ORIGINAL ARTICLE

PEDAL ACCELERATION TIME AN ALTERNATIVE TOOL TO ANKLE-BRACHIAL INDEX IN PERIPHERAL ARTERIAL DISEASE

Eduardo Silva*[1], Joana Iglésias[1], Pedro Lima[2], Luís F. Antunes[1], Manuel Fonseca[1]

[1] Department of Angiology and Vascular Surgery, Coimbra Hospital and University Centre, Coimbra, Portugal
[2] Departement de Chirurgie Vasculaire, Polyclinique du Sidobre, Castres, France

* Corresponding author: eduardodmgsilva@gmail.com

Abstract

***Introduction**: Ankle-Brachial Index (ABI) is a well-established diagnostic tool for evaluating peripheral arterial disease (PAD). Limitations in its application led to the development of alternative diagnostic methods, including Toe-Brachial Index (TBI) and Transcutaneous Pressure of Oxygen (TcPO2), yet these are not as widely available as ABI. Recently, Pedal Acceleration Time (PAT), has gained popularity as a new tool to assess PAD, requiring only an ultrasound. This study seeks to further establish the correlation between ABI and PAT, determining whether PAT can be a reliable alternative for diagnosing and assessing the severity of PAD.*

***Methods:** ABI and PAT were measured in patients attending our consult with no history of vascular or endovascular surgery. Limbs with unmeasurable ABI were excluded. Patients were categorized into groups based on their PAD stage according to the Fontaine classification. Patient demographics, comorbidities and respective ABI and PAT were analysed.*

***Results:** Sixty-nine patients (114 limbs) were included in the study. Mean age 68 ± 11.7 years, 78.3% male and 33.3% diabetic patients. Fifty-three claudicant limbs (46.5%) and 26 limbs (22.8%) with chronic limb threatening ischemia. Pearson correlation coefficient between ABI and PAT, showed a strong negative correlation (r= -0.78; p<0.01). Mean ABI and PAT for limbs in Fontaine stage I were 0.94 ± 0.17 and 82.0 ± 27.4 ms; Fontaine stage IIa 0.69 ± 0.21 and 141.3 ± 57.8 ms; Fontaine stage IIb 0.54 ± 0.14 and 173.4 ± 65.1 ms; Fontaine stage III 0.43 ± 0.15 and 216 ± 33.2 ms; Fontaine stage IV 0.49 ± 0.17 and 206.7 ± 78.1 ms, respectively.*

***Conclusion:** Our study suggests an inverse correlation between ABI and PAT, in accordance with the findings published in the literature, thus supporting the use of PAT as an easily reproducible and efficient alternative to ABI for evaluating the severity of PAD.*

***Keywords**: Pedal Acceleration Time; Ankle-Brachial Index; Peripheral Arterial Disease; Duplex Ultrasound; Diagnosis*

INTRODUCTION

Peripheral arterial disease is a widespread vascular condition that affects millions of individuals worldwide, therefore accurate diagnosis and assessment of the severity of PAD are pivotal in determining appropriate treatment strategies and improving patients' quality of life[1]. Traditionally, ankle-brachial index (ABI) is a common, non-invasive tool for PAD screening, yet it is unable to assess foot perfusion and may be unreliable in conditions like diabetes or chronic kidney disease, where arteries are often non-compressible or heavily calcified[1].

To overcome these challenges, alternative tools like toe-brachial index and TcPO2 were developed. However, TBI may be impractical for patients with foot issues, and TcPO2 devices present challenges of cost and accessibility[1].

Amidst this backdrop of evolving diagnostic tools, recently Sommerset et al. described a new technique to assess foot perfusion and evaluate PAD called pedal acceleration

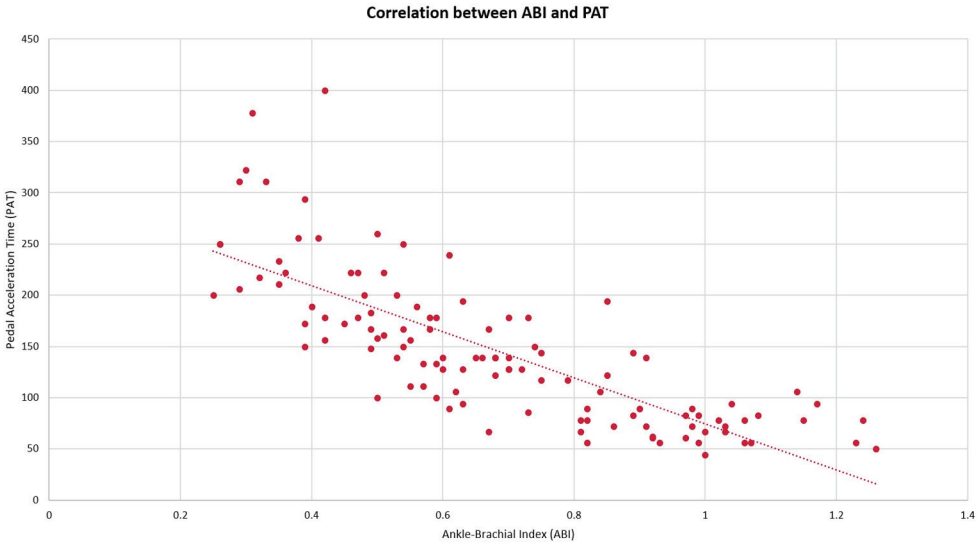

Figure 1 *Scatter plot and linear regression correlating Ankle-Brachial Index with Pedal Acceleration Time.*

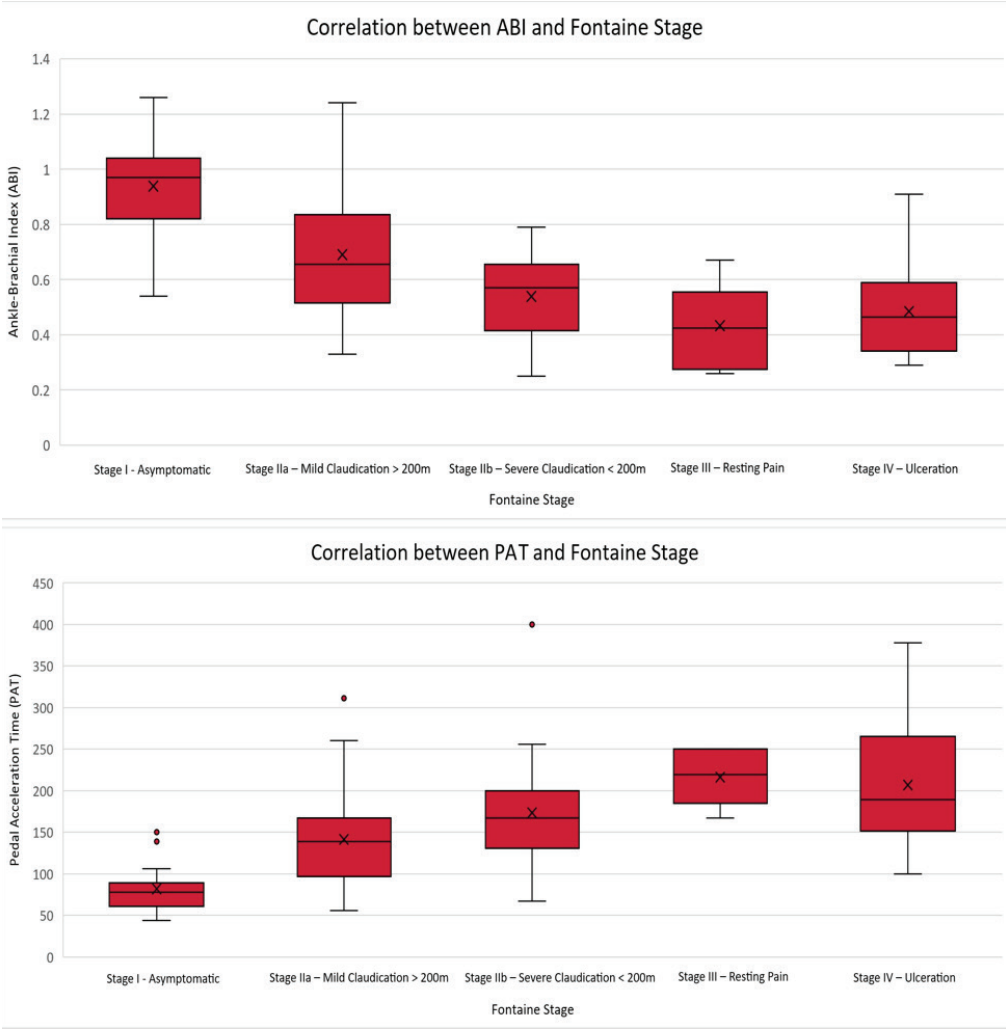

Figure 2 *Box plot for each stage of Fontaine's Classification for Peripheral Arterial Disease and its relation with Ankle-Brachial Index (top) and Pedal Acceleration Time (bottom).*

Table 1 **Population demographics and cardiovascular risk factors.**

Population Characteristics	
Number of Patients	69
Age (years) (mean ± SD)	68 ± 11.7
Gender	
Male	54 (78.3%)
Female	**15 (21.7%)**
Hypertension	52 (75.4%)
Dyslipidemia	47 (68.1%)
Active Smoker or Smoking History	44 (63.8%)
Diabetes	**23 (33.3%)**
Coronary Heart Disease	17 (24.6%)
Stroke	5 (7.2%)
Hemodialysis	1 (1.4%)

time (formerly referred to as plantar acceleration time)[2, 3]. This innovative approach has been rapidly gaining popularity due to its simplicity and efficiency, requiring only a duplex ultrasound, making it not only an accessible, but also a time and cost-effective solution in the realm of PAD diagnosis and severity assessment.

This study aims to build upon and reinforce previous research on PAT2-6 by further analysing and establishing the correlation between ABI and PAT in the context of peripheral arterial disease. We seek to determine whether PAT can provide valuable insights and serve as a reliable alternative to ABI in the diagnosis and assessment of the clinical severity of various stages of PAD.

METHODS

We performed a cross-sectional, observational study conducted between January and April 2023 with a consecutive sample of patients with suspected peripheral arterial disease attending the consult in our Angiology and Vascular Surgery department. ABI and PAT were registered as well as patient demographics and cardiovascular comorbidities, then database retrospective analysis was performed. Ankle-brachial index and pedal acceleration time measurements were taken at the same point in time, by two independent examiners with previous experience in duplex ultrasound. Each examiner measured both ABI and PAT; the highest ABI and the lowest PAT, among the two measurements, was considered for the study.

PAT was measured in milliseconds (ms) from the onset to the peak of the systolic slope; all measurements were performed at the lateral plantar artery of the foot, as described by Sommerset et al.[2], in order to minimize bias. Limbs with an occluded lateral plantar artery were excluded.

ABIs were obtained using a BASIC 3.2, 4 MHz continuous wave doppler probe (Atys Medical, Soucieu-en-Jarrest, France). PATs were measured using an ACUSON NX3TM Elite duplex ultrasound system (Siemens Healthineers, Erlangen, Germany) with a linear array transducer with pulsed-doppler frequencies between 4-12 MHz.

Each limb was considered unique for the analysis and was categorized into groups based on the PAD stage according to Fontaine's classification[7] (Stage I: Asymptomatic; Stage IIa: Mild claudication (>200 meters); Stage IIb: Severe claudication (<200 meters); Stage III: Resting pain; Stage IV: Foot ulcer/ Gangrene). A supervised walking test was performed to assess claudication, based on the ability to walk a pre-measured distance of 200 meters without symptoms, and accordingly classified as mild or severe claudication, as previously described. Stage III and IV were considered as Chronic-Limb Threatening Ischemia (CLTI)[8]. Limbs previously submitted to open or endovascular revascularization, as well as limbs with unmeasurable ABI were excluded. Patients with severe unilateral claudication, CLTI or other conditions, where adequate contralateral limb staging and assessment could not be performed, namely when such conditions precluded an inability to perform the walking test, the latter limb was excluded.

Mean ABI and PAT were calculated for each stage of PAD and the relation between these variables was performed by linear regression analysis and Pearson correlation coefficient calculation. One-way ANOVA testing, followed by post hoc Bonferroni test to determine differences between groups was performed. Statistical significance was established at $p=0.05$. All statistical analysis was conducted using Microsoft Excel version 2019 (Microsoft Corp, Redmond, Washington, USA).

RESULTS

The study included 69 patients with PAD, encompassing a total of 114 limbs, whose demographic characteristics and cardiovascular risk factors are summarized in Table 1. The mean age of the participants was 68 ± 11.7 years, with a predominant male population (n=54; 78.3%). The most common cardiovascular risk factors were hypertension (75.4%) and dyslipidemia (68.1%); one-third of the patients were diabetic (33.3%).

Among the 114 limbs studied, 28 had mild claudication, 25 had severe claudication, 8 had resting pain and 18 had foot ulcers or gangrene. In total, there were 53 (46.5%) claudicant limbs and 26 (22.8%) limbs with chronic-limb threatening ischemia. Thirty-five limbs were asymptomatic, comprising mostly patients referred to our consult for other causes (such as, carotid stenosis, aneurysmatic disease or chronic venous disease), with concomitant signs of lower limb atherosclerosis, which were used as a control group and assigned to stage I disease (Table 2).

Pedal acceleration time revealed a strong negative correlation with ankle-brachial index, with a calculated Pearson correlation coefficient of -0.78 ($p<0.01$) and shown by linear regression analysis (Figure 1). Mean ABI and PAT were calculated for different stages of PAD, respectively: Fontaine stage I 0.94 ± 0.17 and 82.0 ± 27.4 ms; Fontaine stage IIa 0.69 ± 0.21 and 141.3 ± 57.8 ms; Fontaine stage IIb 0.54 ± 0.14 and 173.4 ± 65.1 ms; Fontaine stage III 0.43 ± 0.15 and 216 ± 33.2 ms; Fontaine stage IV 0.49 ± 0.17 and 206.7 ± 78.1 ms (Table 2).

To ensure similar sample sizes across all groups during

ANOVA and post hoc testing, patients in Fontaine stage III and IV were collectively assigned into a single group (CLTI group): mean ABI and TAP in this subset was 0.47 ± 0.17 and 209.6 ± 66.9 ms, respectively. One-way ANOVA test was statistically significant ($p<0.001$). Post hoc test using Bonferroni correction achieved significance for all groups ($p<0.001$), except between stage IIa and IIb ($p=0.062$) and stage IIb and the CLTI group ($p=0.056$).

DISCUSSION

Pedal acceleration time stands out as a straightforward and time-efficient diagnostic tool, characterized by a rapid learning curve and high reproducibility[2, 3]. However, it is crucial to underscore that proficiency in PAT measurement requires a comprehensive understanding of foot vessel anatomy, considering anatomical variations and hemodynamic changes in blood flow. This level of knowledge is particularly relevant to accurately measure and understand PAT, which should come naturally for clinicians and researchers already familiarized with lower limb duplex ultrasound, further reinforcing the accessibility and ease of adoption of this technique.

Furthermore, our findings match previous studies regarding PATs[2], with a strong negative correlation between pedal acceleration time and ankle-brachial index ($r= -0.78$, $p<0.01$) suggesting that as peripheral arterial disease progresses, impaired blood flow at the pedal level causes a consequent increase in PAT, which visually translates into a shallower systolic curve in duplex ultrasound. This correlation not only strengthens the rationale for adopting PAT as a practical and easily reproducible alternative to ABI but also highlights its efficiency in gauging the severity of PAD.

Progressive changes in both ABI and PAT were noticed across all Fontaine stages for PAD, with the exception of stage III which achieved a slightly mean lower ABI and higher PAT than stage IV (Figure 2), although it is likely that these results were influenced by the small sample size. Similarly, despite ANOVA testing showing a significant difference between groups ($p<0.001$), post hoc analysis failed to establish statistical significance between consecutive clinical stages (i.e., IIa and IIb; IIb and CLTI).

These findings emphasize the need for larger sample sizes to further elucidate the nuanced relationships within the Fontaine stages for PAD, yet we consider that this study sheds light on the dynamic nature of PAT across the spectrum of PAD. As the disease progresses through various stages, PAT consistently increases, reflecting the challenges posed by impaired blood flow at the pedal level. This observation reinforces the clinical relevance of PAT as a versatile tool capable of capturing the changes in vascular perfusion associated with the evolving stages of PAD.

Despite the valuable insights provided by our study, it is important to acknowledge its limitations, such as small sample size and the fact it was conducted at a single centre. Future research with a larger population and shared multicentric experience, as well as adequately categorized patients with different PAD stages is needed to further validate our findings and to investigate the prognostic value of PAT in predicting adverse outcomes in patients with PAD, such as limb salvage and amputation rates.

Lastly, additional investigations are needed to explore both the effects of limb revascularization procedures on PAT and its implications for limb perfusion as these could provide valuable insights into treatment outcomes[4, 5], as well as to focus on patients with uncompressible ABIs, as this subgroup often presents unique challenges in terms of diagnosis and management.

CONCLUSION

Our study reaffirms the value of pedal acceleration time as a reliable diagnostic tool in the assessment of peripheral arterial disease and as an alternative to ABI, underscoring the inverse correlation between ABI and PAT.

In light of these findings, we advocate for the incorporation of PAT into routine clinical assessments for PAD, as it offers a quantitative measurement of its severity across different stages of the disease. Additionally, we encourage further research to validate and expand upon our results, ultimately contributing to the improved care and management of individuals affected by PAD.

REFERENCES

1. Criqui MH, Matsushita K, Aboyans V, Hess CN, Hicks CW, et al. Lower Extremity Peripheral Artery Disease: Contemporary Epidemiology, Management Gaps, and Future Directions: A Scientific Statement from the American Heart Association. Circulation. 2021;144:e171-e191. doi:10.1161/CIR.0000000000001005.
2. Sommerset J, Karmy-Jones R, Dally M, Feliciano B, Vea Y, et al. Plantar Acceleration Time: A Novel Technique to Evaluate Arterial Flow to the Foot. Ann Vasc Surg. 2019;60:308-314. doi:10.1016/j.avsg.2019.03.002.
3. Sommerset J, Teso D, Feliciano B, Vea Y, Sentman M, et al. Innovative Arterial Duplex Examination: A Guide to Evaluate Flow in the Foot Using Pedal Acceleration Time. J Vasc Ultrasound. 2019;43:11-17. doi:10.1177/1544316719827328.
4. Teso D, Sommerset J, Dally M, Feliciano B, Vea Y, et al. Pedal Acceleration Time (PAT): A Novel Predictor of Limb Salvage. Ann Vasc Surg. 2021;75:189-193. doi:10.1016/j.avsg.2021.02.038.
5. Sommerset J, Feliciano B, Karmy-Jones R, Vea Y, Dally M, et al. Duplex Ultrasound Defined Angiosome with the use of Pedal Acceleration Time as a Predictor to Wound Healing. J Vasc Surg. 2020;72:e213. doi:10.1016/j.jvs.2020.04.360.
6. Trihan JE, Mahé G, Croquette M, Coutant V, Thollot C, et al. Accuracy of Acceleration Time of Distal Arteries to Diagnose Severe Peripheral Arterial Disease. Front Cardiovasc Med.
7. Fontaine R, Kim M, Kieny R. Surgical treatment of peripheral circulation disorders [in German]. Helv Chir Acta 1954;21: 499–533.
8. Conte MS, Bradbury AW, Kolh P, White JV, Dick F, et al. Global Vascular Guidelines on the Management of Chronic Limb-Threatening Ischemia [published correction appears in Eur J Vasc Endovasc Surg. 2020 Mar;59(3):492-493] [published correction appears in Eur J Vasc Endovasc Surg. 2020 Jul;60(1):158-159]. Eur J Vasc Endovasc Surg. 2019;58:S1-S109.e33. doi:10.1016/j.ejvs.2019.05.006