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.

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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.

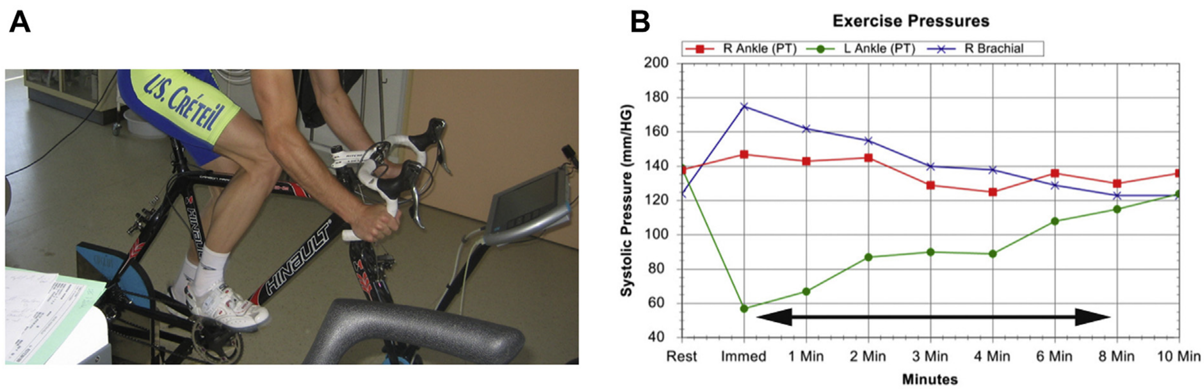

Fig 1. A, Example of stationary bicycle with attached ergometer base to measure peak output power. **B,** Example of ankle brachial systolic pressure output with recorded postexercise pressures at predetermined intervals. The bicycle exercise ankle brachial index (ABI) recovery time (BART), defined as 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.

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 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

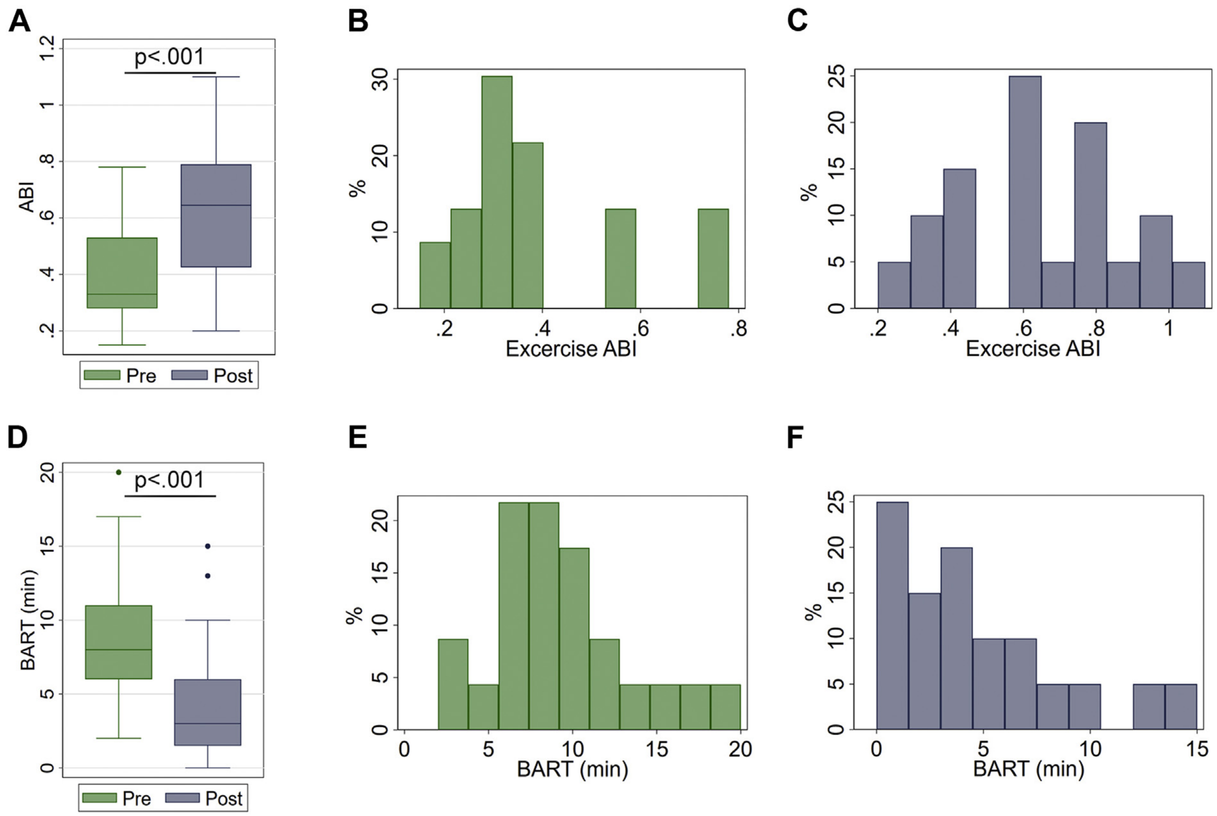

Fig 2. A, Pre- and postoperative difference in exercise ankle brachial indexes (ABIs). **B,** Histogram of preoperative exercise ABIs. **C,** Histogram of postoperative exercise ABIs. **D,** Pre- and postoperative difference in bicycle exercise ABI recovery times (BARTs). **E,** Histogram of preoperative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

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), 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

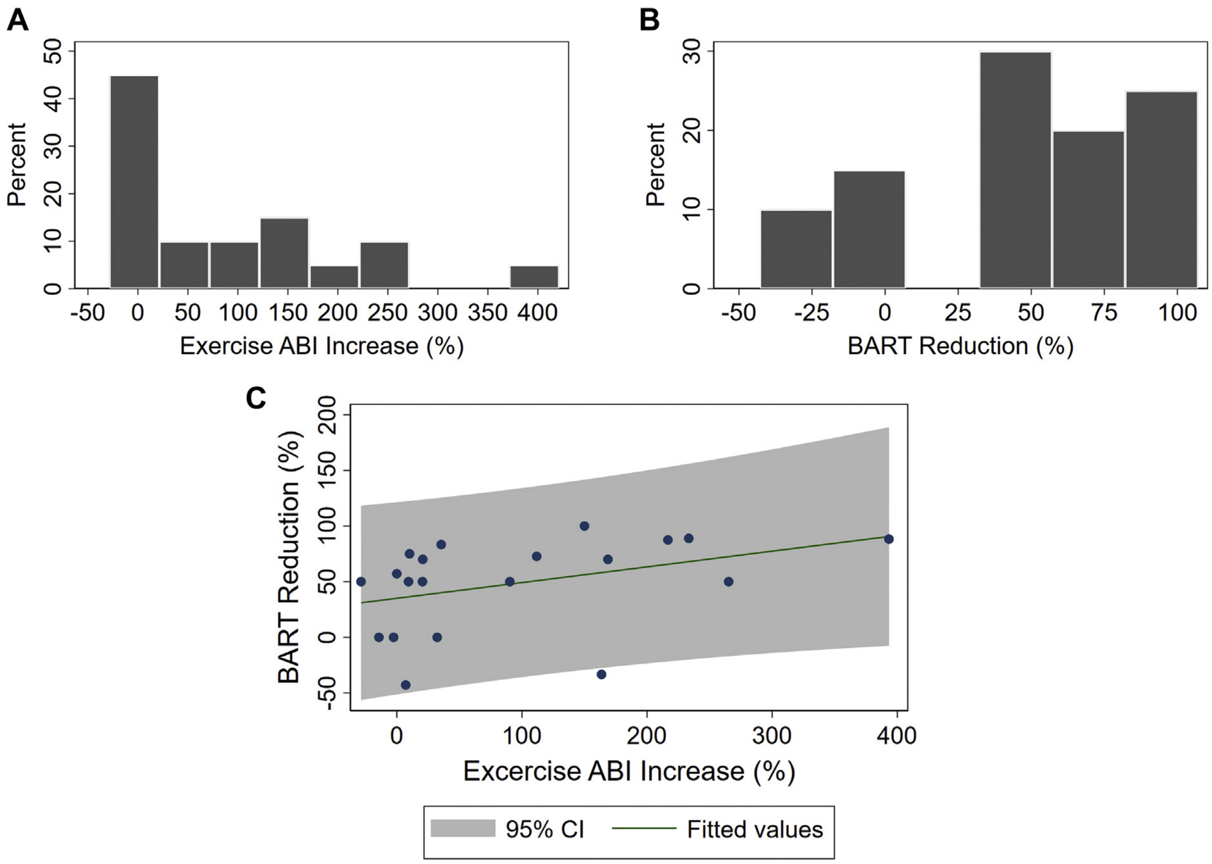

Fig 3. A, Histogram of postoperative percentage of change in exercise ankle brachial index (ABI) compared with preoperative values. **B,** Histogram of postoperative percentage of change in bicycle exercise ABI recovery time (BART) compared with preoperatively. **C,** Scatter plot of relative changes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

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 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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The reliability of duplex ultrasound in diagnosing popliteal artery entrapment syndrome: An observational pilot study

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ABSTRACT

Background and objective: Popliteal artery entrapment syndrome (PAES) is a vascular compression affecting young people. PAES can cause claudication and lead to distal blood flow reduction. Ultrasound could provide a direct and indirect diagnosis approach using different provocative maneuvers. However, the reliability and accuracy of Duplex ultrasound alone to diagnose PAES are uncertain. This study hypothesizes that Duplex ultrasound could lead to false-positive results. Therefore, the study aims to assess the popliteal artery diameter and velocity profile in asymptomatic young people at different provocative maneuvers.
Methods: A prospective study of twenty-three limbs of asymptomatic young individuals aged between 21 and 24 was conducted. All individuals were offered a Duplex ultrasound scan of the popliteal and distal runoff arteries at the vascular ultrasound laboratory. Peak systolic velocity (PSV), spectral waveform, the diameter of the popliteal artery, and distal runoff flow velocities were measured at three positions (neutral, active plantarflexion, and erect on top of toes above and below the knee level. These diagnostic parameters were recorded and analyzed.
Results: The data was collected over two months; the examined individuals were men with an average age of 23 years and a body mass index of 23.16 kg/m. Popliteal artery diameter above the knee at the neutral position was 5.57 mm, active plantarflexion 5.48 mm, and erect on the top of toes 5.69 mm, ($p = 0.624$). PSV means above-knee at neutral, active plantarflexion, and erect on the top of toes positions were 50.80, 56.17, and 61.61, respectively, with a p-value of 0.225. There was a significant difference in the diameter and velocity of the popliteal artery below the knee at active plantarflexion and erect on top of toes positions; the mean diameter at neutral was 4.61, at active plantarflexion 4.57, and at erect on top of toes 3.47 ($p = 0.018$). Furthermore, there was a significant difference in the PSV between measurements, mean at neutral, active plantarflexion, and erect on top of toes, (56.67, 69.43, 93.04) respectively, with a p-value of 0.006.
Conclusion: Duplex ultrasound diagnosis is a valuable imaging technique and can provide important information about the diameter and velocity profile of the popliteal artery at different provocative maneuvers. However, our findings suggest that Duplex ultrasound alone would lead to false-positive results and cannot be elusive in determining the asymptomatic from symptomatic patients with PAES.

1. Introduction

Popliteal artery entrapment syndrome (PAES) is a vascular compression affecting young people. The presence of PAES will cause a lake of calf and feet blood flow circulation. During daily movement activity and stress exercise, patients with PAES will present with pain and cramping in the calf. A study by Hislop et al. (2014) suggested that the cause of PAES can be either anatomical or functional. Other studies indicate that the compression results from anatomical variation in the popliteus muscle are more common than functional (Bradshaw et al., 2021; Hai et al., 2008; Pandya et al., 2019). The usual course of the popliteal artery is between the medial and lateral heads of the

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gastrocnemius muscle. There are two possible explanations for the compression. First, when the gastrocnemius muscle and the popliteus muscle appear abnormal in their anatomic relationship over the popliteal artery. Second is the existence of an anomalous fibrous band or the popliteus muscle (Hai et al., 2008). These will lead to compression over the popliteal artery called PAES. Anatomical variation was first described by Stuart in 1879 and became a known medical condition that primarily affects young athletic individuals (Gokkus et al., 2019; Pandya et al., 2019).

Previous studies suggested that functional popliteal compression may present in the ordinary course of the popliteal artery during leg movement. However, this compression may lead to arterial damage. This will result in leg claudication and pain, referred to as functional entrapment syndrome. Similarly, other studies hypothesized that muscular hypertrophy within the popliteal fossa might be the responsible cause (Henry et al., 2018). However, Pillai stated that occlusion and stenosis of the popliteal artery were seen in untrained young people. The authors also indicate that some degree of compression over the popliteal artery during stress exercise of the foot may occur in 30%–50% of young people (Pillai, 2008).

The true prevalence of PAES is underreported in the literature. The anatomical PAES was reported more in the literature, with an incidence between 0.6% and 3.5% (Collins et al., 1989). The incidence of functional PAES is not well reported. PAES is known to occur bilaterally in around 40% of symptomatic patients (Bradshaw et al., 2021).

An accurate diagnosis is crucial for a better anatomical and dynamical understanding of PAES. Non-invasive imaging techniques such as Duplex ultrasound and cross-sectional imaging play a significant role in diagnosing PAES accurately. Ultrasound is considered a preliminary investigation for PAES. Active plantarflexion, dorsiflexion, and other induced stress of the feet are performed to evaluate arterial compression. The effect of these maneuvers can be seen on an ultrasound directly or indirectly. Direct impact can be visualized through the absence of the popliteal artery course in either position. The distal run-off arteries may have an indirect effect (Altintas et al., 2013; Williams et al., 2015).

A complete anatomical evaluation of PAES is illustrated better by using magnetic resonance imaging (MRI). A wide abnormal finding can be illustrated with MRI. This includes abnormal insertion of the medial head of gastrocnemius, medial displacement, and filling defect in the popliteal artery (Williams et al., 2015). MRI is superior to ultrasound and able to differentiate between anatomical and functional PAES (Ozkan et al., 2008; Lovelock et al., 2021).

In this study, we assess the reliability of Duplex ultrasound using several diagnostic parameters at different stress leg positions in asymptomatic young individuals. Moreover, we determined the effect of active plantarflexion and erect on top of toes positions over the popliteal artery diameter and velocity profile above and below the knee.

2. Materials and methods

2.1. Selection of participants

This prospective observational study was approved by the Institutional Review Board of our university. A total of twenty-three limbs from healthy young people were recruited. The data collection was based on observing individuals' popliteal artery diameter and velocity profile appearance in asymptomatic groups.

All individuals enrolled in the study were scanned by an expert sonographer using conventional ultrasound. All study groups selected for the study were scanned in our ultrasound laboratory for the first time. These healthy individuals were offered a scan using different positions (neutral, active plantar flexion, and erect on top of toes). Several diagnostic parameters were collected and evaluated, such as the diameter of the popliteal artery and velocity profile for the popliteal artery above and below knee level. Alongside clinical history, demographic data such as gender, age, and medical history were recorded for analysis. Individuals were scanned by (Hitachi-405; Hitachi Medical; Tokyo, Japan) using a 7-MHz linear probe.

2.2. Inclusion and exclusion criteria

University faculty and athletic students with no leg swelling, pain, leg discoloration, or history of popliteal artery entrapment syndrome were invited to the ultrasound laboratory to participate in this study. The exclusion criteria included prior history of leg trauma, leg surgery, or documented leg pain, limping, and leg ulceration. Participants under 18 years of age could not sign the consent form.

2.3. Data collection technique

All participants were scanned in three positions. First, neutral position supine with relax muscles. The diameter of the popliteal artery was measured on a longitudinal view, as illustrated in Fig. 1, above and below the knee. A Doppler spectral waveform and velocity measurements were obtained from the popliteal artery above and below the knee, Fig. 2. Also, distal blood flow velocity and Spectral waveform were taken from anterior and posterior tibial arteries. Second, the participants were asked to be in a prone position with active plantar flexion, Fig. 3 and the same parameters were obtained as in the neutral position. Third, the study group was asked to stand on the top of their toes, as illustrated in Fig. 4.

2.4. Statistical analysis

All recorded data were entered into Microsoft Excel and then transferred to SPSS (IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.) for statistical analysis. Continuous variables were expressed as means and standard deviations. Comparison of continuous variables was carried out using the Analysis of Variance (ANOVA). Post hoc comparison was performed to explore the most significant differences between multiple groups means. A p-value <0.05 was considered statistically significant.

3. Results

Twenty-three limbs male individuals had a median age of 23 years (range 21–24) with a mean body mass index of 23.16 ± 1.89 kg/m2. The popliteal artery (Pop. A) diameter above the knee (AK) showed no significant difference at different positions; the mean diameter in the neutral position was 5.57, at active plantarflexion was 5.48 and at erect on top of toes was 5.69, ($p = 0.624$). The popliteal artery PSV above the knee was measured and showed no significant difference between the measurements, mean PSV at neutral, active plantarflexion, and erect on top of toes, (50.80, 56.17, 61.6) respectively, with a p-value of 0.225, (Table 1, Figs. 5 and 6).

The Pop. A diameter below-knee (BK) showed significant diameter difference at different positions, especially in the erect on top of toes position, the mean (mm) diameter at neutral was 4.61, active plantarflexion 4.57 and erect on top of toes 3.47, ($p = 0.018$). The Pop. A PSV BK was showed a significant difference between the measurements, at neutral, active plantarflexion, and erect on top of toes, (56.67, 69.43, 93.04) respectively, with a p-value of 0.006 (Table 2, Fig. 7 and 8). Post hoc comparisons of means and p-values at different positions were analyzed and reported (Table 3). Our findings indicate that erect on top of the toes position significantly impacts the popliteal artery diameter and PSV, especially below the knee.

4. Discussion

Popliteal artery entrapment is considered a serious medical condition. PAES is an abnormal compression over the popliteal artery due to

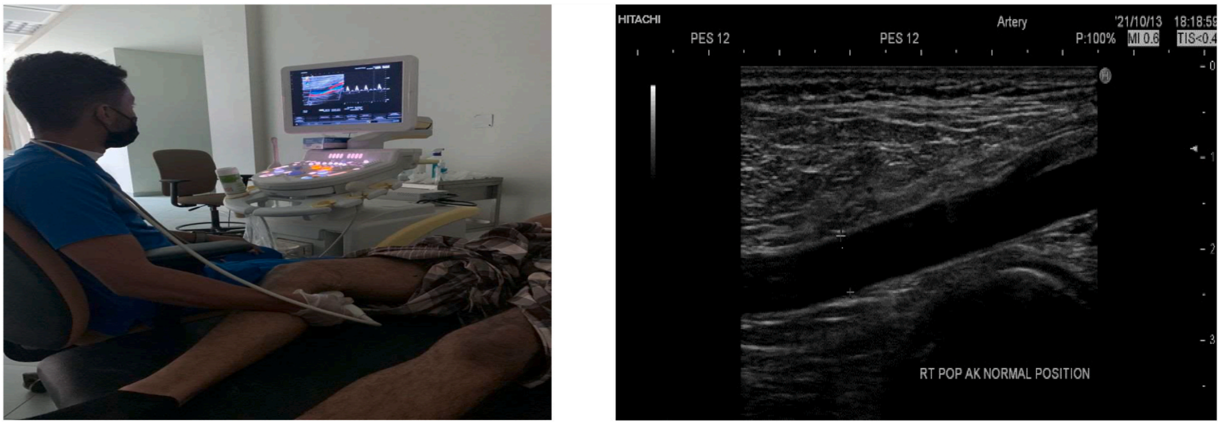

Fig. 1. Measurements of the popliteal artery in a neutral position above the knee.

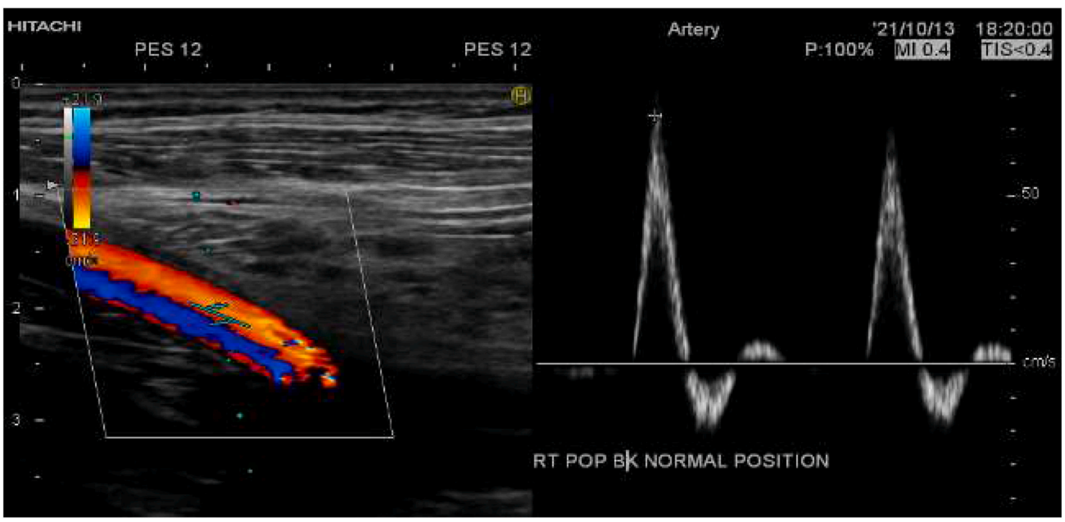

Fig. 2. Duplex ultrasound image of the popliteal artery below the knee Doppler spectral.

Fig. 3. Ultrasound assessment of the popliteal artery in a prone position with active plantar.

Fig. 4. Ultrasound assessment of the popliteal artery on the top of toes position.

either an anatomic relationship anomaly or functional at the knee level (Settembre et al., 2017). The study aims to assess the reliability and accuracy of Duplex ultrasound in imaging and diagnosing the popliteal artery compression in controlled individuals. The diameter and velocity

Table 1
Comparison of popliteal artery (POP.A) diameter above-knee (AK) and Pop.A peak systolic velocity (PSV) AK at different positions.

Variables	Positions	N	Mean	Std. Deviation	P value
Pop. A Diameter AK	Neutral	23	5.57	0.59	0.624
	Active plantarflexion	23	5.48	0.90	
	Erect on top of toes	23	5.69	0.61	
Pop. A PSV AK	Neutral	23	50.80	17.75	0.225
	Active plantarflexion	23	56.17	20.30	
	Erect on top of toes	23	61.61	24.39	

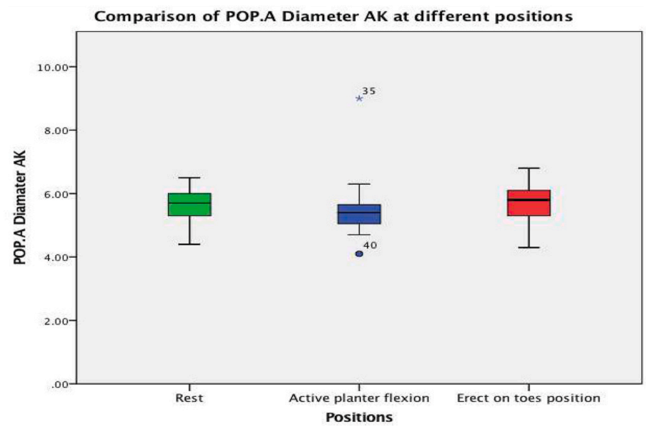

Fig. 5. Comparison of popliteal artery (POP.A) diameter above-knee (AK) at different positions.

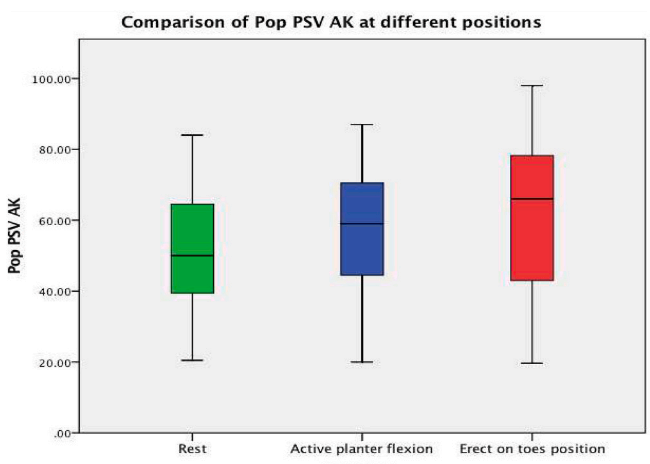

Fig. 6. Comparison of popliteal artery (Pop) peak systolic velocity (PSV) above-knee (AK) at different positions.

Table 2
Comparison of popliteal artery (Pop. A) diameter below-knee (BK) and Pop. A peak systolic velocity (PSV) BK at different positions.

Variables	Position	N	Mean	SD	P value
Pop. A diameter BK	Neutral	23	4.61	0.56	0.018
	Active plantarflexion	23	4.57	2.21	
	Erect on top of toes	23	3.47	1.22	
Pop. A PSV BK	Neutral	23	56.67	21.55	0.006
	Active plantarflexion	23	69.43	32.88	
	Erect on top of toes	23	93.04	52.42	

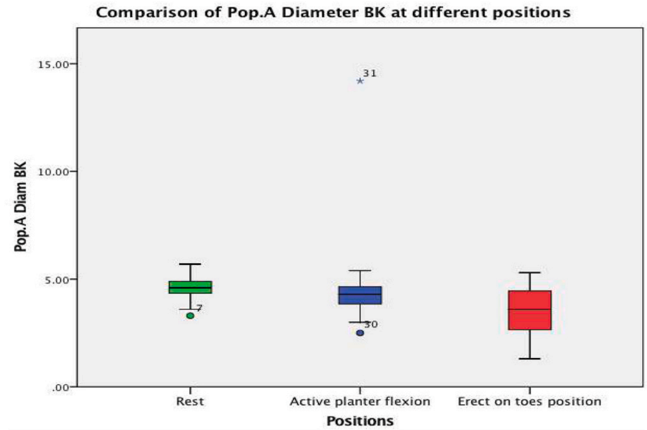

Fig. 7. Comparison of popliteal artery (POP. A) diameter below-knee (BK) at different positions.

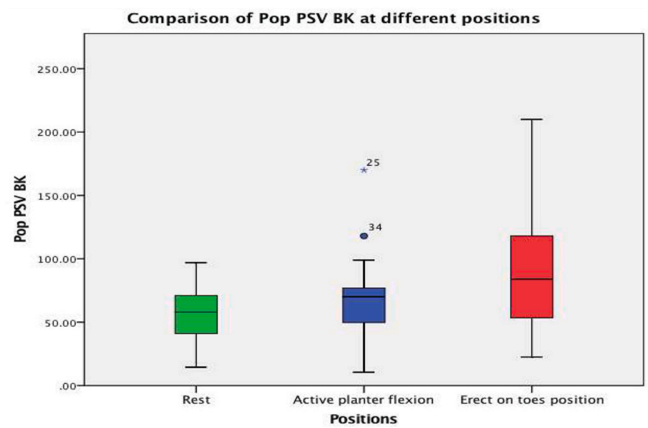

Fig. 8. Comparison of popliteal artery (Pop) peak systolic velocity (PSV) below-knee (BK) at different positions.

Table 3
Multiple comparison of popliteal artery (Pop. A) diameter and peak systolic velocity (PSV) below-knee (BK) (post hoc comparisons).

Variables	Position	P value
Pop. A Diameter BK	Neutral v/s Active plantarflexion	0.914
	Neutral v/s Erect on the top of toes	0.012
	Active planter flexion v/s Erect on the top of toes	0.016
Pop. A PSV BK	Neutral v/s Active plantarflexion	0.257
	Neutral v/s Erect on toes position	0.002
	Active plantarflexion v/s Erect on the top of toes	0.038

profiles were used as diagnostic variables. Our findings demonstrated that Duplex ultrasound could provide false-positive results. The diameter and velocity profile have significantly changed at active plantarflexion and erect on the top of toes positions. PSV increased below the knee level, where the possible compression is commonly located. The diameter of the popliteal artery below-knee has reduced significantly at these provocative maneuvers.

Numerous studies have suggested that the Duplex ultrasound is the first diagnosis choice alongside CT and MRI. The US could provide an initial impression about the popliteal artery diameter and distal runoff vessel flow circulation during induced stress exercise. A study by Altintas et al. (2013) indicated that ultrasound is a helpful technique for pre-and post-operation plans. The author has used ultrasound to assess eleven symptomatic limbs in eight patients. The authors stated that using ultrasound for PAES diagnosis is quite debatable, and the asymptomatic patient may have a compression during active plantarflexion due to physiological phenomena. Our result aligns with this concept where positive velocity and diameter have significantly changed during active plantarflexion and erect on the top of toes.

Another study by Akkersdijk et al. (1995) also suggested that hemodynamical changes were noticed at different positions, and the PSV and waveforms were altered dramatically from rest to active plantarflexion. In our study, PSV and diameter have significantly changed in active plantarflexion and the popliteal artery disappeared during erect on top of toes. This will undeniably cause a false positive result, especially when examining a symptomatic patient. Therefore, additional imaging to clarify the Duplex ultrasound is crucial.

Hai et al. (2008) suggested also that popliteal artery obstruction was present in up to 59% of asymptomatic people. The most common people who may develop PAES were military personnel and athletes. These groups of population are more vulnerable to have their popliteal artery entrap and injured (Liu et al., 2014).

One crucial technical issue finding was countered in our study is that participants could not tolerate the active plantarflexion and erect on top of their toes, which may affect the diagnostic accuracy of the ultrasound. The transducer was unstable and apparent movement was present mimicking accurate measurements of diameter and PSV. This also was suggested by Altintas et al. (2013). They stated that if the plantarflexion test is not correctly performed, false-positive results may occur; the probe must be stabilized, and sudden movements during calf muscle contractions must be avoided.

Duplex ultrasound cannot be used alone as a diagnostic approach to evaluate the popliteal artery compression. Additional imaging is required to provide an accurate picture of the presence of PAES. A combination of imaging modalities and physiological Doppler studies will improve detection and increase diagnostic accuracy (Williams et al., 2015).

Abnormal sonographic features of the popliteal artery such as ectasia, aneurysmal and occlusion may be observed in the popliteal artery before provocative maneuvers. These features are nonspecific abnormalities (Lee et al., 2016). Thus, the role of Duplex ultrasound imaging to diagnose PAES is limited. Based on the result of this study and the review of current literature, standardized diagnostic approach for PAES is important. A combination of non-invasive physiological vascular tests including systolic ankle pressure measurement, pulse volume recording, and duplex ultrasound and MRI using different provocative maneuvers is recommended (Sinha et al., 2012; Williams et al., 2015).

This study has potential limitations; first, due to the small sample size, the finding cannot be generalized. The second one is that the health volunteer should be exercised before and after the ultrasound as most of the symptomatic PAES occur in athletic runners. Future studies should be conducted using a large sample size and examining the healthy volunteers pre-and post-exercise. Moreover, we recommend using Ankle Brachial Pressure Index to assess the pressure difference at different positions as it is challenging to stabilize the probe over the popliteal fossa at active plantarflexion and erect on top of the toes maneuvers.

5. Conclusion

The diagnosis of anatomic popliteal entrapment can be indefinable in a healthy population. Duplex ultrasound could provide false-positive findings and cannot be elusive to determine the asymptomatic from symptomatic. Duplex ultrasound imaging using active plantar flexion and erect on top of toes may not be enough to give an appropriate, accurate diagnosis alone, and further imaging is highly recommended. Duplex ultrasound imaging is beneficial to provide an image of the presence of stenosis, aneurysm, and Doppler spectral waveforms analysis of the popliteal artery, but it cannot confirm the PAES.

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Declaration of competing interest

The authors reported no potential conflicts of interest.

References

Akkersdijk, W. L., de Ruyter, J. W., Lapham, R., Mali, W., & Eikelboom, B. C. (1995). Colour duplex ultrasonographic imaging and provocation of popliteal artery compression. *European Journal of Vascular and Endovascular Surgery, 10*, 342–345. HYPERLINK 10.1016/S1078-5884(05)80054-1.

Altintas, U., Helgstrand, U. V. J., Hansen, M. A., Stentzer, K. F., Schroeder, T. V., & Eiberg, J. P. (2013). Popliteal artery entrapment syndrome: Ultrasound imaging, intraoperative findings, and clinical outcome: Ultrasound imaging, intraoperative findings, and clinical outcome. *Vascular and Endovascular Surgery, 47*, 513–518. HYPERLINK 10.1177/1538574413495466.

Bradshaw, S., Habibollahi, P., Soni, J., Kolber, M., & Pillai, A. K. (2021). Popliteal artery entrapment syndrome. *Cardiovascular Diagnosis and Therapy, 11*(5), 1159–1167. https://doi.org/10.21037/cdt-20-186.

Collins, P. S., McDonald, P. T., & Lim, R. C. (1989). Popliteal artery entrapment: An evolving syndrome. *Journal of Vascular Surgery, 10*(5), 484–490. https://doi.org/10.1016/0741-5214(89)90129-8

Gokkus, K., Sagtas, E., Bakalim, T., Taskaya, E., & Aydin, A. T. (2019). Popliteal entrapment syndrome. A systematic review of the literature and case presentation. *Muscles Ligaments Tendons J, 4*(2), 141. https://doi.org/10.32098/mltj.02.2014.09

Hai, Z., Guangrui, S., Yuan, Z., Zhuodong, X., Cheng, L., Jingmin, L., & Yun, S. (2008). CT angiography and MRI in patients with popliteal artery entrapment syndrome. *American Journal of Roentgenology, 191*(6), 1760–1766. https://doi.org/10.2214/AJR.07.4012

Henry, H. T., Szolomayer, L. K., Sumpio, B. E., & Sutton, K. M. (2018). Popliteal artery entrapment syndrome: Bilateral lower extremity involvement. *Orthopedics, 41*, e295–e298. https://doi.org/10.3928/01477447-20170918-10

Hislop, M., Kennedy, D., & Dhupelia, S. (2014). Functional popliteal artery entrapment syndrome: A review of the anatomy and pathophysiology. *Journal of Sports Medicine & Doping Studies, 4*, Article 1000140. https://doi.org/10.4172/2161-0673.1000140, 02.

Lee, S. J., Kim, O. H., Choo, H. J., Park, J. H., Park, Y. M., Jeong, H. W., Lee, S. M., Cho, K. H., Choi, J. A., & Jacobson, J. A. (2016). Ultrasonographic findings of the various diseases presenting as calf pain. *Clinical Imaging, 40*(1), 1–12. https://doi.org/10.1016/j.clinimag.2015.09.015

Liu, Y., Sun, Y., He, X., Kong, Q., Zhang, Y., Wu, J., & Jin, X. (2014). Imaging diagnosis and surgical treatment of popliteal artery entrapment syndrome: A single-center experience. *Annals of Vascular Surgery, 28*, 330–337. https://doi.org/10.1016/j.avsg.2013.01.021

Lovelock, T., Claydon, M., & Dean, A. (2021). Functional popliteal Artery Entrapment Syndrome: An approach to diagnosis and management. *Int J Sports Med, 42*, 1159–1166. https://doi.org/10.1055/a-1524-1703

Ozkan, U., Oguzkurt, L., Tercan, F., & Pourbaher, A. (2008). MRI and DSA findings in popliteal artery entrapment syndrome. *Diagn Interv Radiology, 14*(2), 106–110. https://pubmed.ncbi.nlm.nih.gov/18553287/.

Pandya, Y. K., Lowenkamp, M. N., & Chapman, S. C. (2019). Functional popliteal artery entrapment syndrome: A review of diagnostic and management approaches. *Vascular Medicine, 24*(5), 455–460. https://doi.org/10.1177/1358863X19871343

Pillai, J. (2008). A current interpretation of popliteal vascular entrapment. *Journal of Vascular Surgery, 48*(6 Suppl), 61S–65S. https://doi.org/10.1016/j.jvs.2008.09.049. discussion 65S.

Settembre, N., Bouziane, Z., Bartoli, M. A., Nabokov, V., Venermo, M., Feugier, P., & Malikov, S. (2017). Popliteal artery entrapment syndrome in children: Experience with four cases of acute ischemia and review of the literature. *European Journal of Vascular and Endovascular Surgery, 53*, 576–582. https://doi.org/10.1016/j.ejvs.2016.12.032

Sinha, S., Houghton, J., Holt, P. J., Thompson, M. M., Loftus, I. M., & Hinchliffe, R. J. (2012). Popliteal entrapment syndrome. *Journal of Vascular Surgery, 55*(1), 252–262. https://doi.org/10.1016/j.jvs.2011.08.050. e30.

Williams, C., Kennedy, D., Bastian-Jordan, M., Hislop, M., Cramp, B., & Dhupelia, S. (2015). A new diagnostic approach to popliteal artery entrapment syndrome. *J Med Radiat Sci, 62*, 226–229. https://doi.org/10.1002/jmrs.121