Short- and long-term outcomes after endarterectomy with autologous patching in endurance athletes with iliac artery endofibrosis

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ABSTRACT

Objective: Endurance athletes such as cyclists may develop intermittent claudication owing to iliac artery endofibrosis after long-lasting extreme hemodynamic challenges. This study investigated short-term (<1.5 years) and long-term (>5 years) satisfaction and safety after a surgical endarterectomy and autologous patching.

Methods: Data of endurance athletes who underwent an endarterectomy for flow limitation of the iliac artery owing to endofibrosis between 1997 and 2015 in one center were studied. Maximal cycling exercise tests, ankle-brachial index with flexed hips, echo-Doppler examination (peak systolic velocity), and contrast-enhanced magnetic resonance angiography were performed before and 6 to 18 months after surgery. Short-term and long-term satisfaction were evaluated using questionnaires. Potential patch dilatation was assessed using echo-Doppler.

Results: Analysis of 68 patients (79 legs; 55.7% males, median age at the time of surgery, 34 years; interquartile range, 26-41 years) demonstrated that cycling workload at symptom onset improved from 226 ± 97 to 333 ± 101 ($P < .001$) Watts. Peak workload increased from 326 ± 111 to 352 ± 93 Watts ($P < .001$). Ankle-brachial index with flexed hips increased from 0.34 (interquartile range [IQR], 0.00-0.47) to 0.59 (IQR, 0.51-0.69; $P < .001$). Peak systolic velocity with extended and flexed hip decreased from 2.04 $m \cdot sec^{-1}$ (IQR, 1.52-2.56 $m \cdot 3sec^{-1}$) to 1.25 $m \cdot sec^{-1}$ (IQR, 0.92-1.62 $m \cdot sec^{-1}$; $P < .001$) and 2.40 $m \cdot sec^{-1}$ (IQR, 1.81-2.81 $m \cdot sec^{-1}$) to 1.15 $m \cdot sec^{-1}$ (IQR, 0.97-1.60 $m \cdot sec^{-1}$; $P < .001$), respectively. Thirty-day major complication rate was 5.1% (hematoma requiring evacuation $n_{Legs} = 2$, septic bleeding from deep infection $n_{Legs} = 1$, and iliac occlusion requiring thrombectomy $n_{Legs} = 1$). In the short term, 91.2% of patients reported symptom reduction with a 93.7% overall satisfaction rate. After a median of 11.1 years (IQR, 7.8-17.6 years), the overall satisfaction was 91.7%; 94.5% of patients reported persistent symptom reduction. Patch dilatation of >20 mm was observed in two patients. Linear mixed model analysis revealed no alarming patch dilatation in the long term.

Conclusions: Endarterectomy with an autologous patch for intermittent claudication owing to iliac artery endofibrosis in endurance athletes shows high rates of patient satisfaction and symptom reduction in both the short and long term. The risk of surgical complications or patch dilatation is mild. A surgical intervention for flow limitation of the iliac artery owing to endofibrosis is safe and successful. (J Vasc Surg 2023;78:514-24.)

Keywords: Iliac stenosis; Endofibrosis; Endurance athletes; Endarterectomy; Vein patch; Cyclists

Sport-related vascular claudication occurs in approximately 20% of professional cyclists.[1] Walder et al[2] were the first to bring attention to the presence of exercise induced vascular disease in young endurance athletes (flow limitations in the iliac artery [FLIA]). Narrowing and stiffness of the vessel limiting lower extremity blood flow is thought to be caused by endofibrosis rather than atherosclerosis.[3-5] Endofibrosis is likely the consequence of pathological vessel wall remodeling induced by repetitive heavy mechanical and hemodynamic loading.

Recent advances in knowledge and diagnostic methods have suggested that three subgroups of FLIA may exist.

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The first type is an iliac flow limitation that is mainly caused by arterial kinking. This kinking is caused by fixation of the artery to surrounding tissue (eg, arterial side branches to the psoas muscle).[1,6,7] The second type of FLIA is related to kinking after excessive vessel lengthening.[8] The third type is resulting from intravascular narrowing of the common and/or external iliac arteries. In clinical practice, a patient may often present with a combination of these three types. Diagnosing the correct type of FLIA is mandatory for determining the optimal surgical management strategy. Without treatment, FLIA often deteriorates and may sporadically result in an acute occlusion of the artery.[9,10] Nonoperative treatment should include attaining a more upright cycling posture, reduction of training volume and intensity, or cessation of provocative sports activities. If these nonoperative measures fail or if the patient wishes to continue provocative sports activities, surgical treatment tailored to the individual and to the type of FLIA may be an option.

If intravascular narrowing is diagnosed as the main cause of FLIA, an endarterectomy with closure using an autologous (venous or arterial) patch may be indicated. A 2016 Delphi consensus study concluded that there is a paucity of literature, especially on the long-term efficacy of surgical interventions.[11-17] Moreover, it is largely unknown whether the patched artery may show failure and restenosis or progressive dilatation over the years given the ongoing intense hemodynamic and mechanical loading. This follow-up study in athletes undergoing an endarterectomy for FLIA evaluated short- and long-term satisfaction, surgical complications, and potential patch dilation over an extended follow-up period.

ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center retrospective cohort study
- **Key Findings:** This study describes the effectiveness, durability, and satisfaction of an iliac endarterectomy with autologous patching in 68 endurance athletes with flow limitations in the iliac artery. Outcome was successful as 95% of the patients reported symptom reduction and a 92% satisfaction rate, and no alarming patch dilatation after a median 12 years of follow-up.
- **Take Home Message:** Endarterectomy with autologous patching is safe and beneficial in the short and long-term in almost all patients with flow limitations in the iliac artery with iliac endofibrosis.

METHODS

Patients. All patients who underwent an iliac artery endarterectomy with autologous patching for endofibrosis causing FLIA between 1997 and 2015 in Máxima Medical Centre (Veldhoven, the Netherlands) were included. Patients who had previously undergone a different procedure for FLIA such as iliac arterial release or shortening but who eventually required an endarterectomy with autologous patching for endofibrosis were also included. Patients were excluded if they were diagnosed with atherosclerosis (based on imaging) rather than endofibrosis. During the same period, iliac arteries of 156 legs were treated for FLIA with an operative technique termed arterial release, as recently published.[18] Iliac arteries of 90 legs underwent a different technique termed arterial shortening (Supplementary Fig, online only), as also reported in an recent article.[19]

Diagnostic protocol. A patient with suspected FLIA was first investigated by a dedicated sports physician with focus on specific symptoms and signs of FLIA, but also to identify other causes of exercise-related leg complaints. Patient history was investigated using a standardized questionnaire concerning family and medical history, level of sport, and symptoms possibly related to FLIA or other causes.[20,21] A detailed physical examination was performed to exclude mainly orthopedic causes. If FLIA was considered likely, duplex ultrasound examination (Fig 1, *A-C*, before 2010 Toshiba SSH-140A; after 2010: Terason T3000, Burlington, MA; now, Epiq Elite, Philips, Best, the Netherlands) scanned both iliacofemoral axes for the presence of intravascular lesions, lengthening, and/or kinking. Peak systolic velocities (PSV) were measured with extended and flexed hips.[6,20,21]

An incremental maximal cycling exercise test (Excalibur Sport, Lode, Groningen, the Netherlands) assessed the peak workload. During this test, patients were instructed to report the onset of symptoms allowing for the estimation of the maximal symptom-free workload (W_{SF}). After maximal exertion, patients were instructed to place their feet on a platform that was placed over the bike to maintain a symmetrical hip flexed cycling position. An adapted ankle-brachial index (ABI_{Flexed}) was then calculated as earlier reported.[20-22] If a blood pressure signal was not detected within 90 seconds, the ABI_{Flexed} was set to zero. In athletes, an ABI_{Flexed} of <0.54 immediately after such a test is considered abnormal. A >23 mm Hg difference between both ankle pressures is also considered abnormal.[20,21]

Patient history, physical examination, and results of cycling test and echo examination were combined to assess the likelihood of FLIA and/or other causes contributing to the leg complaints (Fig 1, *A-C*). If FLIA was diagnosed, a nonoperative treatment (including counselling for sports and cycling position as well as physical therapy for improving, for example, core stability and functional movement disorders in the spine, sacroiliac joint, and/or hips) was first advised. Patients were contacted after 3 months. If the outcome by then was unsuccessful, a contrast-enhanced magnetic resonance angiography (before 2010, Gyroscan T10-NT [1 Tesla]; after 2010, Achieva Nova Dual [1.5 Tesla], both Philips Medical Systems) was performed with extended and flexed hips aimed at visualizing the underlying type of FLIA (Fig 1, *D-F*). If an intravascular stenosis of >15% was identified, they were counselled by a sports physician (G.S.) and vascular surgeon (M.B.) on the potential benefits and risks of an endarterectomy with an autologous patch. If imaging also suggested lengthening and/or kinking, an additional arterial release and/or shortening were also discussed. The study protocol followed the recommendations of the Declaration of Helsinki and received approval by the hospital's medical ethical committee (number N18.054).[23] The study was also registered in the Dutch Trial Register (Trial NL8553).

Surgical treatment. All procedures were performed by a surgeon with extensive experience in the operative treatment of FLIA (M.B.). Via an inguinal incision parallel to Poupart's ligament and splitting of the oblique and transverse abdominal muscles, the fascia envelope of the rectus abdominis muscle was partly incised from lateral side allowing access to the iliac axis by a retroperitoneal approach. The iliac artery was dissected from the ligament of Poupart up to the aortic bifurcation including the first 4 cm of the internal iliac artery. Small arterial side branches to the psoas muscle were transected. Through a second small groin incision the common femoral artery was dissected up to the external iliac artery (EIA). The superficial external pudendal, deep circumflex iliac, and inferior epigastric arteries were preserved. The EIA was transected at its origin and was exteriorized through the groin incision. Through a longitudinal incision, the intimal thickening was removed. Other than during endarterectomy in patients with atherosclerosis, we limited our dissection to the plane between intima and media. If the EIA was too long, a portion of the artery was resected. An autologous patch obtained from the ipsilateral greater saphenous vein (or occasionally from resected arterial portion; $n_{Legs} = 2$) was used to close the external iliac arterial defect using Prolene 5.0. The reconstructed EIA was repositioned retroperitoneally and reanastomosed end to the iliac bifurcation (Fig 1; pictures of the operation are provided in the Appendix [online only]). The wound was closed in layers using absorbable sutures. The removed thickened intima was sent for histological analysis in the majority of cases.[3]

Postoperative regimen. Postoperatively, nonsteroidal anti-inflammatory drugs were administered for 1 week for pain control if necessary. Additionally, patients received 80 mg of acetylsalicylic acid daily for 1 month to minimize the risk of platelet aggregation at the operated vessel wall. Postoperative length of stay was 3 to 4 days. Patients followed a graduated return to sports program for 2 months. Low-resistance cycling was allowed from week 5 onward and unrestricted high-intensity training started from 9 weeks after the operation. Follow-up by telephone occurred at 2 and 8 weeks postoperatively. After 6 to 18 months, a physical examination and imaging were scheduled. Patients were advised to undergo an echo-Doppler examination for monitoring arterial diameters after 3 years and subsequently every 5 years. Patients were informed that it was their own responsibility to initiate these follow-up appointments.

Short-term follow-up. Short-term outcomes were assessed between 6 and 18 months after surgery and involved history taking, physical examination, a maximal exercise test with ABI_{Flexed} measurements, and imaging (duplex ultrasound examination and contrast-enhanced magnetic resonance angiography). A questionnaire determined residual complaints, current sporting activities, ability to perform activities at the desired level, and overall satisfaction. The current status was categorized as healed, significantly improved, improved, same, mildly worse, or significantly worse.

Long-term follow-up. In 2020, patients were invited by postal mail, phone, and/or e-mail for a long-term analysis. They signed an informed consent form if they were willing to participate. They completed a long-term questionnaire (Appendix, online only) that was adapted on the basis of the short-term version with additional items concerning, for example, medical events and reasons for changes in level of sport participation. The medical ethics commission allowed the use of relevant medical files of patients who did not respond, provided that they did not, at an earlier point, sign an affidavit prohibiting the use of their data for research purposes.

If additional operative procedures were required because of persisting complaints within two years after the initial surgical reconstruction, the result was categorized as poor. If a patient reported recurrent complaints after >2 years following an initial success, the case was considered as recurrent FLIA. In both instances, patient overall satisfaction was categorized as unsatisfied, would not undergo surgery with knowledge of the current result, and symptoms significantly worse.

Saphenous venous patch dilatation. Concern is ongoing regarding a potential aneurysmatic degeneration of the saphenous vein patch because these athletic patient populations often continue to be subjected to repeated long periods of high blood pressure during intense exercise.[11,15,24-26] Long-term data regarding this possible complication are scarce. Regular check-ups in our center including an echo-Doppler examination determined the vascular integrity and maximal intraluminal diameter.

Statistical analyses. Normal data distribution was tested using the Shapiro-Wilk test and visual inspection of kurtosis and skewness by means of histograms.

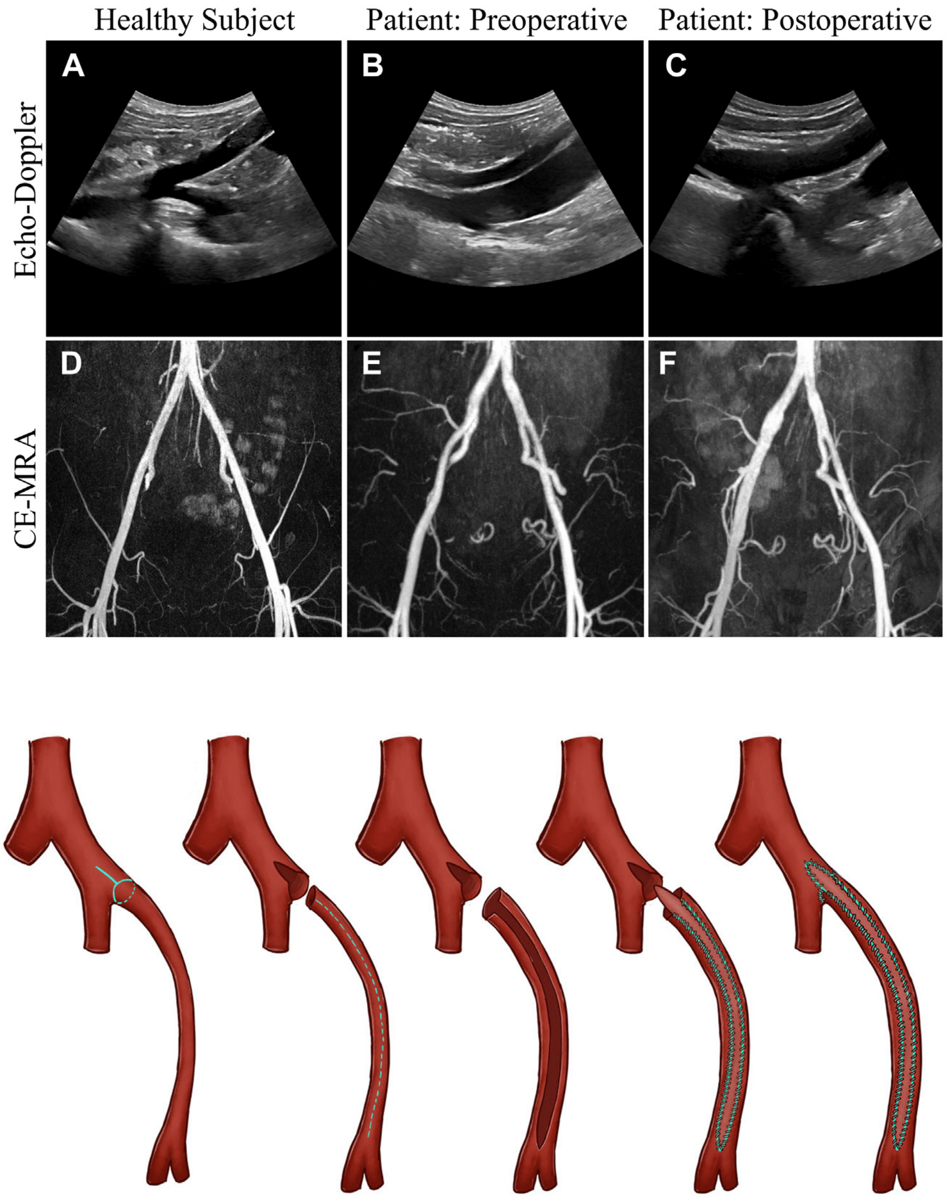

Fig 1. A normal echo-Doppler and contrast enhanced magnetic resonance angiography (*CE-MRA*) in a healthy patient **(A and D)** without signs of arterial stenosis, lengthening or kinking. A flow limitations in the iliac artery (FLIA) patient with symptomatic bilateral external iliac endofibrosis **(B and E)** before surgery. An endarterectomy of the iliac axis with closure using a venous patch was performed on the right side. An CE-MRA 6 months postoperatively (after cycling >8000 kilometers) revealed an open system with a slight dilatation **(C and F)**. Complaints on the left side resolved because overcompensation was no longer required. Below, a schematic overview of a vascular reconstruction of the external iliac artery (EIA) with closure using an autologous patch is shown.

Continuous data were reported as mean and standard deviation in case of normal distribution, or as median and interquartile range (IQR) otherwise. Categorical data were reported as counts with proportions. Most of the analyses were performed on legs ($n_{Legs} = 79$), except where indicated; 11 patients underwent bilateral reconstruction. Potential differences in baseline characteristics between responders and nonresponders with both the short- and long-term questionnaire were tested with a sensitivity analysis. Dependencies among categorical variables (between groups) were determined using the Fisher exact test. Within-patient differences regarding short- and long-term results were tested using an omnibus McNemar-Bowker test. This test examines consistency instead of independence in case of repeated measures and is considered suitable in case of dichotomous preoperative and postoperative results (eg, satisfaction). If this test revealed statistical differences, a

Table I. Characteristics of athletes undergoing an endarterectomy with patch for flow limitations in the iliac artery (FLIA) (data are presented as complete cases)

Characteristics	$n_{Patients} = 68$; $n_{Legs} = 79$
Age during operation, years	34 (26-41)
Male	44 (55.7%)
Female	35 (44.3%)
BMI ($kg \cdot m^{-2}$)	21.8 (1.9)
Family history	19/79 (24.1%)
Smoking (history)	
Yes	2 (2.5%)
No	63 (79.7%)
Former smoker	14 (17.7%)
Type of sports[a]	
Cycling	68 (86.1%)
Speed skating	5 (6.3%)
Triathlon	4 (5.1%)
Running	13 (16.5%)
Level	
Professional	30 (38.0%)
Competition	32 (40.5%)
Recreational	17 (21.5%)
Years of complaints until operation	1.7 (0.8-3.5)
Cycled before onset of complaints, km	125,000 (64,000-209,500)
Cycled until operation, km	175,000 (90,000-250,000)
Side of operation (limbs)[b]	
Left	34 (50.0%)
Right	23 (33.8%)
Both	11 (16.2%)
Histological examination (available in n_{Legs}=54)[b]	
Endofibrosis	48 (88.9%)
Atherosclerosis	1 (1.9%)
Both	1 (1.9%)
No abnormalities	4 (7.4%)

	n_{Legs}	Before	After
Cycling test			
Peak workload, Watt	57	326 (111)	352 (93)[c]
W_{SF}, Watt	56	226 (97)	333 (101)[c]
ABI_{Flexed}	54	0.34 (0.00-0.47)	0.59 (0.51-0.69)[c]
Δ Ankle pressure, mm Hg	54	64 (35-104)	10 (-8-36)[c]
Duplex (echo-Doppler)			
$PSV_{Extended}$ in the EIA, $m \cdot sec^{-1}$	52	2.04 (1.52-2.56)	1.25 (0.92-1.62)[c]
PSV_{Flexed} in the EIA, $m \cdot sec^{-1}$	46	2.40 (1.81-2.81)	1.15 (0.97-1.60)[c]
Duplex and/or CE-MRA			
Detection of functional kinking	55	30/55 (54.5%)	9/55 (16.4%)[c]
Detection of excessive lengthening	61	5/61 (8.2%)	1/61 (1.6%)[c]
Detection of an intravascular lesion[d]	63	63/63 (100.0%)	17/63 (27.0%)[c]

ABI_{Flexed}, Ankle-brachial index with flexed hips; *BMI*, body mass index; *CE-MRA*, contrast-enhanced magnetic resonance angiography; *EIA*, external iliac artery; *PSV*, peak systolic velocity; $PSV_{Extended}$, peak systolic velocity with extended hips; PSV_{Flexed}, peak systolic velocity with flexed hips; *W_{SF}*, symptom-free workload.
Normal values: ABI_{Flexed} ≥0.54; Δ ankle pressure, ≤23 mm Hg; $PSV_{Extended}$ ≤1.48 $m \cdot sec^{-1}$; PSV_{Flexed} ≤1.70 $m \cdot sec^{-1}$.
[a]Multiple answers were possible; data are presented as frequencies and proportion of total legs.
[b]Data presented as frequencies and proportion of total patients.
[c]Significant difference between before and after surgery.
[d]In some cases, the preoperative (and thus postoperative) mild stenosis was accepted by the patient to decrease the surgical risk and/or possible residual complaints.

Table II. Short- and long-term results per operated leg after surgical arterial reconstruction with closure of an autologous patch in patients with flow limitations in the iliac artery (FLIA)

Results	Short term			Long term
	Total	Completed the long-term questionnaire	Did not complete the long-term questionnaire	Completed the long-term questionnaire
	$n_{Patients} = 68$; $n_{Legs} = 79$	$n_{Patients} = 61$; $n_{Legs} = 72$	$n_{Patients} = 7$; $n_{Legs} = 7$	$n_{Patients} = 61$; $n_{Legs} = 72$
Follow-up, years	0.6 (0.5-0.7)	0.6 (0.5-0.7)	0.5 (0.5-0.8)	11.1 (7.8-17.6)[a]
Satisfied total group				
Yes	74 (93.7%)	68 (94.4%)	6 (85.7%)	66 (91.7%)
No	5 (6.3%)	4 (5.6%)	1 (14.3%)	6 (8.3%)
Would undergo surgery with knowledge of the current result				
Yes	76 (96.2%)	69 (95.8%)	7 (100.0%)	69 (95.8%)
No	3 (3.8%)	3 (4.2%)	0 (0.0%)	3 (4.2%)
Cycled after surgery, km	5000 (3500-8500)	5000 (3000-8250)	8000 (6500-54,000)	125,500 (53,500-207,500)[a]
Sports level[b]				
Professional	30 (38.0%)	27 (37.5%)	3 (42.9%)	11 (15.3%)
Competitive	32 (40.5%)	28 (38.9%)	4 (57.1%)	17 (23.6%)
Recreational	17 (21.5%)	17 (23.6%)	0 (0.0%)	42 (58.3%)
Quit sports	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (2.8%)
Complaints[b]				
Healed	56 (70.9%)	51 (70.8%)	5 (71.4%)	39 (54.2%)
Significantly improved	9 (11.4%)	9 (12.5%)	0 (0.0%)	25 (34.7%)
Improved	7 (8.9%)	6 (8.3%)	1 (14.3%)	4 (5.6%)
The same	5 (6.3%)	4 (5.6%)	1 (14.3%)	0 (0.0%)
Mildly worse	1 (1.3%)	1 (1.4%)	0 (0.0%)	1 (1.4%)
Significantly worse	1 (1.3%)	1 (1.4%)	0 (0.0%)	3 (4.2%)

[a]Significant difference in the short and long term.
[b]Empty or low counts prevent accurate testing.

McNemar post hoc test was performed (with Bonferroni correction for multiple testing). To test within-patient differences, or between participating patients and patients who did not fill out the long-term questionnaire, a paired *t* test or unpaired *t* test was applied in case of a normal distribution, and a Wilcoxon signed-rank or Mann-Whitney *U* test otherwise.

A linear mixed model analysis examined the effect of time (years) on patch diameters, after the operation encompassing continuation of strenuous exercise, correcting for multiple patient-specific characteristics. In this mixed model, diameter was considered as the dependent variable, and patient-specific characteristics such as age during the operation, sex, body height, and side of the operation served as independent variables (eg, fixed effects). Time (in years) was included in the model as a random effect. The best time profile (see the Supplementary Table [online only] for further details) was optimized by first using a saturated mean model (eg, including all possible fixed effects and patient-specific covariates). Second-order Akaike information criteria were used for model comparison and for selection of the best fitting model, such as the lower the index, the better the fit. Next, with the chosen time profile the mean model was optimized by means of stepwise backward elimination (eg, fixed effect terms with a *P* value of $>.10$ were left out from the model, starting from the least significant). In the model optimization phase, the maximum likelihood estimation was considered to ensure a fair model comparison. The final model was refit using a restricted maximum likelihood estimation to provide more reliable estimates of the random terms of the model. An illustration of the entire procedure is provided in the Supplementary Table (online only). All statistical analyses were performed using the software R (version 4.2.1; The R Foundation, Vienna, Austria).[27] A *P* value of $<.05$ was considered statistically significant for statistical inference.

RESULTS

Study group. Between 1997 and 2015, 68 ($n_{Legs} = 79$) patients with FLIA, mostly top-level (inter)national cyclists

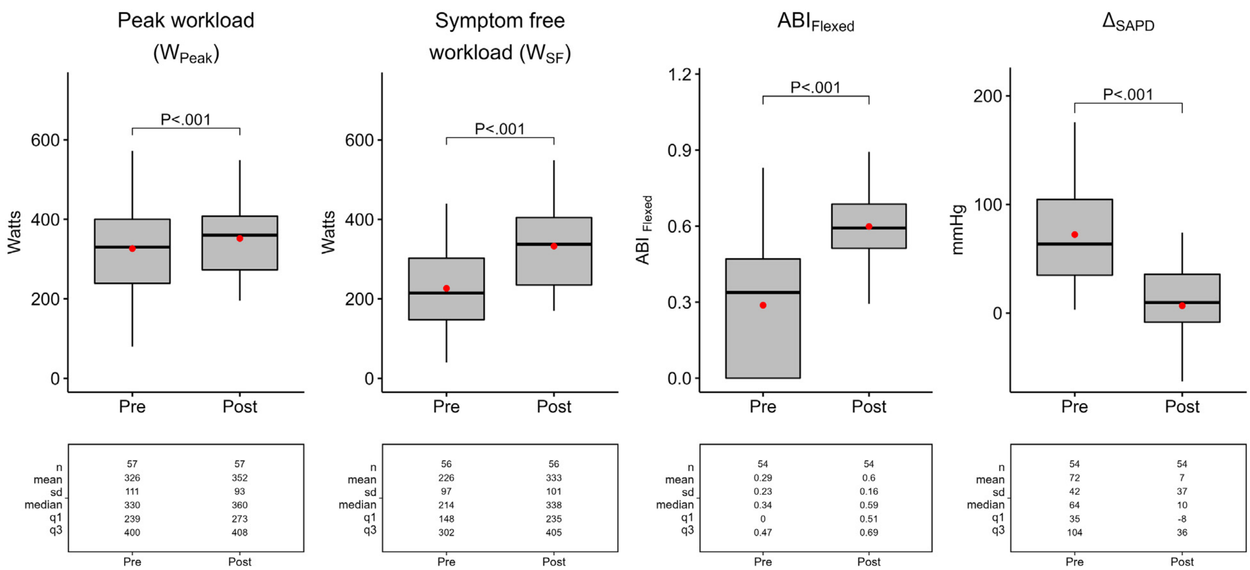

Fig 2. Peak workload (W_{Peak}), symptom-free workloads (W_{SF}), ABI_{Flexed}, and ankle pressure difference after endarterectomy and patch for flow limitations in the iliac artery (FLIA). Boxplot indicates the median and interquartile range; the red dot indicates the mean value. ABI_{Flexed}, ankle-brachial index in flexed posture (normal value ≥0.54); *SAPD*, systolic ankle pressure difference (normal value ≤23 mm Hg).[18,19]

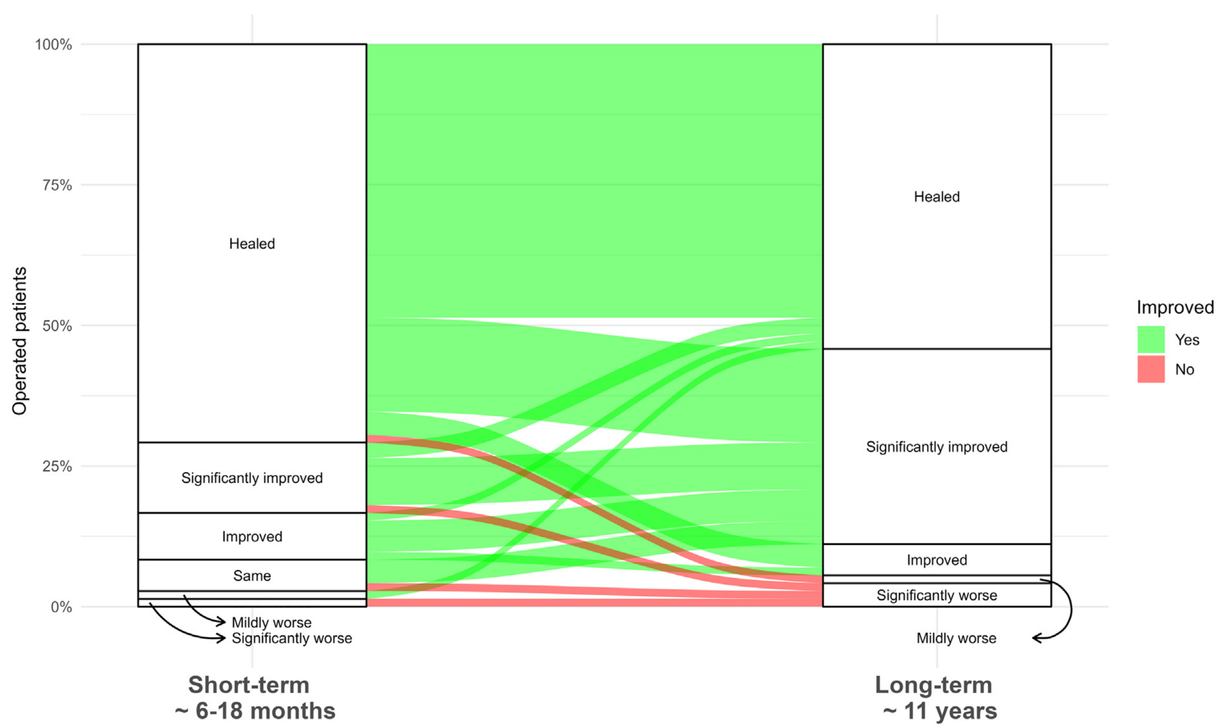

Fig 3. Short-term outcome vs long-term outcome in patients with flow limitations in the iliac artery (FLIA) after surgical reconstruction with closure of an autologous patch.

and speed skaters, underwent an endarterectomy with patching (venous patch $n_{Legs} = 77$, arterial patch $n_{Legs} = 2$). Median patient age at the time of surgery was 34 years (IQR, 26-41 years), and 55.7% were males. Two patients actively smoked (2.5%), and 14 patients had a history of smoking (17.7%). Approximately one-quarter (24.1%) had a family history of cardiac problems or premature atherosclerosis (parents, grandparents, sibling, aunt, or uncle <60 years of age). Most patients (91.1%) performed sports predisposing to FLIA (cycling, triathlon, and/or ice

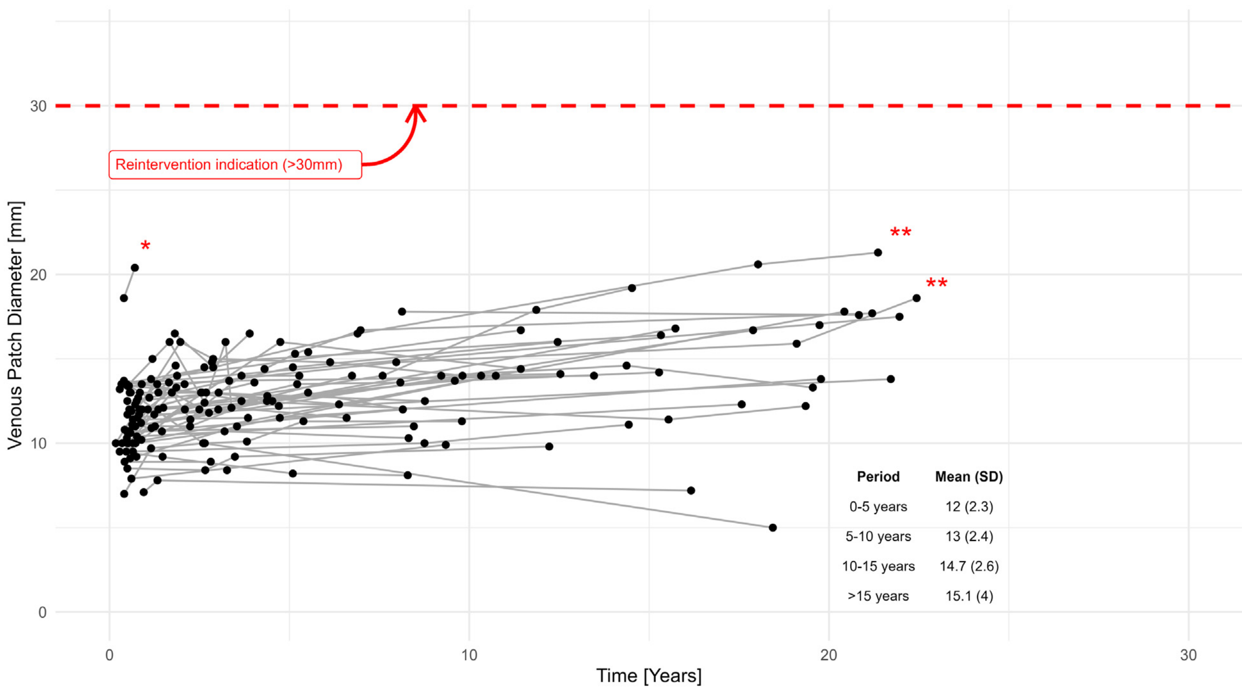

Fig 4. Patch dilatation in patients who received an autologous patch for flow limitations in the iliac artery (FLIA). Red line indicates the reintervention indication (>30 mm) as suggested by the Delphi consensus.[15] Table, mean (standard deviation [*SD*]) diameter at several periods postoperatively. *Operated <1 year for suspected acute dilation. **Patient operated bilaterally, more frequent monitoring required. This patient cycled >700,000 km after his index operations.

speed skating). A slight left leg preponderance (45 left vs 34 right, and both in 11 patients) was found (Table I). Two patients previously underwent arterial shortening for kinking with insufficient relief, and four patients had a previous arterial release (insufficient relief $n_{\text{Patients}} = 3$, recurrent symptoms $n_{\text{Patients}} = 1$). The 30-day mortality was 0 and the 30-day major complication rate was 5.1% ($n_{\text{Legs}} = 4/79$). The number of patients who did not participate in the long-term analysis was small ($n_{\text{Patients}} = 7$). Interestingly, five of these seven patients also did not undergo the short-term analysis. Because the numbers of these nonresponders are very restricted, the chance of nonresponse bias is limited.

Short-term results. Symptom reduction was reported by 91.2%, 6.3% reported no improvement, and 2.6% of patients reported worsening symptoms. A total of 93.7% of patients were overall satisfied (Table II).

Substantial improvement was reached regarding all parameters. Striking were increases in W_{SF} during the cycling test from 226 ± 97 Watts to 333 ± 101 Watts ($P <$ .001) and a greatly improved ankle brachial index (0.34 [IQR, 0.00-0.47] to 0.59 [IQR, 0.51-0.69]; $P <$ .001) (Fig 2 and Table I). Most patients (71.7%) were symptom-free during this maximal cycling test. In the subgroup of patients who continued to report some claudication symptoms, the W_{SF} also increased from 218 Watts (IQR, 148-316 Watts) to 331 Watts (IQR, 234-401 Watts; $P <$ .001).

Echo Doppler examination revealed that the PSV with extended hips and PSV with flexed hips improved from 2.04 $m \cdot sec^{-1}$ (1.52-2.56 $m \cdot sec^{-1}$) to 1.25 $m \cdot sec^{-1}$ (0.92-1.62 $m \cdot sec^{-1}$; $P <$ .001) and 2.40 $m \cdot sec^{-1}$ (1.81-2.81 $m \cdot sec^{-1}$) to 1.15 $m \cdot sec^{-1}$ (0.97-1.61 $m \cdot sec^{-1}$; $P <$ .001), respectively.

Short-term complications (<2 years). The 30-day major morbidity rate was 5.1% ($n_{\text{Legs}} = 4/79$). The first patient required a surgical evacuation of a retroperitoneal hematoma with an uneventful recovery. The second patient developed a patch infection necessitating replacement with a new venous patch 24 days postoperatively. Despite intensive antibiotic treatment, he developed a bleeding on postoperative day 46 at the site of the patch that was treated with an intravascular stent and evacuation of a retroperitoneal hematoma. Culture revealed *Staphylococcus aureus*, possibly contracted from an infected toe nail at the time of the index operation. Two years later, he underwent a novel stent procedure in another hospital and was subsequently again able to participate in a professional world tour cycling team. The third patient suffered from an infected subcutaneous hematoma that was successfully evacuated. The fourth patient developed an iliac occlusion the day after the operation, requiring an iliac and crural thrombectomy and a new venous patch. Interestingly, histologic examination revealed giant cell arteritis, but no sign of endofibrosis or atherosclerosis.

The minor morbidity rate was 3 of 79 (3.8%). The first patient had an allergic skin reaction to iodine that healed in a few weeks. The second patient experienced neuropathic groin pain owing to ilioinguinal nerve traction that resolved in the following weeks. A third patient reported temporary ejaculatory dysfunction that resolved after 6 months. A fair number of patients ($n_{\text{Patients}} = 27$) reported (temporary) superficial groin numbness.

Two patients were reoperated within 1 year after the index operation and were labelled as surgical failures. The first patient, early in this series, was reoperated for possible patch dilatation. The second patient developed a stenosis that was successfully reoperated with a longer venous patch.

Long-term results. A total of 61 of the 65 eligible patients completed the long-term questionnaire after 11.1 years (median, 7.8-17.6; IQR, 93.8% eligible response rate). Three of the 68 original patients had died in the meantime (cancer, car accident, suicide; all $n_{\text{Patients}} = 1$). The participating patients cycled a distance of 125,500 km (IQR 53,500-207,500 km) since surgery. The overall satisfaction was 91.7%. Long-term symptom reduction was similar compared to the short-term results (94.5% vs 91.2%) (Fig 3, Table II).

A lower level of sport participation (eg, competitive vs professional) was reported by one-half of the respondents. Reasons were advanced age (31.9%), role of sports less important (19.4%), ongoing intermittent claudication (11.1%), or another injury (11.1%). Less frequent reasons were lack of time, career switch, family, and/or other medical reasons. Athletes still performed at a competitive (23.6%), recreational (58.3%), or professional level (15.3%). Only two patients (2.8%) had stopped sports altogether, although both still reported satisfaction with the surgical outcome.

Long-term complications. The long-term complication rate was 3.8% ($n_{\text{Legs}} = 3$). One patient developed a restenosis of the EIA owing to intimal hyperplasia 9 months after the index surgery. He was treated successfully with an angioplasty in 2002. A second patient had an acute occlusion of the EIA 2.6 years after the index surgery that was treated successfully with thrombolysis. The last patient developed a restenosis undergoing an unsuccessful angioplasty 7 months postoperatively. Subsequent stenting of the EIA was successful both in the short and long term. Of the two patients who received a stent, it was decided to label the outcomes of these index operations as unsatisfied for overall satisfaction, would not undergo surgery with knowledge of the current result, and significantly worse for symptoms. Local superficial groin numbness continued to be present in seven patients who reported short-term groin numbness.

Histological examination ($n_{\text{Legs}} = 54$). Histology of endovascular material was available in 54 of the operated legs (Table I). Endofibrosis as the only cause of stenosis was confirmed in 88.9% ($n_{\text{Legs}} = 48$). A 26-year-old patient demonstrated signs of both endofibrosis and atherosclerosis (fatty streaks). A second patient aged 51 years had confirmed atherosclerotic disease although endofibrosis was initially suspected. The last four specimens did not contain any characteristic histological abnormalities.

Venous patch dilatation. Fig 4 illustrates diameters of the venous patched segment over time ($n_{\text{Legs}} = 69$). Data were absent in 11 patients (did not present for follow-up $n_{\text{Legs}} = 7$, stent $n_{\text{Legs}} = 2$, arterial patch $n_{\text{Legs}} = 2$). Linear mixed effect model analysis revealed that the only factors contributing to increased patch diameter was sex and time seemingly contributing to a slight increase of the immediate post-operative diameter.[28] The Supplementary Table (online only) provides details of statistical modelling. Interestingly, substantial patient heterogeneity in the evolution of the venous patch diameter over time was observed, as confirmed by the significant patient-specific (linear; eg, random intercept and slope) time effect. This results in the following equation:

$$\textit{Postoperative diameter (mm)} = \underbrace{10.77 + (X_{YEARS} * 0.19) + (X_{SEX} * 1.78)}_{\textit{Fixed effect}} + \underbrace{a_i + (b_i X_{YEARS}) + e_{ij}}_{\textit{Random effect}},$$

where X_{YEARS} is the year after the operation, X_{SEX} is the sex (female = 0, male = 1), a_i is the random intercept, b_i the random slope, and e_{ij} are the residuals.

DISCUSSION

Individuals who perform endurance sports requiring repetitive hip hyperflexion are prone to develop FLIA that may severely hamper a high level performance. If nonoperative treatment fails, surgery such as an iliac artery endarterectomy with or without arterial shortening and closure with an autologous patch may be considered. Our earlier study showed promising short- and mid-term results.[11] The current study shows that the beneficial effects of an endarterectomy are sustained over the years. Long-term complications are minimal, whereas patch diameters are quite stable. However, considering the life expectancy of these otherwise healthy patients is >50 years, continued follow-up of vessel diameter is advised.

In 2012, we reported on the short- and mid-term outcomes of this surgical intervention.[29] At that time, an 89% patient satisfaction rate was found after a mean of 2.4 years. Ammi et al[14] reported a 79% short- to long-term patient satisfaction rate and found improvement or maintenance of athletic performance after a mean of 5.7 ± 4.1 years in 33 patients (n_{Legs} = 34). Wu et al[12] found that 82% were able to return to their prior physical level after a mean of 5.5 years (range, 0.3-16.5 years), although one-half of the population experienced some degree of recurrent symptoms after various surgical techniques including bypass, arterial shortening, or venous patching. Feugier et al[13] reported an improved sports performance in 77% of their 430 participants, and 98% were able to maintain or improve their athletic level in the 3 years after arterial shortening or reconstruction with venous patch. Interestingly, a short- to long-term study in 17 patients with FLIA using a Dacron patch rather than venous material just found a 58.8% overall satisfaction, whereas 17.6% was neutral and 23.5% was unsatisfied after a follow-up of 2.7 years (range, 0.17-6.2 years).[17] The present study using autologous patches found high rates of symptom reduction in the short and long term (91.2% to 94.5%, respectively). A patient might consider the outcome differently resulting in some overlap (eg, one might still experience minor local groin numbness but is able to perform at a maximal effort). Luckily, other questions may reflect satisfaction from a different point of view. For instance, we found a high overall satisfaction level in both the short term (93.7%) and in the long term (91.7%). In addition, similar high rates were found regarding the question whether a patient would have undergone the surgery with the knowledge of the current result (96.2% vs 95.8%, respectively). As such, we believe that, despite some possible overlap accepting some deviations in interpretation, the symptom reduction represents a combined excellent satisfaction. Compared with preoperative performance levels, 95.9% were able to maintain or improve their athletic level in the short term and 69.5% in the long term. These somewhat lower rates of successful long-term performance are likely determined by lower levels of training and competition as well as perceived priorities regarding sport and life that understandably change once getting older.

Given the extreme hemodynamic loading in the iliac arteries in these athletes, it is of paramount importance to understand whether a vein patch can withstand the extreme mechanical and hemodynamic stresses throughout the course of a multiple-year competitive career, and thereafter. The literature on possible patch dilatation is scarce. Peake et al[16] found in a group of 27 patients 1 mild venous patch dilatation (>20 mm) that remained stable over time. Appropriate surveillance protocols for these patients are currently lacking. A 2016 Delphi consensus meeting advised a Doppler ultrasound examination once a year. Intervention is advised if patch dilatation is >30 mm.[15]

The present study found that some degree of patch dilatation is common. Two of our problematic patients need a detailed explanation. The first patient demonstrating patch dilatation of ≤22 mm in the first postoperative year combined with some degree of stenosis distal to the patch underwent a second operation, including patch replacement. However, by that time we had limited experience, because he was one of the first surgical reconstructions. It may have been that the quality of the venous patch during the initial operation was judged wrongly as normal. At present, we now feel confident with our perioperative judgment of the quality of the venous patch. In the second patient, dilatation progressed to 21.4 mm over the course of 21 years after the index operation. Interestingly, this professional cyclist covered >700,000 km postoperatively. He will continue to undergo a yearly check-up. Interestingly, linear mixed model analysis revealed that dilatation is not only determined by time but also by sex as diameter increase is more prominent in males.[28] A standard monitoring program consisting of a first check-up 0.5 to 1.5 years postoperatively followed by a 3-year follow-up examination, and then control every 5 years thereafter is advised.

The current study suffers from a shortcoming including suboptimal follow-up rates owing to logistical, financial, and motivational constraints. It must be appreciated that the whereabouts of professional athletes are mainly directed by international sports events. In addition, insurance companies may not be willing to cover expenses associated with international travelling and follow-up contacts. Moreover, asymptomatic athletes may not feel the urge to undergo these check-ups. We overcame this problem because we invited all patients who did not show up to their advised check-ups for >10 years.

In conclusion, endarterectomy with autologous patching for intermittent claudication owing to iliac artery endofibrosis in endurance athletes with FLIA is safe and successful in the short term and the long term with minimal long-term complications. Although patch diameters are quite stable, a lifetime standard program monitoring of the iliac artery diameter is advised given the life expectancy of these otherwise healthy patients as the majority will continue with extreme hemodynamic loading fitting their competitive lifestyle.

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AUTHOR CONTRIBUTIONS

Conception and design: MVH, FC, GS

Analysis and interpretation: MVH, FC, MB, ML, AB, HS, MS, GS

Data collection: MVH, FC
Writing the article: MVH, FC
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Final approval of the article: MVH, FC, MB, ML, AB, HS, MS, GS
Statistical analysis: MVH, FC, AB
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Additional material for this article may be found online at www.jvascsurg.org.

Supplementary Table (online only). Information on the backward elimination with the Linear mixed model procedure: Model fit comparison

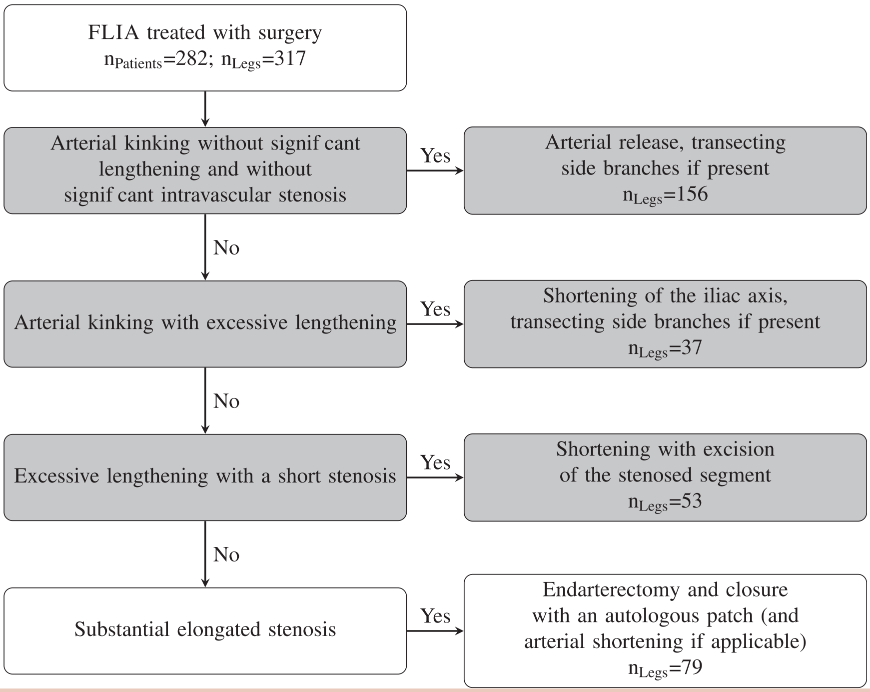
Step		Model name	Meaning	AICc
1	Input models	Mod_1	Random intercept with fixed mean	802.26
		Mod_2	Uncorrelated random intercept and slope	771.62
		Mod_3	Correlated random intercept and slope	773.67
2	Retain model with lowest AICc: Mod_2			
3	Backward elimination (Delete fixed effects deletion with highest *P* value)			

	Fixed effect	*P* value	AICc
i.	Side	.63	769.65
ii.	Length	.28	768.64
iii.	$Age_{Operation}$	.13	768.70
4	Final model: Refit with REML estimation		

Random effects		
Name	**Estimate**	**Standard deviation**
(Intercept)	2.73	1.65
Years (Slope)	0.03	0.16
Residual variance	1.39	1.18

Fixed effects			
Name	**Estimate**	**Standard error**	**T. value**
(Intercept)	10.77	0.34	31.72
Years	0.19	0.03	5.70
Sex	1.78	0.46	3.88

AICc, Second-order Akaike information criterion.
First, the goodness of fit analyses indicated that patient-specific random intercept and slope, independent from each other's was the best choice for our patient data although the variability of the random slope of time was of moderate size (0.02). Then the longitudinal (time) profile is selected with a saturated model (ie, including all fixed effects—years, sex, length, age_operation, and side), then the mean model is optimized deleting the least significant fixed effect term (up to a threshold of 0.10), that is, with the highest *P* value (step 3). Step 4 gives the final linear mixed model effect estimates based on REML estimation.
The T value is the T statistic based on Satterthwaite's method. Pr(>|t|) = statistic *P* value (<.05 is statistically significant).



Supplementary Fig (online only). Flowchart guiding choice of surgery. For athletes with combined causes, a combination of release, shortening, and patching may be indicated. Eight patients had a reintervention encompassing different choice of surgery. *FLIA*, Flow limitations in the iliac artery.