Surgical shortening of lengthened iliac arteries in endurance athletes: Short-term and long-term satisfaction

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ABSTRACT

Objective: Endurance athletes are prone to develop flow limitations in iliac arteries (FLIA). Especially in cyclists and ice speed skaters, excessive hemodynamic loading coupled with hip hyperflexion may cause kinking in lengthened iliac arteries necessitating surgical correction. This study investigated the short-term (≤1.5 years) and long-term (≥5 years) satisfaction of operative shortening of the iliac artery in endurance athletes.

Methods: All patients who were diagnosed and operated for FLIA owing to lengthened and kinked iliac arteries between 1997 and 2015 in one center were analyzed. Short-term follow-up consisted of an incremental maximal cycling test, ankle-brachial index with flexed hips, echo-Doppler examination with peak systolic velocity measurements and contrast-enhanced magnetic resonance angiography before and 6 to 18 months after surgery. Both short- and long-term satisfaction were assessed using questionnaires.

Results: A total of 83 patients (90 operated legs; 96.7% males; median age of 34 years at the time of surgery; interquartile range [IQR], 29-47) were analyzed. In the short-term, 87.5% reported symptom reduction with an 86.4% overall satisfaction rate. Symptom-free cycling improved from 272 ± 84 W to 384 ± 101 W ($P < .001$), whereas the maximal workload increased from 419 ± 72 W to 428 ± 67 W ($P = .01$). The ankle-brachial index with flexed hips increased from 0.55 (IQR, 0.45-0.65) to 0.62 (IQR, 0.52-0.74; $P = .008$), and the peak systolic velocity measured with hips flexed decreased from 2.50 m/s (IQR, 1.77-3.13 m/s) to 1.57 m/s (IQR, 1.20-2.04 m/s; $P < .001$). After a median of 12 years (IQR, 9.0-15.4 years), symptoms were still decreased in 84.1% of patients with an 81.2% overall satisfaction rate (79.5% response rate). Three patients needed a reintervention (recurrent FLIA, n = 2; failure, n = 1).

Conclusions: Operative shortening of a lengthened and kinked iliac artery causing FLIA is successful both in the short- and long-term. (J Vasc Surg 2023;77:588-98.)

Keywords: Surgical technique; Iliac artery; FLIA; Arterial shortening; Endurance athletes

In endurance athletes such as cyclists and ice speed skaters, the iliacofemoral arterial axis is subjected to extreme hemodynamic stress combined with mechanical impingement and strain related to repetitive hip hyperflexion during exercise. A substantial number of these healthy, relatively young individuals experience claudication symptoms owing to flow limitation in the iliac artery (FLIA), including loss of power, pain, muscle cramping, and/or paraesthesias.[1] Atherosclerosis is seldom the underlying cause of this entity.[2,3]

Diagnosing the type of sport-related FLIA is required for determining the optimal management strategy.[4,5] Without treatment, FLIA often deteriorates and may occasionally lead to an arterial occlusion.[2,4] Conservative treatment includes attaining a more upright cycling posture and limiting or avoiding provocative sports.[1,2,6] If conservative treatment fails or if the patient chooses to continue provocative sports activities, iliac artery release, shortening, or endarterectomy with the use of an autologous patch may be indicated.

The categorization and pathology of FLIA are largely unknown. However, we propose that three overlapping types may be distinguished. Patients may experience symptoms either in isolation, or in combination owing to (1) arterial kinking with normal vessel length, in which kinking is triggered often by a psoas side branch or owing to adhesions and scarring, (2) excessive arterial lengthening, which causes or aggravates kinking with or without a short stenosis, or (3) an elongated endofibrotic stenosis. It is highly likely that an unknown proportion of patients

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suffer from a combination of these types.[7,8] If FLIA is exclusively due to iliac artery lengthening and kinking in the absence of other pathology, shortening of the artery is preferred.[2,7] This procedure avoids the use of a venous patch and therefore decreases the risk of potential complications (eg, dilatation). Kinking combined with a short substantial stenosis may require shortening combined with endarterectomy and/or excision of the stenosis.[9-11] In a Delphi consensus, 75% of the participating experts did not believe that arterial kinking alone (with or without excessive lengthening) can cause FLIA in athletes. Earlier studies on isolated arterial kinking research may suggest otherwise.[4,5,10-12] The aim of the present study was to determine satisfaction after surgical treatment in patients suffering with FLIA owing to arterial kinking in the presence of excessive arterial lengthening.

ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center retrospective cohort study
- **Key Findings:** This study describes effectivity, durability and satisfaction of a technique termed surgical shortening of excessive lengthy iliac arteries in 83 endurance athletes having flow limitations in the iliac artery. Outcome was successful with an 81.2% satisfaction rate whereas 84.1% reported persistent symptom reduction after a median of 12 years of follow-up.
- **Take Home Message:** Operative iliac artery shortening is beneficial both in the short- and long-term in most patients with flow limitations in the iliac artery.

METHODS

Participants. Endurance athletes diagnosed with FLIA caused by an excessive iliac arterial length inducing arterial kinking who underwent surgery between 1997 and 2015 were studied. Our center is the only referral center in the Netherlands also treating a substantial portion of patients from outside the country. All patients were diagnosed on the basis of a typical patient history (exercise intensity related leg pain and loss of power), a physical examination excluding other causes, echo-Doppler examination showing characteristic abnormalities (excessive lengthening), maximal exercise test followed by simultaneous ankle and arm blood pressure measurements, and detailed imaging with contrast-enhanced magnetic resonance angiography (CE-MRA) in both supine and flexed hips confirming abnormalities as suggested on echo Doppler imaging.[4,5]

The maximal cycling exercise test (Excalibur Sport, Lode, Groningen, the Netherlands) assessed the maximal workload. Patients were instructed to identify when and where claudication complaints started. The accompanied workload was considered as the symptom-free workload (W_{SF}). Immediately after this test, blood pressure was obtained with the trunk in a horizontal position and flexed hips mimicking the competitive posture followed by measuring simultaneous blood pressures to calculated the adapted ankle-brachial index with flexed hips (ABI_{Flexed}). The diagnostic threshold value of ABI_{Flexed}, immediately after exercise in these athletes is less than 0.54. A more than 23 mm Hg difference between legs is also considered abnormal.[4,5] Routine ABI during rest was not obtained because earlier experiences in our vascular laboratory demonstrated that these values are almost always normal in highly trained elite athletes. Additional information regarding methodology is provided in our previous studies.[4,5,12]

In most cases, conservative treatment including cycling in a more upright posture and limiting or avoiding provocative sports was advised. After 3 months, all athletes were counselled on the effect of this approach. If conservative treatment failed, CE-MRA (before 2010 Gyroscan T10-NT [1 Tesla]; after 2010 Achieva Nova Dual [1.5 Tesla], both Philips Medical Systems, Best, the Netherlands) with flexed and extended hips was performed to visualize the underlying mechanism(s) causing FLIA (Fig 1, *E-H*) and confirming the abnormalities seen during Doppler ultrasound examination.[11,13]

Vessel lengths were judged clinically because no accurate measurement was available at the time of treatment. In earlier research, detailed measurements in a research setting determined possible lengthening as a ratio of the real centerline vessel length and the straight-line distance. The results indicated that there is a large group with fairly normal vessels (common iliac artery [CIA] and external iliac artery [EIA] ratio of <1.1), an intermediate group (ratio 1.10-1.15), and a group with extremely long vessels (>1.15).[13]

Shortening in patients with normal vessel length is not indicated. However, shortening is required in vessels with extreme length and kinking. In cases of intermediate vessel lengths, the most optimal intervention was judged by our surgeon during surgery. After full exposure of the iliac artery, shortening of the vessel was performed if excessive length was observed and kinking occurred by flexing the hip. Patients who had undergone surgical arterial shortening for iliac lengthening and kinking qualified for this study. Cases with a concomitant localized stenosis within the lengthened artery that was resected in the same procedure were included and their satisfaction was also analyzed separately. Patients who had an earlier unsuccessful iliac arterial surgical release and were reoperated for arterial shortening were also included. The study protocol was approved by the hospital's medical ethical committee registered under number N19.062 and in accordance with the recommendations of Declaration of Helsinki. The study is registered in the Dutch Trial Register (Trial NL8553).

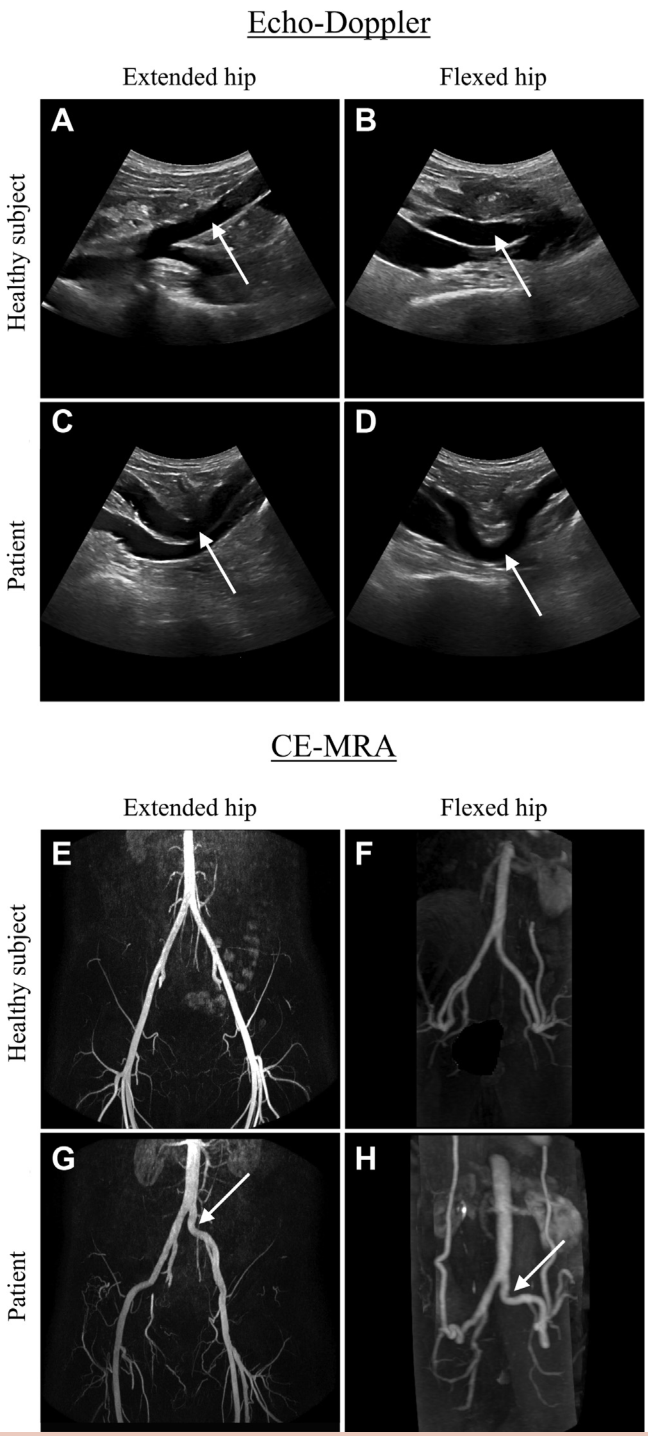


Fig 1. A-D, Echo Doppler examination. In the healthy subject, the iliac axis follows a normal course with extended and flexed hip (**A**, and **B**, *white arrows*). In a patient with FLIA owing to lengthening, the iliac external artery is lengthened in rest, and kinks with flexed hips **(C**, and **D**, *white arrows*). **E-H**, Contrast-enhanced magnetic resonance angiography (*CE-MRA*). In a healthy subject, the visualization of arteries with extended and flexed hips is rather straight **(E and F)**. In contrast, excessive lengthening in a FLIA patient may already be present with extended hips (**G**, *white arrow*). Moreover, kinking with flexed hips may occur (**H**, *white arrow*).[13]

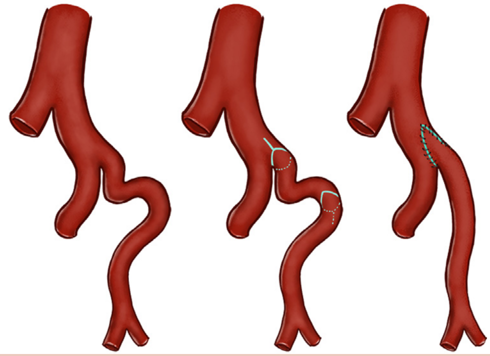


Fig 2. Surgical shortening of the external iliac artery.

Surgical treatment. When echo-Doppler and/or CE-MRA confirmed arterial kinking in combination with an excessive length, patients were extensively counselled on the details of surgery including potential complications, follow-up regimen and short- and long-term success rates. The type of surgery was chosen as shown in Supplementary Fig, (online only). One vascular surgeon (M.B.) operated on all patients.

Entrance to the retroperitoneal space is attained via a 6- to 8-cm incision some 3- to 4-cm cranial and parallel to Poupart's ligament. If both the CIA and EIA demonstrated excessive lengthening, the entire iliac axis requires dissection including the first 4 cm of the internal iliac artery. Once the dissected iliac bifurcation projects in the center of the operative field, the iliac bifurcation is the optimal and safe location to shorten the axis. In contrast, shortening of the middle portion of either the EIA or the CIA would potentially create a stiff section with risk of subsequent stenosis and/or arterial kinking. The natural fixation of the iliac axis is at the aortic, iliac and femoral bifurcation. Adding a scar with subsequent stiffness in a flexible portion of the external or CIA can provoke local kinking on bending. Both the CIA and EIA are straightened to determine how much of the EIA (or CIA) requires resection to achieve a straight line medioventrally on the psoas muscle. In most cases, the EIA is transected at its origin at a 45°angle and the redundant section is removed. The CIA is incised ventrally for 2 cm and an oblique suture line is applied as a sleeve technique creating a wide anastomosis (Fig 2). Additional (eversion) endarterectomy is occasionally performed in patients having a thickened intima. The wound is closed in layers using absorbable sutures.

Nonsteroidal anti-inflammatory drugs were given as standard pain management for 1 week postoperatively. Additionally, patients received 80 mg of acetylsalicylic acid once daily for 1 month to prevent platelet aggregation. They were advised to perform circumduction exercises of the hip joint for 5 weeks to minimize unfavorable fixation of the artery during scar formation. Patients followed a 2-month incremental recovery program. Low resistance cycling was allowed after 6 weeks that progressed to medium to high intensity in the following 3 weeks. Unrestricted training was allowed after 9 weeks. Recovery was monitored by phone appointments after 2 and 8 weeks. After 6 to 18 months, a physical check combined with repeated tests was scheduled. Patients were advised to undergo echo-Doppler control of arterial integrity after 1 and 3 years, and subsequently every 5 years.

Short-term follow-up. Short-term satisfaction was evaluated 6 to 18 months after surgery and consisted of history taking, physical examination, and a maximal cycling exercise test with ABI_{Flexed} measurements. To visualize and verify a successful intervention, echo-Doppler and CE-MRA imaging were performed. As a validated questionnaire was lacking, we designed a questionnaire tabulating residual complaints, overall satisfaction, ability to perform sports at the desired level and current sports activities (Supplementary File 1, online only). The outcomes were categorized as healed, significantly improved, improved, same, mildly worse and significantly worse.

Long-term follow-up. Patients were approached via phone, postal mail, or e-mail for long-term follow-up. If they agreed, an informed consent form was sent by postal mail. If the patient could not be reached or did not respond after two attempts, the hospital's medical ethical committee permitted the use of relevant preoperative, perioperative, and postoperative data that were previously stored in the electronic patient file. A long-term questionnaire was created (Supplementary File 2, online only) that was largely identical to the short-term version with additional items concerning medical events and reasons for changes in level of sport.

In some cases, secondary surgery was indicated for residual or recurrent symptomatic FLIA. If there were persistent complaints and secondary surgery was performed within 2 years after the initial shortening operation, the result of this first operation was tabulated as poor. If a patient reported an initial success but secondary surgery was necessary after more than 2 years, it was considered a recurrent vascular problem. These patients were asked to complete the questionnaire regarding the current status after their second intervention. Their answers regarding the arterial shortening were labelled as unsatisfied, would not undergo surgery with knowledge of the current result and significantly worse.

Statistical analysis. Data were expressed as mean ± standard deviation in case of normal distribution, and as median with an interquartile range (IQR) if not. Data normality was tested using the Shapiro-Wilk test and visual inspection histogram on skewness and kurtosis. Categorical data were presented as counts with proportions. Because seven patients underwent a bilateral operation, most analyses were performed on legs instead of patients. A sensitivity analysis tested potential differences in baseline characteristics between the study group and those who did not complete the long-term questionnaire. The Fisher exact test determined group differences in categorical data. The omnibus McNemar-Bowker test was performed for determining potential differences within-patient categorical data between the short- and long-term follow-up. In case of statistical differences, a pairwise post hoc McNemar test with Bonferroni correction for multiple tests was used. The McNemar test examines consistency rather than independence in repeated measures and is therefore considered a suitable tool for analyzing dichotomous preoperative and postoperative results. The overall number of responses regarding the postoperative symptoms were too low. It was, therefore, arbitrarily chosen to change the six-category levels into four levels by combining significantly worse and mildly worse to worse, and significantly improved and improved to improved, allowing for statistical analysis. In case of a normal distribution, a paired t test was used within the patient group, and an unpaired t test between participating patients and the patients that did not fill in the long-term questionnaire. Otherwise, a Wilcoxon signed rank or Mann-Whitney U test was used. All statistics were performed using the software R (version 4.0.4, Vienna, Austria).[14] A P value of less than .05 was considered statistically significant.

RESULTS

Study group. From 1997 to 2015, three different populations of patients with FLIA underwent surgery in our facility. We here report on a total of 83 patients (90 legs) who underwent a surgical arterial shortening procedure for FLIA. During the same period, we also treated 156 legs with FLIA with an arterial release.[12] In addition, 79 legs with FLIA underwent endarterectomy and closure with an autologous patch (arterial patch n = 3; venous patch n = 76) (Supplementary Fig, online only).

The 30-day mortality rate in these 83 patients was 0. The 30-day morbidity was 2.2% as a surgical evacuation of a retroperitoneal hematoma was required in two operated legs. Baseline characteristics of all patients are depicted in Table I (and in Supplementary Table I (online only) extensively with those who did and did not fill out the long-term questionnaire separately). The median age was 34 years (IQR, 29-47 years). One patient actively smoked and 10 patients had a history of smoking; 18.9% had a positive family history of cardiac problems at less than 60 years of age (parents, sibling, aunt, or uncle), atherosclerosis, or FLIA. One individual had a brother with endofibrosis at the age of 23 years. Most patients (98.9%) were cyclists, triathletes, and/or ice speed skaters. A substantial left-sided preponderance (63 left vs 13 right, 7 both) was found. Two patients had a previous arterial release operation for FLIA (earlier poor outcome n = 1,

Table I. Characteristics and imaging data of patients undergoing iliac artery shortening for FLIA

			Patients ($n_{Patients}$ = 83; n_{Legs} = 90)
Age during operation, years			34 (29-47)[a]
Male			87 (96.7)
Female			3 (3.3)
BMI (kg/m^2)			23.0 (21.6-24.5)
Family history			
Yes			17 (18.9)
No			73 (81.1)
Smoking (history)			
Yes			1 (1.1)
No			79 (87.8)
Ex-smoking			10 (11.1)
Type of sports (multiple answers possible)			
Cycling			81 (90.0)
Speed skating			26 (28.9)
Triathlon			5 (5.6)
Running			3 (3.3)
Level			
Professional			23 (25.6)[a]
Competition			44 (48.9)
Recreational			23 (25.6)
Years of complaints until operation			2.6 (1.3-4.8)
Cycled before onset of complaints, km			138,500 (94,000-217,500)
Cycled until operation, km			200,000 (138,750-325,000)
Side of operation (limbs)			
Left			63 (75.9)
Right			13 (15.7)
Both			7 (8.4)
Location of arterial shortening			
Proximal CIA			4 (4.4)
Central CIA			7 (7.8)
Distal CIA			5 (5.6)
Proximal EIA			73 (81.1)
Central EIA			1 (1.1)
Distal EIA			0 (0.0)
Histological examination[b]			
Endofibrosis			47 (69.1)
Atherosclerosis			7 (10.3)
Both			4 (5.9)
No abnormalities			10 (14.7)
Preoperative and postoperative imaging data	**Legs (n)**	**Before**	**After**
Duplex (echo-Doppler)			
$PSV_{Extended}$ in the EIA, m/s	75	1.47 (1.20-1.87)	1.34 (0.99-1.67)[c]
PSV_{Flexed} in the EIA, m/s	74	2.50 (1.77-3.13)	1.57 (1.20-2.04)[c]
Duplex and/or CE-MRA			

Table I. Continued.

Preoperative and postoperative imaging data	Legs (n)	Before	After
Detection of functional kinking	74		
Detected		74 (100.0)	5 (6.8)[c,d]
Not detected		0 (0.0)	69 (93.2)
Detection of excessive lengthening	75		
Detected		62 (82.7)	1 (1.3)[c]
Not detected		13 (18.3)	74 (98.7)
Detection of a stenosis[e]			
Detected		49 (62.8)	14 (17.9)[c]
Not detected		29 (37.2)	64 (82.1)

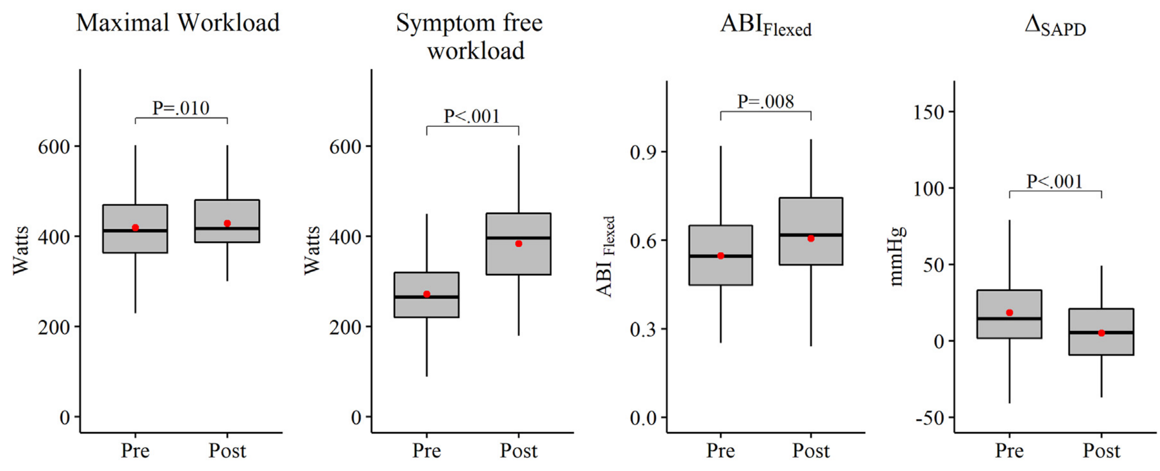
BMI, Body mass index; *CE-MRA*, contrast-enhanced magnetic resonance angiography; *CIA*, common iliac artery; *EIA*, external iliac artery; *PSV*, peak systolic velocity.
Variables are presented per leg instead of per patient because some patients had surgery on both legs. Data are presented as the median (interquartile range) or as frequencies and proportion of total operated legs (%). Imaging data are presented as complete cases.
Normal values for $PSV_{Extended}$ and PSV_{Flexed} are <1.48 and <1.70 m/s respectively.
[a]Significant difference between the participating and the group that did not fill in the long-term questionnaire.
[b]Missing values, owing to, for example, logistic reasons or insufficient tissue.
[c]Significant difference between before and after surgery.
[d]Only echo detection for arterial kinking is present while CE-MRA postoperatively with flexed hips was not performed.
[e]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.

recurrence n = 1). Two patients of the present case series later underwent endarterectomy and closure with a venous patch for ongoing claudication symptoms.

Short-term results ($n_{Patients}$=83; n_{Legs}=90). During the postoperative evaluation at 8.0 months (IQR, 6.3-10.3 months) after surgery, 64.1% of the patients had no complaints at all at maximal workload. W_{SF} increased from 272 ± 84 to 384 ± 101 W ($P < .001$). The maximal workload significantly increased from 419 ± 72 to 428 ± 67 W ($P = .01$). ABI_{Flexed} values after maximal exercise improved from 0.55 (IQR, 0.45-0.65) to 0.62 (IQR, 0.52-0.74), and the pressure difference between legs decreased from 14 mm Hg (IQR, 2-32 mm Hg) to 5 mm Hg (IQR, −9 to 21 mm Hg) ($P = .008$ and $P < .001$, respectively) (Fig 3; Table II and Suplementay Table II, online only). The PSV with flexed hips decreased from 2.50 m/s (IQR, 1.77-3.13 m/s) to 1.57 m/s (IQR, 1.20-2.04 m/s) ($P < .001$). A symptom decrease was observed in 87.5% of the patients, whereas the overall satisfaction rate was 86.4%. Postoperatively, patients reported the same (10.0%), a slight improvement (25.7%), or a large improvement (50.0%) in performance level compared with their preoperative abilities. In ten patients (14.3%), a lower performance level (which might be due to a lower training state) was observed, three of which were unsatisfied in the long-term. Minor complications, reported at the postoperative examination, were predominantly transient superficial groin numbness (13.3%). One patient observed an asymptomatic fibrotic swelling, at the level of the external oblique fascia that was not considered a short-term complication.

Long-term satisfaction ($n_{Patients}$ = 66; n_{Legs} = 70). In Fig 4, short- and long-term complaint reduction after the operation is illustrated. Symptom reduction continued to be high (84.1%) in the long-term, and the McNemar test showed no significant difference between short- and long-term results within individual patients. Overall satisfaction also remained high (81.2%) with no significant difference compared with short-term satisfaction rates.

A total of 42.9% of the patients reported a lower training level 12.0 years (IQR, 9.0-15.4 years) after surgery. Whereas in the questionnaire more answers were possible, approximately one in three patients judged that the role of sports had become progressively less important in their lives as expected after a median of 12 years of performing on a highly competitive or professional level. Advanced age was reported as the cause by 14.3% of the patients, and 18.6% explained a lower level of performance owing to ongoing or recurrent FLIA. A smaller group (12.9%) reported another injury as the cause of decreased sports level. Additional reasons were lack of time, non-FLIA-related medical problems (such as cardiac problems, cerebral infarction, diabetes, and increased complaints of asthma), changes in type of sports, family, and work. With advancing age, ambition level decreased; most athletes performed sports at a decreased competitive (25.8%) or recreational level (63.6%). In addition, only a small group (7.6%) had stopped exertional sports activities all together. In the long-term, 5.7% reported some persistent numbness in the area of the groin and/or upper leg, possibly reflecting nerve damage related to the suprainguinal incision.



	Pre	Post
n	77	77
mean	419	428
sd	72	67
median	412	417
q1	363	387
q3	470	480

	Pre	Post
n	68	68
mean	272	384
sd	84	101
median	265	396
q1	220	315
q3	320	450

	Pre	Post
n	77	77
mean	0.55	0.61
sd	0.17	0.19
median	0.55	0.62
q1	0.45	0.52
q3	0.65	0.74

	Pre	Post
n	76	76
mean	18	5
sd	26	21
median	14	6
q1	2	-9
q3	33	21

Fig 3. Maximal workload, (W_{SF}), ABI_{Flexed}, and pressure difference after arterial shortening 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); *q1*, first quartile, *q3*, third quartile; *SAPD*, systolic ankle pressure difference (normal value, ≤23 mm Hg); *sd*, standard deviation, *W_{SF}*, symptom-free workload.[4,5]

Histological examination (n_{Legs} = 68). On histological examination, a total of 69.1% of the resected arteries contained endofibrosis as a single abnormality. In addition, 10.3% demonstrated atherosclerosis, and 5.9% a combination of the two. Histological abnormalities were absent in 14.7% of the patients. Of the five of these patients who also completed the long-term questionnaire, four were satisfied with the long-term outcome. In patients who did show endofibrosis, imaging and/or intraoperative findings demonstrated a substantial stenosis in 70.6%.

Secondary surgery. A total of three patients (n_{Legs} = 3 [3.6%]) underwent a surgical reintervention. The first patient developed arterial kinking and a substantial stenosis at the suture line. After a surgical reconstruction using a venous patch 1.5 years later the patient reported a significant improvement. The second patient developed endofibrotic narrowing of the EIA and was cured after surgical reconstruction with venous patching 2 years later. The last patient developed a persistent kink in the CIA that was treated with a stent in another hospital 8 years later.

DISCUSSION

Individuals performing endurance sports that require extreme hip flexion are at risk of developing lengthening and kinking of the iliac artery, possibly leading to FLIA. They experience claudication symptoms that may be severely disabling. If conservative measures fail, shortening of the iliac artery may be indicated. The aim of the present study was to determine satisfaction after this surgical procedure. Stable high rates of overall satisfaction and symptom reduction as well as an improved overall performance were illustrated by the finding that most athletes were able to continue their sports on a desired competitive or professional level.

During a Delphi consensus regarding the statement, "Shortening alone of the EIA is effective in treating iliac endofibrosis" all participating experts disagreed to this, including us.[8] In the present study, however, we demonstrate that there is a subgroup of patients with excessive arterial length without endofibrosis (or with only a short segment of endofibrosis that is excised during the same procedure) who benefit from just arterial shortening. A total of 87.5% of these patients experienced symptom reduction afterward. This percentage did not change significantly in the long-term. In addition, 75.7% reported improved performance levels when compared with the preoperative situation. This somewhat lower percentage can be attributed to the fact that performance level is not only determined by complaints of FLIA, but also by the state of training. A few patients who were satisfied with the overall result had a lower performance level given their lower state of training. This outcome is also reflected in the short-term overall satisfaction rate, which was high (86.4%) and remained high in the long-term (81.2%). Stable high rates of overall

Table II. Short- and long-term results per operated leg after surgical arterial shortening for flow limitations in the iliac artery (FLIA)

	Short-term			Long-term
	Total ($n_{Patients} = 83$; $n_{Legs} = 90$)	Participating in long-term questionnaire ($n_{Patients} = 66$; $n_{Legs} = 70$)	Patients who did not fill out the long-term questionnaire ($n_{Patients} = 17$; $n_{Legs} = 20$)	Participating in long-term questionnaire ($n_{Patients} = 66$; $n_{Legs} = 70$)
Follow-up, years	0.7 (0.5-0.9)	0.6 (0.5-0.9)	0.8 (0.6-1.0)	12.0 (9.0-15.4)[a]
Satisfied total group				
Yes	76 (86.4)	59 (85.5)	17 (89.5)	56 (81.2)
No	12 (13.6)	10 (14.5)	2 (10.5)	13 (18.8)
Satisfied patients without a substantial stenosis[b]				
Yes	15 (75.0)	13 (76.5)	2 (66.7)	16 (94.1)
No	5 (25.0)	4 (23.5)	1 (33.3)	1 (5.9)
Satisfied patients with excision of the substantial stenosis[b]				
Yes	47 (88.7)	36 (87.8)	11 (91.7)	31 (75.6)
No	6 (11.3)	5 (12.2)	1 (8.3)	10 (24.4)
Would undergo surgery with knowledge of the current result				
Yes	81 (91.0)	64 (91.4)	17 (89.5)	61 (87.1)
No	8 (9.0)	6 (8.6)	2 (10.5)	9 (12.9)
Cycled after surgery, km	5000 (3000-8000)	5000 (3000-7500)	8000 (4000-8000)	118,000 (72,000-161,000)[a]
Sports level[c]				
Professional	23 (25.6)	14 (20.0)	9 (45.0)	2 (3.0)
Competitive	44 (48.9)	34 (48.6)	10 (50.0)	17 (25.8)
Recreational	23 (25.6)	22 (31.4)	1 (5.0)	42 (63.6)
Quit sports	–	–	–	5 (7.6)
Complaints[c]				
Healed	43 (48.9)	32 (45.7)	11 (61.1)	26 (37.7)
Significantly improved	22 (25.0)	18 (25.7)	4 (22.2)	16 (23.2)
Improved	12 (13.6)	10 (14.3)	2 (11.1)	16 (23.2)
The same	8 (9.1)	7 (10.0)	1 (5.6)	4 (5.8)
Mildly worse	2 (2.3)	2 (2.9)	0 (0.0)	4 (5.8)
Significantly worse	1 (1.1)	1 (1.4)	0 (0.0)	3 (4.3)

Values are median (interquartile range) or number (%).
[a]Significant difference between the short- and long-term variables (complete-case analysis).
[b]Based on imaging (<15% stenosis) or intraoperative findings.
[c]Empty or low counts prevent accurate testing.

satisfaction and symptom reduction as well as an improved overall performance were also illustrated by the finding that most athletes were able to continue their sports on a desired competitive or professional level.

It may be questioned why a 100% success rate was not attained. A total of 13 patients reported unsatisfactory results in the long-term. Six of these patients had residual abnormalities (eg, kinking at the suture line and/or [minor] stenosis). One additional patient chose arterial shortening rather than venous patching given the smaller chance of complications while accepting the possibility of residual symptoms owing to persistent stenosis. Patient number eight also underwent a suboptimal arterial shortening; in hindsight, a vascular reconstruction with closure of a venous patch was required that was performed 2 years later with a good outcome. In four additional patients, other intercurrent illnesses or injuries (eg, Lyme disease, fibromyalgia, lumbar spine fracture, and nerve entrapment) were thought to cause FLIA-like complaints; no vascular abnormalities were found during imaging. We have no information on why the last patient was dissatisfied.

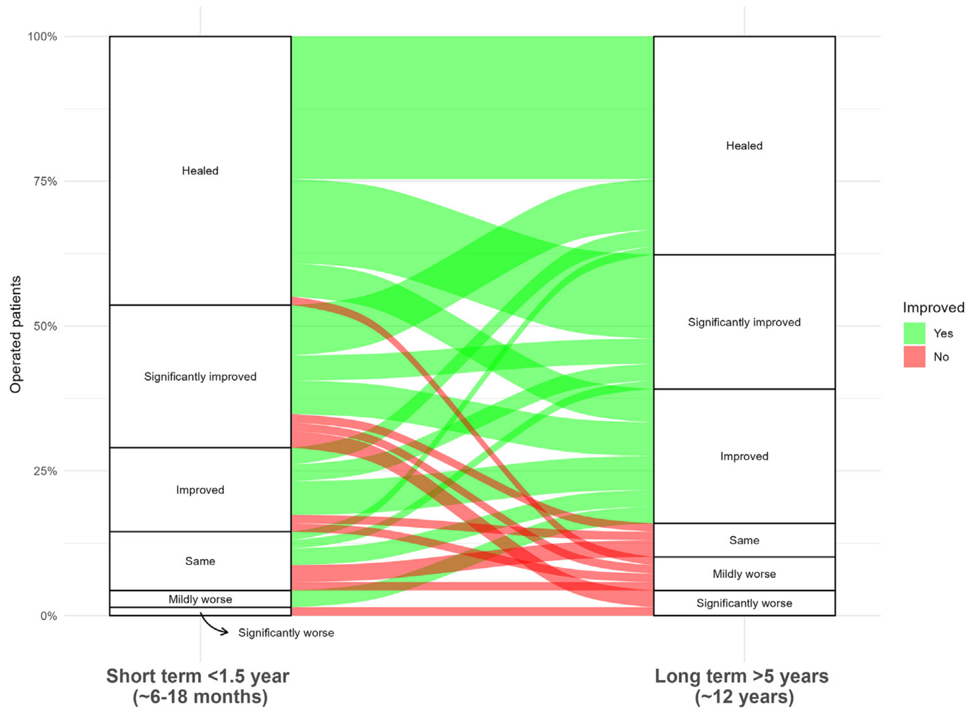


Fig 4. Short- and long-term flow limitations in the iliac artery (FLIA)-related complaints after iliac arterial shortening in endurance athletes (compared with preoperative situation, complete case analysis).

Values of the ABI_{Flexed} were in the normal range preoperatively (0.55; normal threshold value, ≥0.54).[4,5] This finding is in line with earlier findings reporting on a sensitivity of only 43%. As such, our study group ranged from subtle to evident cases of FLIA. The ABI_{Flexed} significantly increased postoperatively from 0.55 (IQR, 0.45-0.65) to 0.62 (IQR, 0.52-0.74). These values differ from standard ABI measured during a (sub)maximal treadmill test. A maximal exercise provocation will often result in a lowered ABI_{Flexed} in healthy individuals. This reaction is considered as a normal physiological response owing to vasodilation after diminished vascular peripheral resistance. For instance, one study found an ABI_{Flexed} of 0.75 ± 0.13 after exercise in healthy subjects.[5] Conversely, the difference between a symptomatic and asymptomatic cycling experience after surgery may be reflected by just a small increase in ABI_{Flexed} as demonstrated in our athletes.

Studies on outcomes after just iliac shortening in this subtype of FLIA were hitherto not performed. However, one study reporting on a combination of various arterial reconstructions including shortening, endarterectomy with vein patch as well as eversion endarterectomy showed a 79% long-term satisfaction rate in a smaller FLIA population (n = 33).[15] A second study with 18 patients reported that 82% were able to return to their prior physical level, yet one-half experienced residual symptoms.[16] A third study on arterial shortening or reconstruction with a venous patch including 350 individuals reported an 87% short-term satisfaction rate. After 5 years, improved sports performance was demonstrated in 77%.[17] Although these three studies all included patients who received a venous patch, the outcomes are comparable with our study. In contrast, the present study is unique; vascular reconstruction only entailed resection of a portion of the artery with an anatomic reconstruction without venous patching. Theoretically, the risk of restenosis is diminished as the suture line is applied with an oblique geometry at the relative wide iliac bifurcation.[2,7,18]

Diverse imaging techniques are used currently for detecting excessive arterial length in patients with FLIA. Optimally, a definite diagnosis is preoperatively provided by a combination of echo-Doppler and CE-MRA. In some patients who were scheduled for an arterial release, perioperative findings revealed unforeseen excessive lengthening after the arterial release. As such, in 13 legs imaging did not preoperatively identify excessive lengthening that was found during surgery (Table I; Supplementary Table II, online only). In 12 of these patients, arterial shortening was executed as the release was judged not solve the problem and excessive length was considered to cause the kinking. One additional patient had a previous successful arterial release for FLIA, but developed symptomatic kinking with narrowing some years later. He was planned for shortening with venous patching, but during the operation the cause of the narrowing seemed to be a dense connective tissue sheath around the CIA, which was removed successfully. Venous patching to the remaining fragile vascular wall was considered an unnecessary additional risk. Unfortunately, the long-term outcome was unsuccessful in his case. These findings underline the diagnostic complexity of FLIA. Therefore, each patient is preoperatively counselled on the various surgical options, but details of the surgery are guided ultimately by the intraoperative findings.

In 29.4% of patients treated with arterial shortening who did show endofibrosis on histologic examination, neither imaging nor intraoperative findings demonstrated any substantial stenosis. This finding suggests that endofibrosis can be present in the intimal wall without a visible stenosis (yet). Without a visible stenosis, we do not embark on patch angioplasty given the inherent risks and the high satisfaction rates of arterial shortening alone.

A left preponderance was noted as also reported in other studies.[12,19] This might be caused by the left-sided position of the aorta causing the left CIA being shorter and having a sharper aorta-iliac take-off angle.[20]

The current study has limitations owing to missing data at short-term follow-up, likely caused by reimbursement issues. Although an almost 100% response on the short-term questionnaire was obtained, actual measurements could only be obtained in approximately 80% of the operated legs; in addition, quite a few patients were living abroad. The response to the long-term questionnaire was 79.5%. A sensitivity analysis found that the non-responding group was younger, performed sports at a higher level and attained a higher preoperative W_{SF} (details in Supplementary Table II, online only). However, differences in overall short-term satisfaction rates and symptoms between the responders and nonresponders were absent. It is assumed that long-term data between these groups are also similar.

In conclusion, the vast majority of athletes who suffer from a type of FLIA owing to a lengthened and kinked iliac axis with or without a short stenosis benefit from arterial shortening. A venous patch is not required in these cases reducing complexity and associated risks while maintaining a high rate of short- and long-term satisfaction.

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AUTHOR CONTRIBUTIONS

Conception and design: MvH, GS
Analysis and interpretation: MvH, DF, MB, ML, AB, HS, GS, MS
Data collection: MvH, DF
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Final approval of the article: MvH, DF, MB, ML, AB, HS, GS, MS
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Additional material for this article may be found online at www.jvascsurg.org.

Supplementary Table I (online only). Characteristics of patients undergoing iliac artery shortening for flow limitations in the iliac artery (FLIA)

	Total group ($n_{Patients}$ = 83; n_{Legs} = 90)	Participating in long-term questionnaire ($n_{Patients}$ = 66; n_{Legs} = 70)	Patients who did not fill out the long-term questionnaire ($n_{Patients}$ = 17; n_{Legs} = 20)
Age during operation, years	34 (29-47)	38 (31-49)	32 (27-34)[a]
Sex			
Male	87 (96.7)	67 (95.7)	20 (100.0)
Female	3 (3.3)	3 (4.3)	0 (0.0)
BMI (kg/m^2)	23.0 (21.6-24.4)	23.1 (21.7-24.7)	22.4 (21.4-24.3)
Family history			
Yes	17 (18.9)	12 (17.1)	5 (25.0)
No	73 (81.1)	58 (82.9)	15 (75.0)
Smoking (history)			
Yes	1 (1.1)	1 (1.4)	0 (0.0)
No	79 (87.8)	62 (88.6)	17 (85.0)
Ex-smoking	10 (11.1)	7 (10.0)	3 (15.0)
Type of sports[b]			
Cycling	81 (90.0)	61 (87.1)	20 (100.0)
Speed skating	26 (28.9)	23 (32.6)	3 (15.0)
Triathlon	5 (5.6)	5 (7.1)	0 (0.0)
Running	3 (3.3)	3 (4.3)	0 (0.0)
Level			
Professional	23 (25.6)	14 (20.0)	9 (45.0)[a]
Competition	44 (48.9)	34 (48.6)	10 (50.0)
Recreational	23 (25.6)	22 (31.4)	1 (5.0)
Years of complaints until operation	2.6 (1.3-4.8)	2.4 (1.3-4.8)	3.2 (1.8-4.7)
Cycled before onset of complaints, km	138,500 (94,000-217,500)	134,000 (92,000-175,000)	164,000 (115,000-275,000)
Cycled until operation, km	200,000 (138,750-325,000)	175,000 (131,000-325,000)	225,000 (194,500-312,500)
Side of operation, limbs[b]			
Left	63 (75.9)	50 (75.8)	13 (76.5)
Right	13 (15.7)	12 (18.2)	1 (5.9)
Both	7 (8.4)	4 (6.1)	3 (17.6)
Location of arterial shortening[c]			
Proximal CIA	4 (4.4)	4 (5.7)	0 (0.0)
Central CIA	7 (7.8)	6 (8.6)	1 (5.0)
Distal CIA	5 (5.6)	5 (7.1)	0 (0.0)
Proximal EIA	73 (81.1)	54 (77.1)	19 (95.0)
Central EIA	1 (1.1)	1 (1.4)	0 (0.0)
Distal EIA	0 (0.0)	0 (0.0)	0 (0.0)
Histological examination[c]			
Endofibrosis	47 (69.1)	39 (75)	8 (53.3)
Atherosclerosis	7 (10.3)	4 (7.7)	2 (13.3)

(Continued on next page)

Supplementary Table I (online only). Continued.

	Total group ($n_{Patients} = 83$; $n_{Legs} = 90$)	Participating in long-term questionnaire ($n_{Patients} = 66$; $n_{Legs} = 70$)	Patients who did not fill out the long-term questionnaire ($n_{Patients} = 17$; $n_{Legs} = 20$)
Both	4 (5.9)	2 (3.8)	2 (13.3)
No abnormalities	10 (14.7)	7 (13.5)	3 (20.0)

BMI, Body mass index; *CE-MRA*, contrast-enhanced magnetic resonance angiography; *CIA*, common iliac artery; *EIA*, external iliac artery; *PSV*, peak systolic velocity.
Values are median (interquartile range) or number (%), unless otherwise noted.
[a]Significant difference between the participating and the group that is lost to follow-up.
[b]Multiple answers were possible; data presented as frequencies and proportion of total legs.
[c]Data presented as frequencies and proportion of total patients.

Supplementary Table II (online only). Functional testing and imaging before and after arterial shortening (data are presented as complete cases)

	Total ($n_{Patients}$ = 83; n_{Legs} = 90)			Participating ($n_{Patients}$ = 66; n_{Legs} = 70)			Patients who did not fill out the long-term questionnaire ($n_{Patients}$ = 17; n_{Legs} = 20)		
	Legs (n)	Before	After	Legs (n)	Before	After	Legs (n)	Before	After
Cycling test									
Maximal workload, W	77	419 ± 72	428 ± 67[a]	64	414 ± 74	423 ± 69[a]	13	443 ± 60	457 ± 47[a]
W_{SF}, W	68	272 ± 84	384 ± 101[a]	55	260 ± 75	374 ± 101[a]	13	322 ± 101[c]	426 ± 93[a]
ABI_{Flexed}[b]	77	0.55 (0.45 to 0.65)	0.62 (0.52 to 0.74)[a]	64	0.55 (0.46 to 0.68)	0.63 (0.53 to 0.74)[a]	13	0.49 (0.42 to 0.56)	0.55 (0.43 to 0.81)
$\Delta_{\text{Ankle pressure}}$, mm Hg	76	14 (2 to 33)	5 (−9 to 21)[a]	63	12 (2 to 33)	4 (−9 to 21)[a]	13	18 (6 to 36)	7 (−12 to 15)[a]
Duplex (echo-Doppler)									
$PSV_{Extended}$ in the EIA, m/s	75	1.47 (1.20 to 1.87)	1.34 (0.99 to 1.67)[a]	63	1.50 (1.20 to 1.94)	1.33 (0.96 to 1.67)[a]	12	1.27 (1.18 to 1.67)	1.43 (1.06 to 1.64)
PSV_{Flexed} in the EIA, m/s	74	2.50 (1.77 to 3.13)	1.57 (1.20 to 2.04)[a]	62	2.50 (1.8 to 3.32)	1.65 (1.23 to 2.08)[a]	12	2.62 (1.76 to 2.80	1.27 (1.07 to 1.49)[a]
Duplex and/or CE-MRA[d]									
Detection of functional kinking (n = 74)									
Detected		74 (100.0)	5 (6.8)[a]	62	62 (100.0)	5 (8.1)[a]	12	12 (100.0)	0 (0.0)[a]
Not detected		0 (0.0)	69 (93.2)		0 (0.0)	57 (91.9)		0 (0.0)	12 (100.0)
Detection of excessive lengthening (n = 75)									
Detected		62 (82.7)	1 (1.3)[a]		55 (88.7)	1 (1.6)[a]		7 (53.8)	0 (0.0)[a]
Not detected		13 (17.3)	74 (98.7)		7 (11.3)	58 (98.4)		6 (46.2)	13 (100.0)
Detection of an intravascular lesion (n = 78)[b]									
Detected		49 (62.8)	14 (17.9)[a]		39 (60.9)	13 (20.3)[a]		10 (71.4)	1 (7.1)[a]
Not detected		29 (37.2)	64 (82.1)		25 (39.1)	51 (79.7)		4 (28.6)	13 (92.9)

ABI_{Flexed}, Ankle-brachial index with flexed hips; *CE-MRA*, contrast-enhanced magnetic resonance angiography; *EIA*, external iliac artery; *PSV*, peak systolic velocity; *W_{SF}*, symptom-free workload.
Values are mean ± standard deviation, median (interquartile range), or number (%).
Normal values: ABI_{Flexed} ≥0.54, Δ ankle pressure (mm Hg) ≤23 mm Hg, $PSV_{Extended}$ <1.48 m/s and for PSV_{Flexed} (m/s) <1.70 m/s.
[a]Significant difference between before and after surgery.
[b]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.
[c]Significant difference between participating and nonparticipating subjects (complete-case analysis).
[d]Empty or low counts prevent accurate testing.