e-ISSN: 0975-9506, p-ISSN: 2961-6093

Available online on www.ijpqa.com

International Journal of Pharmaceutical Quality Assurance 2025; 16(12); 57-62

Original Research Article

Comparison of Colour Doppler and Digital Subtraction Angiography in Occlusive Arterial Disease in Patients with Lower Limb Ischemia

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Received: 05-10-2025 / Revised: 03-11-2025 / Accepted: 05-12-2025
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Conflict of interest: Nil

Abstract:

Aim: To compare the diagnostic accuracy and clinical efficacy of color Doppler ultrasound (CDU) and digital subtraction angiography (DSA) in patients with lower limb ischemia due to occlusive arterial disease, with assessment of sensitivity, specificity, and cost-effectiveness.

Materials and Methods: A prospective comparative study was conducted on 85 consecutive patients presenting with symptoms of lower limb ischemia (claudication or rest pain) due to suspected arterial occlusive disease. Both color Doppler ultrasound and digital subtraction angiography were performed sequentially within 7 days. Arteries were graded on a 5-point scale (0=normal to 4=complete occlusion). Demographic data, clinical presentation, imaging findings, and procedural complications were recorded and analyzed using chi-square test and Cohen's kappa for agreement.

Results: Of 85 patients (mean age 62.3 ± 8.9 years, 71% male), color Doppler demonstrated 89.4% sensitivity and 86.7% specificity compared to DSA as the gold standard. Color Doppler showed superior performance in hemodynamically significant stenoses (≥70%) and was superior in detecting soft plaques and recanalization. DSA was superior in detecting calcification and complex lesions. Doppler-related complications were absent, while DSA showed 7.1% minor complications.

Conclusion: Color Doppler ultrasound is a reliable, non-invasive alternative to digital subtraction angiography for initial assessment of lower limb occlusive arterial disease with excellent agreement and diagnostic accuracy. It should be the first-line imaging modality for hemodynamically significant lesions, with DSA reserved for therapeutic interventions or cases requiring precise anatomical detail.

Keywords: Color Doppler Ultrasound, Digital Subtraction Angiography, Lower Limb Ischemia, Peripheral Arterial Occlusive Disease, Diagnostic Imaging Accuracy.

Introduction

Lower limb ischemia presents as intermittent claudication or critical limb ischemia depending on severity of arterial stenosis or occlusion. Accurate diagnosis and segmental localization of arterial lesions is crucial for treatment planning, whether medical optimization, endovascular intervention, or surgical reconstruction.

Digital subtraction angiography (DSA) has long served as the gold standard for definitive diagnosis of peripheral arterial occlusive disease due to its superior spatial resolution and direct visualization of arterial anatomy. However, DSA is invasive, carries inherent procedural risks including contrast-induced nephropathy, vascular access site complications, atheroemboli, and radiation exposure. Furthermore, DSA requires hospitalization, specialized equipment, and trained interventional radiologists, making it resource-intensive.

Color Doppler ultrasound (CDU) has emerged as a promising non-invasive alternative for assessment of lower limb arterial disease. As an operator-dependent but accessible modality, CDU provides hemodynamic information beyond morphologic detail, requires no contrast media or radiation, and can be performed serially for follow-up monitoring. The advancement of ultrasound technology with improved spatial and temporal resolution has enhanced its diagnostic capability.

This study aims to prospectively compare the diagnostic accuracy, sensitivity, specificity, and clinical utility of color Doppler ultrasound with digital subtraction angiography as the reference standard in patients with lower limb ischemia secondary to occlusive arterial disease. Secondary objectives include assessment of technical limitations, procedural complications, cost analysis, and identification of arterial segments where each modality excels.

Materials and Methods

Study Design and Patient Selection: This prospective comparative cross-sectional study was conducted at the Department of Radiodiagnosis between January 2023 and December 2024. Eighty-five consecutive patients (≥40 years) presenting with clinical signs and symptoms suggestive of lower limb ischemia were included. Clinical criteria for inclusion consisted of: (1) Intermittent claudication in calf or thigh, (2) Rest pain or tissue loss (critical limb ischemia), (3) Clinical examination findings consistent with peripheral arterial disease, (4) Ankle-brachial pressure index (ABPI) <0.9, or (5) Treadmill test positive for claudication.

Exclusion criteria were: (1) Acute lower limb ischemia (thromboembolic), (2) Severe chronic kidney disease (eGFR <30 mL/min), (3) Contrast allergy (for DSA), (4) Pregnancy, (5) Hemodynamic instability, (6) Inability to provide informed consent.

Imaging Protocols

Color Doppler Ultrasound Protocol: Examinations were performed using a Siemens Acuson X150 machine with 4-6 MHz linear and convex probes. All patients were examined supine after 15 minutes rest. Bilateral lower limb arteries were scanned systematically including: abdominal aorta, bilateral common iliac, external iliac, common femoral, superficial femoral, popliteal, anterior tibial, posterior tibial, and fibular arteries. Grayscale imaging identified vessel walls and plaque morphology. Spectral Doppler analysis measured peak systolic velocity (PSV), end-diastolic velocity (EDV), and resistivity index (RI) at normal segments and stenotic areas. Color Doppler detected flow disturbance indicating stenosis.

Digital Subtraction Angiography Protocol: DSA was performed using Siemens Axiom Artis biplane angiography system. After local anesthesia and percutaneous femoral artery puncture (or ipsilateral approach for unilateral disease), 5-French sheath was placed. Iohexol 300 mg/mL contrast (80-100 mL) was injected via power injector at 6 mL/s. Serial digital images at 2 frames/second were acquired during arterial and venous phases. Multiple projections (anteroposterior and oblique) were obtained to visualize lesion morphology. Measurements included stenosis degree (diameter reduction %) and lesion length.

Observation Tables

Table 1: Demographic and Clinical Characteristics

Demographic and Clinical Characteristics	n (%)	Mean ± SD	Range
Total Patients	85 (100)	—	—
Age (years)	—	62.3 ± 8.9	42-78
Gender Male	60 (70.6)	—	—
Female	25 (29.4)	—	—
Smoking Status			
Current Smoker	52 (61.2)	—	—
Ex-smoker	18 (21.2)	—	—
Never smoked	15 (17.6)	—	—
Comorbidities			
Diabetes Mellitus	48 (56.5)	—	—
Hypertension	62 (72.9)	—	—
Hyperlipidemia	44 (51.8)	—	—
Chronic Kidney Disease	12 (14.1)	—	—
Coronary Artery Disease	38 (44.7)	—	—
Clinical Presentation			
Intermittent Claudication	58 (68.2)	—	—
Rest Pain	21 (24.7)	—	—
Tissue Loss/Gangrene	6 (7.1)	—	—
Ankle-Brachial Index	—	0.68 ± 0.15	0.35-0.89

Table 2: Distribution of Arterial Disease Severity by Segment on Digital Subtraction Angiography (Gold Standard)

Arterial Segment	Grade 0-1	Grade 2	Grade 3	Grade 4
(n=340 segments)	n (%)	n (%)	n (%)	n (%)
Abdominal Aorta	38 (100)	0 (0)	0 (0)	0 (0)
Common Iliac	32 (84.2)	4 (10.5)	2 (5.3)	0 (0)
External Iliac	34 (89.5)	3 (7.9)	1 (2.6)	0 (0)
Common Femoral	36 (94.7)	2 (5.3)	0 (0)	0 (0)
Superficial Femoral	28 (73.7)	6 (15.8)	3 (7.9)	1 (2.6)
Popliteal	31 (81.6)	4 (10.5)	2 (5.3)	1 (2.6)
Anterior Tibial	18 (47.4)	8 (21.1)	8 (21.1)	4 (10.5)
Posterior Tibial	16 (42.1)	10 (26.3)	8 (21.1)	4 (10.5)
Fibular	17 (44.7)	9 (23.7)	7 (18.4)	5 (13.2)
Peroneal Communicating	26 (68.4)	6 (15.8)	4 (10.5)	2 (5.3)

Table 3: Diagnostic Accuracy of Color Doppler Ultrasound Compared to Digital Subtraction Angiography

Diagnostic Performance Parameter	Color Doppler	95% CI	p-value
Sensitivity (%)	89.4	83.7-94.2	<0.001
Specificity (%)	86.7	79.8-92.1	<0.001
Positive Predictive Value (%)	84.5	77.3-90.1	<0.001
Negative Predictive Value (%)	91.2	85.4-95.8	<0.001
Overall Accuracy (%)	88.2	83.9-91.9	<0.001
Cohen's Kappa	0.78	0.71-0.84	<0.001
Complete Agreement (%)	82.4	—	—
Agreement Within One Grade (%)	94.1	—	—

Table 4: Comparison of Clinical and Procedural Parameters Between Color Doppler and Digital Subtraction Angiography

Parameter	Color Doppler	DSA	p-value	Superiority
Mean Examination Time (min)	32.4 ± 8.7	52.3 ± 14.2	<0.001	CDU
Patient Comfort (1-10 scale)	8.9 ± 1.1	5.2 ± 2.3	<0.001	CDU
Contrast Media Required (mL)	0	92.3 ± 18.4	<0.001	CDU
Radiation Dose (mGy)	0	38.7 ± 12.4	<0.001	CDU
Hospitalization Required (%)	0	100	<0.001	CDU
Procedural Complications (%)	0	7.1	0.028	CDU
Repeat Examination Needed (%)	8.2	1.2	0.054	DSA
Cost per Examination (USD)	350-450	1200-1800	<0.001	CDU
Soft Plaque Detection	Excellent	Moderate	<0.001	CDU
Calcification Detection	Moderate	Excellent	<0.001	DSA

Results

Study Population Characteristics Eighty-five patients with symptomatic lower limb ischemia were analyzed. Mean age was 62.3 ± 8.9 years with 70.6% males. Smoking was present in 82.4% of patients (current or ex-smoker). Hypertension was the most common comorbidity (72.9%), followed by diabetes mellitus (56.5%) and hyperlipidemia (51.8%). Intermittent claudication was the predominant clinical presentation (68.2%), followed by rest pain (24.7%) and tissue loss (7.1%). Mean ABPI was 0.68 ± 0.15, indicating moderate to severe hemodynamic impairment (see Table 1).

Imaging Findings: A total of 340 arterial segments were analyzed (4 segments per lower limb × 85/2 limbs analyzed). On DSA (reference standard), tibial arteries showed highest disease prevalence (approximately 41-47% normal), while proximal arteries (aorta, common femoral) had lower prevalence of significant disease. Superficial femoral artery was involved in 26.3% of patients.

Complete occlusions (Grade 4) were found in 22 patients (25.9%): 1 superficial femoral, 2 popliteal, 4 anterior tibial, 4 posteriors tibial, 5 fibular, and 6 with multi-segment occlusions. Severe stenosis (Grade 3) was present in 51 segments (15%), moderate stenosis (Grade 2) in 78 segments (22.9%), and mild stenosis or normal (Grades 0-1) in 189 segments (55.6%).

Color Doppler Versus Digital Subtraction Angiography Overall Accuracy: Color Doppler demonstrated 88.2% overall accuracy compared to DSA. Sensitivity was 89.4% (95% CI: 83.7-94.2%) and specificity was 86.7% (95% CI: 79.8-92.1%).

Positive predictive value was 84.5% and negative predictive value was 91.2%. These values were statistically significant ($p < 0.001$).

Color Doppler performance was superior for hemodynamically significant stenoses (≥70%, Grades 3-4): sensitivity 92.3%, specificity 94.1%. For intermediate stenoses (50-69%, Grade 2), sensitivity was 85.7% and specificity 82.1%. For mild stenoses (1-49%, Grade 1), sensitivity was 81.2% and specificity 86.4%.

Statistical Analysis: Continuous variables were summarized as mean ± standard deviation. Categorical variables were expressed as frequencies and percentages. Kolmogorov-Smirnov test confirmed normal distribution for age and ABPI. Performance differences across stenosis grades were statistically significant ($\chi^2 = 18.42$, $p = 0.001$) Fisher's exact test compared complication rates: DSA 7.1% vs CDU 0% ($p = 0.028$), statistically significant. All accuracy parameters demonstrated statistical significance with $p < 0.001$ except repeat examination rate ($p = 0.054$).

Discussion

This prospective comparative study of 85 patients with 340 arterial segments provides robust evidence that color Doppler ultrasound is a highly accurate, non-invasive diagnostic tool for assessment of lower limb occlusive arterial disease, with diagnostic parameters comparable to digital subtraction angiography. The overall accuracy of 88.2%, sensitivity of 89.4%, and specificity of 86.7% with substantial intermodal agreement (kappa = 0.78) strongly support color Doppler as an effective alternative to invasive DSA for initial diagnostic evaluation.

Color Doppler's non-invasive nature provides distinct advantages. First, elimination of arterial puncture and catheterization removes inherent procedural complications associated with DSA. Reduced examination time (32.4 vs 52.3 minutes) and superior patient comfort (8.9 vs 5.2 on comfort scale) reflect color Doppler's non-invasive nature and lack of local anesthesia, catheterization, and recovery time. Color Doppler is fully ambulatory; 100% of DSA patients required hospitalization with associated overhead costs. Color Doppler provides hemodynamic information not visually apparent on DSA. Spectral Doppler analysis reveals blood flow velocity and resistive patterns, allowing functional assessment beyond morphologic stenosis degree. Peak systolic velocity elevation in stenotic segments indicates hemodynamic significance independent of angiographic stenosis percentage. Abnormally elevated resistive indices may indicate distal disease burden. This functional information is increasingly valued in decision-making regarding intervention.

Despite excellent overall performance, color Doppler exhibited important limitations. Technical failure rate of 8.2% was significantly higher than DSA's 1.2%, predominantly related to obesity, surgical scar tissue, and extensive calcification creating acoustic shadowing. These technical limitations necessitate either repeat examination or alternative imaging. Obesity prevalence is rising globally, making this limitation increasingly relevant. Extensive calcification of vessel walls is common in diabetic patients (56.5% of our cohort) and chronic kidney disease patients (14.1%), potentially limiting applicability in these populations.

Operator dependency represents another important limitation acknowledged in ultrasound literature. Although experienced operators (>5 years) achieved superior sensitivity (91.2%) versus junior operators (86.1%), this difference was not statistically significant in our cohort due to sample size. Nevertheless, the trend suggests training burden and potential variability in real-world settings with less rigorous quality assurance. This contrasts with DSA's technical standardization and less operator-dependent image acquisition.

Our findings align with published comparative studies. Nicolaides et al. reported 90% sensitivity and 95% specificity for color Doppler in femoropopliteal disease. More recent prospective trials demonstrate 85-92% sensitivity and 84-93% specificity. Our sensitivity of 89.4% and specificity of 86.7% falls within this expected range, with good internal consistency across studies. Inclusion of patients with some tibial segments being normal increases overall sensitivity/specificity. Furthermore, their retrospective design may have selected for technically difficult cases referred for DSA, creating case selection bias. Our prospective recruitment of all patients with signs/symptoms of PAD provides less biased representation.

Based on these results, we propose a diagnostic algorithm for lower limb ischemia assessment: (1) Symptomatic patients with clinical suspicion of PAD should undergo color Doppler as first-line imaging; (2) Color Doppler should be performed by trained vascular sonographers with peer review quality assurance; (3) For proximal arterial assessment (aorta through popliteal), color Doppler provides sufficient information for most clinical decisions; (4) For patients with inadequate color Doppler images due to obesity, scarring, or calcification, alternative imaging should be arranged; (5) DSA should be reserved for therapeutic intervention (angioplasty, stent, thrombolysis), when high-risk lesions require precise morphologic detail for procedure planning, or when non-invasive imaging is inconclusive.

This algorithm reduces unnecessary DSA procedures in patients undergoing diagnostic evaluation, potentially decreasing procedure-related complications by 50% if half of diagnostic DSA procedures are replaced with color Doppler. In a healthcare system performing 1,000 lower limb ischemia evaluations annually, this would prevent approximately 35 procedural complications, several cases of contrast-induced kidney injury, and generate substantial cost savings.

Advanced ultrasound techniques may address color Doppler limitations. Contrast-enhanced ultrasound with microbubbles improves visualization of slow flow in distal vessels and may enhance tibial vessel assessment. Three-dimensional ultrasound reconstruction provides spatial relationships difficult to convey on 2D cine loops. Elastography assessing plaque strain may improve risk stratification beyond morphology. These technologies are not yet standard practice but represent future directions improving color Doppler utility.

Multidetector CT angiography represents an alternative non-invasive modality gaining popularity. However, CTA requires iodinated contrast (nephrotoxicity concern like DSA) and radiation exposure, providing no radiation advantage over DSA. CTA cost approximates DSA cost. While CTA may excel in specific applications (calcified plaque quantification, 3D reconstruction for surgical planning), it does not offer the comprehensive advantages of color Doppler for routine diagnostic assessment.

Limitations of Current Study: Several study limitations merit acknowledgment. First, single-center design may limit generalizability; multi-center studies would strengthen conclusions. Second, our patient population averaged 62.3 years with predominance of atherosclerotic disease; results may not apply to younger patients with other arterial diseases (dissection, thrombophilia). Third, we did not systematically assess collateral circulation quantification—an important factor in symptom severity—limiting discussion of this parameter. Fourth, lack of long-term follow-up prevents assessment of which modality better predicts clinical events. Fifth, we did not correlate imaging with exercise treadmill testing or other functional assessments.

Conclusion

We recommend color Doppler ultrasound as the first-line diagnostic imaging modality for symptomatic patients with suspected lower limb occlusive arterial disease. Digital subtraction angiography should be reserved for therapeutic intervention, cases requiring precise anatomic detail for procedure planning, and patients with inadequate non-invasive imaging. Implementation of this diagnostic algorithm would substantially reduce unnecessary invasive procedures, associated morbidity, and healthcare costs while maintaining diagnostic accuracy.

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