 30-day postoperative period, a significant difference in the occurrence of cranial nerve palsy was found ($p < 0.001$). This was the lowest in the BPP group (3.6%), compared to venous (11.3%), and polyester (9.9%). No other significant differences were observed between the three groups (Table 3).

3.2 | Follow-up

The median follow-up time was 32 (13–65) months for the total group, 47 (14–77) months for patients with a venous patch, 28 (13–59) months for BPP, and 42 (15–77) months for polyester ($p < 0.001$).

3.3 | Long-term outcomes

No significant differences were observed between venous, BPP, or polyester patches with univariable Cox regression analyses on TIA/CVA and re-intervention (Figure 1 and Online Resource 1). Restenosis occurred significantly less using venous patches (HR:

TABLE 1 Baseline characteristics of patients who underwent carotid endarterectomy with patch angioplasty, divided per patch type and divided per preoperative symptom status (i.e., "asymptomatic carotid artery stenosis" or "symptomatic carotid artery stenosis").

	Venous (n = 309)			Bovine pericardial patch (n = 1000)			Polyester (n = 172)			
	Asymptomatic	Symptomatic	*p*-value	Asymptomatic	Symptomatic	*p*-value	Asymptomatic	Symptomatic	*p*-value	*p*-value (between patch types)
Age—years	66.2 ± 9.5	67.6 ± 9.5	0.497	67.1 ± 7.8	70.6 ± 8.8	<0.001	67.3 ± 6.0	71.9 ± 9.2	0.050	<0.001
Sex—males	19 (76.0)	217 (76.4)	>0.999	63 (79.7)	626 (68.0)	0.031	11 (68.8)	105 (67.3)	>0.999	0.027
Body mass index—kg/m2	27.1 ± 3.0	26.6 ± 3.8	0.534	27.2 ± 4,1	26.7 ± 4.4	0.420	29.6 ± 6.4	27.2 ± 4.8	0.071	0.123
Tobacco use	11 (44.0)	130 (45.0)	>0.999	21 (26.6)	324 (35.5)	0.112	4 (25.0)	61 (39.4)	0.295	0.002
Hypertension	20 (80.0)	190 (66.9)	0.263	61 (78.2)	667 (72.7)	0.252	15 (93.8)	120 (76.9)	>0.999	0.039
Hyperlipidemia	21 (84.0)	243 (85.6)	0.771	63 (80.8)	765 (83.4)	0.530	14 (87.5)	133 (85.3)	>0.999	0.571
Diabetes mellitus	4 (16.0)	41 (14.4)	0.771	21 (26.6)	240 (26.1)	0.894	5 (31.3)	44 (28.2)	0.777	<0.001
Coronary artery disease	9 (36.0)	55 (19.4)	0.068	25 (31.6)	277 (30.1)	0.799	6 (37.5)	50 (32.1)	0.780	0.002

Note: Data are represented as n (%) or mean ± standard deviation.

TABLE 2 Pre-, intra-, and postoperative characteristics of patients who underwent carotid endarterectomy with patch angioplasty, divided per patch type.

	Venous (n = 309)	Bovine pericardial patch (n = 1000)	Polyester (n = 172)	p-value
Preoperative				
Ipsilateral symptoms				0.002
Cerebrovascular accident	126 (40.8)	318 (31.8)	78 (45.3)	
Transient ischemic attack	99 (32.0)	366 (36.6)	54 (31.4)	
Ocular	59 (19.1)	237 (23.7)	24 (14.0)	
Asymptomatic[a]	25 (8.1)	79 (7.9)	16 (9.3)	
Antiplatelet therapy	290 (93.9)	909 (90.9)	152 (88.4)	0.098
Anticoagulation	25 (8.1)	116 (11.6)	29 (16.9)	0.017
Stenosis grade				0.020
<50%[b]	4 (1.3)	6 (0.6)	0 (0.0)	
50%–69%	47 (15.2)	126 (12.6)	36 (20.9)	
70%–99%	258 (83.5)	868 (86.8)	136 (79.1)	
Contralateral occlusion	26 (8.4)	111 (11.1)	13 (7.6)	0.216
Intra-operative				
Operation side-right	156 (50.5)	466 (46.6)	73 (42.4)	0.224
Shunt use	44 (14.2)	119 (11.9)	18 (10.5)	0.410
Postoperative				
Length of hospital stay—days	3 (3–3)	3 (2–4)	3 (3–4)	<0.001

Note: Data are represented as n (%), mean ± standard deviation, or median and interquartile range.

[a]Only selected patients with a carotid artery stenosis of >70%.

[b]Patients who experienced recurrent transient ischemic attacks and underwent extensive neurological workup (and multidisciplinary evaluation).

TABLE 3 Post-operative short-term adverse outcomes (<30 days) of patients who underwent carotid endarterectomy with patch angioplasty, divided per patch type.

	Venous (n = 309)	Bovine pericardial patch (n = 1000)	Polyester (n = 172)	p-value
Mortality	2 (0.6)	10 (1.0)	2 (1.2)	0.770
Transient ischemic attack or cerebrovascular accident	12 (3.9)	34 (3.4)	9 (5.2)	0.450
Coronary artery disease	3 (1.0)	20 (2.0)	3 (1.7)	0.559
Restenosis	5 (1.6)	8 (0.8)	2 (1.2)	0.373
Wound infection[a]	7 (2.3)	14 (1.4)	3 (1.7)	0.481
Cranial nerve palsy	35 (11.3)	36 (3.6)	17 (9.9)	<0.001
Cervical hematoma	14 (4.5)	45 (4.5)	10 (5.8)	0.687
Requiring re-exploration	9 (2.9)	35 (3.5)	6 (3.3)	0.173

Note: Data are represented as n (%).

[a]including cervical wound (n = 4) and harvesting site (n = 3) of the venous graft.

0.56 [0.36; 0.86], $p = 0.008$) compared to BPP (reference category). There was no difference between polyester and BPP regarding restenosis (HR: 0.76 [0.46; 1.24], $p = 0.273$). In the univariable Cox regression analysis, venous patch types (reference category) showed the lowest all-cause mortality compared to BPP (HR: 1.42 [1.08; 2.01], $p = 0.014$) and polyester patches (HR: 2.20 [1.52; 3.20], $p < 0.001$). Polyester patches were

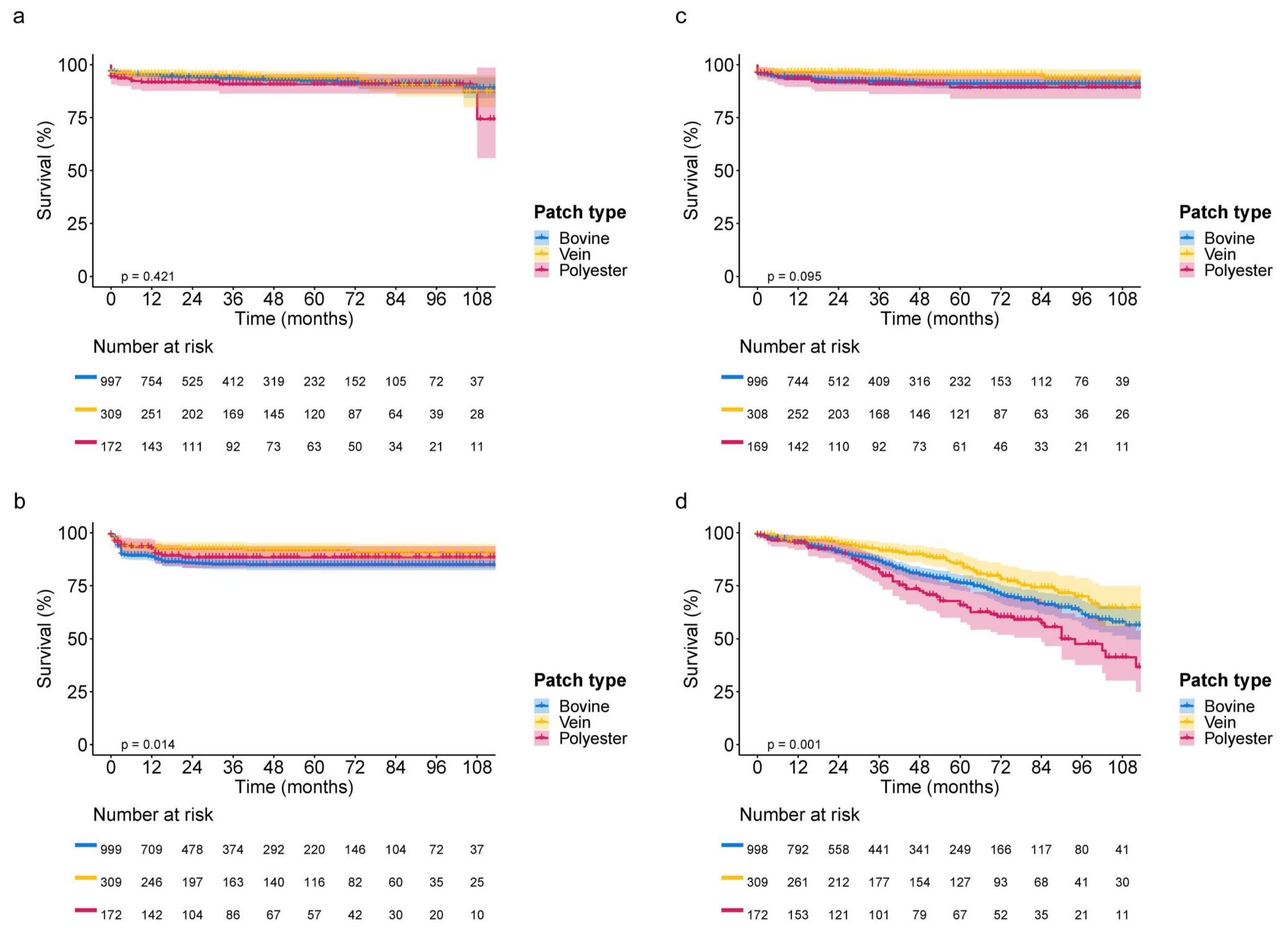

FIGURE 1 Survival curves per patch type for different outcomes (A): transient ischemic attack or cerebrovascular accident (ipsilateral), (B): restenosis (ipsilateral), (C): reintervention (ipsilateral), (D): all-cause mortality. [Colour figure can be viewed at wileyonlinelibrary.com]

associated with higher all-cause mortality (HR: 1.49 [1.11; 2.00]; $p = 0.007$) compared to BPP.

Variables that were eligible as confounders for the multivariable model included age, sex, tobacco use, hypertension, diabetes mellitus, CAD, ipsilateral symptoms, antiplatelet therapy, anticoagulation, stenosis grade, and hospital. After adjusting for confounders in the multivariable Cox regression analyses (reference category = BPP), no significant differences were observed between the patch materials regarding the four main outcomes, including ipsilateral TIA/CVA (venous: $p = 0.490$, polyester: $p = 0.152$), ipsilateral restenosis (venous: $p = 0.137$, polyester: $p = 0.938$), ipsilateral re-intervention (venous: $p = 0.095$, polyester: $p = 0.938$), and all-cause mortality (venous: $p = 0.124$, polyester: $p = 0.562$) (Table 4).

3.4 | Cranial nerve palsy

After 1 year of follow-up, persistent symptoms of CNP were observed in two patients with a venous patch, one patient with BPP, and three patients with a polyester patch who had a short-term (<30 days) CNP. No significant differences were observed between the three patch types ($p = 0.158$).

3.5 | Patch infection

One (0.1%) patient with a BPP and three (1.8%) patients with a polyester patch developed a graft infection ($p = 0.011$), while patch infection was not scored in the venous patch group. The BPP patient presented with septic bleeding (2 weeks postoperatively). Replacement surgery was performed using a venous patch and intraoperative cultures showed *Klebsiella oxytoca*. Graft infection in patients with a polyester patch was diagnosed at 6, 37, and 57 months, respectively. Two of the three patients with an infected polyester patch also underwent venous reconstruction. Intraoperative cultures were positive for *Staphylococcus aureus* in one patient and the other patients' cultures were negative (possibly due to long-term preoperative antibiotic

TABLE 4 Multivariable Cox regression analyses of the effect of patch type on TIA/CVA, restenosis, re-intervention, and all-cause mortality.

Outcome	Predictor (reference: bovine pericardial patch)	β (95% CI)	HR (95% CI)	p-value
Transient ischemic attack or cerebrovascular accident (ipsilateral)[a]	Venous	0.19 (−0.35; 0.73)	1.21 (0.70; 2.08)	0.490
	Polyester	0.49 (−0.35; 1.15)	1.63 (0.84; 3.16)	0.152
Restenosis (ipsilateral)[b]	Venous	−0.36 (−0.83; 0.11)	0.70 (0.44; 1.12)	0.137
	Polyester	−0.00 (−0.58; 0.57)	1.00 (0.56; 1.78)	0.989
Re-intervention (ipsilateral)[c]	Venous	−0.53 (−1.15; 0.09)	0.59 (0.32; 1.10)	0.095
	Polyester	0.03 (−0.64; 0.70)	1.03 (0.53; 2.01)	0.938
All-cause mortality[d]	Venous	−0.29 (−0.65; 0.08)	0.75 (0.52; 1.08)	0.124
	Polyester	0.13 (−0.30; 0.55)	1.13 (0.74; 1.73)	0.562

Note: (tested: age, sex, tobacco use, hypertension, diabetes mellitus, coronary artery disease, ipsilateral symptoms, antiplatelet therapy, anticoagulation, stenosis grade, hospital).

[a]adjusted for age, sex, hypertension, anticoagulation, hospital.

[b]adjusted for age, sex, tobacco use, hypertension, diabetes mellitus, ipsilateral symptoms, anticoagulation, stenosis grade, hospital.

[c]adjusted for age, hypertension, diabetes mellitus, ipsilateral symptoms, antiplatelet therapy, hospital.

[d]adjusted for age, tobacco use, hypertension, coronary artery disease, anticoagulation, hospital.

therapy). The third patient was treated conservatively because he/she was physically unable to undergo surgical treatment.

4 | DISCUSSION

Our analysis revealed no significant differences between autologous venous patch, BPP, nor polyester patch for primary CEA regarding the occurrence of TIA/CVA, restenosis, re-intervention, and all-cause mortality after adjusting for confounders.

Our observations are largely confirmative with existing literature.[9,19] In a registry study, comparing different closure techniques, BPP revealed the lowest re-intervention and restenosis rate. However, these outcomes were only compared at 1-year follow-up.[3] A meta-analysis comparing BPP to other materials (including Dacron and venous patches) also found no superior patch type with regard to short-term TIA, CVA, or mortality.[20] A recently published Cochrane review found little to no differences between venous and synthetic material regarding long-term adverse outcomes such as TIA/CVA. Although the authors stated that more trial data was necessary to draw conclusions, they found that BPP may lower the risk of perioperative fatal TIA/CVA and mortality compared to synthetic grafts.[21] Furthermore, none of the studies compared BPP to venous patches, and only two studies compared BPP to synthetic patches. Therefore, the strength of the current study is the comparison of all three of them with a large number of patients and long-term follow-up.

Our study highlights the rarity of patch infection across all patch types with the highest prevalence among patients with a polyester patch. This corresponds with earlier published literature.[10] Biological materials (autologous vein or xenograft) seem to be more resistant to infection compared to synthetic material. The infection resistant property of BPP is possibly due to the fact that it is made of acellular material causing reendothelialization.[8] Due to these properties, the use of bovine pericardium is gaining popularity in other vascular surgical procedures when an infection is present in the surgical field.[22–24] In carotid surgery, autologous material is still the primary choice of treatment when a patient is diagnosed with a graft infection in a non-acute setting. This is underlined by the results of our study (0% patch infection).[25]

The only statistically significant difference that we observed was on CNP, with the lowest prevalence among BPP patients. However, after 1 year of follow-up, persistent symptoms were rare and no differences were observed between the three groups. In contrast to our previously published single-center study, no significant differences in short-term cervical hematoma were found between BPP and polyester.[8] These results are similar to another large study that compared BPP to other CEA techniques which also showed no significant differences between groups regarding short-term presentation of a hematoma requiring surgical re-exploration.[4]

4.1 | Limitations

Although this is one of the largest cohorts comparing the long-term follow-up of different kinds of patches for CEA, limitations of this study exist, including the retrospective nature of the analysis and the heterogeneity of the patient population. However, the occurrence of the outcomes are low, without significant differences between the three patch types. Therefore, it is not likely that in larger groups, a clinically relevant difference will be found. The patients included in this study were operated in two different centers. However, the procedures were similar at both hospitals. Additionally, we corrected for "hospital location" in the multivariable analyses.

5 | CONCLUSION

For patients undergoing primary CEA, long-term follow-up showed that venous, bovine, and polyester patches are safe options for closure and were comparable in terms of rate of CVA, restenosis, re-intervention, and all-cause mortality. Vascular graft infection was rare in all groups. This study confirms that the choice of patch material used for CEA remains in the hands of the operating team.

AUTHOR CONTRIBUTIONS

David J. Liesker: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; validation; visualization; writing – original draft; writing – review & editing. **Barzi Gareb**: Conceptualization; formal analysis; investigation; methodology; resources; validation; visualization; writing – original draft; writing – review & editing. **Bart T. Köhlen**: Conceptualization; data curation; formal analysis; investigation; methodology; resources; validation; writing – original draft; writing – review & editing. **Simone J.A. Donners**: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; resources; validation; writing – original draft; writing – review & editing. **Gert J. de Borst**: Conceptualization; funding acquisition; investigation; methodology; resources; supervision; validation; writing – original draft; writing – review & editing. **Clark J. Zeebregts**: Conceptualization; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; writing – original draft; writing – review & editing. **Ben R. Saleem**: Conceptualization; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; writing – original draft; writing – review & editing.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST STATEMENT

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ETHICS STATEMENT

The Medical Ethical Institutional Review boards of both centers granted dispensation for the study from the Medical Research Involving Human Subjects Act (WMO) obligation in accordance with Dutch law on patient-based medical research obligations (registration numbers UMCU 2022/896 and UMCG 2021/493). Consequently, informed consent was not obtained. All patient-related data were processed anonymously and stored electronically in agreement with the Declaration of Helsinki – Ethical principles for medical research involving human subjects.

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