ORIGINAL ARTICLE

Superior Mesenteric Artery Doppler Ultrasound as a Non-Invasive Tool for Monitoring Disease Activity in Crohn's Disease: Validation Against Quantitative Magnetic Resonance Imaging-Based Reference Standards

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ABSTRACT

Background: Crohn's disease activity monitoring is expensive in low-resource settings. Superior mesenteric artery (SMA) Doppler measuring flow rate, pulsatility index (PI) and resistive index (RI) can detect splanchnic hyperaemia of active intestinal inflammation. We validated SMA Doppler indices against quantitative MR enterography (MRE) indices, the simplified Magnetic Resonance Index of Activity (sMaRIA) and London score.

Methods: Cross-sectional diagnostic accuracy study in 50 Crohn's disease patients. Activity was classified by sMaRIA (active, score of 1 or more; inactive, score of 0) and London score (active, 4.1 or more). Receiver operating characteristic curve analysis assessed diagnostic accuracy; Spearman's correlation examined Doppler-MRE associations.

Results: Fifteen patients (30%) had active and 35 (70%) had inactive disease. Active disease showed higher SMA flow rate (712 vs 322 ml/min), lower PI (1.66 vs 2.68) and lower RI (0.70 vs 0.83; all p<0.001). Flow rate achieved the highest accuracy (area under the curve 0.992; 95% CI 0.971–1.000); at a cut-off of 514 ml/min or more, sensitivity was 100%, specificity 97.1%, positive predictive value 93.8% and negative predictive value 100%. PI of 1.88 or less gave 97.1% specificity. Flow rate correlated strongly with sMaRIA (rho +0.770) and moderately with London score (rho +0.662; both p<0.001).

Conclusion: SMA Doppler reliably tracks Crohn's disease activity against quantitative MRE reference standards. A two-step strategy, flow rate 514 ml/min or more confirmed by PI 1.88 or less, identifies active disease without radiation, supporting SMA Doppler as a low-cost surrogate for serial monitoring in resource-limited settings.

Keywords: Crohn's disease; superior mesenteric artery Doppler; MR enterography; disease activity monitoring; diagnostic accuracy; ultrasound

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INTRODUCTION

Crohn's disease (CD) is a chronic, relapsing, transmural inflammatory disorder of the gastrointestinal tract with a substantial and growing global burden.[1,2] Treat-to-target strategies mandate repeated, objective monitoring of luminal inflammatory activity, aiming for mucosal and transmural healing rather than symptom control alone.[3,4] MR enterography (MRE), endorsed by international society guidelines as the preferred non-invasive modality for serial CD monitoring, offers excellent soft-tissue contrast, multiplanar capability, and freedom from ionising radiation.[5,6]

Wide adoption of MRE for serial disease monitoring is severely constrained, particularly in low- and middle-income countries, by limited infrastructure, cost and radiologist availability. Inflammatory bowel disease incidence is rising rapidly in several such settings, where MRI scanner density is markedly lower than in high-income

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countries and per-scan costs are prohibitive for repeated monitoring.[7] Clinical indices such as the Crohn's Disease Activity Index (CDAI)[8] are confounded by functional symptoms and correlate poorly with endoscopic or histological inflammation.[9,10] There is therefore a need for validated low-cost surrogates for serial CD activity monitoring.

Active intestinal inflammation in CD provokes splanchnic hyperaemia through mesenteric neoangiogenesis, capillary recruitment, and reduced vascular resistance in the superior mesenteric artery (SMA) territory directly interrogable by pulsed-wave Doppler ultrasound.[11,12] SMA Doppler measures flow volume (ml/min), pulsatility index (PI) and resistive index (RI), all of which shift predictably with inflammation towards higher flow and lower resistance.[12,13] Prior studies demonstrated that SMA flow volume distinguishes active from inactive CD, with mean values of 564–1588 ml/min in active versus 288–421 ml/min in inactive disease.[13-16] However, most landmark studies used the CDAI as the reference standard, a recognised methodological limitation given that CDAI reflects patient-reported symptoms rather than objective tissue-level inflammation.[9,17] Notably, Sjekavica et al.[15] observed that SMA parameters alone showed considerable grey-zone overlap between active and inactive CD in some patients and that mural artery parameters in the thickened bowel wall provided superior discrimination; the present study therefore addresses this limitation by validating Doppler against objective MRE-based reference standards.

The present study advances this field by validating SMA Doppler against two independent, quantitative MRE-based disease activity indices: the simplified Magnetic Resonance Index of Activity (sMaRIA/Global sMaRIA) and London score, providing a methodologically rigorous framework directly relevant to treat-to-target monitoring. To our knowledge, this is the first study to evaluate all three SMA Doppler parameters against both sMaRIA and London scores as dual MRE reference standards in a CD cohort.

The primary aim was to determine the accuracy of SMA Doppler in tracking CD activity status as defined by MRE. Secondary aims were to quantify correlations between Doppler parameters and quantitative MRE scores, and to identify optimal thresholds for a sequential monitoring algorithm.

MATERIALS AND METHODS

Study design and setting

A single-centre cross-sectional diagnostic accuracy study was conducted in a tertiary academic referral centre. The study was designed as an open enrolment study, enrolling all consecutive eligible CD patients attending the department during the specified data collection period (April 2024 to December 2025). Ethical approval was granted by the Institutional Ethics Committee (Ref: 31/2024). Written informed consent was obtained from all participants. The study adhered to the STARD 2015 reporting guidelines for diagnostic accuracy studies.

Study population

Patients with established CD referred for MRE-based disease activity assessment were eligible. Inclusion criteria: age 10 years or more; confirmed CD (by standard endoscopic, histological, and radiological criteria); ability to fast for 6 hours or more. Exclusion criteria: patients with septic complications or obstruction; history of surgical resection of gut; pregnancy; MRE contraindications (ferromagnetic implants, severe claustrophobia, estimated glomerular filtration rate below 30 ml/min/1.73 m²).

SMA Doppler protocol

SMA Doppler sonography was performed on a LOGIQ P5 system (3.5–5 MHz convex transducer) following a minimum six-hour fast. Patients were positioned supine. The SMA was identified in the longitudinal plane; the Doppler sample volume was placed 1–2 cm distal to the aortic origin with insonation angle 60° or less. Three consecutive spectral traces were averaged. PI and RI were calculated automatically by the machine software from the spectral Doppler waveform. SMA cross-sectional area was calculated using the average of three anteroposterior diameter measurements in the sagittal plane; flow volume (ml/min) = mean velocity (cm/s) × cross-sectional area (cm²) × 60. All SMA Doppler examinations were performed by a single experienced radiologist blinded to MRE results, clinical data and patient symptoms.

MR enterography protocol and disease activity indices

MRE was performed on a 1.5T system on the same day as the Doppler exam. Oral contrast consisted of 1400 ml of 2.5% mannitol solution; intravenous hyoscine butylbromide (20 mg) was administered 5 minutes before

the MR exam. The MRE protocol included coronal and axial T2-weighted half-Fourier acquisition single-shot turbo spin-echo (HASTE), balanced true fast imaging with steady-state precession, fat-suppressed T2-weighted, and pre- and three-phase post-gadolinium T1-weighted volumetric interpolated breath-hold examination (VIBE) sequences.

Disease activity was classified independently by experienced gastrointestinal radiologists blinded to Doppler results, clinical indices and patient symptoms, using two validated MRE-based indices. The simplified MaRIA (sMaRIA/Global sMaRIA) score was calculated per bowel segment as: (1 × wall thickness above 3 mm) + (1 × mural oedema) + (1 × perienteric fat stranding) + (2 × ulceration); active disease: sMaRIA of 1 or more; inactive: sMaRIA of 0.18 The London score (restricted to patients with small-bowel CD involvement) was calculated as: 1.79 + (1.34 × mural thickness) + (0.94 × mural T2 signal score [0–3]); active: London score of 4.1 or more.[19]

Statistical analysis

Data were analysed using SPSS v24.0 (IBM Corp., Armonk, NY, USA). Normality was assessed by the Shapiro–Wilk test; PI and RI showed non-normal distributions in the active group, and SMA flow rate showed a non-normal distribution in the inactive group (Shapiro–Wilk, $p<0.05$ in each case); all three parameters are therefore presented as median [interquartile range (IQR)] and as mean ± standard deviation (SD). Group comparison used the Mann–Whitney U test. Spearman's rank correlation coefficient (rho) assessed associations between Doppler parameters and quantitative MRE scores (interpreted as: below 0.3 weak; 0.3–0.7 moderate; above 0.7 strong). Receiver operating characteristic (ROC) curve analysis assessed diagnostic accuracy; the Youden index identified optimal cut-off values; area under the curve (AUC) and 95% confidence intervals (CIs) for all diagnostic accuracy metrics (sensitivity, specificity, positive predictive value [PPV], negative predictive value [NPV], and overall accuracy) were estimated by bootstrap resampling (2000 iterations). For SMA flow rate, 95% CIs for sensitivity and NPV were not estimable, as all 2000 bootstrap iterations yielded 100.0%; this is expected given that the cut-off was placed at the minimum observed flow rate among active patients. A p-value below 0.05 was considered statistically significant.

RESULTS

Study population

Fifty patients with confirmed CD were included (28 male [56%], 22 female [44%]). Based on MRE, 15 (30%) had active and 35 (70%) inactive CD. Among active patients, the sex distribution was 9 male and 6 female; among inactive patients, 19 male and 16 female. sMaRIA scores among active patients ranged from 1 to 8 (mean 4.07 ± 2.05); 13 (87%) had mild-to-moderate activity (sMaRIA 1–6) and 2 (13%) severe activity (sMaRIA 7 or more). All 35 inactive patients had sMaRIA = 0. London score was calculable in 47 of 50 patients (3 excluded: exclusively colonic disease, where the London index is not applicable); mean London score was 5.92 ± 1.57 in active and 2.27 ± 0.48 in inactive patients.

Comparison of SMA Doppler parameters: active versus inactive CD

All three SMA Doppler parameters showed statistically significant differences between active and inactive CD (Table 1; Figure 1). Active disease was characterised by a markedly hyperdynamic SMA circulation: flow rate exceeded that of inactive disease by more than twofold (median 712 [IQR 611–894] vs 322 [IQR 292–378] ml/min; mean 761.3 ± 201.1 vs 345.1 ± 79.4 ml/min; $p<0.001$). Resistance parameters were significantly lower in active disease: PI (median 1.66 [IQR 1.42–1.75] vs 2.68 [IQR 2.50–2.84]; mean 1.71 ± 0.42 vs 2.64 ± 0.35; $p<0.001$) and RI (median 0.70 [IQR 0.69–0.73] vs 0.83 [IQR 0.76–0.89]; mean 0.719 ± 0.046 vs 0.818 ± 0.072; $p<0.001$). The IQRs of active and inactive groups showed no overlap for SMA flow rate.

Diagnostic accuracy of SMA Doppler as a monitoring tool

ROC analysis demonstrated excellent accuracy for all three parameters (Table 2; Figure 2). SMA flow rate achieved an AUC of 0.992 (95% CI 0.971–1.000). At the optimal cut-off of 514 ml/min or more (Youden index), SMA flow rate yielded sensitivity 100% (not estimable by bootstrap; all 2000 iterations 100%), specificity 97.1% (95% CI 90.9–100.0), PPV 93.8% (95% CI 80.0–100.0), NPV 100% (not estimable; all iterations 100%), and overall accuracy 98.0% (95% CI 94.0–100.0). The perfect sensitivity and

NPV indicate that no MRE-active patient had a flow rate below this threshold, establishing it as a reliable screening parameter.

PI achieved an AUC of 0.917 (95% CI 0.803–1.000). At the optimal cut-off of 1.88 or less, PI yielded sensitivity 86.7% (95% CI 66.7–100.0), specificity 97.1% (95% CI 90.6–100.0), PPV 92.9% (95% CI 75.0–100.0), NPV 94.4% (95% CI 85.7–100.0), and accuracy 94.0% (95% CI 86.0–100.0). The 97.1% specificity makes PI the most effective confirmatory parameter. RI achieved an AUC of 0.886 (95% CI 0.769–0.973); at cut-off 0.74 or less: sensitivity 86.7% (95% CI 66.7–100.0), specificity 82.9% (95% CI 69.7–94.1), PPV 68.4% (95% CI 45.8–88.2), NPV 93.5% (95% CI 82.9–100.0), accuracy 84.0% (95% CI 74.0–94.0).

Correlation with quantitative MRE disease activity indices

Spearman's correlation confirmed significant associations between all three Doppler parameters and both MRE indices (Table 3; Figure 3). SMA flow rate showed a strong positive correlation with sMaRIA (rho = +0.770, $p<0.001$, n = 50) and a moderate positive correlation with London score (rho = +0.662, $p<0.001$, n = 47). PI showed moderate negative correlations with sMaRIA (rho = −0.668, $p<0.001$) and London score (rho = −0.500, $p<0.001$, n = 47). RI showed moderate negative correlations with sMaRIA (rho = −0.622, $p<0.001$) and London score (rho = −0.579, $p<0.001$, n = 47). All correlations were significant at $p<0.001$.

DISCUSSION

This study demonstrates that SMA Doppler ultrasound reliably tracks CD activity when validated against objective, quantitative MRE-based reference standards. Three principal findings emerge: (i) SMA flow rate 514 ml/min or more identifies MRE-active CD with 100% sensitivity and 97.1% specificity (AUC 0.992), functioning as an effective screening tool; (ii) PI 1.88 or less delivers the highest specificity (97.1%, AUC 0.917), serving as the confirmatory step; (iii) all three Doppler parameters correlate significantly with quantitative sMaRIA and London scores, confirming that SMA haemodynamics mirror transmural inflammatory burden across the full disease activity spectrum.

The physiological basis is well established. Active intestinal inflammation in CD triggers neoangiogenesis and capillary recruitment in the SMA territory, reducing downstream vascular resistance and manifesting as increased flow volume and reduced PI and RI.[11,12,20] The non-overlapping IQRs in SMA flow rate between active (611–894 ml/min) and inactive (292–378 ml/min) groups illustrate the magnitude of haemodynamic change associated with MRE-defined active CD.

Our AUC values compare favourably with the diagnostic performance reported in earlier studies. Van Oostayen et al.[13,14] established foundational SMA flow data against clinical and radiological reference standards. Yekeler et al.16 reported 83% sensitivity and 100% specificity at a 500 ml/min threshold using CDAI, concordant in direction with the present findings but validated against a less objective reference. Sjekavica et al.[15] importantly observed that SMA flow parameters showed considerable grey-zone overlap between groups in some patients, and that mural artery resistance index in the thickened bowel wall provided superior individual-segment discrimination. The present study addresses this concern through MRE-based reference classification, which provides an objective, quantitative measure of transmural inflammatory burden across all bowel segments and removes the confounding introduced by purely clinical reference standards. Karoui et al.[17] reported RI–CDAI correlation r = −0.46 and PI–CDAI r = −0.39, substantially lower than our RI–sMaRIA rho = −0.622 and PI–sMaRIA rho = −0.668. This difference is likely because MRE-based scoring directly captures objective transmural structural changes — wall thickening, mural oedema, ulceration, and fat stranding — without the confounding of functional symptoms inherent to CDAI.[9,17]

The complementary diagnostic profiles of SMA flow rate and PI support a rational two-step monitoring strategy. A flow rate below 514 ml/min reliably excludes active CD (NPV 100%), sparing the patient from MRE and therapeutic escalation. Where flow rate meets or exceeds the threshold, PI 1.88 or less confirms active disease with 97.1% specificity, enabling confident identification of patients requiring MRE for anatomical characterisation: penetrating complications, stricture extent or presurgical planning.

The strong SMA flow rate–sMaRIA correlation (rho = +0.770) demonstrates a graded, continuous relationship between splanchnic haemodynamics and the degree of

Table 1. Comparison of SMA Doppler parameters between active and inactive Crohn's disease (n = 50). CD, Crohn's disease; IQR, interquartile range; sMaRIA, simplified Magnetic Resonance Index of Activity; SD, standard deviation; SMA, superior mesenteric artery.

Parameter	Active CD (n = 15)	Inactive CD (n = 35)	p-value[1]
SMA flow rate (ml/min), mean ± SD	761.3 ± 201.1	345.1 ± 79.4	<0.001
SMA flow rate, median [IQR]	712 [611–894]	322 [292–378]	
Pulsatility Index, mean ± SD	1.71 ± 0.42	2.64 ± 0.35	<0.001
Pulsatility Index, median [IQR]	1.66 [1.42–1.75]	2.68 [2.50–2.84]	
Resistive Index, mean ± SD	0.719 ± 0.046	0.818 ± 0.072	<0.001
Resistive Index, median [IQR]	0.70 [0.69–0.73]	0.83 [0.76–0.89]	
sMaRIA/Global sMaRIA score, mean ± SD	4.07 ± 2.05	0.00 ± 0.00	<0.001
London score (n = 47), mean ± SD	5.92 ± 1.57	2.27 ± 0.48	<0.001

[1]*Mann–Whitney U test.*

Table 2. Diagnostic accuracy of SMA Doppler parameters for discriminating active from inactive Crohn's disease (n = 50; 15 active, 35 inactive). Cut -off values by Youden index. All 95% CIs by bootstrap resampling (2000 iterations). AUC, area under the curve; CI, c onfidence interval; NPV, negative predictive value; PI, pulsatility index; PPV, positive predictive value; RI, resistive index; SMA, superior mesenteric artery.

Parameter	AUC (95% CI)	Cut-off	Sensitivity % (95% CI)	Specificity % (95% CI)	PPV % (95% CI)	NPV % (95% CI)	Accuracy % (95% CI)
SMA flow rate	0.992 (0.971–1.000)	=514 ml/min	100.0 (n.e.)[2]	97.1 (90.9–100.0)	93.8 (80.0–100.0)	100.0 (n.e.)[2]	98.0 (94.0–100.0)
PI	0.917 (0.803–1.000)	=1.88	86.7 (66.7–100.0)	97.1 (90.6–100.0)	92.9 (75.0–100.0)	94.4 (85.7–100.0)	94.0 (86.0–100.0)
RI	0.886 (0.769–0.973)	=0.74	86.7 (66.7–100.0)	82.9 (69.7–94.1)	68.4 (45.8–88.2)	93.5 (82.9–100.0)	84.0 (74.0–94.0)

[2]*n.e. = not estimable; all 2000 bootstrap iterations yielded 100.0%.*

Table 3. Spearman's rank correlation coefficients (rho) between SMA Doppler parameters and quantitative MRE disease activity indices. sMaRIA correlation: all 50 patients. London score correlation: 47 patients with small -bowel involvement. All correlations: p<0.001. sMaRIA, simplified Magnetic Resonance Index of Activity; PI, pulsatility index; RI, resistive index; SMA, superior mesenteric artery.

Parameter	sMaRIA rho (n = 50)	p-value	London score rho (n = 47)	p-value
SMA flow rate	+0.770	<0.001	+0.662	<0.001
PI	- 0.668	<0.001	- 0.500	<0.001
RI	- 0.622	<0.001	- 0.579	<0.001

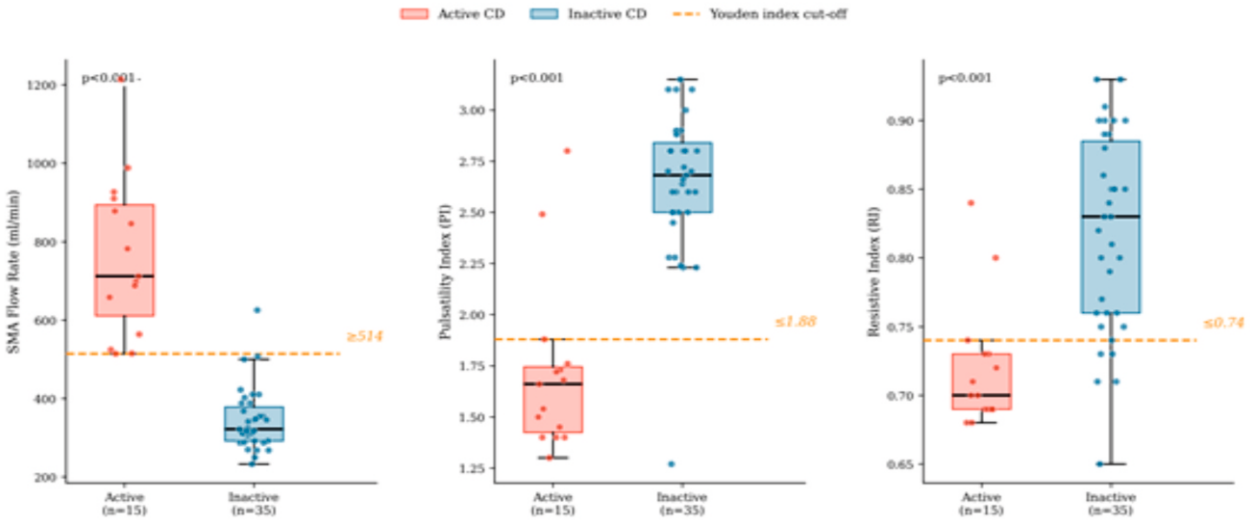


Fig. 1. Box plots with jitter overlay comparing SMA Doppler parameters between active (n = 15, red) and inactive (n = 35, blue) Crohn's disease groups, classified by MR enterography (sMaRIA/Global sMaRIA reference standard). Box plots show the interquartile range (IQR) and median; whiskers extend to 1.5×IQR; individual patient values are overlaid as jittered dots. The orange dashed line denotes the optimal diagnostic cut-off (Youden index): SMA flow rate ≥514 ml/min; pulsatility index (PI) ≤1.88; resistive index (RI) ≤0.74. All parameters showed statistically significant differences between groups (Mann–Whitney U test, p<0.001).

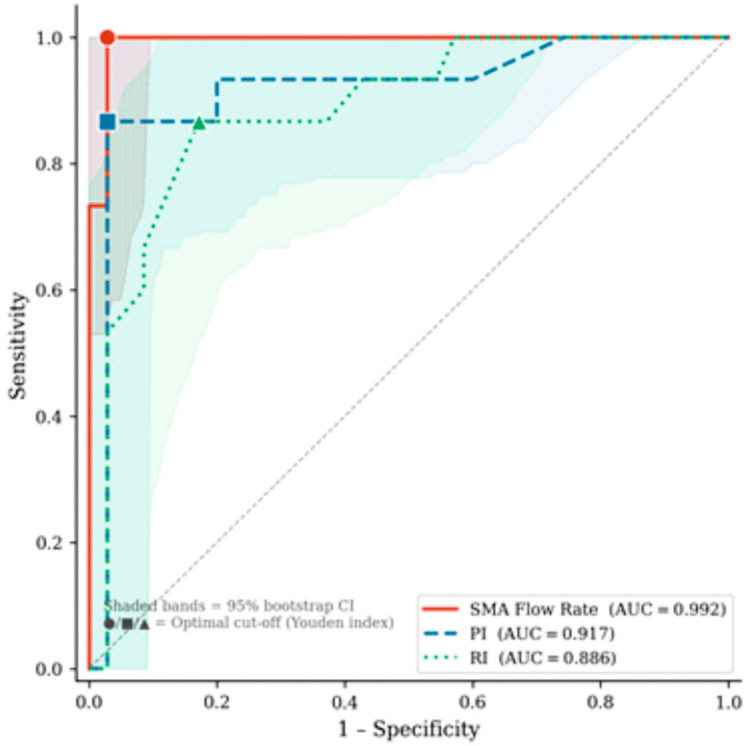


Fig. 2. Receiver operating characteristic (ROC) curves illustrating the diagnostic accuracy of SMA flow rate (AUC 0.992), pulsatility index (PI, AUC 0.917), and resistive index (RI, AUC 0.886) for discriminating active from inactive Crohn's disease, using MR enterography (sMaRIA) as the reference standard (n = 50). Filled symbols mark the optimal operating point (Youden index) on each curve. Shaded bands represent 95% bootstrap confidence intervals (2000 iterations).

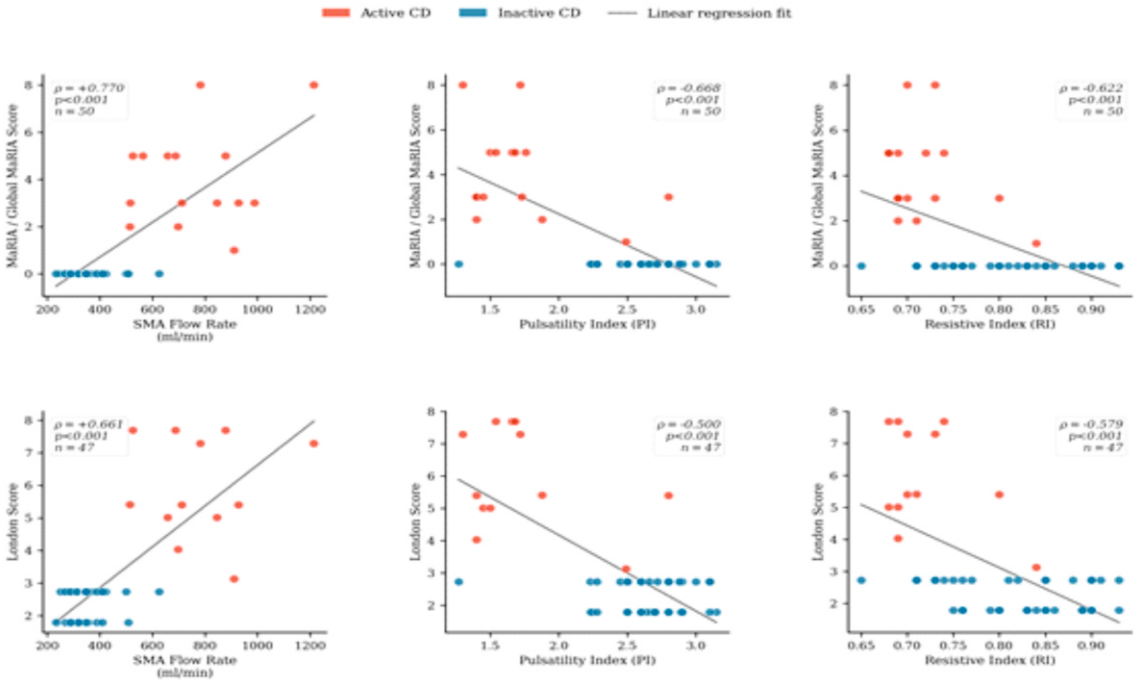


Fig. 3. Scatter plots showing Spearman's rank correlations between SMA Doppler parameters and quantitative MRE disease activity indices. Upper row: sMaRIA/Global sMaRIA score (n = 50). Lower row: London score (n = 47; three patients with exclusively colonic Crohn's disease excluded). All correlations: p<0.001.

transmural inflammatory burden, an essential characteristic of a monitoring biomarker. The somewhat weaker correlations with London score compared to sMaRIA reflect the restriction of the London index to small-bowel segments, while sMaRIA captures ileocolonic activity.

The clinical implications are most significant for serial monitoring in resource-limited settings, where CD incidence is rising but MRI infrastructure remains substantially limited.[7,21] Positioning SMA Doppler as the first-line monitoring tool would offer meaningful practical benefit: ultrasound machines are present at all levels of the healthcare system; examination cost is a fraction of MRE; no oral contrast, intravenous contrast, sedation or radiation is required. The proposed algorithm of SMA Doppler first, MRE reserved for Doppler-positive or anatomically complex cases, would substantially reduce MRI demand whilst maintaining objective monitoring standards.

Strengths include the use of two independent validated quantitative MRE reference standards with full blinding of both readers to all clinical information, systematic evaluation of three complementary Doppler parameters with formal ROC and correlation analyses, bootstrap confidence intervals for all diagnostic metrics, and conduct in a real-world referral setting with routinely available equipment.

Limitations must be acknowledged. The sample size (n = 50; 15 active) is modest; derived thresholds require external validation in independent larger cohorts. All Doppler examinations were performed by a single operator; interobserver and intraobserver reproducibility studies are needed. Medications with vasoactive splanchnic properties (biologics, corticosteroids, aminosalicylates) were not formally stratified and may independently influence SMA haemodynamics.

In conclusion, SMA Doppler ultrasound reliably tracks CD activity status when validated against quantitative MRE reference standards. The proposed two-step monitoring strategy of SMA flow rate 514 ml/min or more as a radiation-free and high-sensitivity screening test, confirmed by PI 1.88 or less as a highly specific confirmatory parameter provides a reliable and low-cost surrogate for MRE in serial CD monitoring. The strong graded correlations with sMaRIA and London scores confirm that SMA Doppler reflects transmural inflammatory burden across the activity spectrum, justifying its integration within treat-to-target CD monitoring algorithms, particularly where MRE access is limited.

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Conflicts of Interest: None declared.

Data Availability Statement

The de-identified dataset supporting the conclusions of this article is available from the corresponding author upon reasonable request, subject to institutional data-sharing protocols.

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