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ORIGINAL ARTICLE

The Most Accurate Ultrasonographic Finding for Diagnosis of Lower-Extremity Arterial Disease in Patients with Critical Limb Ischemia

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Abstract

Purpose: To search for the most accurate duplex ultrasound finding for diagnosis of arterial stenosis and occlusion in patients with critical limb ischemia.

Design: Retrospective analysis of prospective data collection.

Materials and methods: The sensitivity, specificity, predictive value, and accuracy of duplex ultrasound findings were evaluated from 312 arterial segments of 26 patients with critical limb ischemia who undergo duplex ultrasound scanning within 30 minutes after femoral run-off angiography.

Result: Combining the findings from B-mode with color and spectral PW Doppler ultrasound showed the higher accuracy than using one finding, with increased sensitivity and negative predictive value. Combined > 50% decrease in diameter seen on B-mode ultrasound with PSV ratio ≥ two-fold, relative to the proximal segment, showed the highest accuracy for diagnosis of suprapopliteal arterial lesion. (The sensitivity was 94.7%, the negative predictive value was 98.9%, the accuracy was 84.6%). Combined color Doppler ultrasound findings, with increased PSV ≥ two-fold relative to the proximal segment, and monophasic with broadening spectrum at the examined segment, were the most accurate findings for diagnosis of infrapopliteal arterial lesion. (The sensitivity was 87.6%, the negative predictive value was 82.1%, the accuracy was 76.9%).

Conclusion: Findings from the B-mode, color, and spectral PW Doppler ultrasound are essential for the duplex examination of lower-extremity arterial disease. B-mode and color Doppler ultrasound in particular are important for anatomical information and combining anatomical with hemodynamic information from spectral PW Doppler ultrasound yields the best accuracy. Combining the PSV ratio with findings from B-mode ultrasound produces the most accurate findings when diagnosing suprapopliteal arterial lesion. In infrapopliteal arteries, diagnosis by B-mode ultrasound is limited. Combining the PSV ratio with the presence of monophasic flow, a broadening spectrum at the examined segment, and color Doppler findings shows the best accuracy in diagnosing infrapopliteal arterial lesion.

Abbreviations

PAD: Peripheral Arterial Disease; CLI: Critical Limb Ischemia; PW: Pulse Wave; PSV: Peak Systolic Velocity; CTA: Computed Tomography Angiography; MRA: Magnetic Resonance Angiography; DSA: Digital Subtraction Angiography; CFA: Common Femoral Artery; SFA: Superficial Femoral Artery; Pop A: Popliteal Artery; ATA: Anterior Tibial Artery; DPA: Dorsalis Pedis; PTA: Posterior Tibial Artery; PRF: Pulse Repetition Frequency

Introduction

Critical limb ischemia (CLI) is the most severe manifestation of peripheral arterial disease (PAD) and presents with severe, chronic rest pain or ischemic skin lesions (ulcer or gangrene). It is the major cause of amputation of ischemic limbs in the United States; the annual incidence of CLI is 500 to 1000 cases per million people [1,2]. Revascularization by endovascular or open surgical technique is recommended, depending on the severity of the disease. Many imaging modalities can identify an arterial lesion that is a candidate for endovascular or open surgical technique.

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Angiography is the gold-standard diagnostic test [3,4] but it is a high-risk, invasive, and costly procedure [5]. Computed tomography angiography (CTA), using multidetector computed tomography (MDCT) technology and magnetic resonance angiography (MRA), is highly accurate in diagnosing PAD, equivalent to digital subtraction angiography (DSA). MRA produces an image without contrast or interference from calcium. CT acquisition is rapid and less prone to motion artifacts than MRA is, but its disadvantage is exposure to doses of radiation and iodinated contrast. Streak artifacts from heavy calcification or metallic materials result in limited evaluation of vascular patency [6].

The first study of duplex ultrasound for diagnosis of PAD was published in 1985 [7]. Today, duplex ultrasound is widely available for the screening and diagnosis of vascular lesions, without the disadvantage of radiation exposure. It is easily repeatable, free of risk, and relatively cost effective and causes minimal discomfort. Several studies have shown that duplex ultrasound has good sensitivity, specificity, and diagnostic agreement with DSA in assessment of lower-extremity arterial disease [4,5,8-16].

The peak systolic velocity (PSV) quantified by spectrum analysis from spectral pulsed-wave (PW) Doppler ultrasound was the most common criterion used for diagnosis and categorizing the severity of the disease in most previous studies [4,5,8-16]. Although increased PSV of more than 100%, compared with the adjacent proximal segment or a PSV ratio of ≥ 2.0, shows the best combination of sensitivity, specificity, predictive value, and accuracy for the diagnosis of stenosis [10], the duplex scanning protocol must begin with B-mode and color Doppler ultrasound to identify the lesion and assess blood flow before sampling the Doppler signal by spectral PW Doppler ultrasound. The waveform feature analysis (triphasic or monophasic, acceleration time, spectral broadening, turbulence, or direction) and velocity measurement can be obtained at the proximal, distal, and overall points of the lesion when suspicion of abnormality exists [4,5,8-16]. Using mutual interpretation of the findings from B-mode, color, and spectral PW Doppler ultrasound (waveform analysis and velocity measurement) is the key concept of using duplex ultrasound for the diagnosis of vascular pathology.

The aim of this study is to evaluate the sensitivity, specificity, predictive value, and accuracy of findings from B-mode, color, and spectral PW Doppler ultrasound and search for the most accurate findings for diagnosis of arterial stenosis and occlusion in patients with critical limb ischemia. The result of the study will be helpful when the findings from B-mode, color, and spectral PW Doppler ultrasound are inconsistent with other findings.

Materials and Methods

Patient population

In this prospective study, duplex ultrasound was performed on 26 patients with critical limb ischemia (the ankle-brachial index of 0.4 or less) who were sent to undergo femoral run-off angiography. All patients scheduled for angiography were enrolled in the study and gave informed consent. The duplex ultrasound scan was conducted by a first-year fellowship student in interventional radiology, under supervision of an experienced vascular radiologist, within 30 minutes after finishing a DSA examination. The study was approved by the ethics review board of the hospital, and written informed consent was obtained from all patients.

Imaging technique

The arterial system of the patient's lower extremity was evaluated by means of L9-3 mHz and L12-5 mHz linear array transducers (iU22 Ultrasound system; Philips, Bothell, WA, USA), scanning from the common femoral artery (CFA) to the dorsalis pedis artery (DPA) and the distal part of the posterior tibial artery (distal PTA). B-mode, color, and spectral PW Doppler ultrasound scans were obtained at each examined segment. The lower-extremity artery was divided into 12 segments: The CFA, the proximal part of the superficial femoral artery (Pro SFA), the middle part of the superficial femoral artery (Mid SFA), the distal part of the superficial femoral artery (Dis SFA), the popliteal artery (Pop A), the proximal part of the anterior tibial artery (Pro ATA), the middle part of the anterior tibial artery (Mid ATA), the distal part of the anterior tibial artery (Dis ATA), the dorsalis pedis artery (DPA), the proximal part of the posterior tibial artery (Pro PTA), the middle part of the posterior tibial artery (Mid PTA), and the distal part of the posterior tibial artery (Dis PTA).

The peroneal artery was excluded from this study due to incomplete data collection. Up to 50% of cases cannot obtain the optimized image or signal from the peroneal artery by using the L9-3 mHz or L12-5 mHz linear array transducers.

The scanning protocol begins with B-mode ultrasound for each segment, followed by color and spectral PW Doppler ultrasound, respectively. The Doppler signal was sampled by placing the sample gate at the suspicious site of stenosis (decreased luminal diameter and/or color aliasing seen on the B-mode and color Doppler ultrasound result) with 30-60 degree angle correction and 1.5-2.0 mm as the sample gate size. The spectral waveform at the stenotic site and just 1-2 cm proximal to the stenotic site were recorded, and the peak systolic velocity (PSV) of the two adjacent sites was compared.

Grading of stenosis from the duplex ultrasound scan was classified and referenced from angiographic grad-

Table 1: Criteria for diagnosis and grading of stenosis in B-mode and color Doppler ultrasound.

	< 75% Stenosis	≥ 75% Stenosis	Occlusion
B-mode US	No plaque or thrombus Plaque or thrombus < 50% of luminal diameter	Plaque or thrombus ≥ 50% of luminal diameter	Plaque or thrombus with no visible lumen
Color Doppler US	Color filled > 50% of luminal diameter	Color filled < 50% of luminal diameter and color aliasing	No color filled

Table 2: Criteria for diagnosis and grading of stenosis in spectral PW Doppler ultrasound.

	< 75% Stenosis	≥ 75% Stenosis	Occlusion
Spectral waveform at the examined segment	Triphasic No or minimal broadening spectrum	Monophasic Broadening spectrum	No flow detected
Spectral waveform from distal point to the examined segment	Normal	Monophasic with reduce velocity	Monophasic with reduce velocity or No flow detected
PSV at the examined segment	No increased or Increase in PSV < two-fold relative to the proximal segment	Increase in PSV ≥ two-fold relative to the proximal segment	No flow detected

Table 3: Grading system of the femoral run-off angiogram.

	< 75% Stenosis	≥ 75% Stenosis	Occlusion
Angiographic finding	No or decreased luminal diameter < 50% relative to adjacent normal segment	Decreased luminal diameter ≥ 50% relative to adjacent normal segment	Non-contrast filled segment relative to normal anatomical location

ing as < 75% stenosis, ≥ 75% stenosis, and total occlusion. The findings from the B-mode, color, and spectral PW Doppler ultrasound scans were evaluated separately. The criteria for diagnosis and grading of stenosis in B-mode and color Doppler ultrasound are shown in Table 1 and, for the spectral PW Doppler ultrasound scan, in Table 2.

The femoral run-off angiography was performed with dedicated angiographic equipment (Infinix/VC; Toshiba, Japan) by two experienced interventional radiologists; using a contralateral approach, they placed the catheter's tip at the distal aorta and obtained images of the anteroposterior (AP) view of the aortic and iliac bifurcation, using 10 ml of contrast, rate 5 ml/second, with pressure at 300 PSI. The catheter tip was then placed at the CFA (femoral head), and images of the AP view of the CFA, SFA, and popliteal artery were obtained using 6-8 ml of contrast, rate 3 ml/second, with pressure at 300 PSI. They then obtained images of the AP view of the ATA, PTA, peroneal artery, and arch of the foot and the lateral view of the iliac bifurcation of the ATA, PTA, peroneal artery, and arch of the foot, using 12-20 ml of contrast, rate 3-4 ml/second, with pressure at 300 PSI. The angiographic findings are reported by grading system in Table 3. Evaluation of the Doppler ultrasound findings was conducted in a blinded fashion to angiography.

For analytic purposes, the angiographic finding was considered the standard of reference. If both stenosis and occlusion were found within the same segment, the occlusion was used for statistical analysis. Regardless of the number of stenoses, single or multiple sites of stenosis within the same segment were considered a stenotic segment. The sensitivity, specificity, predictive values, and accuracy of each duplex ultrasound finding for the detection of ≥ 75% stenosis and occlusion were calculated from two-way contingency tables using standard definitions. The categorical variable (gender) was evaluated by chi squared tests. The continuous variables (age) was evaluated by mean with standard deviation (SD). A P-value < 0.05 was considered statistically significant. The STATA version 13 (Stata Corp, College Drive, Texas, USA) statistical software was used to analyze the data.

Results

Twenty-six limbs from 15 men and 11 women were eligible for the study. The age of the patient ranged from 42 to 88 years (68.62 ± 10.38 years). The distribution of the patients' age was normal. No significant difference between the patients' gender was observed.

From the total of 312 segments (one limb was divided into 12 segments), the angiography shows abnormality in 152 segments (48.72%). Stenosis was found in 67 segments (44.08%), and occlusion was found in 85 segments (55.92%), and stenosis and occlusion were found

Table 4: Sensitivity, specificity, predictive values, and accuracy of duplex ultrasound findings in diagnosis of suprapopliteal arterial lesions.

	Sensitivity	Specificity	PPV	NPV	Accuracy
Ultrasound finding					
1. B-mode ultrasound	72.2% (26/36)	88.3% (83/94)	70.3% (26/37)	89.2% (83/93)	83.8% (109/130)
2. Color Doppler ultrasound	65.8% (25/38)	86.9% (80/92)	67.6% (25/37)	86% (80/93)	80.8% (105/130)
3. Increased PSV ≥ two-fold relative to the proximal segment	79.2% (19/24)	83% (88/106)	51.3% (19/37)	94.6% (88/93)	82.3% (107/130)
4. Monophasic flow and broadening spectrum at the examined segment	59% (25/42)	86.3% (76/88)	67.6% (25/37)	81.7% (76/93)	77.7% (101/130)
5. Monophasic flow with reduced velocity at the distal segment	40% (4/10)	86.8% (66/76)	28.6% (4/14)	91.7% (66/72)	81.4% (70/86)
Combining two ultrasound findings					
1 + 2	86.4% (19/22)	83.3% (90/108)	51.3% (19/37)	96.8% (90/93)	83.8% (109/130)
1 + 3	94.7% (18/19)	82.9% (92/111)	48.6% (18/37)	98.9% (92/93)	84.6% (110/130)
1 + 4	85.7% (18/21)	82.6% (90/109)	48.6% (18/37)	96.8% (90/93)	83.1% (108/130)
2 + 3	94.4% (17/18)	82.1% (92/112)	45.9% (17/37)	98.9% (92/93)	83.8% (109/130)
2 + 4	81.8% (18/22)	82.4% (89/108)	48.6% (18/37)	95.7% (89/93)	82.3% (107/130)
Combining three ultrasound findings					
1 + 2 + 3	93.7% (15/16)	96.8% (92/95)	40.5% (15/37)	98.9% (92/93)	82.3% (107/130)
1 + 2 + 4	93.3% (14/15)	79.8% (91/114)	37.8% (14/37)	97.8% (91/93)	80.8% (105/130)

to be more common in the infrapopliteal segment than in the supra-popliteal segment (115 vs. 37 segments, 75.66% vs. 24.34%, respectively). The most common sites of stenosis were at the proximal and distal ATAs, and the most common sites of occlusion were at the mid and distal ATAs.

The B-mode ultrasound scans were performed on all 312 segments. However, 182 segments of the infra-popliteal artery were excluded from the analysis due to limitations of B-mode ultrasound criteria for evaluation. Seventy-eight segments of the popliteal artery, DPA, and distal PTA and 61 segments of occlusion and pre-occlusion were excluded from the accuracy analysis of monophasic flow with reduced velocity of the distal segment, because the protocol did not include examination of the tibioperoneal artery and the artery distal to the ankle joint.

A single finding from the B-mode, color, and spectral PW Doppler ultrasound showed good results for detection of supra-popliteal arterial lesions (CFA, SFA, and Pop A). The sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of each finding are shown in Table 4. The presence of thick intimal plaque or intraluminal thrombus, causing > 50% decrease in diameter seen on the B-mode ultrasound, shows the highest specificity (88.3%), positive predictive value (70.3%), and accuracy (83.8%) of all the other findings. The highest accuracy was found at the proximal end of the SFA (accuracy 96.0%, receiver operating characteristic [ROC] area 0.972). The increased PSV ≥ two-fold relative to the proximal segment (PSV ratio ≥ 2) shows the highest sensitivity (79.2%) and negative predictive value (94.6%).

When the two findings are combined, the overall accuracy of each pair was higher than when using one finding for diagnosis, with increased of sensitivity and

Table 5: Sensitivity, specificity, predictive values, and accuracy of duplex ultrasound findings in diagnosis of infrapopliteal arterial lesions.

	Sensitivity	Specificity	PPV	NPV	Accuracy
Ultrasound finding					
1. Color Doppler ultrasound	79.0% (94/119)	66.7% (42/63)	81.7% (94/115)	62.7% (42/67)	74.7% (136/182)
2. Increased in PSV ≥ two-fold relative to the proximal segment	85.7% (48/56)	46.8% (59/126)	41.7% (48/115)	88.1% (59/67)	58.8% (107/182)
3. Monophasic flow and broadening spectrum at the examined segment	64% (87/136)	39.1% (18/46)	75.6% (87/115)	26.9% (18/67)	57.7% (105/182)
4. Monophasic flow with reduced velocity at the distal segment	70% (7/10)	44% (33/75)	14.3% (7/49)	91.7% (33/36)	47.1% (40/85)
Combining two ultrasound findings					
1 + 2	84.9% (45/53)	45.7% (59/129)	39.1% (45/115)	88.1% (59/67)	57.1% (104/182)
1 + 3	79.1% (72/91)	53.3% (48/90)	62.6% (72/115)	71.6% (48/67)	65.9% (120/182)
Combining three ultrasound findings					
1 + 2 + 3	87.6% (85/97)	64.7% (55/85)	73.9% (85/115)	82.1% (55/67)	76.9% (140/182)

negative predictive value. The criterion of monophasic flow with reduced velocity at the distal segment was excluded from the accuracy analysis of combined findings because it was not equal and involved a small number of segments. Using the decreased luminal diameter seen on the B-mode ultrasound and the ≥ two-fold PSV ratio relative to the proximal segment shows the highest accuracy (84.6%) for diagnosis. However, a combination of three findings, from the B-mode, color, and spectral waveform for diagnosis shows no increase of accuracy.

The accuracy of duplex ultrasound in diagnosing infra-popliteal arterial lesions (ATA, DPA, and PTA) was lower than that in diagnosing supra-popliteal artery lesions. The B-mode ultrasound resolution had limited ability to depict the thrombus thickness and luminal diameter precisely, so the finding from the B-mode ultrasound was excluded from the accuracy analysis. The sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of the color and spectral PW Doppler ultrasound findings are shown in Table 5.

Color filling < 50% of the luminal diameter and the color aliasing seen on the color Doppler ultrasound show the highest positive predictive value (81.7%) and accuracy (74.7%) compared to the findings from spectral PW Doppler ultrasound for diagnosis of infrapopliteal arterial lesions. The highest accuracy was shown at the distal part of the PTA (accuracy 80.8%, ROC area 0.821). Combined findings from the color Doppler ultrasound and one finding from the spectral PW Doppler ultrasound show no more accuracy than using the finding from the color Doppler ultrasound alone. This is contrary to the color Doppler ultrasound finding combined with two findings from the spectral waveform (increased in PSV ≥ two-fold, relative to the proximal segment and monophasic with broadening spectrum at the examined segment), which shows increased sensitivity, negative predictive value, and accuracy (sensitivity 87.6%, negative predictive value 82.1%, and accuracy 76.9%).

Discussion

The results from this study show good accuracy in detecting stenosis and/or occlusion of the lower-extremity arterial system in patients with critical limb ischemia. The duplex scanning in supra-popliteal arteries (CFA, SFA, and popliteal artery) were more accurate than that for the infra-popliteal arteries (ATA, DPA, and PTA), similar to results from previous studies [17,18], because the supra-popliteal artery was larger, easier to visualize, and had higher flow, whereas the infra-popliteal artery was smaller, with lower flow.

Most of the previous studies [4,5,8-16] show good results in detecting lower-extremity arterial lesions by using velocity criteria and the presence of PSV increased more than 100% compared with the adjacent proximal segment or a PSV ratio of ≥ 2.0; this shows the best combination of sensitivity, specificity, predictive value, and accuracy for diagnosing stenosis [10]. The results from this study show that the presence of thick intimal plaque or intraluminal thrombus causing > 50% decrease in diameter, seen on B-mode ultrasound, shows the highest specificity, positive predictive value and accuracy, compared to the other findings used to diagnose supra-popliteal arterial lesions. In addition, the presence of color filling < 50% of the luminal diameter with color aliasing, seen on color Doppler ultrasound, shows the highest specificity, positive predictive value, and accuracy of all the other findings for infra-popliteal arterial lesions. The PSV ratio of ≥ 2.0 is not the most accurate finding when using only this finding for diagnosis.

B-mode ultrasound shows higher accuracy than findings from color and spectral PW Doppler ultrasound in diagnosing supra-popliteal arterial lesions. Unfortunately, B-mode ultrasound is limited in its ability to enable evaluation of infrapopliteal arterial lesions due to their small size and calcification of infra-popliteal arteries, especially in patients with critical limb ischemia. The posterior acoustic shadow from a calcified wall of a small artery will obscure the vascular lumen. The thrombus thickness and luminal diameter cannot be measured accurately by using B-mode ultrasound alone, without a color-flow image. However, a calcified wall is very helpful when distinguishing the small artery from an adjacent vein and surrounding structures. B-mode ultrasound is still useful and routinely used in both supra-popliteal and infrapopliteal arterial examinations for localizing the arteries.

Because B-mode and color Doppler ultrasound provided anatomical detail and used decreased luminal diameter similarly to digital subtraction angiography (DSA) for diagnosing arterial lesions, B-mode and color Doppler ultrasound was the most accurate in diagnosing supra-popliteal and infra-popliteal arterial lesions, respectively. DSA tended to overestimate because it did not opacify the segments just proximal and distal to the occlusions and demonstrated only one plane of anatomical stenosis [3], which sometimes produced results that conflicted with the ultrasound results.

Besides providing anatomical detail, color Doppler ultrasound also showed hemodynamic information, especially when the artery was stenosed. Color aliasing was presented due to greatly sped-up red blood cell velocity while passing through the stenotic site. However, color aliasing could appear as an artifact when an improper pulse repetition frequency (PRF) (the PRF is too low) was used [19] or when focal blood velocity at the tortuosity segment was increased; or a lesion might be missed when reading the turbulent flow and artifacts from calcification appear. Color aliasing artifacts were important factors that caused lower specificity, positive predictive value, and accuracy of color Doppler ultrasound than B-mode ultrasound did.

Spectral PW Doppler ultrasound can give hemodynamic information and thus can be used to diagnose vascular stenosis and occlusion. No Doppler signal is detected if there is no moving blood flow in the vascular lumen. Gradually increasing spectral width (broadening the spectrum) shows the PSV when the luminal diameter is reduced. High-grade stenosis (50-99% diameter reduction) produces the most severe flow disturbance with markedly increased PSV. Monophasic waveform with loss of the reverse-flow component, extensive broadening of the spectrum, and PSV increased > 100% relative to the adjacent proximal segment can be observed and used as the criterion of spectral PW Doppler ultrasound for diagnosis of high-grade stenosis and monophasic waveform with reduced systolic velocity of the distal segment [7]. From this study, the increased ≥ two-fold PSV, relative to the proximal segment, showed higher sensitivity and accuracy than did the presence of monophasic flow with broadening spectrum at the examined segment or monophasic flow with reduced velocity at the segment distal to the examined segment. This result supports and correlates with most of the previous studies [4,5,8-16], which prefer to use the increase in PSV ratio between stenotic and pre-stenotic segments for the diagnosis of arterial stenosis.

The reason the PSV ratio shows higher accuracy than the presence of broadening spectrum and monophasic flow with reduced velocity of the distal segment is that the increased PSV ratio cannot be caused by any kind of Doppler artifacts or technical errors. Furthermore, use of the ratio between the PSV of two adjacent segments (pre-stenosis and stenosis) can compensate for any errors during the sampling Doppler signal or measurement of the PSV at each segment. Broadening spectrum can occur frequently in vessels with wall irregularity and is normally found during the examination of small arteries [19]. Monophasic flow with reduced velocity of a distal segment may be not found in multifocal stenosis or proximal to the occluded segment, which is usually seen in patients with critical limb ischemia.

The accuracy of ≥ two-fold increased PSV, relative to the proximal segment, is increased when combined with findings from B-mode ultrasound, which provides anatomical detail and becomes the most accurate finding when diagnosing the supra-popliteal arterial lesion. Unfortunately, the finding from B-mode ultrasound was excluded from the accuracy analysis of the infra-popliteal arterial lesion. Without the accurate anatomical information from B-mode ultrasound, combining a two-fold increase in PSV with findings from the color Doppler ultrasound does not increase accuracy any better than using the single finding from each Doppler mode. The color aliasing artifact may lead to using an improper site for the sampling Doppler signal. This disadvantage can be corrected by combining the finding of monophasic flow with broadening spectrum at the examined segment. High PSV without monophasic flow and a broadening spectrum does not indicate a true stenosis. This study confirms that combining color findings and two-fold increased PSV relative to the proximal segment with monophasic flow and broadening spectrum shows the highest accuracy for diagnosis of infrapopliteal arterial lesions.

This study shows the maximum accuracy of duplex ultrasound for diagnosis of lower-extremity arterial disease when combined with anatomical information from B-mode ultrasound and hemodynamic information from Doppler ultrasound. When accurate anatomical information is not available, especially in infra-popliteal arteries, more than one form of hemodynamic information from Doppler ultrasound should be used for increased accuracy.

There are some limitations in this study due to the small number of cases and its single-center design. Duplex ultrasound was performed by a first-year fellowship radiologist perhaps inexpert in constant scanning protocol and setting. No further optimization process or artifact correction was done. The rationale of this study design was to evaluate the accuracy of each finding ingenuously, with the shortest scan time. The results from this study suggest the accuracy of ultrasound findings even when conducted by someone with less expertise. The stenosed and occluded lesions were not separated in this study. If there is stenosis and occlusion within the same segment, the occlusion will be interpreted as the result. All factors may cause rather lower accuracy than the results from previous studies. Further study of selective stenosis or occlusion analysis, and including the aortoiliac segment, tibioperoneal artery, plantar artery, and arch of foot scanning in the protocol, will be useful and may show better accuracy in detecting the presence of delayed systolic upstroke, monophasic flow with reduced velocity of the distal segment than the results in this study.

Conclusion

B-mode, color, and spectral PW Doppler ultrasound are required for duplex examination of lower-extremity arterial disease. B-mode ultrasound can enable the physician to diagnose the examined artery for stenosis or occlusion. Color Doppler ultrasound offers the benefit of additional capability to locate and diagnose lower-limb ischemia, especially when B-mode ultrasound is limited, and using anatomical information from B-mode and color Doppler ultrasound allows good accuracy for diagnosis. However, combined hemodynamic information from the spectral waveform provided by spectral PW Doppler ultrasound allows even better accuracy. The presence of PSV increased two-fold relative to the proximal segment (PSV ratio ≥ 2) shows the highest accuracy of all the other spectral findings. Combining the PSV ratio with findings from B-mode ultrasound offers the most accurate finding for diagnosis of supra-popliteal arterial lesions. In infra-popliteal arteries, diagnosis by B-mode ultrasound is limited. Combining the PSV ratio with the presence of monophasic flow and broadening spectrum at the examined segment with color Doppler findings shows the best accuracy in diagnosis of infra-popliteal arterial lesions.

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