From the Society for Clinical Vascular Surgery

Bicycle exercise ankle brachial index recovery time as a novel metric for evaluating the hemodynamic significance of external iliac endofibrosis in competitive cyclists

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ABSTRACT

Subtle radiographic findings can increase the challenge of diagnosing external iliac artery endofibrosis. We evaluated a new metric, the bicycle exercise ankle brachial index recovery time (BART), in a cohort of cyclists with symptomatic external iliac artery endofibrosis. BART was defined as the time required in minutes for the ankle brachial index to return to 0.9 after a period of exercise. Surgical correction resulted in an improvement in BART postoperatively (4.5 ± 4.1 vs 9.1 ± 4.3 minutes; $P < .001$), with improved values correlating with better patient satisfaction. Documentation of the BARTs before and after surgical treatment provides an additional measure of postoperative hemodynamic improvement. (J Vasc Surg Cases Innov Tech 2021;7:681-5.)

Keywords: Exercise ankle-brachial index; External iliac endofibrosis; Recovery time

External iliac artery endofibrosis (EIAE) is a rare cause of vascular claudication affecting ≤10% to 20% of high-performance cyclists.[1,2] However, the diagnosis of EIAE has remained challenging, with multiple studies highlighting the need for more specific diagnostic metrics.[1-3] At present, the exercise ankle brachial index (ABI) is the standard of care in the diagnostic workup of EIAE.[4] Although most patients will show significant improvement in the exercise ABI after surgical correction, in our institution's experience, we have recognized a significant proportion of patients with minimal improvement in the exercise ABI despite significant symptom improvement after repair. The goal of the present study was to introduce a new exercise hemodynamic metric—the bicycle exercise ABI recovery time (BART)—to further characterize the pre- and post-treatment lower extremity hemodynamics in limbs undergoing surgical correction of EIAE.

METHODS

Study cohort. A single-center, retrospective, medical record review was performed of consecutive patients who had undergone surgical treatment of EIAE from 2011 to 2020. The patients in the present series included high-performance athletes with a history of competitive cycling and symptomatic EIAE confirmed by cross-sectional imaging studies (eg, computed tomography angiography with provocative hip flexion and supine positioning). Starting in 2011, a bicycle exercise ABI protocol was developed to include recording the postexercise BART at predetermined intervals. This was performed during each patient's preoperative consultation and again at 3 to 6 months postoperatively at our institution's accredited vascular laboratory. All the patients provided verbal consent, and our local institutional review board approved the present study.

Exercise ABI protocol. Our institution's bicycle exercise ABI protocol is summarized as follows. After recording the resting ABIs, the patients were asked to cycle on a stationary bicycle with an ergometer to measure the peak power (Fig 1, *A*). The cycling power was incrementally increased until the maximum threshold was reached. Next, the postexercise ABI was recorded at 1-minute intervals for the first 4 minutes and at 2-minute intervals thereafter until the ABI had returned to baseline. The pre- and postexercise ABIs were charted, and the BART was measured, with BART defined as the time required for the ABI to return to a normal value of 0.9 (Fig 1, *B*). A longer BART indicates more hemodynamically significant disease, and a shorter BART, less hemodynamically significant disease.

Treatment approach and follow-up protocol. The study cohort included patients who had presented with both external iliac artery stenosis and occlusion, which were preferentially treated with patch angioplasty

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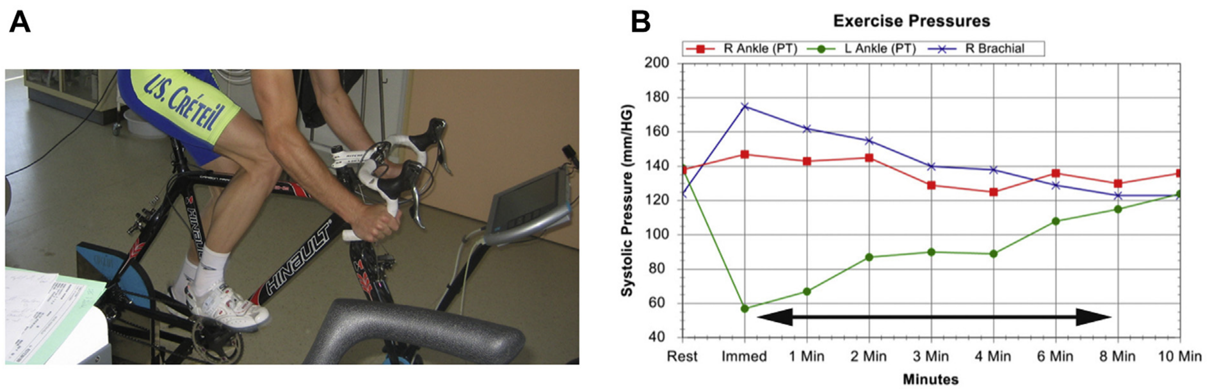

Fig 1. A, Example of stationary bicycle with attached ergometer base to measure peak output power. **B,** Example of ankle brachial systolic pressure output with recorded postexercise pressures at predetermined intervals. The bicycle exercise ankle brachial index (ABI) recovery time (BART), defined as the time required for the ABI to return to a value of 0.9, is indicated by the *arrow. Immed,* Immediately; *L,* left; *PT,* posterior tibial; *R,* right.

and interposition grafting, respectively. After functional recovery at 3 to months postoperatively, a formal postoperative exercise ABI test was performed to document changes in the lower extremity exercise hemodynamics. The exercise ABIs and BARTs were also recorded at the subsequent annual follow-up intervals. All patients were interviewed by telephone in 2020 and asked to participate in a post hoc follow-up survey to determine their current activity level, symptom improvement, and overall satisfaction with the surgical outcome.

Statistical analysis. Histogram analysis was performed of the exercise ABIs and BARTs. Wilcoxon rank sum tests and Fisher exact tests were used to compare the continuous and categorical variables, respectively. Linear regression models were created to assess the relationship between changes in the exercise ABIs and BARTs. A P value <.05 was considered statistically significant for all analyses. All statistical analyses were performed using Stata, version SE16.0 (StataCorp LP, College Station, Tex).

RESULTS

A total of 21 cyclists had undergone surgical treatment in 23 limbs (11 left, 8 right, 2 bilateral) for EIAE. Most of the patients were women (61.9%), with a mean age of 42 ± 9.7 years. The most performed procedure was bovine patch angioplasty of the external iliac artery (n = 17; 73.9%). Four limbs (17.4%) had undergone interposition bypass grafting for iliac occlusion, of which two limbs (8.7%) had had previously occluded bypass grafts. These two patients underwent revision bypass with shortening of the graft length owing to a redundant arterial length. The mean follow-up for this cohort was 25 ± 18.3 months, with five cases of restenosis (31.7%) and two cases of occlusion (8.7%) during the follow-up period. All cases of restenosis and occlusion had occurred after the initial postoperative exercise ABI and were treated with revision surgery.

Pre- and postoperative exercise hemodynamics. Surgical treatment resulted in a significant increase in the mean exercise ABI (0.38 ± 0.18 vs 0.63 ± 0.23; $P < .001$; Fig 2, *A*). Most limbs had had a preoperative exercise ABI of <0.66 (n = 20; 86.9%). Three limbs (13.1%) had had an exercise ABI of 0.66 to 0.8 despite imaging findings and symptoms consistent with EIAE (Fig 2, *B*). However, a significant number of limbs had continued to have an exercise ABI less than the normal threshold of 0.66 postoperatively (n = 11; 55%; Fig 2, *C*).

The preoperative BARTs were ≥2 minutes in 23 limbs (100%), ≥6 minutes in 20 patients (86.9%), and ≥10 minutes in 10 limbs (43.5%), with a mean BART of 9.1 ± 4.3 minutes (Fig 2, *D*). The postoperative BARTs were <2 minutes in 5 limbs (25%), ≥2 minutes in 15 limbs (75%), ≥6 minutes in 6 patients (30.0%), and ≥10 minutes in 3 limbs (15%), with a mean postoperative BART of 4.5 ± 4.1 minutes (Fig 2, *E*). Overall, the mean BART had significantly decreased from pre-to postoperative testing (9.1 ± 5.3 vs 4.5 ± 4.1 minutes; $P < .001$; Fig 2, *F*).

The relative per-limb changes in the exercise ABIs and BARTs after surgical treatment varied significantly (Fig 3, *A* and *B*). Although most patients (n = 11; 55.0%) had experienced an increase ≥25% in the exercise ABIs postoperatively, 9 (45.0%) had experienced improvement of <25% in the exercise ABI and 4 (20.0%) had had no change or a reduced exercise ABI. In contrast, a larger majority (n = 15; 75.0%) had experienced a reduction of ≥50% in the BART after treatment, with 3 patients (15.0%) exhibiting no change in BART and 2 (10.0%), an increased BART. The postoperative increase in the exercise ABI showed a nonstatistically significant linear correlation with the BART reduction (coefficient, 0.14; 95% confidence interval, −0.02 to 0.3; $R^2 = 0.15$; $P = .09$),

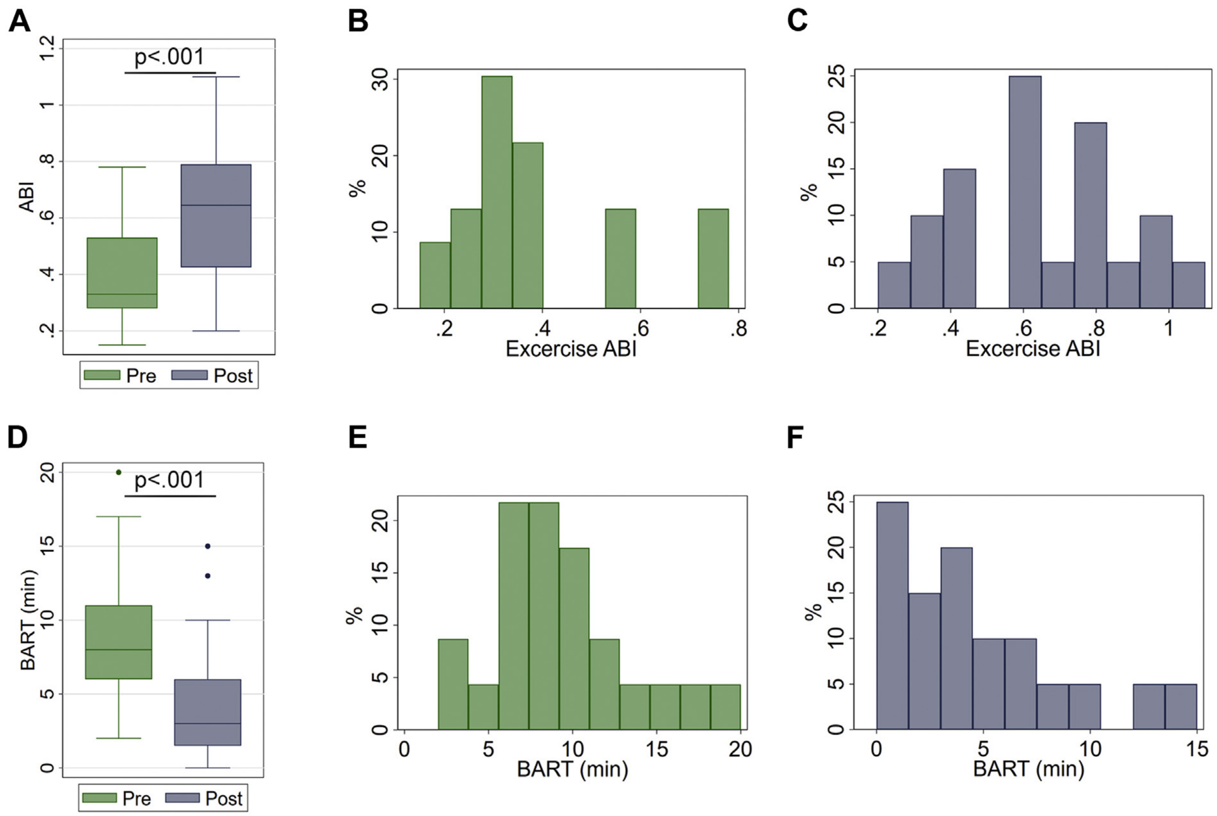

Fig 2. A, Pre- and postoperative difference in exercise ankle brachial indexes (ABIs). **B,** Histogram of preoperative exercise ABIs. **C,** Histogram of postoperative exercise ABIs. **D,** Pre- and postoperative difference in bicycle exercise ABI recovery times (BARTs). **E,** Histogram of preoperative BARTs. **F,** Histogram of postoperative BARTs.

with several limbs showing modest increases in the ABI (range, 0%-15%) and concurrent large reductions in the BART (Fig 3, *C*). Of the limbs with postoperative exercise ABIs remaining at <0.66 (n = 11), more than one half had had a >50% reduction in the BARTs after treatment (n = 6; 54.5%). Of the five limbs in five patients with no reduction in the BART, three had had a small (range, 0.1-0.2) increase in the exercise ABI, and two had had no change in the exercise ABI postoperatively.

The patients with limbs with a reduction of ≥50% in the BART were significantly more likely to report overall satisfaction with their functional outcome (100% vs 50.0%; *P* = .044). However, the BART reduction did not correlate with the numeric satisfaction level (*P* = .53; Table). Of the five patients without a 50% reduction in BART, concurrent duplex ultrasound at the postoperative exercise ABI testing revealed no evidence of recurrent disease for four patients (80%). Two of these patients reported improved cycling performance despite no improvement in the BART, and two patients reported no change in the symptoms postoperatively but had elected not to undergo additional cross-sectional imaging or additional procedures. One of the five patients was lost to follow-up after postoperative exercise ABI testing without undergoing additional imaging studies or completing the functional survey.

DISCUSSION

We have described BART as a new hemodynamic metric for documenting the exercise hemodynamics in limbs affected by EIAE. Although we found improvement in both the exercise ABI and BART after treatment, significant differences were found in the degree of improvement between the metrics, suggesting the subtlety of minor hemodynamic changes and how they might affect elite cyclists. Nearly one half of our cohort had minimal or no change in their exercise ABI after treatment. In contrast, three quarters of our cohort had had a >50% reduction in BART postoperatively. Several limbs with modest changes in the exercise ABI were found to have a >50% reduction in the BART. In addition, a reduced BART appeared to correlate well with postoperative functional recovery. Overall, we believe these findings support the additional value of BART in pre- and postoperative testing of patients with EIAE and that centers providing care for these patients should consider adopting more outcomes than improvement in the exercise ABIs alone. At our institution, we now routinely

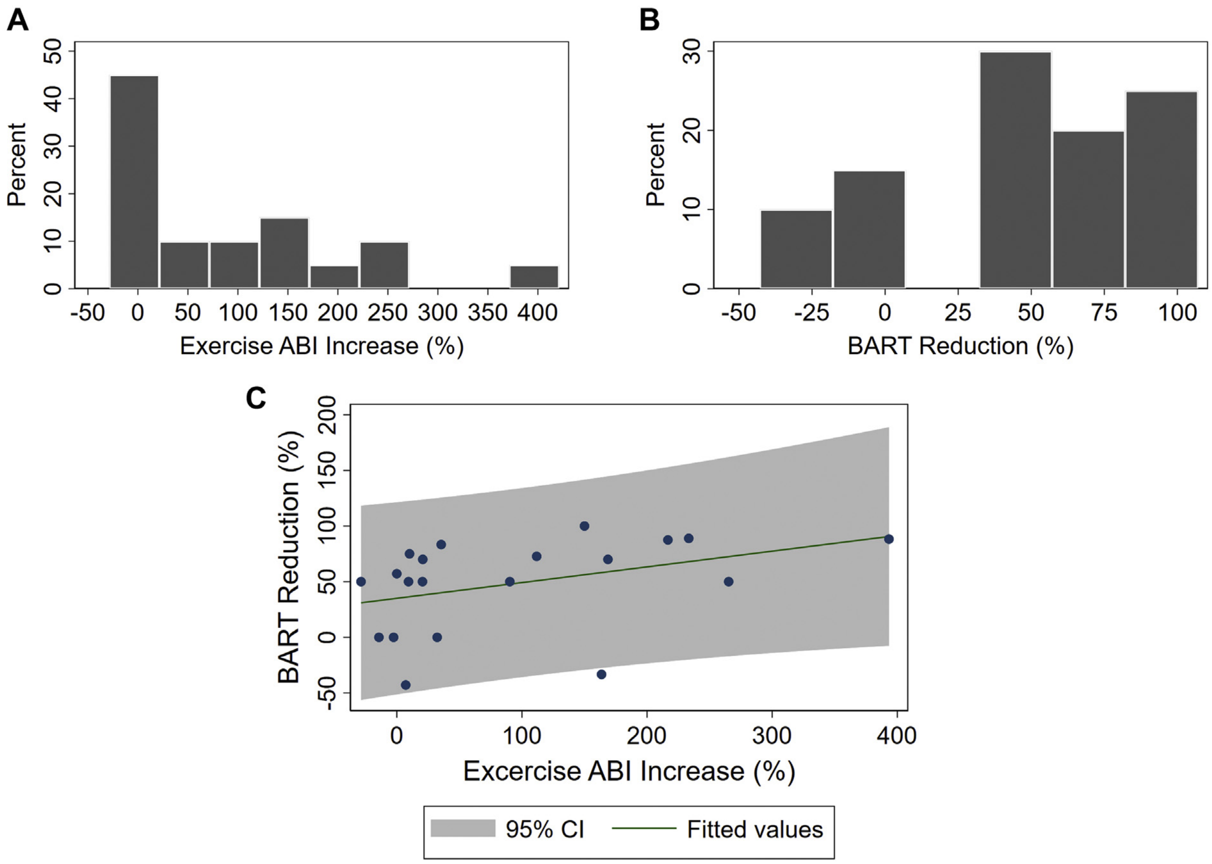

Fig 3. A, Histogram of postoperative percentage of change in exercise ankle brachial index (ABI) compared with preoperative values. **B,** Histogram of postoperative percentage of change in bicycle exercise ABI recovery time (BART) compared with preoperatively. **C,** Scatter plot of relative changes in exercise ABI against changes in BARTs. *CI,* Confidence interval.

Table. Overview of functional outcomes from postoperative ad hoc survey questionnaire for total cohort and stratified by BART outcomes[a]

		BART reduced >50%		
Functional outcome	**Total cohort (n = 19)**	**Yes (n = 13)**	**No (n = 4)**	***P* value**
Overall satisfaction with functional outcome	16 (84.2)	13 (100)	2 (50.0)	.044
Satisfaction level (scale, 1-10)	8.5 (8-9)	8.5 (8-9)	6 (2-9.5)	.53
Return to activity				
At least some level	18 (94.7)	13 (100)	3 (75.0)	.23
"High" level	14 (73.6)	11 (76.5)	2 (50.0)	.21
Prior competitive level	13 (68.4)	10 (70.5)	2 (50.0)	.54

BART, Bicycle exercise ankle brachial index recovery time.
Data presented as number (%) or median (interquartile range).
[a]Patients without available survey data or postoperative exercise ankle brachial indexes were excluded from analysis.

measure the BARTs for all patients undergoing evaluation and treatment of EIAE. We rely on this metric as an objective marker of the exercise hemodynamics independently of the patient-reported symptoms, which are inherently subjective and dependent on the patient's effort, exercise intensity, and perception of pain and discomfort. Adverse changes in the BART during extended follow-up should raise suspicion for recurrent disease, and such patients should undergo additional imaging studies (eg, computed tomography angiography with provocative maneuvers, duplex ultrasound), as needed.

The reported studies describing diagnostic testing for EIAE remain sparse. Abraham et al[4] had previously demonstrated that an exercise ABI of 0.66 had 90% sensitivity and 87% specificity to diagnose moderate EIAE lesions. However, their study did not report the changes in the exercise ABI after surgical repair. Shalhub et al[5] demonstrated the additional utility of performing immediate duplex ultrasound after exercise testing. They found vasospasm was a cause of low-limiting EIAE lesions, emphasizing the importance of multimodality testing.[5] In another series, Bender et al[6] described the use of both cycling tests and duplex ultrasound for patients before and after repair of EIAE. They found significant improvements in peak cycling power, exercise ABI, and peak systolic velocities after treatment.[6] The changes in the postoperative exercise ABI in their study were similar to those in our study. They also found a significant increase in the average maximum working capacity from 5.35 W/kg to 5.70 W/kg postoperatively ($P < .005$). Similar to BART, documenting the maximum working capacity might provide an additional measure of hemodynamic improvement in these patients.

CONCLUSIONS

A comparison of the BARTs before and after surgical treatment of EIAE provides an additional measure of postoperative hemodynamic improvement, which might be more sensitive than improvement in the exercise ABI alone. Improvement in the BART (eg, shorter times) might also correlate with overall functional recovery after treatment. We propose that the BART should be measured routinely as a clinical marker of disease severity during the preoperative evaluation and tracked postoperatively to document hemodynamic improvement after repair of EIAE.

REFERENCES

1. Peach G, Schep G, Palfreeman R, Beard JD, Thompson MM, Hinchliffe RJ. Endofibrosis and kinking of the iliac arteries in athletes: a systematic review. Eur J Vasc Endovasc Surg 2012;43:208-17.
2. Hinchliffe RJ, D'Abate F, Abraham P, Alimi Y, Beard J, Bender M, et al. Diagnosis and management of iliac artery endofibrosis: results of a Delphi consensus study. Eur J Vasc Endovasc Surg 2016;52:90-8.
3. Schep G, Schmikli SL, Bender MHM, Mosterd WL, Hammacher ER, Wijn PFF. Recognising vascular causes of leg complaints in endurance athletes. Part 1: validation of a decision algorithm. Int J Sports Med 2002;23:313-21.
4. Abraham P, Bickert S, Vielle B, Chevalier JM, Saumet JL. Pressure measurements at rest and after heavy exercise to detect moderate arterial lesions in athletes. J Vasc Surg 2001;33:721-7.
5. Shalhub S, Zierler RE, Smith W, Olmsted K, Clowes AW. Vasospasm as a cause for claudication in athletes with external iliac artery endofibrosis. J Vasc Surg 2013;58:105-11.
6. Bender MHM, Schep G, Bouts SW, Backx FJG, Moll FL. Endurance athletes with intermittent claudication caused by iliac artery stenosis treated by endarterectomy with vein patch—short- and mid-term results. Eur J Vasc Endovasc Surg 2012;43:472-7.

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