Limitations of ultrasonic duplex scanning for diagnosing lower limb arterial stenoses in the presence of adjacent segment disease

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Purpose: **The purpose of this study was to provide a quantitative evaluation of the effect of adjacent segment lesions on disease classification in lower limb arteries by ultrasonic duplex scanning.**
Methods: **Lower limb arterial duplex scanning from the distal aorta to the popliteal artery was performed in 55 patients. Arterial lesions evaluated by visual interpretation of Doppler spectra were compared blindly with those measured by angiography.**
Results: **To recognize severe stenoses (50% to 100% diameter reduction) in any arterial segment, duplex scanning had sensitivity and specificity rates of 74% and 96%, respectively. However, sensitivity and specificity rates increased to 80% and 98%, respectively, when there was no 50% to 100% diameter-reducing lesion in adjacent segments, whereas they decreased to 66% and 94%, respectively, when there was at least one 50% to 100% diameter-reducing lesion in adjacent segments. Moreover, among the 48 duplex misclassifications underestimating or overestimating the degree of arterial stenoses, 30 (62.5%) involved a segment with at least one 50% to 100% lesion in adjacent segments. The segments mostly affected by proximal and distal arterial lesions were the popliteal arteries and the common and deep femoral arteries, where it was found that 86% (24/28) of the misclassifications involved the presence of either proximal or distal severe stenoses.**
Conclusion: **The results demonstrated that the presence of multiple stenoses was an important limitation of duplex scanning for the detection and quantification of lower limb arterial disease. (J VASC SURG 1994;19:650-7.)**

Very few studies have reported in vivo observations on the performance of duplex scanning for diagnosing lower limb arterial stenoses in the presence of multisegmental disease. In fact, most studies are based on quantitative parameters extracted from continuous-wave Doppler signals recorded in the common femoral artery, at rest, and during reactive hyperemia for the detection of severe stenoses in the aortoiliac segment. In these studies the discriminant power of the quantitative parameters was evaluated in the presence of superficial femoral arterial lesions.[1-4] Although some of these parameters seemed to be independent of the status of the superficial femoral artery, they have not gained widespread clinical acceptance because continuous-wave Doppler scanning does not provide sufficient information on the extent and location of the disease to allow planning of surgical intervention.[5] For this reason, conventional and color-flow duplex scanning are actually the most common noninvasive methods for studying aortoiliac and femoropopliteal disease.[6-12] In some of the first important studies that used duplex scanning, it was stated that the presence of multisegmental disease did not influence the performance of the technique,[7,8] although no specific results were presented to validate this conclusion. However, among these studies, Kohler et al.[7] reported that the sensitivity for detecting severe stenoses was decreased

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in low-flow segments distal to a total occlusion. In a recent duplex scanning study, Moneta et al.[12] presented an extensive set of classification results including some on the effect of multilevel inflow and outflow disease. On the basis of segmental pressure measurements, the population was divided into four clinical groups: no significant arterial occlusive disease, inflow (aortoiliac) disease, outflow (infrainguinal) disease, and multilevel inflow and outflow disease. According to criteria similar to those defined by Jager et al.,[8] each arterial segment was evaluated by duplex scanning and compared with the angiographic status. The authors concluded that duplex scanning appeared to be relatively unaffected by the clinical disease pattern determined by segmental pressure. When interpreting those results, it is important to be aware of the limitations of segmental pressure measurements in assessing both inflow and outflow disease.

Theoretically to overcome the influence of upstream and downstream stenoses, a new method[11,13] based on the computation of the ratio of the velocity at the site of the lesion divided by that before or after the lesion on the same segment was proposed. It was reported that this ratio should be related directly to changes in cross-sectional area and not the amount of blood flow because this index is based on the assumption that the amount of blood flow at one point of the segment is the same as that found at any other point (if there are no side branches). It is important to note that this method can work successfully only if the reference recording site (proximal or distal to the stenosis) is normal and located several diameters from any arterial lesion. In practice it may be difficult to obtain such a reference on the same segment, especially (1) if the lesion is severe and localized at the origin of the arterial segment and (2) if there is more than one lesion within the segment.

In summary there is no evidence that the evaluation of lower limb arterial disease based on any Doppler spectrum criteria (visual or quantitative) is independent of the presence of proximal or distal disease. The objective of this article is to report our clinical experience based on visual interpretation of Doppler spectra. More specifically, the effect of the presence of adjacent segment disease on duplex classification performance was evaluated. The hypothesis supporting this work was that the presence of adjacent segment disease is an important cause of misclassifications. In addition to the aforementioned results, the problem of detecting aortoiliac (inflow) disease, femoropopliteal (outflow) disease, and both multilevel inflow and outflow disease was addressed.

PATIENTS AND METHODS

Subjects for this study were recruited among patients referred to the Hôtel-Dieu de Montréal Hospital for arteriographic examination of the lower limb arteries.[14] All patients scheduled for arteriography gave informed consent as required by the Ethics Committee of the Hôtel-Dieu de Montréal Hospital. Only patients for whom the arteriographic examination was performed within 3 months of the Doppler examination were included. For each patient the ankle/brachial index (systolic ankle pressure divided by systolic brachial pressure) was measured to evaluate the clinical status of the lower limbs, although no segmental pressure measurement was performed as a screening test to estimate the level of disease.

Doppler studies were performed with an Ultramark 8 duplex scanner (Advanced Technology Laboratories, Bothell, Wash.). The arterial segments examined in each limb were the distal aorta, the common and external iliac arteries, the common and deep femoral arteries, the superficial femoral artery, and the popliteal artery (13 segments per patient). A mechanically oscillating probe operating at 5 MHz was used for all Doppler recordings. The sample volume was placed in the center stream of the artery where flow velocities are maximal. According to the manufacturer's specifications, the sample volume used for all recordings had a length of 1.5 mm in the direction of the axial beam, which is much smaller than the diameter of the arterial segments studied. Segments were initially examined to assess the presence or absence of disease. Representative signals from all segments were then recorded at midcourse of the segment if normal or at the site of most severe disease. The latter was identified by the technologist at the site of maximal flow disturbances, spectral broadening, and increased Doppler frequencies. Spectral analysis criteria similar to those of Jager et al.[8] were used for grading arterial stenoses into five classes: normal, 1% to 19%, 20% to 49%, and 50% to 99% diameter reduction, and occlusion. To standardize the recordings, the patients were asked to rest in the supine position for at least 30 minutes in a controlled-temperature environment (21° to 23° C). The high-pass filter used to remove clutter attributable to slow-motion effects was set at 100 Hz and the angle between the sound beam and the vessel axis was maintained as close as possible to 60 degrees for all recordings.

Table I. List of the arterial segments considered to be proximal and distal to the one under study

Segment	*Adjacent sigment*	
	Proximal	*Distal*
Distal aorta		Common and external iliac
Common iliac	Distal aorta	External iliac and common femoral
External iliac	Distal aorta and common iliac	Common femoral
Common femoral	Common and external iliac	Deep and superficial femoral
Deep femoral	Common femoral	Superficial femoral
Superficial femoral	Common and deep femoral	Popliteal
Popliteal	Superficial femoral	

As a gold standard, conventional biplane contrast angiographic studies were performed on all patients to evaluate duplex scanning performance. Each angiographic film was read by an experienced angioradiologist, and the view showing the most severe lesion was used for estimating the percentage of diameter-reducing lesion. On the basis of caliper measurements of the normal and residual arterial diameter of each segment, as judged by the angioradiologist, the severity of the disease was classified into five categories: 0%, 1% to 19%, 20% to 49%, 50% to 99%, and 100% of arterial diameter reduction. Neither the angioradiologist nor the technologist performing the noninvasive studies was aware of each other's results.

For the specific objective of the study, a severe stenosis was defined as an arterial segment having a 50% or greater diameter-reducing lesion. Multisegmental disease was defined by the presence of at least two severe stenoses in two adjacent segments. Table I details the segments considered to be adjacent (either proximal or distal) to the one under study. This definition of multisegmental disease is based only on our experience because the effect of a severe stenosis on the Doppler signal waveform recorded in a proximal and distal segment is hardly predictable and has never been evaluated clearly in clinical practice. It should be noted in Table I that no proximal or distal segment is given for the aorta and popliteal arteries because the status of the proximal aorta and the tibial arteries was not available. The cases in which more than one stenosis was present within the same arterial segment were not considered as multisegmental disease because only the Doppler signal from the stenosis with the greatest systolic velocity or the most severe disturbances was analyzed.

It is recognized that aortoiliac disease is a key question for the treatment of patients with claudication. However, the detection of the aortoiliac lesion in a patient with both aortoiliac and femoropopliteal disease is very difficult. To aid in planning operative arterial reconstruction, it is also important to know whether the disease is in the aortoiliac or femoropopliteal tract or both. So, in addition to the consideration of each arterial segment individually, duplex scanning performance was also evaluated on an arterial tract basis. The "aortoiliac tract" consists of the aorta and the iliac artery grouped together, whereas the "femoropopliteal tract" combines the femoral and popliteal arteries. So inflow disease was defined as the presence of a 50% to 100% lesion in at least one segment of the aortoiliac arterial tract, whereas outflow disease was defined as the presence of a 50% to 100% lesion in at least one segment of the femoropopliteal arterial tract. Multilevel disease was defined as the presence of a 50% to 100% lesion in both the aortoiliac and femoropopliteal tracts.

RESULTS

In this study, 55 patients with a mean age of 60 ± 11 years (range 27 to 77 years) were evaluated by ultrasonic duplex scanning and arteriography. The patients' symptoms were claudication (60%), rest pain (25%), ulcer and gangrene (2%), no symptoms (5%), and others (8%). From these patients, a total of 73 segments (and 11 arterial tracts) were not included in the study for the following reasons: (1) 10 segments could not be evaluated by angiography, (2) 36 segments could not be visualized adequately by duplex scanning, (3) 12 segments (two sides) could not be used because of prior bypass grafting, and (4) 15 common or external iliac segments were missing because our initial protocol included only one recording for this segment. More than half of the 36 segments that were not visualized adequately were associated with patients who were examined at the beginning of the study. The population thus provided a total of 642 lower limb arterial segments and 99 aortoiliac and femoropopliteal arterial tracts. Table II gives, for the 99 aortoiliac and femoropopliteal tracts, the distribution of

inflow/outflow disease based on the presence of a 50% to 100% diameter-reducing stenosis, as determined by angiography. Twenty-nine legs showed no severe aortoiliac or femoropopliteal disease, whereas 17 legs had inflow disease and 41 legs had outflow disease. Multilevel inflow and outflow disease was present in 12 legs. The mean ankle-brachial index for all patients was 0.75 ± 0.22 (range 0.30 to 1.26). This index was 0.97 ± 0.13 for patients having no 50% to 100% diameter-reducing stenosis, 0.65 ± 0.17 for those having inflow or outflow disease, and 0.61 ± 0.16 for those having both inflow and outflow disease.

A two-way contingency table for disease classification into five categories by duplex scanning and angiography is given in Table III. An overall accuracy of 68% (438/642) was obtained, which resulted in a Kappa[15] value of 0.43 compared with angiography. To discriminate 50% or greater diameter-reducing lesions from less than 50% lesions, duplex scanning had a sensitivity of 74%, a specificity of 96%, a positive predictive value of 80%, and a negative predictive value of 95%. Sensitivity, specificity, positive predictive value, and negative predictive value to distinguish 0% to 99% diameter-reducing lesions from occlusions were, respectively, 95%, 99%, 87%, and 100%. Seven of the eight misclassifications involved segments having another occlusion in the segment immediately proximal (five cases) or distal (two cases), whereas the remaining error involved an occluded segment classified in the 50% to 99% category.

To study the effect of adjacent segment disease on the performance of duplex scanning, the presence of a 50% or greater lesion in the proximal or distal segment to the one under study (as defined in Table I) was determined. For each arterial segment the duplex performance in discriminating severe stenoses from nonsevere stenoses is presented in Table IV, as is the occurrence of proximal or distal disease. Results indicate that although the accuracy and specificity for all arterial segments were always higher than 88%, the sensitivity ranged between 36% and 100%. The best sensitivity was obtained for the aorta and the worst sensitivity was associated with the common femoral artery. Table V summarizes, for all segments, the duplex scanning performance for detecting a 50% or greater lesion in either the absence or presence of disease in adjacent segments. As indicated in Table V, the overall accuracy, sensitivity, and specificity of the duplex scanning reached 95%, 80%, and 98%, respectively, in the absence of adjacent segment disease, whereas they decreased to 89%, 66%, and 94%, respectively, in the presence of adjacent segment disease.

Table II. Distribution of disease in the aortoiliac and femoropopliteal tracts according to angiography

	Aortoiliac tract	
Femoropopliteal tract	*0%-49%*	*50%-100%*
0%-49%	29	17
50%-100%	41	12

On the basis of the definition of arterial tracts and multilevel disease presented in the Methods section, Table VI presents classification results in the aortoiliac and femoropopliteal tracts as a function of the lower limb status (no disease, inflow disease, outflow disease, and inflow/outflow disease). Results indicate that, independently of the lower limb disease status, duplex scanning shows a sensitivity of 83% and a specificity of 96% for detecting severe stenosis in the aortoiliac tract and a sensitivity of 87% and a specificity of 93% for detecting severe stenosis into the femoropopliteal tract. The accuracy for detecting a 0% to 49% versus 50% to 100% lesion in the aortoiliac tract was always higher than 90%, except when multilevel disease was present. In this case the accuracy was reduced to 67%. For the femoropopliteal tract, the accuracy was higher than 93% when there was no outflow disease and was reduced to 83% in presence of multilevel disease.

DISCUSSION

The results presented in Table III are comparable to those published previously in the literature,[6-11] in which a general agreement with angiography always below 78% (between 35% and 78%) is reported. Although we can anticipate a high degree of correlation between pulsed-wave Doppler scanning and angiography, it remains that perfect agreement should not be expected because arteriography is more an "anatomic gold standard" than a "hemodynamic gold standard."[16] Furthermore, it is known that intraobserver and interobserver variability exists in the reading of angiograms even when broader classifications of disease are used.[8] Despite the technical limitations in comparing duplex results with those of angiography, we believe that they do not account for most of the misclassifications shown in Table III. Our hypothesis to explain most of the duplex misclassifications relies on the presence of adjacent segment disease.

Table III. Two-way contingency table (five categories) of duplex scanning versus angiography

	Duplex classification (n)				
Angiography (%)	*0%*	*1%-19%*	*20%-49%*	*50%-99%*	*100%*
0	333	53	21	6	5
1-19	11	10	4	0	0
20-49	39	27	18	8	1
50-99	16	4	7	37	0
100	1	0	0	1	40

Overall accuracy = 68%; Kappa = 0.43. The total number of arterial segments is 642.

Table IV. Duplex scanning versus angiography in detecting 0% to 49% and 50% to 100% diameter-reducing stenoses for each of the 642 arterial segments

	Duplex classification (n)				
	Correctly classified		*Misclassified*		*Accuracy/sensitivity/specificity (%)*
Arterial segment	*0%-49%*	*50%-100%*	*0%-49%*	*50%-100%*	
Distal aorta	52 (20-4)	1 (0-1)	0 (0-0)	1 (0-1)	98/100/98
Common iliac	71 (13-1)	16 (1-2)	3 (0-0)	2 (0-0)	93/84/97
External iliac	85 (19-5)	6 (0-1)	4 (1-0)	4 (1-2)	92/60/96
Common femoral	94 (26-36)	4 (2-1)	7 (4-2)	2 (1-1)	92/36/98
Deep femoral	79 (11-23)	4 (1-3)	5 (2-3)	2 (1-0)	92/44/97
Superficial femoral	52 (6-1)	44 (16-0)	4 (0-1)	2 (0-0)	94/92/96
Popliteal	83 (7-31)	3 (1-2)	5 (2-1)	7 (1-6)	88/37/92
All	516 (102-101)	78 (21-10)	28 (9-7)	20 (4-10)	93/74/96

Numbers in parentheses indicate the numbers of segments having at least one 50% to 99% proximal or distal stenosis and one proximal or distal occlusion, respectively. The total number of arterial segments is 642.

Table V. Duplex scanning versus angiography in detecting 0% to 49% and 50% to 100% diameter-reducing stenoses for the arterial segments studied as a function of the adjacent segment status

	Duplex classification (n)				
	Correctly classified		*Misclassified*		*Accuracy/sensitivity/specificity (%)*
Adjacent segment status	*0%-49%*	*50%-100%*	*0%-49%*	*50%-100%*	
0%-49%	313	47	12	6	95/80/98
50%-100%	203	31	16	14	89/66/94
All	516	78	28	20	93/74/96

The total number of arterial segments is 642.

We believe that the effect of the presence of adjacent segment disease is an important problem for the accurate detection and quantification of lower limb arterial disease by Doppler ultrasonography. In our study, only 39% (234/594) of the correctly classified segments display concomitant disease in adjacent segments compared with 63% (30/48) of the misclassified segments (Table IV). More precisely, results indicate that, among the 28 duplex misclassifications underestimating the degree of severe stenoses, 57% involve a segment having a proximal or distal segment with a 50% to 100% diameter-reducing lesion. More striking is that, among the 20 misclassifications overestimating the degree of nonsevere stenoses, 70% involve a segment having a proximal or distal segment with a 50% to 100% diameter-reducing lesion. Another interesting observation is that 10 of the 12 misclassifications in the popliteal artery involve the presence of a proximal disease, which resulted in a sensitivity of only 37%. The common and deep femoral arteries are also highly affected because, respectively, eight of the nine and six of the seven misclassifications involve the presence of disease in adjacent segments (sensitivity

Table VI. Duplex scanning versus angiography in detecting 0% to 49% and 50% to 100% diameter-reducing stenoses in the 99 aortoiliac and femoropopliteal tracts as a function of the lower limb status (no disease, inflow disease, outflow disease, and inflow/outflow disease)

Lower limb status (angiography)	*Arterial tract*	*Duplex classification (n)*				*Accuracy/sensitivity/specificity (%)*
		Correctly classified		*Misclassified*		
		0%-49%	*50%-100%*	*0%-49%*	*50%-100%*	
No severe disease	Aortoiliac	28	0 (0)	0 (0)	1	97/–/97
	Femoropopliteal	27	0 (0)	0 (0)	2	93/–/93
Inflow disease	Aortoiliac	0	16 (3)	1 (0)	0	94/94/–
	Femoropopliteal	16	0 (0)	0 (0)	1	94/–/94
Outflow disease	Aortoiliac	39	0 (0)	0 (0)	2	95/–/95
	Femoropopliteal	0	36 (15)	5 (0)	0	88/88/–
Inflow/outflow disease	Aortoiliac	0	8 (0)	4 (0)	0	67/67/–
	Femoropopliteal	0	10 (3)	2 (0)	0	83/83/–
All disease	Aortoiliac	67	24 (3)	5 (0)	3	92/83/96
	Femoropopliteal	43	46 (18)	7 (0)	3	90/87/93

Numbers in parentheses indicate the numbers of tracts having more than one segment with a 50% to 100% lesion within the same tract.

of 36% and 44%, respectively). In fact, for these three segments, 86% (24/28) of the misclassifications involve the presence of either proximal or distal severe stenoses. Results presented in the literature [7,11,12] also indicate lower sensitivity for detecting lesions in these three arterial segments (compared with that obtained for the aorta, iliac, or superficial femoral arteries), although no reason was presented to explain this situation.

Figs. 1 and 2 illustrate the problem described above in which two popliteal segments displaying a severe proximal stenosis were misclassified. Fig. 1 shows the Doppler waveforms associated with a 50% to 99% popliteal artery lesion, as evaluated by angiographic examination. Although the waveform derived from the popliteal segment did not exactly fit the criteria associated with a less than 50% lesion (no significant increase in peak systolic velocity, triphasic waveform, and no extensive spectral broadening), it was nevertheless judged as having a less than 50% lesion presuming that the monophasic shape and spectral broadening of the Doppler waveform was caused by the presence of more proximal disease. The effect of this severe proximal stenosis was to reduce blood flow in the distal segments, thus making the interpretation of the Doppler signal at the popliteal level much more difficult. On the other hand, Fig. 2 shows an example of the Doppler waveforms recorded from a patient with a less than 50% popliteal arterial lesion and a superficial femoral occlusion, as evaluated by angiography. The occlusion was correctly detected by duplex examination but the popliteal artery stenosis was misclassified. Although there was no flow through the superficial femoral artery, an important system of collateral vessels appeared and provided flow to the popliteal artery. Because the popliteal artery displayed high velocity and turbulent flow characteristics normally associated with a severe lesion, this segment was classified as a 50% to 99% lesion.

Conventional ultrasonic duplex scanning has proved to be a useful diagnostic tool in the assessment of lower limb arterial disease. Many studies, including this one, have demonstrated its capability to discriminate patent and occluded segments and to assess lesions less or greater than 50%. In this study 36 arterial segments were not assessed adequately by the technologist. In most of the cases the use of a color-flow duplex scanner would have solved the difficulty to localize and detect blood flow in these arteries. A major limitation of duplex scanning that, to our knowledge, has never been pointed out is its lower sensitivity in the presence of adjacent segment disease. We demonstrated in this report that the presence of disease adjacent to the segment of interest is an important problem for the accurate detection and quantification of lower limb arterial disease. Although the number of segments involved in the study is limited, we observed that (1) 63% (30/48) of the misclassifications in detecting 0% to 49% and 50% to 100% diameter-reducing lesions within a specific segment involved the presence of either proximal or distal severe stenoses and (2) the common and deep femoral and popliteal artery segments were particularly affected by the presence of adjacent segment disease. We also demonstrated that the accuracy to detect aortoiliac lesions in patients with both inflow and outflow disease was only 67%

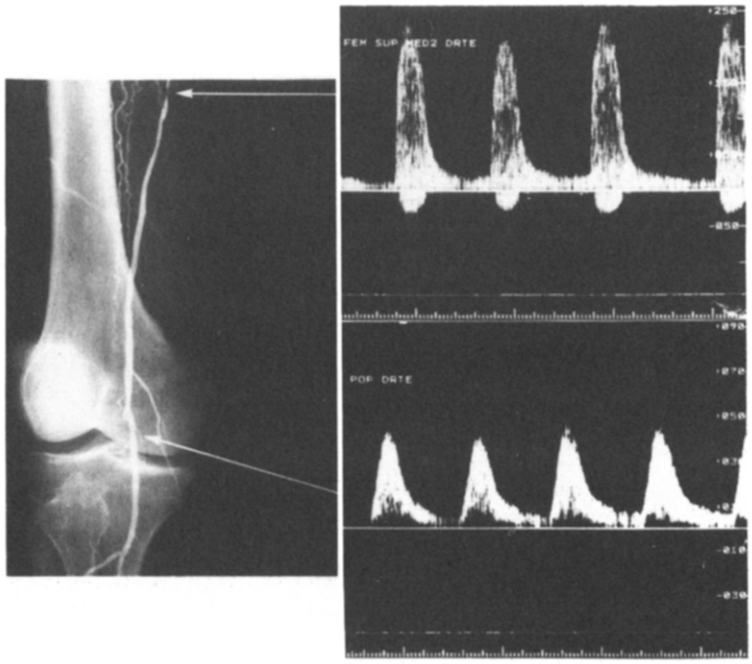

Fig. 1. Angiography and Doppler scanning waveforms recorded from patient with 50% to 99% popliteal artery lesion that was misclassified (as normal) by duplex examination because of presence of severe superficial femoral artery lesion.

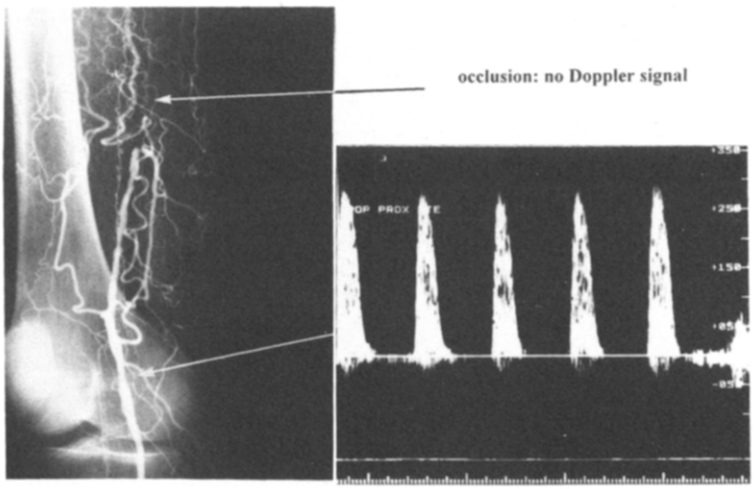

Fig. 2. Angiography and Doppler scanning waveforms recorded from patient with 20% to 49% popliteal artery lesion that was misclassified (50% to 99%) by duplex examination because of presence of superficial femoral artery occlusion.

compared with 94% in patients with only inflow disease. Thus caution is advised in the clinical application of conventional duplex scanning in patients with multisegmental disease or multilevel disease. New objective and quantitative criteria extracted from the Doppler spectra are probably needed to solve this limitation specifically. More fundamental studies may be needed to understand and quantify the effect of a proximal and distal stenosis on the evaluation of a given segment. Finally, although color-flow duplex scanning represents a significant technologic advancement, further evalua-

tion is necessary to demonstrate its potential to circumvent the clinical difficulty associated with adjacent segment disease.

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