

Peripheral arterial aneurysms: A prospective study of 30 cases

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Abstract. Peripheral arterial aneurysms (PrAAs), characterized by localized dilatation, arise from the complex interplay between biological processes within the arterial wall and the hemodynamic forces affecting the arterial wall. The main objective of the present study was to identify and analyze short-term and long-term outcomes of surgical repair in this patient population. A retrospective analysis was performed on 30 patients operated for PrAAs over 10 years. Data were reviewed, and the outcomes of open revascularization were analyzed. Clinical categories, operative indications and statistical analyses were defined. A total of 32 PrAAs were treated in 30 patients, consisting of 22 (73.3%) men and 8 (26.7%) women. There were 28 (93.3%) unilateral and 2 (6.7%) bilateral PrAAs with a mean aneurysmal diameter of 3.4167 ± 1.00438 cm. A total of 6 aneurysms (18.75%) were asymptomatic at presentation (Group 1), 20 aneurysms (62.5%) had chronic limb-threatening ischemia (Group 2) and 6 aneurysms (18.75%) presented with acute limb ischemia (Group 3). All 32 PrAAs were repaired by interposition graft (endoaneurysmorrhaphy) and the conduit was an autogenous great saphenous vein graft in the majority of the patients with the minority repaired using prosthetics [Group 1, n=21 (70.0%); Group 2, n=3 (10.0%) and Group 3, n=6 (20.0%)]. In the first 30 days, systemic complications occurred in 3 patients only. No amputation was needed in the first 30 days and no mortality was recorded. The overall 2-year primary patency was 26/32 (81.25%). For the great saphenous vein, the primary patency was 19/21 (90.47%), and the secondary patency was 20/21 (95.23%). The 2-year freedom from re-intervention owing to PrAA

recurrence was 100%. Overall limb loss was 6.25 % (2/32). In conclusion, the present study confirmed the effectiveness of open surgical repair, especially endoaneurysmorrhaphy, in achieving significant outcomes, including primary and secondary patency rates, and minimal rates of limb loss and mortality.

Introduction

The criteria for defining arterial aneurysms as ‘a permanent localized dilatation of an artery having at least a 50% increase in diameter compared with the expected normal diameter of the artery in question’ was established by the Ad Hoc Committee on Reporting Standards of the Society for Vascular Surgery in 1991 (1). Aneurysmal dilatation of an artery results from the structural weakening of the arterial wall, primarily due to factors such as atherosclerosis, trauma, infection or post-stenotic abnormalities. Peripheral arterial aneurysms (PrAAs) exclude the aorta, iliac, cerebral and coronary arteries (2).

True aneurysms involve all three layers of the normal arterial wall and are the most common type. By contrast, pseudoaneurysms, commonly referred to as false aneurysms, are enveloped by a thin fibrous capsule in place of the typical arterial wall layers (3-5).

Popliteal artery aneurysms (PAAs) are relatively uncommon, with an incidence of <0.1% in the general population; however, they account for >70% of PrAAs (6). These aneurysms predominantly affect men and typically occur around the age of 65 years; ~50% of the cases are bilateral and are often associated with abdominal aortic aneurysms (AAAs). Notably, >50% of patients present with symptoms, the most common being acute limb ischemia caused by thromboembolic complications, which are linked to elevated rates of morbidity and limb loss (5,6).

Within a 5-year period, ~68-74% of patients with untreated PAAs experienced complications. These primarily included distal embolization, thrombosis and rupture. Notably, thromboembolic complications were associated with a marked risk of major amputation (20-59%) and mortality (up to 11%) (7). By contrast, elective repair had a certain risk (~10%) for long-term limb loss in patients with low surgical risk. Thus, for PAAs reaching a diameter of 2 cm, elective surgical intervention is generally recommended (8).

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Femoral artery aneurysms (FAAs) are the second most common type of PrAA, following PAAs. However, common FAAs (CFAAs) are relatively uncommon, while isolated superficial FAAs (SFAAs) and profunda femoris artery aneurysms are even rarer (9). Infra-PAAs (aneurysms of all arteries distal to the popliteal artery, including posterior tibial, anterior tibial and peroneal arteries) are a rare occurrence, primarily stemming from traumatic causes, with the majority being false aneurysms (10).

Upper limb aneurysms are an uncommon occurrence, constituting ~1% of all cases of PrAAs. Mostly they are subclavian-axillary artery aneurysms, which manifest at the outer border of the first rib, and the 3rd part of the axillary artery. These aneurysms, which are primarily post-stenotic in nature from thoracic outlet syndrome, are induced by factors such as the cervical rib or fibrous band (11).

Recently, endovascular treatment options have been employed to manage PrAAs, yielding diverse outcomes. Currently, the use of endovascular treatment for peripheral aneurysms should be reserved for specific cases involving high-risk patients. Until the development of devices that can counteract issues such as thrombosis and possibility of migration, as this part of the artery is highly mobile a tent in this position may end by extrinsic compression due to acute knee joint flexion. Traditional open surgery will remain the preferred treatment option (7,8,12). Open surgical treatment options include *in-situ* arterial replacement or a bypass with an autologous or prosthetic graft. To reduce the risk of late recurrence of the aneurysm, endoaneurysmorrhaphy is preferred compared with simple ligation of the artery proximal and distal to the aneurysm. Thrombolysis has also been used to improve outflow in patients with acute presentations (6).

The primary aim of the present study was to investigate the true PrAAs in a cohort of 30 selected patients who underwent open surgical repair. The present study identified and analyzed the risk factors associated with the development of PrAAs, assessing the impact of comorbidities on the treatment outcomes of patients with PrAAs. In addition, the study analyzed the long- and short-term outcomes of surgical repair for true PrAAs in the studied patient group.

Patients and methods

Study design and patients' demographics. A retrospective analysis of prospectively collected data was performed for 30 consecutive patients operated on for PrAAs from different anatomical locations over 10 years. A total of 32 PrAAs were treated in the 30 patients, which comprised 22 (73.3%) men and 8 (26.7%) women. The age distribution ranged from 52 to 87 years with a mean of 61.77 ± 6.83 years. The majority of patients (55.3%) were in their 70s and 80s. The clinical data of patients diagnosed with PrAAs and admitted to our institution (Department of Cardiovascular Surgery, Shar Teaching Hospital, Sulaymaniyah, Iraq) between January 2013 and January 2023 were reviewed, and the outcome of open revascularization was analyzed. The present study protocol was approved by the ethics and scientific committees of the Kurdistan Board for Medical Specialties (approval no. 1115) on June 6, 2023. The Rutherford classification was used

to categorize both acute and chronic limb ischemia, and as criteria for primary and secondary patency (13).

During the data collection, patients with true atherosclerotic PrAAs who underwent open surgical repair and completed follow-up for a minimum of 18 months were included in the present study. All patients diagnosed with false PrAAs or recurrent aneurysms, patients who had undergone a previous endovascular repair, and patients who had not completed 18 months of follow-up were excluded from the study. Smoking, body mass index (BMI), and cardiac, pulmonary and renal risk factors were documented using the criteria of the Department of Veterans Affairs National Surgical Quality Improvement Program (14).

Finally, patients were divided into three groups: Group 1 (asymptomatic limbs), Group 2 (symptoms of chronic limb ischemia), and Group 3 (limbs with acute limb ischemia) (7). Indications for operation included acute limb ischemia, PrAAs with compressive symptoms or disabling claudication, asymptomatic PrAAs with an aneurysm 2 cm in size, those with mural thrombi and evidence of previous thromboembolism.

Operative technique. A medial approach was used for revascularization of all PAAs. If the aneurysm involved the proximal popliteal artery, the superficial femoral or common femoral artery was used as the inflow for the bypass. In the case of a distal PAA, one of the tibial arteries or the peroneal artery was the site of the distal anastomosis. Proximal and distal ligation were usually used for small aneurysms. Endoaneurysmorrhaphy was performed most commonly in patients with an aneurysm >2 cm or if large genicular arteries were noted on preoperative imaging. The aneurysms were opened, the thrombi evacuated and the lumens of backflow small arteries are oversewn without frequently needing to transect the medial head of the gastrocnemius muscle. Reconstruction was performed with an autologous or prosthetic conduit or interposition graft. A prosthetic graft was used only if a suitable autologous vein was not available.

CFAAs were revascularized using a longitudinal approach within the femoral triangle. Iliofemoral bypass was conducted using polytetrafluoroethylene (PTFE) or Dacron grafts. In the case of a SFAA, revascularization was performed by open repair through a longitudinal mid-thigh approach and using a PTFE graft. For both posterior tibial and PAAs, a medial approach was used, with excision and repair performed using a great saphenous vein (GSV) graft. Brachial artery aneurysm repairs were performed using a right medial longitudinal approach, which involved a GSV graft.

The case series of the present study included one left subclavian-axillary artery aneurysm. The cervical X-ray revealed a complete cervical rib; the approach used was supraclavicular with extension to the infraclavicular fossa, and the repair was performed by GSV with cervical and 1st rib resection.

Information on concomitant aneurysms was obtained from reports of imaging studies and from the history of previous aneurysm repairs. Out of all the 30 patients in the present study, 25 underwent ultrasound imaging of the contralateral popliteal fossa, and 22 underwent computed tomography angiography (CTA) imaging of the aortoiliac vessels.

Follow-up information was obtained from the medical records, and outpatient questionnaires were used to establish

Table I. Demographic data and risk factors of 30 patients with 32 peripheral arterial aneurysms.

Socio-demographic characteristic	Group 1 (n=6)	Group 2 (n=20)	Group 3 (n=6)	Total (n=32)	ANOVA test result	P-value
Age, years	60.8±16.3	69.0±9.03	73.8±4.9	-	2.408	0.109
<50	2 (40.0)	2 (10.5)	0 (0)	4 (13.3)	4.525	0.304
50-75	3 (60.0)	11 (57.9)	5 (83.3)	21 (63.4)		
>75	0 (0.0)	6 (31.6)	1 (16.7)	7 (23.3)		
Sex					2.876	0.306
Male	3 (60.0)	13 (68.4)	6 (100.0)	22 (73.3)		
Female	2 (40.0)	6 (31.6)	0 (0.0)	8 (26.7)		
Presentation side					4.348	0.332
Bilateral	1 (20.0)	1 (5.3)	0 (0.0)	2 (6.7)		
Left	3 (60.0)	6 (31.6)	3 (50.0)	12 (40.0)		
Right	1 (20.0)	12 (63.2)	3 (50.0)	16 (53.3)		
Smoking PY	19.0±26.1	35.5±24.4	47.8±23.8	-	0.889	0.171
None	3 (60.0)	5 (26.3)	1 (16.7)	9 (30.0)	5.720	0.209
≤50	2 (40.0)	8 (42.1)	1 (16.7)	11 (36.7)		
>50	0 (0.0)	6 (31.6)	4 (66.6)	10 (33.3)		
BMI, kg/m ²	24.0±3.0	23.1±2.5	23.7±1.5	-	0.320	0.725
Underweight	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1.521	0.516
Normal	4 (80.0)	14 (73.7)	3 (50.0)	21 (70.0)		
Overweight	1 (20.0)	5 (26.3)	3 (50.0)	9 (30.0)		
Obese	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)		
Comorbidities					6.762	0.739
Ischemic heart disease	3 (50.0)	15 (34.1)	5 (35.7)	23 (35.9)		
Arrhythmia	0 (0.0)	1 (2.3)	2 (14.3)	3 (4.7)		
Diabetes	1 (16.7)	14 (31.8)	4 (28.6)	19 (29.7)		
Chronic kidney disease	0 (0.0)	4 (9.1)	0 (0.0)	4 (6.3)		
Chronic obstructive pulmonary disease	0 (0.0)	3 (6.8)	0 (0.0)	3 (4.7)		
Hypertension	2 (33.3)	7 (15.9)	3 (21.4)	12 (18.8)		
Total number of comorbidities	6	44	14	64		

Values are expressed as n (%) or mean ± standard deviation. Group 1, asymptomatic; group 2, chronic limb ischemia; group 3, acute limb ischemia. PY, pack year; BMI, body mass index.

survival and limb loss. Patients were seen 1 month after the operation. A second follow-up was observed at 3 months. Patients were then followed up for 6-24 months with intervals of 3 months. Outpatient visit data were collected, and the patency rates were calculated based on the findings of the last imaging study performed.

Statistical analysis. The data were collected and entered into a spreadsheet; after coding, they were transferred to SPSS (version 22; IBM Corp.) Descriptive and quantitative analyses were then performed. The relationship between initial findings and subsequent morbidity and mortality were determined using Fisher's exact test for nominal variables and the continuous variables were associated using the t-test One-way analysis of variance was used to determine statistically significant differences between the means of three groups. A two-tailed $P < 0.05$ was considered to indicate statistical significance.

Results

Patient demographics. Between 2013 and 2023, 30 patients were diagnosed with 32 PrAAs. Open surgical revascularizations were performed in all patients for 32 PrAAs and two associated AAAs. All patient demographics and their comorbidities are described in Table I. Patients were classified according to Rutherford's classification of chronic and acute limb ischemia. Out of all the 30 patients, 22 (73.3%) were men and 8 (26.7%) were women. The age ranged from 45 to 80 years with a mean age of 67.33 years. According to the type of clinical presentation, both men and women were subdivided into three groups: Group 1 comprised 6 patients with asymptomatic aneurysms; Group 2 included 20 patients with chronic symptoms; and Group 3 included 6 patients with acute limb ischemia (Table I). Out of all the 30 patients, 28 patients (93.3%) had unilateral PrAAs and 2 (6.7%) had bilateral PrAAs. A total of 12 patients (40.0%) had a left-side

Table II. Clinical data of 30 limbs with 32 PrAAs.

Clinical data	Limbs with PrAA
Group 1	6 (18.8)
Asymptomatic	6
Group 2 ^a	20 (62.5)
I Mild claudication	0
II Moderate claudication	3
III Severe claudication	4
IV Ischemic rest pain	2
V Minor tissue loss	5
VI Major tissue loss	6
Group 3 ^a	6 (18.8)
I Viable	0
Ila Marginally threatened	2
Ilb Immediately threatened	4
III Irreversible	0

^aRutherford *et al* (10). Values are expressed as n or n (%). Group 1, asymptomatic; group 2, chronic limb ischemia; group 3, acute limb ischemia. PrAAs, peripheral arterial aneurysms.

presentation and 16 (53.3%) had a right-side presentation ($P=0.383$) (Table I). Regarding risk factors, 30.0% of the patients were non-smokers and among the smokers, the mean pack years were 19.0 ± 26.1 for Group 1, 35.5 ± 24.4 for Group 2 and 47.8 ± 23.8 for Group 3. Which means the majority were smokers. Again, there was a significant difference among the groups with the majority belonging to group 3.

There was no significant difference in the BMI among Groups 1, 2 and 3. Regarding comorbidities, 23 (35.9%) patients had ischemic heart disease, 19 patients (29.7%) had diabetes, 12 patients (18.8%) were hypertensive, 4 patients (6.3%) had chronic kidney disease, 3 patients (4.7%) had chronic obstructive pulmonary disease and 3 (4.7%) patients had arrhythmia.

A total of 6 patients (21.8%) with PrAAs were asymptomatic (Group 1), 20 patients (59.37%) had chronic limb-threatening ischemia (Group 2) and 6 patients (18.75%) had acute limb ischemia (Group 3) (Table II). Group 2, composed of 19 (59.37%) participants, presented with chronic limb-threatening ischemia and was further subdivided according to the Rutherford classification as follows: Class II moderate claudication, comprising 3 (10%) patients; class III severe claudication, also comprising 4 patients (10%); class IV ischemic rest pain, comprising 2 (6.7%) patients; class V minor tissue loss, comprising 5 (16.7%) patients; and class VI major tissue loss, comprising 6 (20%) patients. Group 3 (acute limb ischemia) was subdivided into classes IIa, 'marginally threatened', comprising 2 (6.7%) patients, and IIb, 'immediately threatened', comprising 4 (13.3%) patients.

Intraoperative findings. Intraoperative measurements were used when recorded; 12 PrAAs (12/32, 37.5%) had a thrombus. After the initial round of imaging and investigations, a runoff was found in 12/32 (37.5%) of the cases.

PAAs comprised 23 (71.8%) patients; PAA was the most prevalent PrAA. After PAA, the most common aneurysms were CFAAs, comprising 4 (12.5%) patients; aneurysms of the brachial artery, comprising 2 (6.25%) patients; SFAAs, affecting 1 (3.1%) patient; PTAAAs, affecting 1 (3.1%) patient; and arteries of the subclavian and axillary, affecting 1 (3.1%) patient. CTA was performed in 22 cases (73.3%). There was at least one remote aneurysm in 4 (13.2%) patients, and 2 (6.7%) of these were afflicted bilaterally.

The diameter of the aneurysm was measured with ultrasound in 15 affected patient limbs and a CTA scan in 16 limbs. The mean aneurysmal diameter on Doppler ultrasound was 3.4250 ± 1.06355 cm (range: 2.20-6 cm), and on CTA it was 3.4167 ± 1.00438 cm (range: 2.00-5.9 cm).

Current or previous deep vein thrombosis (DVT) was present in two limbs (6.6%) ($P=0.262$). In both limbs, the aneurysm was in the popliteal artery. Furthermore, both affected patients were in Group 2. Neither patient had an aneurysm rupture. An association was observed between AAAs and PrAAs, with two patients observed to have concomitant AAAs and PAAs (Table III).

All 32 PrAAs were repaired by interposition graft (endoaneurysm repair). A 1st rib resection was required in one case. The medial popliteal approach was used for all isolated PAAs ($n=20$, 66.7%). Laparotomy and medial approaches were used for PAAs associated with AAA ($n=2$, 6.7%). The longitudinal approach in the femoral triangle or cubital fossa was used for 7 (23.3%) cases, including CFAAs ($n=4$, 13.3%), SFAAs ($n=1$, 3.3%) and brachial artery aneurysms ($n=2$, 6.7%). The supraclavicular longitudinal approach was used for the only subclavian artery aneurysm ($n=1$, 3.1%). No significant association was present among the different approaches, $P=0.215$ (Table IV). The conduits used were autogenous GSV ($n=21$, 70.0%), or prosthetic grafts, including Dacron ($n=3$, 10.0%) or expanded PTFE (ePTFE) ($n=6$, 20.0%) (Table IV).

Post-operative outcome. In the first 30 days, systemic complications occurred in 3 patients. Group 2 suffered the most complications (9.37%, 3/32). Within Group 2, 2 patients suffered from anterior acute coronary syndrome. The first patient suffered an acute anterior myocardial infarction (MI), which was treated by coronary catheterization and stenting at 1 week postoperatively. The second patient suffered an anterior MI, which was treated conservatively. Within Group 1, patient 3 suffered a chest infection following the second operation. On post-operative day 3, the patient also developed acute limb ischemia (ALI), which was treated by revision of the anastomosis and distal embolectomy (Table IV). In addition, in the first 30 days, two patients developed ALI post-operatively (2/32, 6.25%, $P=0.055$). Patient 1 was from Group 3, whose first presentation was acute limb ischemia (immediately threatened), and developed thrombosis of the graft (Dacron graft was used). Revision and embolectomy were performed 48 h post-operatively. The second patient from Group 1 developed ALI, which was treated by revision of the anastomosis and distal embolectomy (Table IV).

Mean ICU and hospital stays were 3-8 days in Group 1, 3-15 days in Group 2 and 5-0 days in Group 3 ($P=0.521$) (Table IV). In the first 30 days post-operation, 2 patients

Table III. Peripheral arterial aneurysms with AAA association and deep vein thrombosis.

Variable	AAA ^a		ANOVA test	P-value
	Not present	Present		
Deep vein thrombosis			0.217	0.262
No	30 (93.8)	29 (90.6)		
Yes	2 (6.6)	3 (9.37)		
Diseased artery	2 (6.3)	0 (0.0)	4.523	0.649
Common femoral artery	4 (12.5)	1 (3.1)		
Popliteal artery	23 (71.8)	2 (6.3)		
Posterior tibial artery	1 (3.1)	0 (0.0)		
Superficial femoral artery	1 (3.1)	0 (0.0)		
Subclavian and axillary arteries	1 (3.1)	0 (0.0)		

Values are expressed as n (%). AAA, abdominal aortic aneurysm.

developed surgical site infections (SSIs). Specifically, a patient from Group 1 developed superficial SSI treated by antibiotics, and the other patient from Group 3 developed deep SSI treated by repeated debridement (Table IV).

The 2-year primary patency rate was 26/32 (81.25%), and the overall secondary patency rate was 28/32 (87.5%). For GSV graft, the primary patency was 19/21 (90.47%) and the secondary patency was 20/21 (95.23%). Primary and secondary patency of the synthetic conduit (Dacron) graft were 1/3 (33.33%) and 2/3 (66.66%), respectively, and for ePTFE grafts, primary and secondary patency were 6/6 (100%) (Fig. 1).

No patients underwent amputation in the first 30 days. There were no deaths up to the 30-day post-operative period. To salvage a failing operation (n=2), two reinterventions were performed in the first 30 days. During follow-up (first 30 days post-operation), 2 patients underwent two salvage operations. The first had acute ischemia, and the second had chronic ischemia with rest pain. At long-term follow-up, two grafts became occluded. Patients who underwent endoaneurysmorrhaphy during the first operation did not receive re-intervention in 100% of cases.

Overall limb loss was 2/32 (6.25%), and in Group 2, it was 10.5% (2/19) (Table VI and Fig. 1). The graph shows the graft patency over time in the 3 groups. The rate of patency was comparable over time. The 2-year cumulative limb salvage rate was 100% for Group 1, 89.5% for Group 2 and 100% for Group 3 (Table VI). Patients with GSV grafts had less limb salvage at 2 years than those with PTFE grafts (90.5% vs. 100%, $P=0.632$). In Group 3, the 2-year limb salvage with GSV and Dacron grafts was 100%. There was no limb loss in Group 1 and none in Group 3 (GSV, Dacron, ePTFE grafts used for the bypass).

In Group 2, two amputations, consisting of an above-knee amputation and one distal phalanx amputation, were performed. The patient who required an above-knee amputation had comorbid hypertension and diabetes mellitus with moderate intermittent claudication; they were treated with GSV endoaneurysmorrhaphy. At 12 months post-operation, the patient presented with acute irreversible ischemia. A total of 1 patient succumbed at 3 months post-operation from acute

coronary syndrome; they were from Group 2 and had been implanted with an ePTFE graft (Table V).

Discussion

The present study aimed to examine the existing evidence concerning the natural progression and treatment of PrAAs and, more precisely, PAAs. It also aimed to apply decision theory techniques to establish the circumstances in which conservative management would be considered suitable. The present study confirmed the effectiveness of open surgical repair, which aligns with findings from previous studies that reported similar patency rates and minimal complications (12,14-16).

In the present study, PrAA rupture was not observed, and the most frequent primary complication observed was thromboembolism leading to acute limb ischemia. Notably, patients with PAAs exhibited an increase in local pressure on the popliteal vein, thus increasing the risk of popliteal vein thrombosis. This risk factor was associated with aneurysm size, with both PAA cases in this study measuring 3.6x3.2 cm. In addition, both patients in Group 2 presented with chronic limb ischemia, including major tissue loss. Furthermore, ~6.7% of the patients had experienced DVT, either during the study or preceding it. These findings are partially comparable with a number of other studies (12-14).

For asymptomatic patients and patients with mild-to-moderate claudication, the indication for intervention is less clear. Other factors that influence surgical decision-making are the development of symptoms, aneurysm size, mural thrombi, evidence of previous thromboembolism and anatomical risks of surgical repair (15,17).

The findings of Huang *et al* (17) suggested that thromboembolism may be the predominant complication in cases of PAA, while rupture remains rare. This previous study emphasized that the heightened risk of popliteal vein thrombosis was due to local compression, with 6% of the participants in the study having a history of current or previous DVT. Michaels and Galland (18) used Markov decision analysis to determine the ideal management of PAAs. This previous

Table IV. Surgical techniques and early postoperative outcomes (30 days post-operation).

Item	Group 1 (n=7)	Group 2 (n=19)	Group 3 (n=6)	Total	ANOVA test	P-value
Surgical technical approach					6.740	0.298
Laparotomy and medial approach	1 (20.0)	1 (5.3)	0 (0.0)	2 (6.7)		
Longitudinal approach in the femoral triangle or cubital fossa	0 (0.0)	4 (26.3)	2 (33.3)	6 (23.3)		
Medial approach to popliteal artery	4 (60.0)	15 (68.4)	4 (66.7)	23 (66.7)		
Supraclavicular and longitudinal approach	1 (20.0)	0 (0.0)	0 (0.0)	1 (3.1)		
Procedure					3.834	0.167
Repair	4 (80.0)	19 (100.0)	6 (100.0)	29 (96.7)		
Repair and bypass	1 (20.0)	0 (0.0)	0 (0.0)	1 (3.3)		
Graft type					6.148	0.112
Great saphenous vein	5 (100.0)	12 (63.2)	4 (66.7)	21 (70.0)		
Dacron	0 (0.0)	1 (5.3)	2 (33.3)	3 (10.0)		
Expanded polytetrafluoroethylene	0 (0.0)	6 (31.6)	0 (0.0)	6 (20.0)		
Duration, minutes	152.0±23.9	148.9±28.1	160.0±16.7	-	0.422	0.662
Amount of blood lost, ml	740.0±181.7	194.5±44.6	245.8±100.3	-	0.346	0.710
Hospitalization time, days	1.8±0.81	3.98±0.94	1.83±0.74	-	0.672	0.521
Surgical site infection					4.282	0.126
No	4 (80.0)	19 (100.0)	5 (83.3)	28 (93.3)		
Yes	1 (20.0)	0 (0.0)	1 (16.7)	2 (6.7)		
Bleeding					NS	
No	5 (100.0)	18 (100.0)	6 (100.0)	29 (100.0)		
Yes	0 (0.0)	1 (3.3)	0 (0.0)	1 (3.3)		
Early post-operative ischemia					7.237	0.126
48 h post-operative graft occlusion	0 (0.0)	0 (0.0)	1 (16.7)	1 (3.3)		
ALI on 3rd day post-operation	1 (20.0)	0 (0.0)	0 (0.0)	1 (3.3)		
No signs of distal ischemia were noticed post-operatively, no more rest pain	4 (80.0)	19 (100.0)	5 (83.3)	28 (93.3)		
Systemic complication, n (%)					1.311	0.509
No	4 (80.0)	17 (89.5)	6 (100.0)	27 (90.0)		
Yes	1 (20.0)	2 (10.5)	0 (0.0)	3 (10.0)		
Total number of treated aneurysms	6	20	6	32		

Values are expressed as n (%) or the mean ± standard deviation. Group 1, asymptomatic; group 2, chronic limb ischemia; group 3, ALI. ALI, acute limb ischemia; NS, not significant.

study indicated that conservative management could be used for asymptomatic patients, as the rate of aneurysmal enlargement was <10% per year and they were less likely to suffer adverse events.

A retrospective analysis (19,20) of popliteal aneurysms suggested that small aneurysms (≤2 cm) may not be as benign as previously considered. Despite their small size, these aneurysms may be lined with thrombi that can embolize the infra-popliteal arteries. Notably, 64% of the small aneurysms in these two series were partially thrombosed, which was not significantly different from the incidence of thrombosis in larger aneurysms (70%). In addition, complete thrombosis of the popliteal aneurysm was not associated with aneurysm size in the present series. Similar findings were obtained in the case series of the present study.

A review of 12 publications revealed that the development of symptoms was at an average of 14% per year (range, 5-24%) (18). In a study conducted by Lowell *et al* (20), asymptomatic patients with PAAs were monitored without surgical intervention, with an average follow-up duration of 17 months. During this timeframe, 18% of the patients exhibited symptoms. Risk factors associated with the development of symptoms included aneurysm size exceeding 2 cm, poor runoff and the presence of a mural thrombus (P<0.05).

Treatment for PAAs has become more aggressive to prevent limb loss. The current literature on PAAs has been limited primarily to surgical series, with a minor description of patients treated conservatively (21,22). Following PAAs, FAAs represent the most prevalent PrAAs. These aneurysms can occur bilaterally and are commonly associated with additional

Table V. Early and late post-operative outcomes.

Item	Group 1 (n=7)	Group 2 (n=19)	Group 3 (n=6)	Total	ANOVA test	P-value
AAA					1.311	0.509
Not present	4 (80.0)	17 (89.6)	6 (100.0)	27 (90.0)		
Present	1 (20.0)	2 (10.5)	0 (0.0)	3 (10.0)		
Vein thrombosis					0.801	>0.999
No	5 (100.0)	17 (89.5)	6 (100.0)	28 (93.3)		
Yes	0 (0.0)	2 (10.5)	0 (0.0)	2 (6.7)		
Amputation					0.801	>0.999
No	5 (100.0)	17 (89.5)	6 (100.0)	28 (93.3)		
Yes	0 (0.0)	2 (10.5)	0 (0.0)	2 (6.7)		
Death					0.164	>0.999
No	5 (100.0)	18 (94.7)	6 (100.0)	29 (96.7)		
Yes	0 (0.0)	1 (5.3)	0 (0.0)	1 (3.3)		
Graft type					6.148	0.112
Dacron	0 (0.0)	1 (5.3)	2 (33.3)	3 (10.0)		
ePTFE	0 (0.0)	6 (31.6)	0 (0.0)	6 (20.0)		
Great saphenous vein	5 (100.0)	12 (63.2)	4 (66.7)	21 (70.0)		
Graft patency ^a					2.370	>0.999
Early failure of the graft	0 (0.0)	1 (5.3)	0 (0.0)	1 (3.3)		
No patency (late)	0 (0.0)	1 (5.3)	0 (0.0)	1 (3.3)		
Patency	5 (100.0)	17 (89.5)	6 (100.0)	28 (93.3)		

^aThe duration of graft patency over time. Values are expressed as n (%). Group 1, asymptomatic; group 2, chronic limb ischemia; group 3, acute limb ischemia. AAA, abdominal aortic aneurysm; ePTFE, expanded polytetrafluoroethylene.

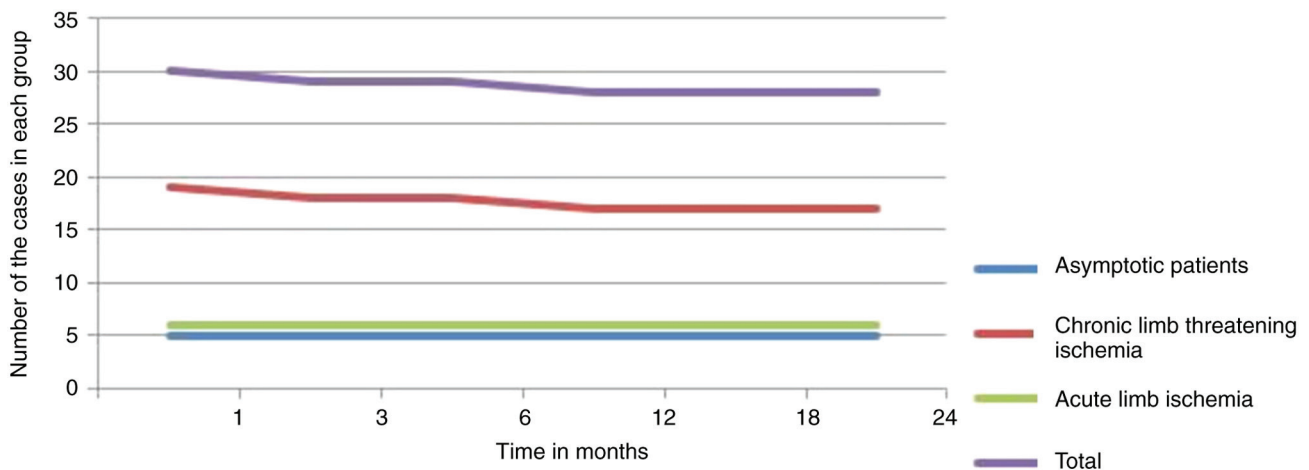


Figure 1. Short- and long-term outcomes in the three groups. All patients who followed the clinicians' instructions were included. The graph shows the graft patency over time, which was comparable in the 3 groups.

arterial aneurysms, particularly those in the aortic region. It is recommended that symptomatic FAAs larger than 3 cm undergo treatment (23). In the upper extremities, aneurysmal development at the level of the brachial and radial arteries is most commonly secondary to trauma, invasive interventions and atrioventricular fistulae for hemodialysis. True aneurysms of the subclavian artery are uncommon, accounting for only 0.1% of all PrAAs. In addition, post-stenotic

dilatation or atherosclerotic degeneration serve a role in their etiology (24-26).

In the present study, the size of PrAAs measured by duplex scan (3.4 ± 1.06 cm) emerged as a critical risk factor for thrombus formation. The significance of thrombus formation size indicated that even small aneurysms pose a heightened risk of thrombus development, leading to limb ischemia and the potential for amputation. Consequently, in the present

Table VI. Association between graft type and amputation, and graft patency.

Item	Graft type				P-value
	Dacron (n=3)	Expanded polytetrafluoroethylene (n=6)	Great saphenous vein (n=21)	Total (n=32)	
Amputation					0.999
No	3 (100.0)	6 (100.0)	19 (90.5)	28 (93.3)	
Yes	0 (0.0)	0 (0.0)	2 (9.5)	2 (6.7)	
Graft patency					0.517
Early graft failure ^a	0 (0.0)	1 (16.7)	0 (0.0)	1 (3.3)	
No patency	0 (0.0)	0 (0.0)	1 (4.8)	1 (3.3)	
Patency	3 (100.0)	5 (83.3)	20 (95.2)	28 (93.3)	

^aThe duration and rate of graft patency. Values are expressed as n (%).

study, even asymptomatic patients underwent surgical repair as a preventive measure to avert limb loss. Notably, no notable difference was detected in the diameter of PrAAs when assessed using duplex ultrasound and CTA, both yielding a mean measurement of 3.4 ± 1.06355 cm. Consequently, neither method demonstrated superiority in size measurement.

Others have also reported a heightened incidence of complications in this particular group (patients with acute limb ischemia) (27,28). However, it is worth noting that one publication covering 51 patients, including 14 who underwent emergency repair, indicated no instances of early mortality or cardiac complications (28,29). In the series of the present study, acute ischemia was associated with an 8% risk of early limb loss and a 15% risk of late limb loss.

In another study, the preferred graft was a GSV, which was implanted through a medial approach. The GSV is advantageous due to the ease of vein harvesting and convenient access to the anastomotic sites to ensure optimal inflow and outflow. In two thirds of the cases, the femoral artery served as the location for the proximal anastomosis, while the infra-popliteal artery was utilized distally in a quarter of the operations (30-32). The potential benefits of employing tibial arteries for distal anastomosis as needed have been underscored by a number of authors. For all but small, thrombosed aneurysms, endoaneurysmorrhaphy should be performed to prevent late recurrence, and this recommendation extends to other PrAAs (33-35).

In our center, endoaneurysmorrhaphy was performed for all patients. Re-intervention was observed in only two cases. This approach demonstrated a notably high patency rate when compared with alternative techniques observed in other studies. Surgical intervention for upper-extremity aneurysms should be initiated without delay. Risk factors combined with the minimal morbidity associated with repair suggest that surgical repair should be performed routinely for true upper extremity arterial aneurysms (36,37).

In the present study, the follow-up for graft patency was 2 years. All 6 patients with PTFE grafts had 100% patency. In those with GSV grafts, primary patency was 90.47% and secondary patency was 95.23%, which was significantly higher for GSV compared with Dacron grafts. Dacron graft primary patency was 33.33% and secondary patency was 66.66%. The

standard approach for interposition grafting typically involves using a prosthetic graft, with PTFE being the most commonly utilized material. The choice of graft material has become a topic of some debate. This is because a prosthetic graft, especially PTFE, is well suited in size to the enlarged popliteal artery (32,36).

Additionally, a considerable number of patients with PAAs exhibit good-to-excellent runoff, ensuring high flow and prolonged patency of a prosthesis (17). In a study by Pulli *et al* (29), no significant difference in patency at 60 months was observed between 118 PTFE grafts (71.5%) and 34 vein grafts (79.9%). However, it is worth noting that the number of limbs at risk during this time interval was not reported.

The present study is limited by its interpretations being drawn from a single center only and further by its retrospective analysis; however, the data were collected prospectively. The limitations of the present study include the single-center design and a relatively small sample size, which may introduce bias. Additionally, the follow-up period of a minimum of 18 months might not capture long-term outcomes or complications. Longer follow-up durations would provide more comprehensive insights into the durability of the interventions and the occurrence of late complications or recurrences.

Although general management guidelines as outlined in the present study report were followed, the selection of graft material, surgical technique, and indications for elective surgery were at the discretion of the operating vascular surgeon. No randomization was performed to evaluate different techniques. The present study supports the efficacy of open surgical repair, particularly endoaneurysmorrhaphy, in achieving high primary and secondary patency rates, and low rates of limb loss and mortality. These findings suggest that open repair should remain a preferred treatment option for PrAAs. Despite the challenges posed by acute limb ischemia and systemic complications, early intervention and meticulous follow-up contribute to reducing adverse events.

Moving forward, future research should focus on the risk factors and pathophysiological mechanisms underlying PrAA development, and evaluate the comparative effectiveness of endovascular and open surgical approaches in larger, multi-center studies. Future research should focus on

identifying specific risk factors and pathophysiological mechanisms underlying PrAA development, as well as comparing the long-term outcomes of endovascular vs. open surgical approaches in a larger, multi-center cohort.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

RSS assisted in surgeries, follow-up, data collection, study design and statistical analysis. AYI performed manuscript revision and statistical analysis. AB was the surgeon in charge of the present study design, performed follow-up, collected the data, revised the manuscript and performed statistical analysis. RSS and AB confirm the authenticity of all the raw data. All authors read and approved the final version of the manuscript.

Ethics approval and consent to participate

Written informed consent was obtained from all patients to participate in the present study.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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