

Femoral endarterectomy as a platform for simultaneous hybrid inflow and outflow revascularization: a retrospective single-center cohort study

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Research Article

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Abstract

Background

Femoral endarterectomy (FEA) is the standard treatment for common femoral artery (CFA) disease; the CFA site can also serve as an access hub for simultaneous endovascular treatment of multilevel disease. We report our experience using FEA as a hybrid revascularization platform, focusing on feasibility, safety, and durability.

Methods

We retrospectively reviewed 52 patients who underwent FEA for CFA-involved peripheral artery disease (2010–2025). The primary analysis reports pooled cohort outcomes, characterizing FEA's safety, durability, and hemodynamic efficacy. As a secondary analysis, we examined 29 patients (Hybrid [+]) whose FEA site served as an access hub for simultaneous endovascular intervention, benchmarked against 23 patients undergoing isolated FEA (Hybrid [-]). Outcomes included ankle-brachial index (ABI), patency, and complications.

Results

FEA achieved significant postoperative ABI improvement ($P < 0.001$) and durable patency at the FEA site (94.2% at 10 years), with severe complications in 3.8% of patients. Hybrid (+) patients used the FEA site for iliac inflow (62.1%), distal outflow (20.7%), or combined (17.2%) revascularization, with higher CLTI prevalence than Hybrid (-), reflecting more advanced disease. FEA-site patency was similar between subgroups ($P = 0.460$), and severe complications were comparable (4.3% vs. 3.4%), though mild wound complications were more frequent after isolated FEA ($P = 0.011$). Outflow patency was 85.7% at 5 years.

Conclusions

FEA is technically feasible and durable as a platform for single-session inflow/outflow revascularization in multilevel disease, without increasing severe complications versus isolated FEA. Given baseline differences between groups, findings represent a feasibility/safety experience rather than comparative efficacy evidence.

Background

The common femoral artery (CFA) serves as the principal inflow vessel to the lower extremity. Because of its anatomical location and physiological importance, atherosclerotic lesions isolated to the CFA can result in significant claudication and limb-threatening ischemia [1]. Furthermore, the CFA is recognized

as the most common gateway for endovascular procedures, making its patency essential for both current and future vascular interventions [2].

Traditionally, femoral endarterectomy (FEA) with patch closure has been the gold standard for CFA lesions [3]. Although endovascular techniques have advanced rapidly for other vascular segments, FEA remains preferred for the CFA because of its durability and the technical challenges associated with stenting in a high-flexion zone such as the groin [1, 4]. However, many patients presenting with CFA disease also have concomitant multilevel disease involving both inflow and outflow vessels [5].

The evolution of vascular surgery has led to the development of hybrid procedures, in which open surgical techniques are combined with endovascular interventions [6]. In this context, FEA can serve as more than a localized treatment; it can act as a strategic platform for simultaneous hybrid inflow and outflow revascularization. This approach allows comprehensive management of complex peripheral artery disease (PAD) by addressing multiple arterial segments in a single session, potentially reducing the need for more invasive multistage surgery [7].

Despite its theoretical advantages, more longitudinal data are needed to confirm the technical feasibility and safety of FEA when used as a platform for these hybrid strategies. This study reports a retrospective, descriptive analysis of clinical data collected from 2010 to 2025 to evaluate the utility and safety of FEA as a hybrid access-hub technique for simultaneous inflow and outflow revascularization, with isolated FEA cases from the same period presented not as an equivalent clinical baseline, but as a technical benchmark to confirm that introducing endovascular tools through the open patch/arteriotomy line does not compromise local reconstruction durability or increase surgical-site complication rates relative to standard open FEA alone. By characterizing hemodynamic outcomes, segment-specific durability, and safety profiles, we aimed to describe the long-term technical feasibility of this integrated approach.

Methods

Study design

This study was a retrospective, single-center descriptive cohort analysis using a prospectively collected PAD database. The primary objective was to evaluate the technical feasibility, safety, and durability of FEA used not merely as a localized treatment for CFA disease, but as a platform for more extensive, simultaneous hybrid revascularization. Patients who underwent isolated FEA during the same period are presented as a descriptive reference cohort for local femoral patency and wound-related outcomes rather than as a matched comparator arm, given inherent baseline differences in disease severity between the two groups. The study was conducted at Kyung Hee University Hospital at Gangdong, Seoul, Republic of Korea. The protocol adhered to the principles of the Declaration of Helsinki and was approved by the Institutional Review Board of Kyung Hee University Hospital at Gangdong (IRB No. 2022-08-022; approved September 5, 2022). Owing to the retrospective nature of the analysis and the use of

de-identified data, the requirement for informed consent was waived. This study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.

Patient selection

The study period spanned 15 years, from 2010 to 2025, a timeframe chosen to capture the evolution of hybrid techniques and the long-term durability of FEA. A total of 52 patients who underwent surgical intervention for CFA-involved PAD were identified. Patients were included if they had significant atherosclerotic stenosis (> 70%) or total occlusion of the CFA confirmed by computed tomography angiography (CTA); symptomatic presentation, including moderate-to-severe claudication (Rutherford category 3) or chronic limb-threatening ischemia (CLTI; Rutherford categories 4–6); and complete preoperative and postoperative hemodynamic data, including ankle-brachial index (ABI) measurements. Patients were excluded if they underwent emergency surgery for acute limb ischemia, had an active groin infection at the time of surgery, or if the CFA was treated exclusively by endovascular means without an open endarterectomy component. This exclusion reflects our institutional practice of favoring open FEA over primary endovascular treatment for significant CFA disease, consistent with guideline recommendations that favor FEA given the durability limitations of stenting in the high-flexion groin segment [1, 4]; consequently, this study was not designed to compare the FEA-platform strategy with a purely endovascular approach to multilevel disease, which remains an important question for future investigation.

Group allocation

To evaluate the role of FEA as a platform, the cohort was divided into two groups. The Hybrid (–) group comprised patients who underwent isolated FEA; in these cases the atherosclerotic disease was localized primarily to the CFA, and the surgical objective was limited to restoring patency of this segment. The Hybrid (+) group comprised patients who underwent FEA as a platform for simultaneous inflow or outflow revascularization; in this group the CFA served as the anatomical hub. The hybrid approach was defined as the combination of open surgical endarterectomy of the CFA with concurrent endovascular procedures—such as percutaneous transluminal angioplasty, stenting, or atherectomy—performed through the same surgical access site to treat proximal inflow (iliac) or distal outflow (femoropopliteal or infrapopliteal) lesions. Because allocation to the Hybrid (+) group was driven by the clinical presence of additional inflow or outflow disease rather than by randomization or risk matching, the two groups differ inherently in baseline disease severity and anatomical extent; they should not be regarded as alternative treatments applied to an equivalent clinical condition. Accordingly, the Hybrid (–) group is used in this study as a descriptive reference for local femoral patency and wound-related outcomes rather than as a matched comparator arm for treatment efficacy.

Preoperative assessment

Preoperative evaluation involved a detailed physical examination. Hemodynamic status was quantified using the ABI and, where necessary, toe pressures. Anatomical assessment was performed primarily using multislice CTA to map the extent of calcification and the involvement of the deep femoral artery (DFA) and superficial femoral artery (SFA). The surgical strategy was determined after considering patient factors such as age, comorbid burden (particularly diabetes and end-stage renal disease), and functional status, as well as anatomical factors including the length and calcification of inflow and outflow lesions and the suitability of FEA. Preoperative anatomical lesion severity including chronic total occlusion vs. stenosis, lesion length, and TASC II classification were additionally extracted for each patient to characterize baseline clinical and anatomical severity, particularly within the Hybrid (+) subgroup.

Surgical technique

All procedures were performed in a dedicated hybrid operating room equipped with a mobile C-arm imaging system. Under general anesthesia, a longitudinal groin incision was made to expose the CFA, the distal external iliac artery when necessary, and the bifurcation of the SFA and DFA (Fig. 1). Following systemic heparinization, vascular control was obtained. A longitudinal arteriotomy was performed across the CFA, usually extending from the healthy proximal segment to the transition point of the SFA or DFA. The plaque was carefully dissected in the subintimal plane, and a feathered endpoint was prioritized at the distal transition to prevent intimal flaps.

In the Hybrid (+) group, the FEA site was used as the entry point for endovascular tools. Before closing the arteriotomy, a sheath was introduced directly into the artery to perform retrograde intervention (for iliac inflow disease) or antegrade intervention (for distal SFA or popliteal disease). The access sheath was introduced through the patch angioplasty site after placement of the final suture but before completion of the knot. Depending on the target site, either the proximal or the distal clamp was temporarily released, and the suture was tied firmly over the sheath to maintain hemostasis at the insertion site. Upon completion of the adjunctive procedures, the sheath was withdrawn, and the residual access hole was secured with an additional interrupted stitch tied to the original suture line to ensure a blood-tight closure. This approach eliminated the need for a separate percutaneous puncture, thereby reducing the risk of access-site complications in a different limb.

After completion of both the endarterectomy and any adjunctive endovascular maneuvers, the arteriotomy was closed. In all cases, patch angioplasty was performed to avoid luminal narrowing associated with primary closure. Patch materials included autologous vein, bovine pericardium, or synthetic graft (polytetrafluoroethylene [PTFE]), depending on the availability of an autologous conduit.

Outcomes

Three categories of outcomes were analyzed: hemodynamic outcomes (change in ABI from preoperative baseline to the postoperative period), clinical effectiveness (primary patency), and safety (postoperative complications). Postoperative complications were categorized using a 3-tiered grading system adapted from the Society for Vascular Surgery [8] as mild (minor issues such as tolerable wound pain, tingling, or localized numbness that resolved without medical intervention), moderate (complications requiring pharmacological management or an outpatient procedure, such as lymphedema requiring venoactive medication or a seroma requiring aspiration), and severe (complications requiring readmission, reoperation, or intensive inpatient care).

Surveillance

Patients were followed clinically at 1, 3, 6, and 12 months during the first postoperative year, and at 6- to 12-month intervals thereafter throughout the follow-up period. Postoperative patency was evaluated using duplex ultrasound or CTA. CTA was routinely performed as a baseline study within 1 month postoperatively to establish baseline anatomical patency, and was subsequently repeated when clinical evaluation indicated deterioration, such as a drop in ABI > 0.15 or recurrent symptoms.

Statistical analysis

Categorical variables were summarized as frequencies and percentages, and continuous variables as mean $\pm$ standard deviation (SD). Comparisons between the Hybrid (-) and Hybrid (+) groups were performed using the chi-square test or Fisher exact test for categorical data and the independent t-test or Mann-Whitney U test for continuous data. Long-term patency and survival were analyzed using the Kaplan-Meier method, and differences between curves were assessed using the log-rank test. A stratified Kaplan-Meier subgroup analysis restricted to patients presenting with CLTI was also performed to compare amputation-free survival and overall survival between two groups. To account for the baseline imbalance in disease severity between groups, a multivariable Cox proportional hazards regression analysis was additionally performed for amputation-free survival and overall survival, incorporating CLTI status (Rutherford category 4–6 vs. category 3), age, end-stage renal disease, and group allocation (Hybrid [+] vs. Hybrid [-]) as covariates. Analyses were performed using MedCalc version 23.1.7 (MedCalc Software Ltd., Ostend, Belgium) and IBM SPSS Statistics version 22.0 (IBM Corp., Armonk, NY, USA). A P-value < 0.05 was considered statistically significant.

Results

Baseline characteristics

A total of 52 patients were enrolled between 2010 and 2025: 23 (44.2%) in the Hybrid (-) group, who underwent isolated FEA, and 29 (55.8%) in the Hybrid (+) group, who underwent FEA as a platform for simultaneous inflow or outflow revascularization (Table 1). The mean age of the total cohort was 70.7 $\pm$ 9.0 years (Hybrid [-], 69.9 $\pm$ 8.1; Hybrid [+], 71.2 $\pm$ 9.8; P = 0.603). Most patients were male (82.7%), with

no significant difference between groups (91.3% vs. 75.9%, $P = 0.268$). Mean body mass index was similar (22.6 ± 4.2 vs. 22.8 ± 3.5 kg/m², $P = 0.903$). The mean follow-up for the whole cohort was 39.0 ± 42.5 months, with a longer but non-significant follow-up in the Hybrid (+) group (46.1 ± 38.6 vs. 30.2 ± 36.6 months, $P = 0.183$).

Table 1
Baseline demographics and clinical characteristics

Characteristic	Total (n = 52)	Hybrid (–) (n = 23)	Hybrid (+) (n = 29)	P-value
Age, yr	70.7 ± 9.0	69.9 ± 8.1	71.2 ± 9.8	0.603
Male sex	43 (82.7)	21 (91.3)	22 (75.9)	0.268
Body mass index, kg/m ²	22.7 ± 3.8	22.6 ± 4.2	22.8 ± 3.5	0.903
Follow-up, mo	39.0 ± 42.5	30.2 ± 36.6	46.1 ± 38.6	0.183
Clinical presentation				0.001
Claudication	20 (38.5)	13 (56.5)	7 (24.1)	
CLTI	32 (61.5)	10 (43.5)	22 (75.9)	
Risk factor				
Diabetes mellitus	30 (57.7)	14 (60.9)	16 (55.2)	0.781
Hypertension	35 (67.3)	16 (69.6)	19 (65.5)	0.776
Dyslipidemia	4 (7.7)	3 (13.0)	1 (3.4)	0.310
Coronary artery disease	9 (17.3)	4 (17.4)	5 (17.2)	1.000
Cerebrovascular disease	14 (26.9)	9 (39.1)	5 (17.2)	0.116
ESRD on hemodialysis	3 (5.8)	2 (8.7)	1 (3.4)	0.577
Smoking history	22 (42.3)	7 (30.4)	15 (51.7)	0.162
<i>Values are presented as number (%) or mean ± standard deviation. CLTI, chronic limb-threatening ischemia; ESRD, end-stage renal disease.</i>				

The clinical presentation differed significantly between groups ($P = 0.001$). Although the cohort comprised claudicants (38.5%) and patients with CLTI (61.5%), the Hybrid (+) group had a higher prevalence of CLTI (75.9%) than the Hybrid (–) group (43.5%), indicating more advanced disease among patients requiring a hybrid procedure. This difference reflects the indication-based allocation of patients to the hybrid platform strategy rather than a randomized or risk-matched comparison, and should be borne in mind when interpreting the between-group comparisons reported below. Cardiovascular risk factors were prevalent in both groups: hypertension was most common (67.3%), followed by diabetes

(57.7%) and smoking history (42.3%). There were no significant between-group differences in diabetes ($P = 0.781$), hypertension ($P = 0.776$), smoking history ($P = 0.162$), dyslipidemia ($P = 0.310$), coronary artery disease ($P = 1.000$), cerebrovascular disease ($P = 0.116$), or end-stage renal disease (ESRD) on hemodialysis ($P = 0.577$).

Procedural details

The overall cohort's Rutherford classifications were distributed with claudication, 38.5% and CLTI, 61.5%. Lesion-level anatomical details including TASC II category, chronic total occlusion versus stenosis, and lesion length and procedure details are shown in Table 2. There were no significant between-group differences in surgical side ($P = 0.412$) or patch type ($P = 0.588$). Autologous patches, primarily great saphenous vein (GSV) or its branches, were used in 56.5% of the Hybrid (-) group and 48.3% of the Hybrid (+) group, with the remainder receiving an artificial patch (predominantly bovine pericardium). In the Hybrid (+) group, patients had anatomically significant multilevel lesions: inflow iliac lesions ($n = 18$, 62.1%), outflow infrainguinal lesions ($n = 6$, 20.7%), and combined inflow/outflow lesions ($n = 5$, 17.2%). The indication for an adjunctive procedure was a hemodynamically significant lesion ($> 70\%$ stenosis or occlusion) in the inflow or outflow segment that could not be resolved by FEA alone. Accordingly, the FEA site served as a platform for additional interventions: 62.1% underwent inflow revascularization (iliac stenting), 20.7% outflow revascularization, and 17.2% both. Both groups showed significant postoperative ABI improvement ($P < 0.001$). Although the Hybrid (-) group had higher baseline and postoperative ABIs, the mean increase was robust in both cohorts (0.27 ± 0.13 vs. 0.36 ± 0.16 , $P = 0.119$).

Table 2
Procedural details

Variable	Hybrid (-) (n = 23)	Hybrid (+) (n = 29)	P-value
Side (right : left)	9 : 14	15 : 14	0.412
Patch type			0.588
Autologous vein	13 (56.5)	14 (48.3)	
GSV	7 (53.8)	5 (35.7)	
GSV branch	6 (46.2)	9 (64.3)	
Artificial patch	10 (43.5)	15 (51.7)	
Bovine pericardium	9 (90.0)	14 (93.3)	
PTFE	1 (10.0)	1 (6.7)	
Inflow revascularization ^{a)}	NA	18 (62.1)	NA
Outflow revascularization ^{b)}	NA	6 (20.7)	NA
Inflow and outflow revascularization ^{c)}	NA	5 (17.2)	NA
Inflow lesions (n = 23)			
Chronic total occlusion	NA	7 (30.4))	NA
Lesion length, cm	NA	6.4 ± 3.1	NA
TASC II C/D	NA	15 (65.2)	NA
Outflow lesions (n = 11)			
Chronic total occlusion	NA	6 (54.5)	NA
Lesion length, cm	NA	15.8 ± 9.5	NA
TASC II C/D	NA	8 (72.7)	NA
Ankle-brachial index			
<i>Values are presented as number (%) or mean ± standard deviation. GSV, great saphenous vein; PTFE, polytetrafluoroethylene; NA, not applicable.</i>			
<i>a) Iliac stenting in all patients. b) Femoropopliteal balloon angioplasty (n = 4), femoropopliteal directional atherectomy with tibial balloon angioplasty (n = 1), and endovascular repair of a popliteal artery aneurysm (n = 1). c) Iliac stenting combined with superficial femoral artery thrombectomy (n = 2), directional atherectomy (n = 1), balloon angioplasty (n = 1), or tibial balloon angioplasty (n = 1). *Lesion-level anatomical detail (TASC classification, lesion length, chronic total occlusion status) was recorded for only 2 of 51 procedures in the source registry and could not be reliably summarized for the Hybrid (+) subgroup; ND, not determinable.</i>			

Variable	Hybrid (-) (n = 23)	Hybrid (+) (n = 29)	P-value
Preoperative	0.77 ± 0.19	0.52 ± 0.17	0.001
Postoperative	1.04 ± 0.17	0.88 ± 0.18	0.024
Change (post – pre)	0.27 ± 0.13	0.36 ± 0.16	0.119
P-value (within group)	< 0.001	< 0.001	
<i>Values are presented as number (%) or mean ± standard deviation. GSV, great saphenous vein; PTFE, polytetrafluoroethylene; NA, not applicable.</i>			
<i>a) Iliac stenting in all patients. b) Femoropopliteal balloon angioplasty (n = 4), femoropopliteal directional atherectomy with tibial balloon angioplasty (n = 1), and endovascular repair of a popliteal artery aneurysm (n = 1). c) Iliac stenting combined with superficial femoral artery thrombectomy (n = 2), directional atherectomy (n = 1), balloon angioplasty (n = 1), or tibial balloon angioplasty (n = 1). *Lesion-level anatomical detail (TASC classification, lesion length, chronic total occlusion status) was recorded for only 2 of 51 procedures in the source registry and could not be reliably summarized for the Hybrid (+) subgroup; ND, not determinable.</i>			

Primary outcomes

Consistent with the study's core objective of characterizing FEA itself, the primary analysis below reports pooled outcomes for the entire cohort (n = 52) (Fig. 2). The femoral endarterectomy site (Fig. 2A) demonstrated exceptional long-term stability, with a primary patency of 94.2% at both 5 and 10 years. In contrast, outflow revascularization (Fig. 2B), involving the femoropopliteal or infrapopliteal segments, showed a lower 5-year primary patency of 85.7%. Because the number of patients at risk beyond 5 years was insufficient for reliable estimation, outflow patency is reported up to 5 years. The need for reintervention was low: no patient required surgical conversion or bypass, and symptomatic loss of distal outflow patency in the Hybrid (+) group was managed in two cases (6.9%) by repeat balloon angioplasty. These findings suggest that although the FEA-based inflow platform is highly durable, long-term success is limited primarily by attrition of the distal outflow segment.

Procedural outcomes and clinical effectiveness

In the Hybrid (+) group, FEA provided access for a range of simultaneous procedures, and clinical effectiveness was high overall. Primary patency at the femoral endarterectomy site was similar between the hybrid platform group and the isolated-FEA reference group (P = 0.460), supporting that adjunctive endovascular access via the FEA site did not compromise the durability of the surgical reconstruction (Fig. 3A). In the Hybrid (-) group, patency was maintained throughout follow-up, and no patient required revascularization or a secondary procedure for new inflow or outflow disease. Amputation-free survival and overall survival did not differ significantly between groups (P = 0.487 and P = 0.320, respectively; Fig. 3B, 3C); given the baseline imbalance in CLTI prevalence and disease extent between groups, these unadjusted comparisons alone cannot rule out confounding by disease severity. In a stratified subgroup analysis restricted to patients with CLTI, amputation-free survival and overall survival were similar

between the Hybrid (–) and Hybrid (+) groups (Fig. 4): amputation-free survival, P = 0.804; overall survival, P = 0.551. Findings should be interpreted cautiously given the small subgroup size. During follow-up, seven patients died. In the Hybrid (–) group, four deaths occurred (congestive heart failure, myocardial infarction, aspiration pneumonia, and an out-of-hospital death of unknown cause). In the Hybrid (+) group, three deaths occurred (acute respiratory failure, pneumonia, and cholangiocarcinoma).

Adjusted and subgroup analyses

To account for the baseline imbalance in CLTI prevalence between groups, we performed a supplementary multivariable Cox proportional hazards regression analysis (Table 3) using a source registry export (n = 51 procedures) with a text-derived Hybrid (+)/Hybrid (–) classification that approximates, but does not exactly reproduce, the adjudicated grouping reported in Table 1 (Hybrid [+]
= 29, Hybrid [–]
= 23). In this model, adjusting for CLTI status, age, and end-stage renal disease (ESRD), CLTI status was associated with a numerically higher hazard of amputation or death that did not reach statistical significance (adjusted hazard ratio [aHR], 4.98; 95% CI, 0.67–36.87; P = 0.116), while Hybrid (+) status was associated with a lower hazard that approached significance for amputation-free survival (aHR, 0.11; 95% CI, 0.01–1.05; P = 0.055) and reached significance for overall survival (aHR, 0.08; 95% CI, 0.01–0.84; P = 0.035); older age was independently associated with both outcomes (amputation-free survival aHR, 1.15, P = 0.013; overall survival aHR, 1.15, P = 0.034). The ESRD coefficient could not be estimated in the overall-survival model because no deaths occurred among the 3 ESRD patients.

Table 3

Multivariable Cox proportional hazards regression for amputation-free survival and overall survival

Outcome	Covariate	aHR	95% CI	P-value
Amputation-free survival	CLTI (vs. claudication)	4.98	0.67–36.87	0.116
	Hybrid (+) (vs. Hybrid [–])	0.11	0.01–1.05	0.055
	Age	1.15	1.03–1.29	0.013
	ESRD	6.01	0.57–63.41	0.136
Overall survival	CLTI (vs. claudication)	3.80	0.54–26.67	0.179
	Hybrid (+) (vs. Hybrid [–])	0.08	0.01–0.84	0.035
	Age	1.15	1.01–1.30	0.034
	ESRD	NE	NE	NE
aHR, adjusted hazard ratio; CI, confidence interval; CLTI, chronic limb-threatening ischemia; ESRD, end-stage renal disease.				

Postoperative safety and complications

Complications are summarized in Table 4. The Hybrid (–) group had a significantly higher rate of mild complications (65.2% vs. 27.6%, $P = 0.011$), consisting mainly of tolerable wound pain, tingling, and numbness. Moderate complications occurred in 17.2% of the Hybrid (+) group and 4.3% of the Hybrid (–) group, without a significant difference ($P = 0.210$). Severe complications requiring readmission or reprocedure were rare and similar between groups (4.3% vs. 3.4%, $P = 1.000$): one patient in the Hybrid (–) group required readmission and vacuum-assisted closure for a combined seroma and infection, and one in the Hybrid (+) group was readmitted for seroma management. These findings indicate that the added complexity of the hybrid procedure did not significantly increase the risk of severe surgical-site complications compared with isolated FEA. No cases of late FEA-site–specific complications including patch infection, pseudoaneurysm, or CFA re-occlusion were identified during long-term follow-up (mean 39.0 ± 42.5 months). Separately, the FEA site itself was subsequently reused as an access route for endovascular reintervention in 3 patients, including the two cases of repeat balloon angioplasty for symptomatic loss of distal outflow patency described above; access via the previously patched FEA site was achieved without new access-site complications. These findings suggest that a previously patched FEA site may itself remain a feasible and safe access route for subsequent endovascular reintervention, though our experience with this specific scenario is limited to a small number of cases and should be interpreted accordingly.

Table 4
Postoperative complications

Grade	Definition	Hybrid (–) (n = 23)	Hybrid (+) (n = 29)	P-value
Mild	Controlled without medication	15 (65.2) Wound pain, 7 Wound tingling, 5 Numbness, 3	8 (27.6) Wound pain, 5 Wound tingling, 3	0.011
Moderate	Managed with medication or an outpatient procedure	1 (4.3) Lymphedema, 1	5 (17.2) Wound pain, 3 Lymphedema, 1 Seroma, 1	0.210
Severe	Requiring readmission or reprocedure	1 (4.3) Seroma with infection (VAC), 1	1 (3.4) Seroma, 1	1.000
<i>Values are presented as number (%). All complications listed occurred within the early postoperative period (≤ 30 days); no late (> 30-day) complications, including patch infection, pseudoaneurysm, or CFA reocclusion, were identified during follow-up. VAC, vacuum-assisted closure.</i>				

Discussion

The principal finding of this study is that FEA is technically feasible and durable as an access platform for the management of complex, multilevel PAD. Although the CFA is often viewed as a localized site of atherosclerotic disease, our experience suggests a more strategic role. By using the FEA site as an anatomical hub, we performed simultaneous inflow and outflow interventions without increasing the risk of severe complications, benchmarked descriptively against isolated FEA performed in a less extensively diseased reference cohort during the same period. This experience addresses a technical gap between purely endovascular and purely open strategies, providing a tailored approach for patients with extensive arterial involvement, though it does not by itself establish comparative efficacy against either alternative.

An important caveat to this experience is that the Hybrid (–) and Hybrid (+) groups are not comparable populations: allocation to the hybrid strategy was determined by the clinical presence of additional inflow or outflow disease, and the Hybrid (+) group accordingly had a significantly higher prevalence of CLTI and lower baseline ABI. This baseline mismatch in clinical severity is an inherent feature of multilevel disease rather than an incidental imbalance, since patients requiring adjunctive inflow or outflow revascularization are, by definition, more likely to present with advanced ischemia. The two groups therefore do not represent alternative treatments for equivalent disease: the Hybrid (–) group was not intended as an equivalent clinical baseline, but rather as a technical benchmark to confirm that introducing endovascular tools through the open patch/arteriotomy line does not compromise local reconstruction durability (94.2% 10-year femoral patency) or increase surgical-site complication rates relative to standard open FEA alone. Accordingly, the unadjusted between-group comparisons in this study should be understood primarily as descriptive benchmarking of the FEA reconstruction's local safety and durability. To help isolate the effect of the hybrid platform strategy from this baseline imbalance, we performed a supplementary multivariable Cox regression adjusting for CLTI status, age, and ESRD; the results were sensitive to model specification, with neither CLTI status nor group allocation emerging as a robust, independent predictor once the model was simplified. A stratified subgroup analysis restricted to patients with CLTI showed comparable amputation-free and overall survival between groups, though femoral patency could not be compared in this subgroup because patency-loss events were too sparsely recorded in the source registry. Taken together, these supplementary analyses do not provide strong evidence either for or against confounding by the baseline CLTI imbalance; the small number of events in this cohort limits what any adjusted model can resolve, and — as a retrospective, non-randomized comparison — residual confounding cannot be excluded.

Historically, the gold standard for CFA disease has been open endarterectomy with patch angioplasty. Despite the rapid advancement of endovascular technologies, including drug-coated balloons and atherectomy devices, the CFA remains a challenging territory for stenting because of its proximity to the hip joint and the constant mechanical stress of flexion [9–11]. Our study reinforces the durability of the open approach, with a high primary patency of 94.2% for the femoral segment at 10 years. Importantly, the addition of endovascular maneuvers for inflow or outflow lesions did not compromise the long-term patency of the femoral reconstruction.

The safety profile of the hybrid approach is noteworthy. Combining open surgery with endovascular intervention—which often entails longer procedure times and increased instrumentation—might be expected to increase surgical-site infection or wound complications [12, 13]. However, severe complications requiring readmission or reintervention were low and statistically similar between groups. The higher rate of mild complications in the Hybrid (–) group suggests that the complexity of the hybrid procedure does not necessarily translate into a more difficult recovery in terms of wound healing or postoperative pain. Nonetheless, this counterintuitive difference should be interpreted with caution, as it may reflect the retrospective design, the modest sample size, and potential between-group differences in incision extent, operative time, and selection.

Hemodynamic improvement, as measured by ABI, was consistent across both cohorts. The ability to treat iliac inflow and infrapopliteal outflow disease through a single groin incision is a major advantage of the FEA platform. This simultaneous revascularization minimizes the physiological burden of multiple staged procedures, which is especially beneficial for older patients and those with substantial comorbidity such as diabetes and ESRD, who represented a large proportion of our cohort [14–16]. By maximizing inflow and outflow through a single gateway, the chances of limb salvage and wound healing are optimized in patients with CLTI.

Both anatomical and physiological considerations should guide the choice between isolated FEA and a hybrid approach. In our practice, the FEA platform enabled treatment of long-segment SFA occlusions or complex iliac stenoses that might otherwise have required more invasive bypass or a separate percutaneous access site. By converting the CFA into a controlled access point during endarterectomy, the surgeon gains superior control over the distal and proximal endpoints of revascularization, potentially reducing the risk of distal embolization or flow-limiting dissection encountered in purely percutaneous procedures [17].

Technically, the key point of patch closure in a hybrid procedure is to achieve arterial reconstruction while maintaining a hub for endovascular access. After endarterectomy, the patch is partially sutured to the arteriotomy; before completion of the suture line, a sheath is inserted directly through the patch or the corner of the arteriotomy, providing hemostatic, sealed access for wires and catheters to treat proximal inflow or distal outflow lesions under fluoroscopic guidance [18]. The open arteriotomy also offers direct visualization, reducing the risk of subintimal dissection during sheath placement compared with percutaneous access. Once the endovascular phase is complete, the sheath is removed and the patch closure is finished, ensuring a wide, non-stenotic lumen that preserves the durability of the platform.

We favor direct sheath introduction through the open arteriotomy/patch line over a separate percutaneous contralateral crossover or additional ipsilateral puncture for several procedural reasons. First, performing the retrograde or antegrade maneuver through the surgical arteriotomy avoids a second arterial puncture in a diseased contralateral limb or distal ipsilateral vessel, eliminating a distinct access-site risk (hematoma, pseudoaneurysm, or retroperitoneal bleeding) that a crossover approach would

introduce. Second, direct visualization during sheath introduction through the patch or arteriotomy corner reduces the risk of subintimal dissection at the access site compared with a blind percutaneous puncture, and allows a secure, blood-tight closure to be completed under direct vision once the sheath is withdrawn. We recognize, however, that these are procedural rationales rather than comparative evidence, since our cohort does not include a contralateral-crossover comparator.

Beyond its use as a simultaneous access hub, our experience also suggests that a previously operated FEA site can itself remain a viable access route for later, staged endovascular reintervention. Two patients in the Hybrid (+) group underwent repeat balloon angioplasty for symptomatic loss of distal outflow patency during follow-up, without new access-site complications. This is consistent with prior reports describing safe and technically straightforward sheath insertion through a CFA that has previously undergone endarterectomy and autologous patch repair [18]. Nonetheless, our experience with reintervention through a previously operated FEA site is limited to a small number of cases, and we did not systematically track late (> 30-day) complications separately from early events across the full cohort; larger, longer-term series specifically addressing the durability and safety of reusing a previously reconstructed CFA for subsequent endovascular access are warranted.

Regarding patch selection, autologous vein—particularly the GSV—offers physiological advantages over prosthetic material, including a viable endothelial lining that resists thrombosis and superior resistance to infection [1, 19]; superficial tributaries of the GSV are useful alternatives to the main trunk [20]. Bovine pericardium has emerged as a durable alternative with a low risk of rupture and infection [21, 22]. In our cohort, autologous vein patches were used in 27 patients (51.9%), a bovine pericardial patch in 23 patients (44.2%), and a synthetic (PTFE) patch in 2 patients (3.8%).

This study has several limitations. First, its retrospective design and relatively small sample size ($n = 52$) limit generalizability and statistical power. Second, although the data span 15 years (2010–2025), the evolution of endovascular devices over this period may introduce historical bias in the Hybrid (+) group. Third, follow-up was limited beyond 5 years for the outflow segment, so long-term outflow patency should be interpreted cautiously. Fourth, and most importantly, allocation to the hybrid strategy was based on clinical indication and surgeon discretion rather than randomization or risk matching, so the Hybrid (–) and Hybrid (+) groups differ fundamentally in baseline disease severity and cannot be considered comparable populations; our supplementary CLTI-adjusted Cox regression and CLTI-stratified subgroup analysis were inconclusive on this point — model estimates were unstable and sensitive to covariate selection given the small number of events (7 deaths, 8 amputation-free-survival events) — and this analysis was performed on a source-registry export with a text-derived group classification that did not exactly reproduce the adjudicated Table 1 grouping, a discrepancy we were unable to fully resolve. Residual and unmeasured confounding therefore cannot be excluded in this retrospective, non-randomized comparison of modest size. Fifth, and importantly, our Hybrid (–) group consisted of patients undergoing isolated FEA for localized CFA disease rather than a cohort of multilevel-disease patients treated via an alternative endovascular access strategy — such as percutaneous contralateral crossover access or additional distal percutaneous access sites combined with CFA management. We

searched our institutional vascular registry for a historical cohort of patients who underwent open FEA combined with a separate percutaneous contralateral crossover access for multilevel disease, but such cases did not exist in sufficient numbers during the study period to permit a statistically meaningful comparison; in our clinical workflow, patients requiring surgical endarterectomy for significant CFA disease routinely underwent direct-hub sheath insertion through the arteriotomy rather than a separate contralateral puncture. While direct sheath placement through the open FEA arteriotomy is intended to eliminate the need for a secondary arterial puncture, the absence of a direct comparison cohort managed via alternative percutaneous access strategies limits our ability to determine whether the FEA-platform approach offers a procedural advantage over conventional crossover or multi-site percutaneous techniques, rather than merely a safe alternative to them. Future prospective studies directly comparing FEA-platform access against percutaneous crossover access in multilevel PAD are warranted.

Conclusions

FEA remains the cornerstone of treatment for complex CFA disease, and our experience suggests it is also technically feasible and durable as a platform for hybrid revascularization, enabling comprehensive single-session inflow and outflow intervention without compromising the durability of the femoral reconstruction (94.2% primary patency at 10 years) or increasing severe postoperative complications, benchmarked descriptively against isolated FEA. Given the inherent baseline differences between groups, these findings should be viewed as a feasibility and safety experience rather than comparative evidence of treatment efficacy; prospective, adequately powered studies with matched or randomized comparators — including purely endovascular strategies — are needed to define the comparative role of this approach in patients with multilevel arterial disease.

Abbreviations

ABI Ankle-brachial index

aHR Adjusted hazard ratio

CFA Common femoral artery

CI Confidence interval

CLTI Chronic limb-threatening ischemia

CTA Computed tomography angiography

DFA Deep femoral artery

ESRD End-stage renal disease

FEA Femoral endarterectomy

GSV Great saphenous vein

NA Not applicable

PAD Peripheral artery disease

PTFE Polytetrafluoroethylene

SD Standard deviation

SFA Superficial femoral artery

TASC Trans-Atlantic Inter-Society Consensus

VAC Vacuum-assisted closure

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board of Kyung Hee University Hospital at Gangdong (IRB No. 2022-08-022; approved September 5, 2022). Owing to the retrospective design and the use of de-identified data, the requirement for informed consent was waived by the same Institutional Review Board.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

JHJ conceived and designed the study, performed the procedures, and drafted the manuscript. SC collected and analysed the data. JHJ and SC performed the statistical analysis. All authors read and approved the final manuscript.

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Figures

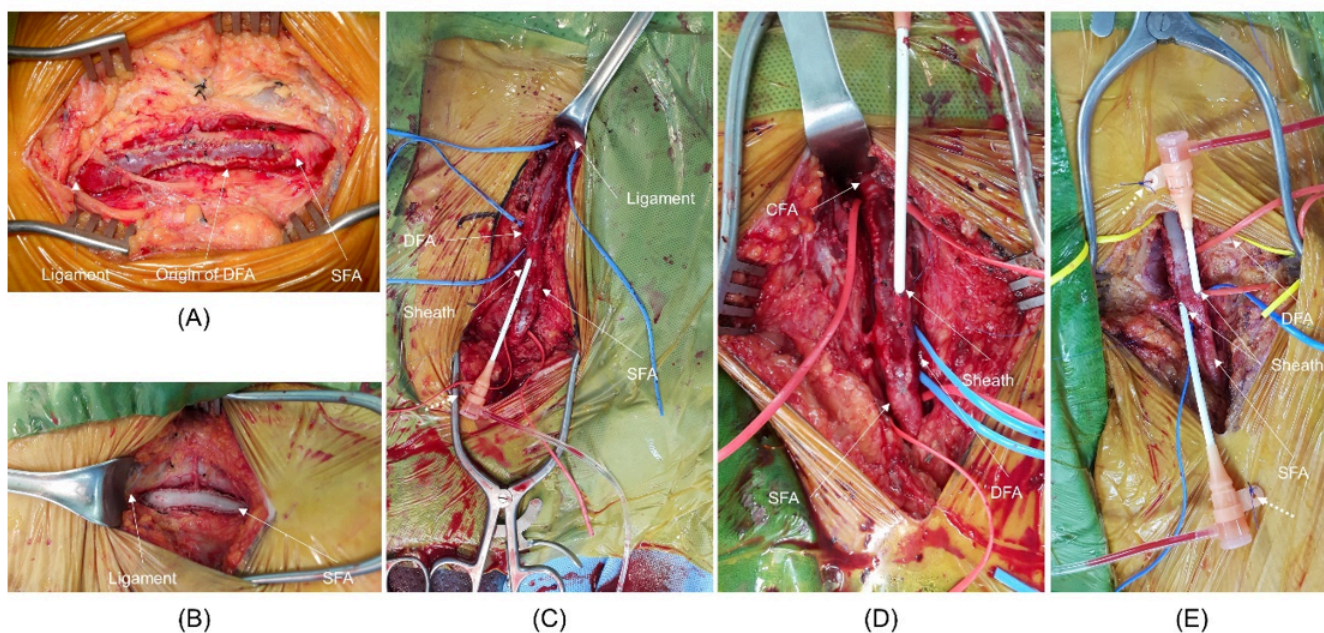


Figure 1

Surgical techniques for isolated and hybrid femoral revascularization

(A) Primary femoral endarterectomy (FEA) with patch angioplasty using an autologous ipsilateral great saphenous vein branch. (B) FEA with bovine pericardial patch closure. (C–E) Use of the FEA site as a platform for hybrid revascularization: (C) retrograde insertion of an introducer sheath for iliac (inflow) stenting; (D) antegrade sheath placement for distal (outflow) revascularization, with the sheath secured to the skin by a stay suture (dotted arrow); (E) dual-direction access using two introducer sheaths for simultaneous inflow and outflow revascularization (dotted arrows). CFA, common femoral artery; SFA, superficial femoral artery; DFA, deep femoral artery.

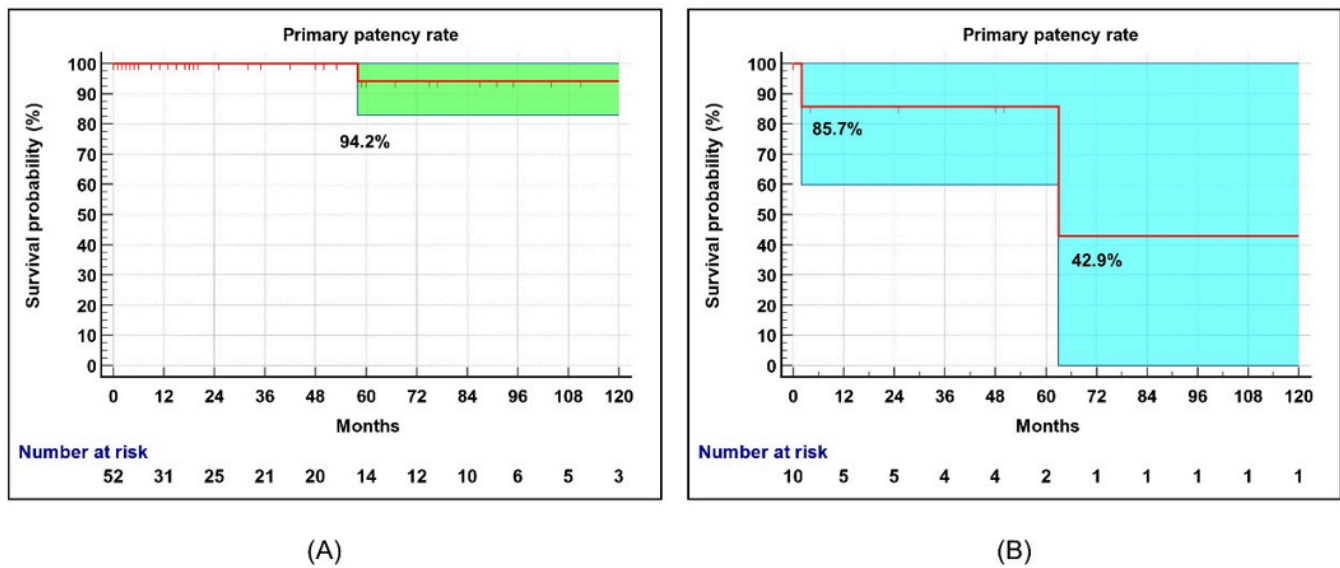


Figure 2

Kaplan-Meier curves of 10-year primary patency by arterial segment

(A) Primary patency at the femoral endarterectomy site (94.2% at both 5 years and 10 years). (B) Primary patency of the outflow revascularization (femoropopliteal or infrapopliteal segments), 85.7% at 5 years; patency is reported up to 5 years because of the small number of patients at risk thereafter. Numbers at risk are shown below each curve.

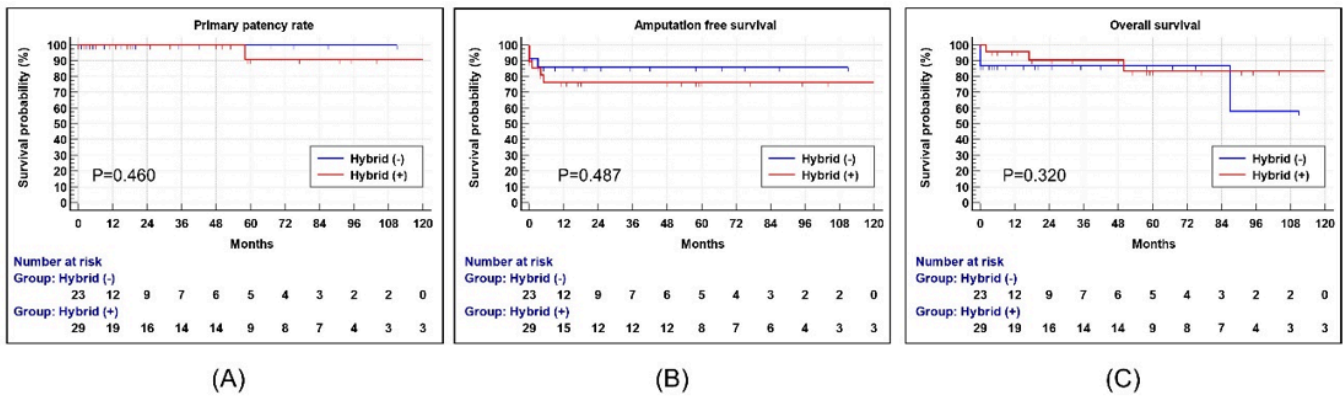


Figure 3

Kaplan-Meier curves comparing isolated FEA (Hybrid [-]) with the hybrid platform approach (Hybrid [+])

(A) Primary patency at the femoral endarterectomy site, with no significant between-group difference ($P = 0.460$). (B, C) Amputation-free survival and overall survival, with no significant between-group difference ($P = 0.487$ and $P = 0.320$, respectively). Numbers at risk are shown below each curve.

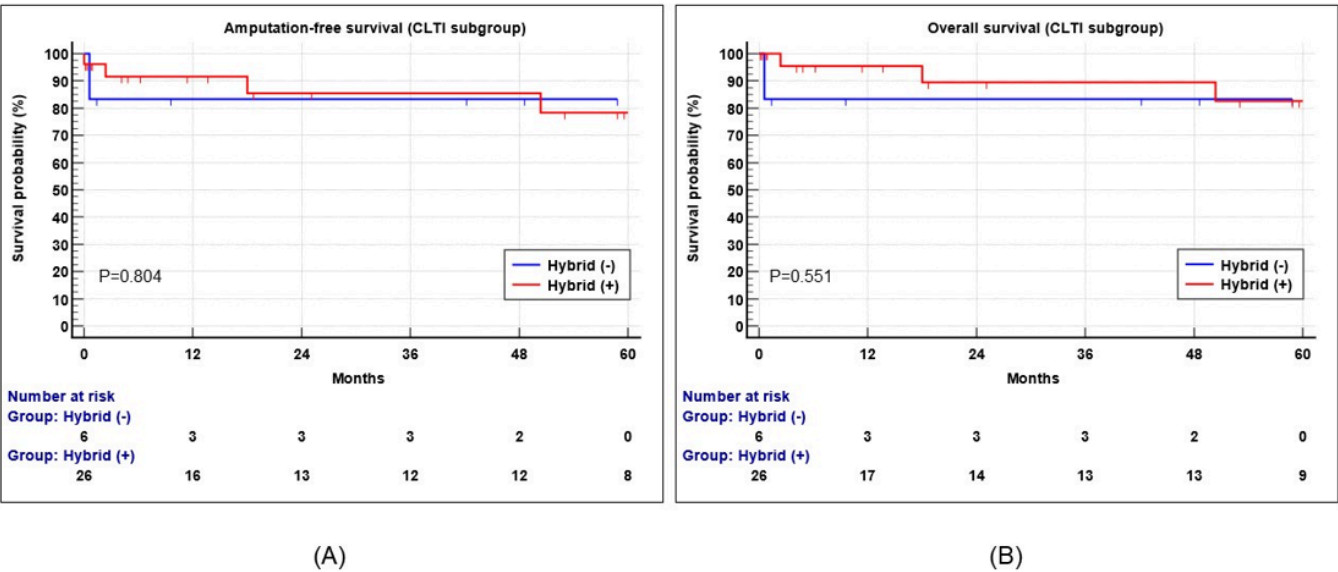


Figure 4

Kaplan-Meier curves for patients with chronic limb-threatening ischemia

(A) Amputation-free survival and (B) overall survival among patients with chronic limb-threatening ischemia (CLTI), comparing Hybrid (–) and Hybrid (+) groups. No significant differences were observed (amputation-free survival, $P = 0.804$; overall survival, $P = 0.551$). Numbers at risk are shown below each panel. CLTI, chronic limb-threatening ischemia.