Relationship Between the Angle of Popliteal Artery Trifurcation Branches and Atherosclerosis Burden in Chronic Peripheral Arterial Disease

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Abstract

Aim: The aim of this study was to investigate the relationship between the angles of the popliteal artery trifurcation branches and atherosclerosis burden in patients with peripheral arterial disease (PAD).

Methods: Digital subtraction angiography (DSA) images of patients who underwent angioplasty for lower extremity PAD between April 2021 and 2023 were retrospectively analyzed. The study excluded non-type 1a popliteal artery branching variations, critical stenosis or occlusion cases, and those with motion artifacts or previous femoropopliteal bypass operations. Angles of the anterior tibial artery (ATA), posterior tibial artery (PTA), and fibular artery (FA) were measured. Atherosclerosis burden was scored from 0 to 18 based on luminal narrowing and occlusion in each artery. Spearman correlation analysis was used to examine the relationship between trifurcation angles and atherosclerosis burden.

Results: A total of 68 patients were included, with a mean age of 65 years. Angioplasty was performed on the right side in 56% of patients and on the left side in 44%. The ATA angle showed a weak positive correlation with atherosclerosis burden (r_s = 0.144, p = 0.29). In contrast, PTA and FA angles exhibited moderate (r_s = 0.398, p = 0.001) and strong (r_s = 0.599, p < 0.001) positive correlations, respectively.

Conclusions: This study highlights the significant association between the angulation of popliteal artery trifurcations and atherosclerosis burden, suggesting that vessel geometry should be considered in the management of PAD.

Keywords: *Atherosclerosis, peripheral arterial disease, angioplasty, trifurcation artery, digital subtraction angiography*

1. Introduction

Peripheral artery disease (PAD) in the lower limbs is an atherosclerotic disease of the arteries supplying the legs.[1] PAD affects more than 230 million adults worldwide and is associated with an increased risk of several adverse clinical outcomes.[2] Risk factors for PAD include smoking, diabetes, high blood pressure, high cholesterol, advanced age, family history of heart disease, obesity, physical inactivity, poor diet, and certain chronic conditions such as kidney disease and metabolic syndrome.[2,3]

The popliteal artery, a major conduit in the lower extremities, often exhibits variations in branching, particularly trifurcation. A classification for the variation of popliteal artery trifurcation branches has been defined.[4] The popliteal artery typically bifurcates into its terminal branches within the posterior compartment of the leg.

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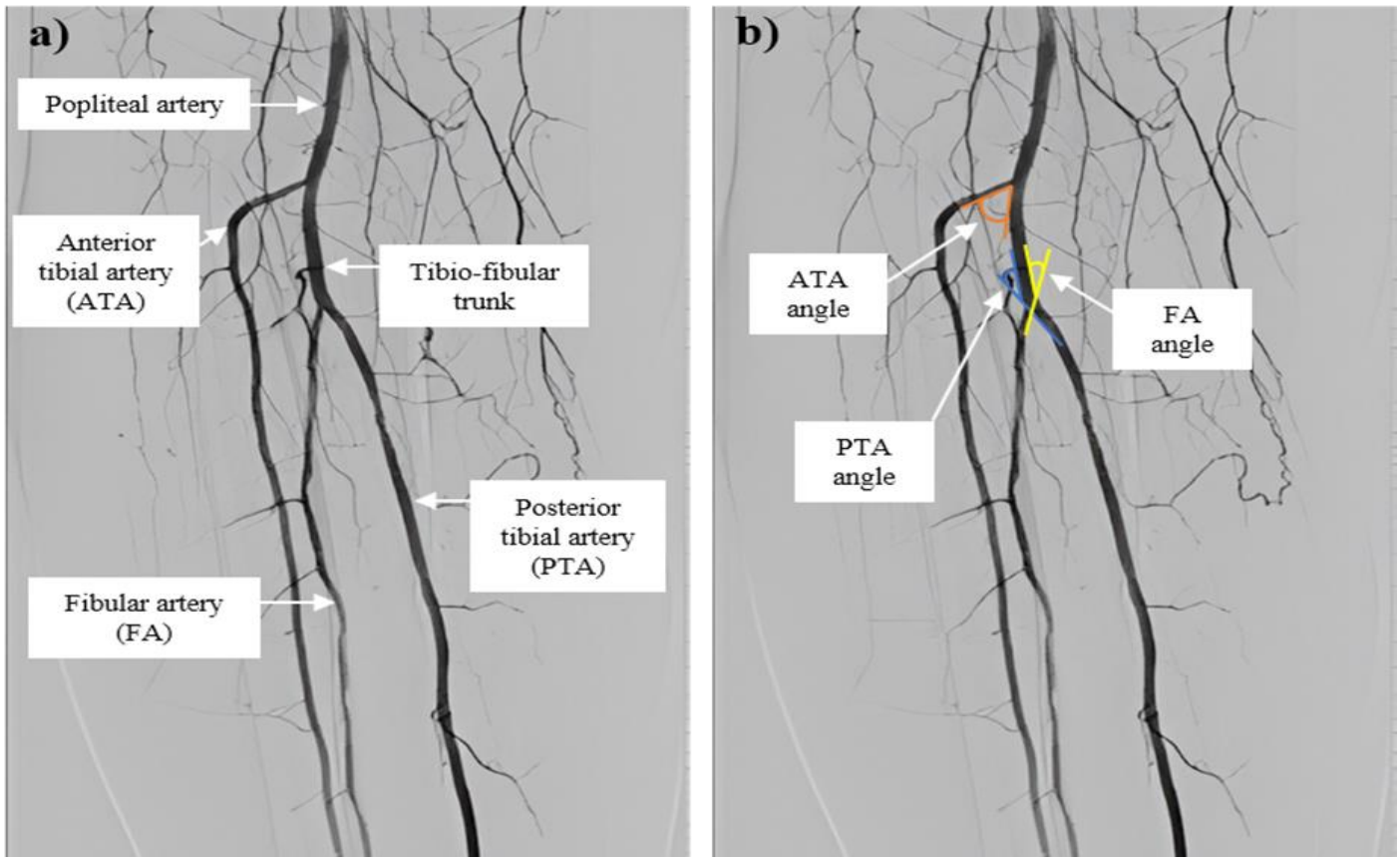
The first branch is the anterior tibial artery (ATA), followed by the tibio-fibular trunk, which further divides into the fibular artery (FA) and the posterior tibial artery (PTA) (**Figure 1**). Many studies have reported that this branching pattern, classified as type 1a, is observed in almost 90% of cases.[5,6] Understanding the variations in popliteal artery trifurcations is essential for surgeons and interventional radiologists when performing procedures such as bypass surgeries or angioplasty in the lower extremities. Although there are many studies in the literature to describe the variations of the popliteal trifurcation branches, we did not find any studies investigating the variations in the degree of angulation of these branches and their possible effects.

The endothelium that lines the vascular system is highly susceptible to hemodynamic forces that exert themselves at the vessel's luminal surface in the direction of blood flow. While numerous biochemical and mechanical factors regulate endothelial cells, wall shear stress (WSS) is one of the most critical regulators of endothelial functions.[7] Studies have highlighted the importance of vessel shape, velocity distribution, and WSS in atheroma location, progression, and clinical outcomes.[8-11] One study reported that an increase in the angle of branching of the coronary arteries creates more

Figure 1
A 58-year-old woman with a right diabetic foot wound



a) The DSA image shows a type 1a trifurcation branching pattern in the popliteal artery.
b) An angle measurement of the popliteal artery trifurcation branches is shown. The angle of the anterior tibial artery (ATA) is orange; the angle of the posterior tibial artery (PTA) is blue; and the angle of the fibular artery (FA) is yellow.

turbulent and oscillatory flow, and that this flow contributes to endothelial dysfunction, which is the precursor to atherosclerosis, by reducing WSS.[12] In light of these data, the aim of this study was to investigate whether there is an association between the degree of angulation in the trifurcation branches of the popliteal artery and the burden of atherosclerosis.

2. Materials and methods

The local ethics committee approved this study (ethics no. 565473, date: 12.07.2024). Informed consent was not obtained from patients due to the retrospective nature of the study.

2.1. Study population

Digital subtraction angiography (DSA) images of 104 patients undergoing percutaneous transluminal angioplasty (PTA) for lower-extremity peripheral artery disease at our Interventional Radiology Unit between April 2021 and 2023 were retrospectively evaluated. Other branching variations of the popliteal artery other than type 1a were excluded from the study, as were cases of critical stenosis and/or occlusion of the superficial femoral and popliteal arteries, along with those exhibiting motion artefacts, the presence of metallic orthopaedic materials, a history of femoropopliteal bypass operations, and below-knee amputations. For the remaining 68 patients, data were collected on age and sex, smoking, hypertension, high cholesterol, renal dysfunction, heart failure, and diabetes.

2.2. Digital subtraction angiography

After skin sterilization and local anaesthesia, a 6F introducer was inserted into the superficial femoral artery using the Seldinger method under ultrasound guidance. Diagnostic images were then obtained with four separate DSA scans using non-ionic contrast material. For each scan, a 10-cc bolus of contrast was administered. The first DSA image was obtained for the superficial femoral artery, the second for the femoropopliteal artery, the third for the trifurcation arteries, and the last for the pedal arteries.

2.3. Image analysis

In the DSA image, including the femoropopliteal region, angle measurements were performed separately for ATA, PTA, and FA. The ATA angle was measured from the branching site of the popliteal artery, and the PTA and FA angles were measured from the branching site of the tibio-fibular trunk. The method used for measuring the angle is shown in Figure 1.

A scoring system was designed to quantify the atherosclerosis burden of the trifurcation arteries. The segment of the trifurcation arteries from the origin to the intermalleolar level was divided into three equal parts: proximal, middle, and distal (Figure 2). Each equal segment was scored between 0 and 6, according to the visual scoring system below.

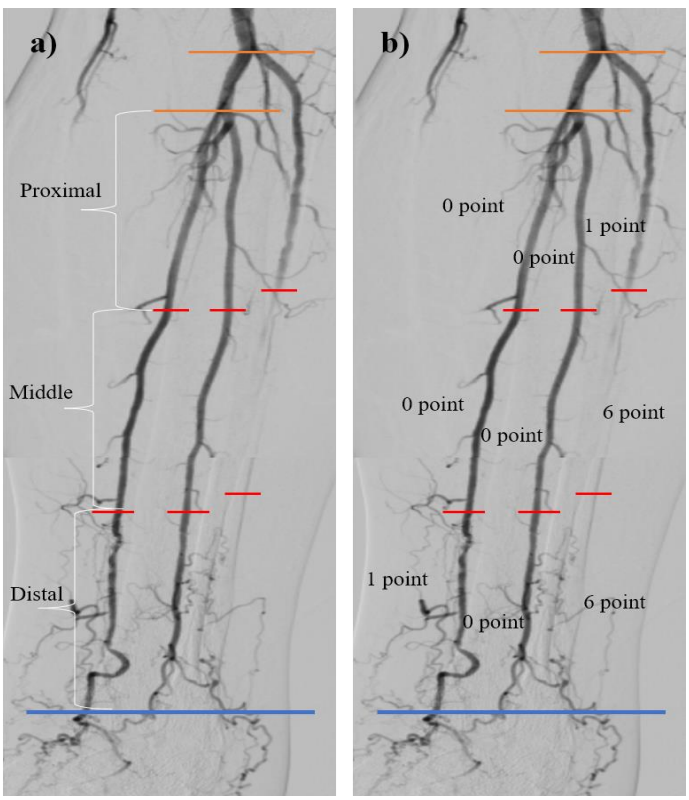
0 points: *completely normal lumen.*
1 point: *<50% luminal narrowing affecting less than half of the segment.*

2 points: *<50% luminal narrowing affecting more than half of the segment.*
3 points: *≥50% luminal narrowing affecting less than half of the segment.*
4 points: *≥50% luminal narrowing affecting more than half of the segment*
5 points: *total occlusion affecting less than half of the segment*
6 points: *total occlusion affecting more than half of the segment*

In total, an atherosclerosis burden score between 0 and 18 was calculated for each trifurcation artery. An example of the scoring system is shown in Figure 2. To enhance the accuracy of the subjective scoring system used for assessing atherosclerosis burden, measurements were performed by two independent observers.

Figure 2

A 72-year-old male patient with an ischaemic wound on the left foot.



a) The division of each trifurcation artery into proximal, middle, and distal segments is shown. Orange lines show the origin of ATA, PTA, and FA; blue lines show the intermalleolar line; and red lines show the division of the arteries into three equal segments.
b) To calculate the atherosclerotic burden of the trifurcation arteries, the scores given to each segment are shown. In total, ATA received 13 points, PTA 1 point, and FA 0 points.

2.4. Statistical analysis

Statistical analysis was performed using SPSS software (version 26.0, SPSS, Chicago, IL, USA). The Shapiro-Wilk test was used to determine whether the data set conformed to a normal distribution. Normally distributed data were expressed as mean ±standard deviation, and non-normally distributed data were expressed as median (25th–75th percentile).

The level of agreement between the observers was evaluated using the intraclass correlation coefficient (ICC). An ICC value above 0.75 was considered to indicate high agreement, a value between 0.4 and 0.75 was considered to indicate moderate agreement, and a value below 0.4 was considered to indicate low agreement.

The relationship between the angle of the trifurcation arteries and the burden of atherosclerosis was examined using the Spearman correlation test. In a positive or negative direction, a Spearman correlation coefficient (r_s) of 1 indicates an excellent monotonic relationship; less than 0.4 to 0.7 indicates a moderate relationship; less than 0.2 to 0.4 indicates a weak relationship; and 0 indicates no monotonic relationship. $p < 0.05$ was considered statistically significant.

3. Results

A total of 68 patients were included in the study. The mean age was 65 ± 11 years. Of the patients, 56 (82%) were male and 12 (18%) were female. Smoking was reported in 47 patients (69%). Hypertension was prevalent in 59 patients (87%), while 10 patients (15%) had high cholesterol levels. Renal dysfunction was observed in 34 patients (50%) and heart failure in 29 patients (43%). Additionally, 55 patients (81%) were diagnosed with diabetes mellitus (Table 1).

Table 1

Demographic and clinical features of the patients

n: 68	n(%)
Age	65±11
Gender (male-female)	56 (82%) - 12 (18%)
Smoking	47 (69%)
Hypertension	59 (87%)
High cholesterol	10 (15%)
Renal dysfunction	34 (50%)
Heart failure	29 (43%)
Diabetes mellitus	55 (81%)

Angioplasty was performed on the right side in 38 patients (56%), and on the left side in 30 patients (44%). The trifurcation angles were 58° ± 11° for ATA, 23° ± 8° for PTA, and 15° ± 8° for FA.

Table 2

Presence and burden of atherosclerotic lesions in the trifurcation arteries

n: 68	
Angioplasty (right-left)	38 (56%) - 30 (44%)
Trifurcation arteries angle degree	
• Anterior tibial artery	58°±11°
• Posterior tibial artery	23°±8°
• Fibular artery	15±8°
Localizations of atherosclerotic lesions	
• Anterior tibial artery	56 (82%)
• Posterior tibial artery	50 (73%)
• Fibular artery	27 (40%)
Burden of atherosclerosis	
• Anterior tibial artery	11 (5-15) points
• Posterior tibial artery	9 (3-16) points
• Fibular artery	3 (0-11) points

Atherosclerotic lesions were located on ATA in 56 patients (82%), on PTA in 50 patients (73%), and on FA in 27 patients (40%). Atherosclerosis burden was calculated as 11 (5–15) points for the ATA, 9 (3–16) points for the PTA, and 3 (0–11) points for the FA (Table 2). An ICC value of 0.82, indicating high agreement, was obtained.

The results of Spearman's correlation test between the trifurcation angle and the burden of atherosclerosis showed the following monotonic relationships: For the ATA, Spearman's rho (r_s) was 0.144 with a p-value of 0.29, suggesting a weak positive monotonic relationship that is not statistically significant. For the PTA, Spearman's rho was 0.398 with a p-value of 0.001, indicating a moderate positive monotonic relationship that is statistically significant. For the FA, Spearman's rho was 0.599 with a p-value of less than 0.001, indicating a strong positive monotonic relationship that is statistically significant (Table 3).

Table 3

Spearman's correlation test results between trifurcation angle and atherosclerosis burden

	rs	p
Anterior tibial artery	0,144*	0,29
Posterior tibial artery	0,398*	0,001
Fibular artery	0,599*	<0,001

rs (Spearman's rho), Spearman correlation coefficient.
**Correlation is significant at the 0.01 level (2-tailed).*

4. Discussion

The results of this study showed varying degrees of correlation between the angles of different trifurcation branches and the extent of atherosclerosis, highlighting the potential impact of vessel geometry on the progression of atherosclerotic disease.

The results showed that the ATA angle had a weak positive correlation with atherosclerotic burden, which was not statistically significant. Conversely, the angles of the PTA and FA showed moderate and strong positive correlations with atherosclerosis burden, respectively, both of which were statistically significant. This finding indicates that larger angles of the PTA and FA are associated with a greater severity of atherosclerosis in these branches. These correlations suggest that larger branch angles may contribute to disturbed flow patterns, such as increased turbulence and oscillatory shear stress, which are known to promote endothelial dysfunction and atherogenesis.[13] Previous research has shown that regions of low and oscillatory wall shear stress are more prone to atherosclerosis due to the resulting endothelial injury and inflammatory responses.[14] Our study confirms these findings in the context of the popliteal artery trifurcation and highlights the importance of considering vessel geometry in the assessment and management of PAD. Since we could not find a similar study in the literature, we could not compare our results, but there are studies reporting that vessel geometry is associated with atherosclerosis formation in coronary arteries.[8,15,16]

The clinical implications of this study are important for interventional radiologists and vascular surgeons. Understanding the relationship between trifurcation angles and atherosclerotic burden can inform the planning and execution of endovascular procedures. For example, when performing angioplasty or stenting, identifying regions of increased atherosclerotic burden associated with specific vessel angles may help to anticipate complications and optimise treatment strategies.

This study had several limitations. Firstly, the visual scoring used to calculate the burden of atherosclerosis is an estimate. The development and use of more objective measurement methods, such as automated software-based analysis, should be considered in future studies to further reduce potential biases. In addition, it is clear that atherosclerosis is not only associated with variations in vessel geometry. There are many possible etiological factors. However, this study was designed to investigate the effect of a single possible factor. Finally, the exclusion of variations other than type 1a aimed to evaluate the effect of vessel geometry on atherosclerotic burden in a more homogeneous group of patients. However, this limitation may limit the generalizability of the findings to a larger population of patients with different popliteal artery variations.

5. Conclusion

In conclusion, this study found a significant association between the degree of angulation of the popliteal artery trifurcations and atherosclerotic burden. Investigating the effects of interventions designed to alter flow patterns and shear stress in patients with unfavourable trifurcation angles may provide new therapeutic avenues to reduce PAD burden. Future research should aim to confirm these findings in larger prospective cohorts and explore the underlying mechanistic pathways linking vascular geometry and atherosclerosis.

Statement of ethics

Ethical permission was obtained from the Aydın Adnan Menderes Faculty of medicine Clinical / Human Research Ethics Committee ethics no. 565473, date: 12.07.2024

Source of Finance

The authors declare that they have received no financial support for this study

Conflict of interest statement

The authors declare that they have no conflict of interest.

Authors' contributions

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by AT&AA. The first draft of the manuscript was written by AT&AA, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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