From the Society for Clinical Vascular Surgery

Contemporary outcomes of open and endovascular popliteal artery aneurysm repair

Andrew E. Leake, MD, Efthymios D. Avgerinos, MD, Rabih A. Chaer, MD, Michael J. Singh, MD, Michel S. Makaroun, MD, and **Luke K. Marone, MD,** *Pittsburgh, Pa*

Objective: **The purpose of this study was to evaluate contemporary practice and outcomes of open repair (OR) or endovascular repair (ER) for popliteal artery aneurysms (PAAs).**
Methods: **Consecutive patients with PAA treated at one institution from January 2006 to March 2014 were reviewed under an Institutional Review Board-approved protocol. Demographics, indications, anatomic characteristics, and outcomes were collected. Standard statistical methods were used.**
Results: **A total of 186 PAAs were repaired in 156 patients (110 ORs, 76 ERs) with a mean age of 71 ± 11 years, and most were male (96%). Mean follow-up was 34.9 ± 28.6 months for OR and 28.3 ± 25.8 months for ER ($P = .12$). Comorbidities were similar between groups. OR was used in more patients with PAA thrombosis (41.8% vs 5.3%; $P < .001$), acute ischemia (24.5% vs 9.2%; $P = .010$), and ischemic rest pain (34.5% vs 6.6%; $P < .001$). Mean tibial (Society for Vascular Surgery) runoff score was 5.0 for OR vs 3.3 for ER ($P = .006$). OR was associated with increased 30-day complications (22% vs 2.6%; $P < .001$) and mean postoperative stay (5.8 vs 1.6 days; $P < .001$). There was no difference in 30-day mortality (OR, 1.8%; ER, 0%; $P = .56$) or major amputation rate (OR, 3.7%; ER, 1.3%; $P = .65$). Primary, primary assisted, and secondary patency rates were similar at 3 years (OR, 79.5%, 83.7%, and 85%; ER, 73.2%, 76.3%, and 83%; P = NS). Among 130 patients presenting electively without acute ischemia or thrombosed PAA (63 ORs and 67 ERs), OR had better 3-year primary patency (88.3% vs 69.8%; $P = .030$) and primary assisted patency (90.2% vs 73.5%; $P = .051$) but similar secondary patency (90.2% vs 82%; $P = .260$). ER thrombosis was noted in 8 of 24 patients treated in 2006-2008 (33%; mean time to failure, 49 months) but in only 4 of 51 patients treated in 2009-2013 (7.8%; mean time to failure, 30 months), suggesting a steep learning curve.**
Conclusions: **ER is a safe and durable option for PAA, with lower complication rates and a shorter length of stay. OR has superior primary patency in patients treated electively but no difference in midterm secondary patency and amputations. (J Vasc Surg 2016;63:70-6.)**

Popliteal artery aneurysms (PAAs) are the most common peripheral artery aneurysms with an overall prevalence of 7.4 per 100,000 patients.[1] Often asymptomatic, repair is indicated to prevent limb-threatening lower extremity ischemic complications. The first description of surgical repair of a PAA was in 1795 by John Hunter, who successfully ligated a large PAA at the adductor canal.[2] To date, open repair (OR) with PAA exclusion and bypass or direct endoaneurysmorrhaphy has been the "gold standard" management strategy to prevent ischemic complications.

The first endovascular repair (ER) of a PAA was described by Marin et al[3] in 1994. As with most surgical techniques, there has been a rapid evolution of technology and application of endovascular therapy for the management of PAA. Early reports yielded modest results with high thrombotic complications, putting into question the broader application of ER.[4] There has been one prospective trial evaluating OR vs ER that is now more than a decade old and suffered from limited power to make definitive conclusions.[5] More recently, several retrospective studies[6-10] have failed to show significant differences between the surgical and endovascular options.

The objective of this study was to review our clinical experience with the management of PAA and to evaluate the application and outcomes of OR and ER in a large series with midterm follow-up.

METHODS

Patients who underwent a surgical or endovascular repair of a PAA from January 2006 to March 2014 were retrospectively reviewed. The University of Pittsburgh's Institutional Review Board approved this study before data collection, and a waiver of consent was granted. All procedures were performed at one of the University of Pittsburgh Medical Center hospitals by board-certified vascular surgeons. Demographic and comorbid conditions were collected and are listed in Table I. Patient

From the Division of Vascular Surgery, Department of Surgery, University of Pittsburgh Medical Center.
Author conflict of interest: none.
Presented at the Forty-third Annual Symposium of the Society for Clinical Vascular Surgery, Miami, Fla, March 29-April 2, 2015.
Correspondence: Andrew E. Leake, MD, 200 Lothrop St, Ste A-1017, Pittsburgh, PA 15213 (e-mail: leakeae@gmail.com).
The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a conflict of interest.
0741-5214

http://dx.doi.org/10.1016/j.jvs.2015.08.056

Table I. Patient characteristics

Medical condition	*OR (n = 96)*	*ER (n = 60)*	P *value*
Age, years, mean	70.5	72.7	.17
Male	95.8	96.7	.99
Coronary artery disease	48.0	49.2	.98
Hypertension	78.1	78.0	.98
Hyperlipidemia	66.7	61.0	.48
Peripheral vascular disease	33.3	40.7	.36
Current tobacco use	43.5	31.6	.1
Congestive heart failure	13.5	13.6	.99
COPD	15.6	15.3	.95
Diabetes	25.0	22.0	.67
ESRD	3.1	3.3	.99
Statin use	56.3	51.7	.58
Aspirin use	65.6	58.3	.36
Clopidogrel use	20.8	40.0	.01

COPD, Chronic obstructive pulmonary disease; *ER,* endovascular repair; *ESRD,* end-stage renal disease; *OR,* open repair.
Data are presented as percentages unless otherwise indicated.

presentation was classified as either elective or with acute ischemia requiring urgent intervention. Presence of mural thrombus was defined as thrombus occupying >50% of the lumen. All available angiograms and computed tomography angiograms were reviewed to assign a modified runoff score, which assesses popliteal and tibial artery runoff defined by Society for Vascular Surgery reporting guidelines.[11,12]

Open and endovascular procedural details were collected. Specific endovascular characteristics included open cutdown or percutaneous approach, stent number, and stent diameters. All endografts used were covered self-expanding Viabahn stent grafts (W. L. Gore & Associates, Flagstaff, Ariz). Postoperative dual antiplatelet agents (clopidogrel and aspirin) were used for most ERs and selectively after OR, unless contraindications were present. Outcomes of interest included length of stay, patency, reinterventions, complications, and major amputations. Complications collected included bleeding requiring intervention, infection, thrombosis within 30 days, and major medical events (stroke, myocardial infarction).

Nominal variables were compared between groups using the χ^2 test or Fisher exact test, and continuous variables were compared with the Mann-Whitney *U* test or Kruskal-Wallis test, depending on the number of groups. Kaplan-Meier survival analysis was used for patency estimations. Statistical analyses were performed with Stata 12 (StataCorp LP, College Station, Tex), and P value $< .05$ was considered statistically significant.

Clinical management. The vascular surgeon involved selected the procedure on the basis of clinical presentation and anatomic evaluation by computed tomography angiography or digital subtraction angiography. Catheter-directed thrombolysis was performed before repair in select patients with non-limb-threatening ischemia. Selection of ER was dependent on adequate access and a suitable, disease-free landing zone below the aneurysm of adequate diameter and at least 2.0 cm in length before any tibial takeoff. Contralateral access was chosen when feasible, but the presence of a previous endovascular aneurysm repair or other access issues required an antegrade access in many procedures. Stent graft size and length were determined by preoperative computed tomography angiography or angiography, especially in urgent cases. The majority of patients presenting with acute ischemia were managed with OR, with some exceptions in the latter part of the study period.

RESULTS

Patient characteristics. A total of 186 PAAs were repaired in 156 patients. OR was performed in 110 limbs, and 76 limbs underwent ER. Mean age at the time of the procedure was 71.4 ± 10.1 years, and a majority of patients were male (96.2%) with hypertension (78.1%), hyperlipidemia (64.5%), and tobacco use (71.6%). Most patients were taking a statin (62.8%) and an antiplatelet agent (aspirin, 62.8%; clopidogrel, 28.2%). There were no major differences in preoperative characteristics between surgical groups, except the prevalence of clopidogrel use (ER, 40%; OR, 21%, $P = .010$; Table I). Other aneurysms identified in this cohort included abdominal aortic aneurysms in 71 patients (47.3%), with 46 (30.7%) undergoing previous repair (OR, 30.1%; ER, 31.6%; $P = .85$). Femoral artery aneurysms were less prevalent and were identified in 15 patients (10.0%; OR, 11.8%; ER, 7%; $P = .41$). Bilateral PAAs were identified in 91 patients (49.7%) at presentation (OR, 52.3%; ER, 46.1%; $P = .41$).

There were differences in presentation between the two groups (Table II). A larger percentage of OR patients presented with acute ischemia (OR, 24.5%; ER, 9.2%; $P < .001$), rest pain (OR, 34.4%; ER, 9.2; $P < .001$), and a thrombosed PAA (OR, 41.8%; ER, 5.3%; $P < .001$). There were no differences in PAA size or the presence of mural thrombus between the two groups. Modified runoff score was significantly worse for OR than for ER (OR, 8.8 ± 6.0; ER, 3.6 ± 3.0; $P < .001$). Ruptured PAA was a rare occurrence in this series (OR, 1.0%; ER, 3.9%; $P = .31$).

OR was predominantly performed through a medial approach (81.5%), with a posterior approach used in 18.5%. Conduits for bypass included 79 great saphenous veins (GSVs; 73.2%), 27 prosthetics (25.7%), and 3 arm veins (2.8%). ER was performed percutaneously in 47 patients (61.8%) or through femoral cutdown in 27 patients (38.2%). Ipsilateral antegrade was performed in 41 patients (54%) or contralateral retrograde was used in 35 patients (46%) for femoral access. Median stent diameter was 8 mm (range, 6-8 mm), and the mean number of stents used was 1.8 ± 0.8. Adjuvant thrombolysis was used in some cases before definitive choice of repair method (OR, 10.9%; ER, 6.6%; $P = .439$). Thrombolysis was more frequently used in cases of acute ischemia (13 of 15 cases) and PAA thrombosis (12 of 15 cases), with improvement in runoff achieved in 12 of 15 cases.

Outcomes. Technical success was 100% in all ER and OR patients. The length of stay after the procedure was significantly shorter for ER (1.6 ± 3.7 days) than for OR (5.8 ± 4.5 days; $P < .001$). ER had significantly fewer

Table II. Preoperative characteristics, all patients, and elective patients

	All patients			*Elective patients*		
Preoperative characteristics	*OR (n = 110)*	*ER (n = 76)*	P *value*	*OR (n = 63)*	*ER (n = 67)*	P *value*
Presentation						
Acute ischemia	24.5	9.2	<.001	0	0	.99
Rest pain	34.5	6.6	<.001	0	0	.99
Claudication	19.1	9.2	.094	7.5	15.9	.34
PAA thrombosed	41.8	5.3	<.001	0	0	.99
Anatomic						
PAA diameter, mm	28.2	28.9	.69	28.1	27.9	.928
Mural thrombus	90.4	82.4	.12	81.5	88.1	.31
No. of tibials	1.8	2.3	.001	2.02	2.35	.048
Runoff score	8.8	3.6	<.001	5.1	3.1	.142

ER, Endovascular repair; *OR*, open repair; *PAA*, popliteal artery aneurysm.
Data are presented as percentages unless otherwise indicated.

30-day complications (2.6%) vs OR (18.2%; $P < .001$). ER complications included one access hematoma requiring exploration (after a cutdown) and one early type Ia endoleak that required proximal extension. There were no major medical, infectious, or 30-day thrombotic complications after ER. OR complications included incision breakdown and infections (10%), bleeding (5.5%), bypass thrombosis <30 days (1.8%), and a stroke (1.8%). There were no differences in 30-day mortality (OR, 1.8; ER, 0%; $P = .56$).

Follow-up was available for 96% of patients, with a mean duration of 34.9 ± 28.6 months for OR and 28.3 ± 25.8 months for ER ($P = .024$). Duplex ultrasound was available for review in 82% of all ER patients in the entire study period, with four identified endoleaks (6.4%). Three type II endoleaks were observed without incident, and one type Ia endoleak was identified and successfully treated with proximal extension.

Reintervention rate within the study period was not significantly different between the two groups (OR, 3.6%; ER, 9.2%; $P = .13$), with a similar mean number of procedures per patient (OR, 1.75; ER, 1.28). There was no difference in major amputations during the study period (OR, four patients [3.7%]; ER, one patient [1.3%]; $P = .65$). At 1 year, primary, primary assisted, and secondary patency rates were 89.1%, 92.1%, and 92.1% for OR and 88.8%, 92.0%, and 95.4% for ER (Fig 1). At 3 years, the rates were 79.5%, 83.7%, and 85.0% for OR and 73.2%, 76.3%, and 83.0% for ER. For patients who underwent OR, prosthetic bypass had a marginally better 3-year primary patency rate (prosthetic, 92%; GSV, 74%; $P = .078$) with no difference in secondary patency compared with GSV bypass (prosthetic, 92.8%; GSV, 81.4%; $P = .26$).

Elective patients. Because OR was used more often in emergency situations, a subgroup analysis of elective patients presenting without acute ischemia or a thrombosed PAA was performed to better compare the outcomes of OR and ER. A total of 130 patients, 63 ORs and 67 ERs, were included. There were no differences in demographics or PAA presentation (Table II) among this population. Overall, early outcomes were still better with ER, with shorter length of stay (OR, 4.6 ± 3.7 days; ER, 1.3 ± 2.4 days; $P < .001$) and fewer complications (OR, 11 patients [17.7%]; ER, three patients [4.5%]; $P = .012$; Table III). There was no difference in 30-day mortality (OR, one patient [1.6%]; ER, no patients; $P = .67$). OR had significantly better primary patency at 1 year and 3 years compared with ER (1 year: OR, 96.7% vs ER, 89.0%; and 3 years: OR, 88.3% vs ER, 69.8%; $P = .032$; Fig 2), but there was no difference in secondary patency between groups (1 year: OR, 96.7% vs ER, 94.8%; and 3 years: OR, 90.2% vs ER, 82.0%; $P = .26$).

Acute ischemia. Of all the 186 limbs treated, 34 presented with acute limb ischemia (18.3%). The majority, 27 limbs (79.4%), were treated with OR (vs seven limbs [20.5%] with ER). ER received preoperative thrombolysis in four of seven cases and had a mean number of open tibial vessels of 1.57 ± 0.95. There was one ER failure in this subgroup, which failed at 14 months and was converted to a bypass. There was one amputation with a patent endograft due to advanced ischemia at presentation. More than one third of the acute ischemia OR patients underwent preoperative thrombolysis (10 of 27 limbs) with a mean tibial runoff score of 1.05 ± 0.85. In this OR cohort, there were a total of six failures, with a mean time to failure of 25.6 ± 24.3 months. The complication rate for the OR group was 25.9% (7 of 27).

Failures. There were a total of 12 ER failures. A majority of patients presented with signs and symptoms of acute ischemia (8 of 12 patients); the remaining were asymptomatic after ER failure. No anatomic or clinical predictor of failure could be demonstrated in this somewhat small cohort. We did notice, however, a clustering of these events early in our experience. The entire study cohort was divided into the first 2 years or early experience (2006-2008, 24 ERs performed) and contemporary experience (2009-2013, 54 ERs performed). There was no difference in the proportion of ERs performed in either study period (early experience, 24 of 59 procedures [40.6%]; current

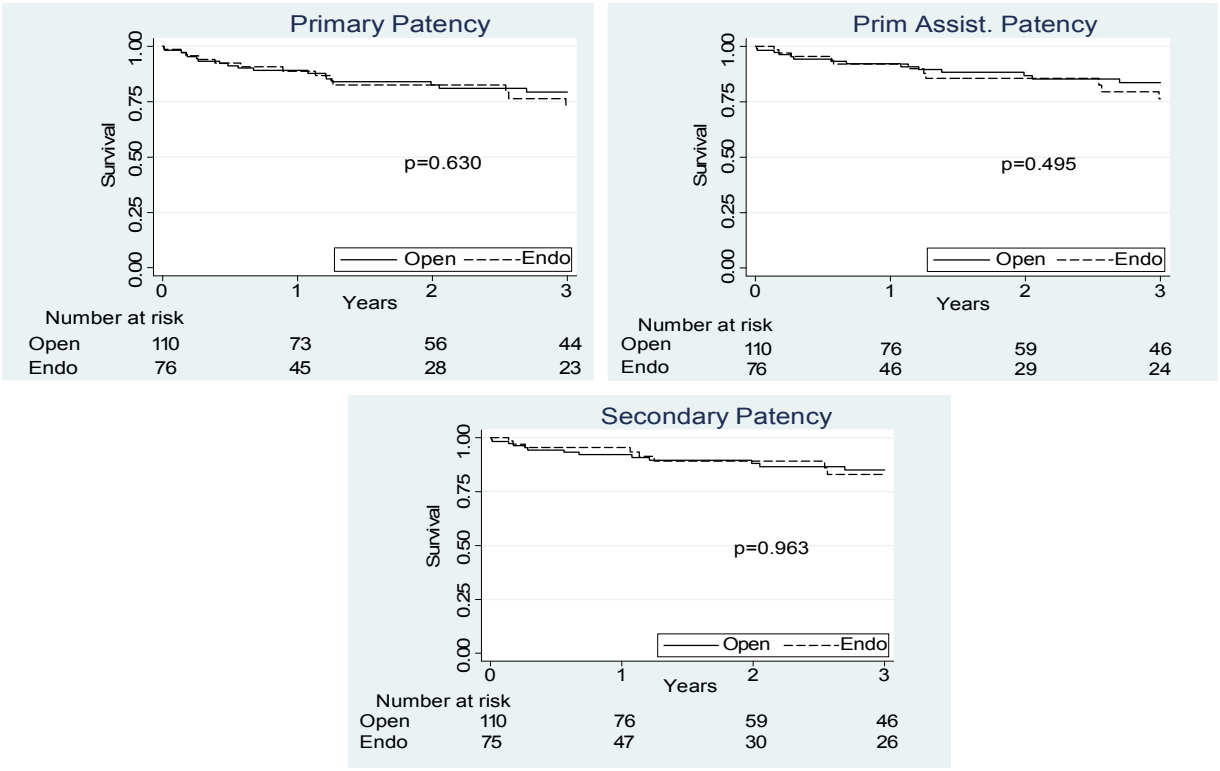

Fig 1. Primary, primary assisted, and secondary patency in all patients.

Table III. Surgical outcomes

	All patients			*Elective patients*		
Surgical outcomes	*OR (n = 110)*	*ER (n = 76)*	P *value*	*OR (n = 63)*	*ER (n = 67)*	P *value*
Length of stay, days	5.8	1.6	<.001	4.6	1.3	<.001
Follow-up, months	34.9	28.3	.02	40.5	29.1	.02
Reinterventions	3.6	9.2	.13	3.2	8.9	.28
Thirty-day complications	18.2	2.6	<.001	17.7	4.5	.012
Thirty-day mortality	1.8	0	.56	1.6	0	.67
Major amputation	3.7	1.3	.65	3.2	0	.23

ER, Endovascular repair; *OR,* open repair.
Data are presented as percentages unless otherwise indicated.

experience, 51 of 123 procedures [41.5%]; $P = .92$). Early experience with ER resulted in higher thrombosis rates compared with our contemporary results (Table IV). During the first 2 years of performing ER, thrombosis occurred in 8 of 24 patients (33%), whereas contemporary results identified 4 of 51 patients with eventual ER failure (7.8%; $P = .007$ vs early). There was no difference in the mean time to eventual ER failure (1.61 ± 1.1 years vs 0.99 ± 1.36 years; $P = .21$). At last follow-up, five patients (42%) maintained secondary patency, three patients were converted to bypass (25%), and the remaining were asymptomatic not requiring intervention (four patients [33%]). No ER failures led to a major amputation.

There were 15 OR failures throughout the study period. There was no temporal relationship between failures. Mean time to OR failure was 1.25 ± 1.61 years. OR failures were managed with redo lower extremity bypasses in three patients (20%) and maintenance of secondary patency by thrombolysis in two (13%); four (27%) were asymptomatic, not requiring any further procedures. Four of the failures led to a major amputation, and the remaining two were ligated because of infectious complications.

DISCUSSION

Adoption of ER for PAA has been relatively more restrained than similar procedures for abdominal and

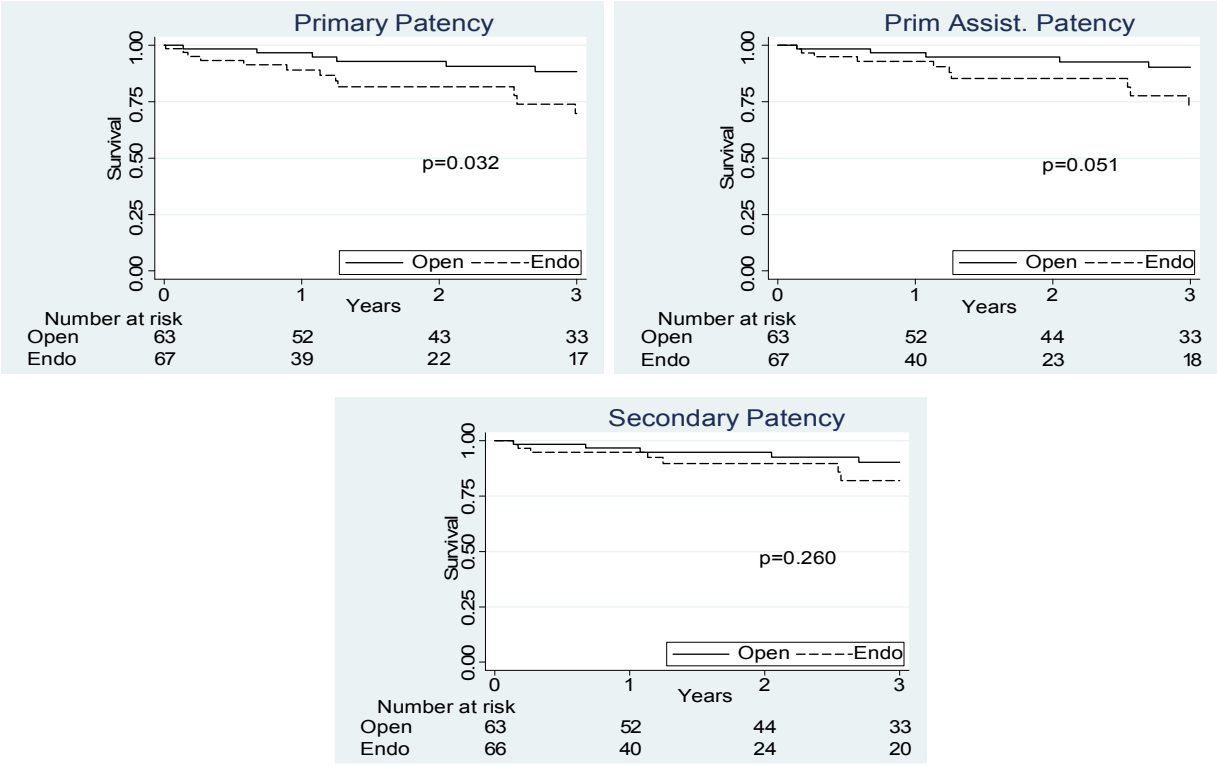

Fig 2. Primary, primary assisted, and secondary patency in nonacute and nonthrombosed patients.

thoracic aortic aneurysms, despite a similar pattern of improving early postprocedural outcomes but questionable long-term durability. Sudden thrombosis leading to amputation has been the major concern limiting widespread application of the technology, notwithstanding the fact that similar events can occur with OR. To date, there have been no studies justifying this concern, including our current report, or conversely demonstrating a superiority of ER over OR since its introduction in 1994.[3] Clinical application in the United States was not fully used until 2005, when the Viabahn stent graft was approved by the Food and Drug Administration. We report here the experience of a large center with implementing ER for select patients with PAA during an 8-year period and compare outcomes of both modalities. This study represents the largest single-center ER experience from a comparative study.

Demographics of our cohort were typical for PAA patients, with the majority being elderly and male. The presence of concomitant aneurysms was consistent with previous reports, with almost 50% incidence of abdominal aortic aneurysm and bilateral PAAs.[13] The major differences between our two treatment groups were in runoff score and clinical presentation, illustrating the prevailing concern about long-term durability of ER in the face of disadvantaged runoff, which is also more likely in patients presenting with acute events.

Despite increased ER utilization since its first description, there continue to be limited long-term outcomes reported.[14] OR, the gold standard, has a reported 5-year primary patency of 66% to 76% and a secondary patency of 84% to 87%,[13,15] with very good limb salvage rates. Long-term follow-up for ER has been reported only from limited single-center experiences, with 5-year primary patency of 70% to 84% and secondary patency of 76% to 100%, not too dissimilar from OR.[16,17] Results from two comparative studies have reported midterm outcomes, with ER primary patency ranging between 64% and 88%[9,18] and a secondary patency of 88%[18] at 3 years. OR had similar 3-year primary patency of 71% to 73%[9,18] and secondary patency of 86%.[18] This was also shown in a tabular review with similar pooled secondary patency (ER, 85%; OR, 81%) out to 3 years.[19] These results are consistent with our primary patency (OR, 80%; ER, 73%) and secondary patency (OR, 85%; ER, 83%).

The attractiveness of ER is clearly in the initial periprocedural outcomes as 30-day results consistently favor ER over OR. The decrease in early morbidity with ER is not surprising, and our series is consistent with recent reports of shorter length of stay[9,20] and fewer 30-day complications[9,10,20] with ER. Tsilimparis et al[19] found similar complication rates for OR with an average rate of 16%. The increased early complications in OR, as shown in our series and others, seem to be mostly due to wound

Table IV. Early experience vs current experience with endovascular repair (*ER*) of popliteal artery aneurysm (*PAA*)

	Early experience (2006-2008)	*Current experience (2009-2013)*	P *value*
Total PAA repairs	59	123	—
% ER (No.)	40.6 (24)	41.5 (51)	.92
Stent thrombosis, %	33	7.8	.007
Time to failure, years	1.6	.99	.21

complications. Our results also corroborate the literature findings of no significant difference in early mortality between the two modalities. The patency rates for prosthetic bypasses did not seem to be inferior to saphenous vein. Because most of them were used through a posterior approach (17 of 27), it may be that short interposition segments with relatively well preserved outflow may allow the use of prosthetic grafts in the treatment of PAAs with better results than are expected from the occlusive disease literature. The numbers, however, are too small for strong recommendations to be provided.

To lessen the clear selection bias due to differences in presentation between groups, elective patients underwent additional analysis. There were no differences in clinical presentation, tibial runoff score, or comorbidities in this subgroup. A majority of the OR patients in the elective group underwent a medial approach (69%) with use of the GSV (84%). Similar trends were again noted at 30 days, with increased length of stay (OR, 4.6 days; ER, 1.3 days) and complications (OR, 18%; ER, 5%) with OR. Primary patency was significantly improved with OR in this population (3 years: OR 88.3% vs ER 69.8%; $P = .03$). There was no difference in secondary patency, however (OR, 90.2%; ER, 82.0; $P = .26$). Huang et al[20] found similar results in OR for elective patients (3-year primary patency: OR 85% vs ER 75%), with no statistical difference. This suggests that in elective patients, OR may be more appropriate for healthy patients.

In review of the entire cohort, we reviewed all failures and attempted to identify predictors of failure. Unfortunately, none of the multivariable models identified any significant predictors of failure, including runoff score. This was probably due to heterogeneity of the failures and their relatively small number. Our first ER of PAA was in 2006, and after examination of temporal patterns of failure, we noted that a majority of the failures occurred early in our ER experience. Our improvement in outcomes is likely related to a change in selection of patients and a technical learning curve. ER is now preferred in patients with limited life expectancy or medical comorbidities judged to be at risk for development of complications and in all patients with favorable anatomy. Particular attention is given to adequate runoff and landing zones. Care is taken not to oversize the endograft, and more than one stent is often required for appropriate transitions. Furthermore, our technique has changed with increasing the sealing zone length to at least 2.0 cm of normal, nonaneurysmal vessel. Provocative maneuvers (knee flexion) are also performed after ER to ensure that there is no kinking of the stent graft. If kinking is identified, additional ballooning is performed. In cases of no resolution, the knee is then splinted for 4 weeks to prevent full knee flexion. There have also been several modifications to the Viabahn stent graft during the study period with introduction of the heparin-bonded surface (2007) and a decreased delivery profile (2007 and 2011), which may also play a role in the decreased failure rate. OR continues to be our choice for anatomy that is unsuitable for ER, limb-threatening ischemia, or patients with long life expectancy. We favor the posterior approach for disease limited to the popliteal fossa and saphenous vein conduits for long-segment bypass.

Our study has clear limitations expected from a single-center retrospective review. Patients were selected for either ER or OR, and most acute patients underwent OR, introducing a significant selection bias. Although the study is one of the larger comparative studies for PAA, it is likely underpowered to show any major statistical differences in long-term patency. This review, however, does add further insight into the evolving treatment of ER for PAA.

Our series as well as others have failed to show major differences in long-term outcomes between ER and OR. OR continues to be the gold standard in elective patients because of increased durability, but despite higher primary occlusion rates in ER, there has been no increase in limb loss or worsening of clinical outcomes. Both procedures seem to have excellent midterm patency out to 3 years. Similar to endovascular aneurysm procedures in other territories, appropriate anatomy appears to be important for success, although data are lacking to support this statement. Patients with inadequate anatomy—specifically, poor landing zones due to vessel size or encroachment onto anatomic collaterals, severe tortuosity of the popliteal segment, and compromised outflow—should continue to undergo OR. The population that receives the most benefit from ER appears to be one with adequate anatomy and at high risk for development of either medical or infectious complications.

CONCLUSIONS

ER is a safe and durable option for PAA, with lower complication rates and a shorter length of stay. OR has superior primary patency in patients treated electively but no difference in midterm secondary patency and amputations. Long-term outcomes are needed to evaluate the durability of ER.

AUTHOR CONTRIBUTIONS

Conception and design: AL, RC, MM, LM
Analysis and interpretation: AL, EA, RC, MS, MM, LM

Data collection: AL
Writing the article: AL, EA, LM
Critical revision of the article: EA, RC, MS, MM, LM
Final approval of the article: LM
Statistical analysis: AL, EA
Obtained funding: Not applicable
Overall responsibility: LM

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Submitted Jun 4, 2015; accepted Aug 5, 2015.