**Comparison of small intestinal contrast ultrasound with magnetic resonance enterography in paediatric Crohn’s disease**

**Running title:**

**SICUS in paediatric Crohn’s disease**

Aishah Hakim1, BSc (Hons), MBBS, MRCS, Core Surgical Trainee

Christopher Alexakis2, BSc (Hons), MBBS, MRCP, Research Gastroenterology Registrar

James Pilcher3, MSc, MRCP, FRCR, Consultant Radiologist

Demitrios Tzias3, BSc (Hons) MBBS, FRCR, Consultant Radiologist

Sally Mitton4, MBBS, MD, MRCP, FRCPCH, Consultant Paediatric Gastroenterologist

Thankam Paul4, MBBS, MRCP, Consultant Paediatric Gastroenterologist

Sonia Saxena5, MSc, MD, FRCGP, Professor in Primary Care

Richard Pollok 1,2, FRCP, BSc, PhD, DTM&H, Reader and Consultant Gastroenterologist

Shankar Kumar 6, BSc (Hons), MBBS, Academic Clinical Fellow in Radiology

1Medical School, St George’s Hospital, Cranmer Terrace, London, SW17 0RE, UK  
2Department of Gastroenterology, St George's University Hospitals NHS Foundation Trust, Blackshaw Road, London, SW17 0QT, UK   
3Department of Radiology, St George's University Hospitals NHS Foundation Trust, Blackshaw Road, London, SW17 0QT, UK  
4Department of Paediatric Gastroenterology, St George's University Hospitals NHS Foundation Trust, Blackshaw Road, Tooting, London, SW17 0QT, UK  
5Child Health Unit, School of Public Health, Imperial College London, 332 Reynolds Building, Charing Cross Campus, London, W6 8RP, UK  
6Centre for Medical Imaging, University College London, 2nd Floor Charles Bell House, 43-45 Foley Street, London, W1W 7TS, UK

Corresponding author:

Dr Shankar Kumar

Centre for Medical Imaging,

University College London,

2nd Floor Charles Bell House,

43-45 Foley Street, London,

W1W 7TS

UK

shankar.kumar@ucl.ac.uk Contact number: +44 7949628454

**Contributors**

SK, RP and AH conceived and designed the study; RP and SK led and co-ordinated the study. JP and DT performed the ultrasound studies in the older patient group. AH, SK and CA collated and analysed the data. All authors contributed to the preparation and revision of the manuscript.

**Conflicts of Interest**

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**Abstract**

**Aim**

To compare the diagnostic yield of small intestinal contrast ultrasonography (SICUS) with magnetic resonance enterography (MRE) in routine clinical practice in a cohort of paediatric patients investigated for Crohn’s disease (CD) attending a UK tertiary centre.

**Methods and results**

Patients with suspected or established CD who underwent SICUS were identified retrospectively. SICUS was compared to conventional trans-abdominal ultrasound (TUS), ileocolonoscopy (IC) and MRE. Accuracy and agreement of SICUS in detecting small bowel lesions and CD-related complications were assessed using kappa (κ) coefficient statistics. Ninety-three patients (median age 15 years, range 2–17, 49 male) underwent SICUS; 58 had suspected and 35 established CD. In suspected CD, sensitivity and specificity of SICUS in detecting CD small bowel lesions were 81.8% and 100% and for trans-abdominal ultrasound (TUS) 85.7% and 87.5%, respectively. In established CD, sensitivity and specificity of SICUS were 98.7% and 100% and TUS 80% and 100%, respectively. Agreement between SICUS and IC was substantial for the presence of lesions (κ=0.73) but fair with TUS (κ=0.31). Agreement between SICUS and IC was almost perfect for detecting strictures (κ=0.84) with a sensitivity of 100% and specificity of 97.6%. When comparing SICUS and TUS with MRE, agreement for the presence of lesions was substantial (κ=0.63) and moderate (κ=0.53) respectively. Agreement between SICUS and MRE was substantial for detecting strictures (κ=0.77) and dilatation (κ=0.68).

**Conclusions**

SICUS offers a radiation-free alternative for assessing paediatric small bowel CD, with diagnostic accuracy that is comparable to MRE and IC, supporting its wider use in routine practice.

**Keywords**

Crohn’s disease, Gastroenterology, Imaging, Paediatric Crohn’s disease, Small bowel, Small intestine, Ultrasound

**Introduction**

Crohn’s disease (CD) occurs in approximately 4 children per 100,000 in Europe and North America, and its incidence is rising.1-3 CD affects the small bowel in as many as two thirds of cases in children.4 Diagnosis is often difficult since children may not present with the classical triad of diarrhoea, pain and weight loss.5 Delays in diagnosis and treatment can lead to growth retardation and pubertal delay, often advanced by the time a diagnosis is made.6,7 There is also an increased risk of developing complications such as intestinal strictures and fistulae.8-10

The relapsing nature of CD necessitates intermittent, but lifelong radiological assessment, in the past commonly undertaken with small bowel follow-though (SBFT) and CT enterography.11,12 However, retrospective studies have confirmed that both adults and children with CD may have high levels of cumulative exposure to diagnostic ionising radiation, drawing attention to the need for alternative, accurate, radiation-free techniques. 13-17 In view of this, magnetic resonance enterography (MRE) is now more frequently employed to assess paediatric CD, providing an accurate tool to assess disease extent and distribution, depicting both intestinal and extra-intestinal disease-related complications.18 It is favoured due to its inherent multi-planar capability and ability to provide excellent soft-tissue contrast resolution without exposure to ionising radiation.19 However, it is expensive, time-consuming and sometimes poorly tolerated, particularly in children who may not be able to lie still during the procedure without general anaesthetic.

Trans-abdominal ultrasound (TUS) has been used to evaluate small bowel CD in both children and adults but may be hampered by the presence of endoluminal gas, which can obscure pathology.20,21 Administering oral contrast before performing abdominal ultrasound distends the small bowel and improves bowel wall visualisation. Studies have validated small intestinal (oral) contrast-enhanced ultrasonography (SICUS) in evaluating adult with Crohn’s disease,22-25 but very few studies in children, for whom this imaging technique is well suited, have been published and none have evaluated its use in routine clinical practice.26,27 Here, we describe our 5-year experience of SICUS in routine clinical practice, introduced as part of service improvement at a single regional referral centre, retrospectively comparing its diagnostic accuracy to conventional TUS, MRE and IC in evaluating children and adolescents with suspected or established CD.

**Methods**

The study protocol was approved by the hospital local ethics and research and development committees as part of an on-going local audit of service development. Patient confidentiality was maintained through anonymisation of collected data. We followed the Standards for Reporting of Diagnostic Accuracy (STARD) criteria for reporting studies considering diagnostic accuracy.28

*Study design and setting*

Since January 2009, SICUS has been available to children and adolescents with signs and symptoms of small intestinal disease in addition to conventional investigations and performed at the discretion of the responsible clinician. We retrospectively identified all patients less than 18 years of age who had been assessed by SICUS between January 2009 and December 2013 from the radiology information system database, cross-referenced with the ultrasound department’s booking diary to ensure a comprehensive dataset. We also determined which of these patients with CD underwent bowel resection within 6 months of undergoing SICUS or MRE from electronic patient records. Their surgical notes were reviewed together with TUS, IC and MRE reports, performed within 6 months of the SICUS study (Figure 1). We collated demographic data, C-reactive protein (CRP), erythrocyte sedimentation rate (ESR) and faecal calprotectin (FC) within two weeks of each imaging investigation, as surrogate markers of disease severity. Radiological findings were compared to assess the accuracy and agreement of SICUS in diagnosing CD and its related complications including proximal dilatation.

*Features of Crohn's disease*

A diagnosis of small bowel CD was entertained if SICUS detected one or more of the following features in the context of a consistent clinical presentation: (1) increased bowel wall thickness ≥ 3 mm; (2) absence of peristalsis; (3) stiffened bowel loop, defined as an intestinal loop that remained unchanged during trans-abdominal compression with the ultrasound probe; (4) presence of a stricture, fistula or abscess; (5) absence of wall stratification; (6) increased mural or mesenteric power Doppler (vascular) activity; (7) mesenteric lymph node hypertrophy; and (8) fat creep caused by mesenteric fat hypertrophy.22

**Radiology**

*SICUS*

After a 6 hour fast, a baseline ultrasound of the abdomen and pelvis was performed, using either an Aplio XG (Toshiba Medical Systems, Tochigi, Japan) with a 1.5-6MHz curvilinear array, or a Logic 9 (GE Healthcare, Milwaukee, WI, USA) with a 2-5MHz curvilinear array, to assess for any solid visceral pathology that might explain the patient’s presenting symptoms. Initial small bowel evaluation was also undertaken looking for any areas of bowel wall thickening, loss of normal wall stratification, or mesenteric thickening, using a combination of high-frequency curvilinear and linear transducers (3–9 and 6–11 MHz on the Aplio and 4–12 MHz on the Logic 9). The patient then consumed the contrast medium: paediatric formulation polyethylene glycol (Movicol®). Each sachet of contrast medium was dissolved in 250 mL tap water in preparation for SICUS. For children less than 50kg, 1-3 sachets according to their weight were used at the discretion of the radiologist; otherwise 4 sachets were used. Intermittent scans were then performed over the next 30 minutes, or until the solution had moved through to the distal ileum. Features of the small bowel were confirmed by its location, mucosal fold pattern, and its motility. Adjacent bowel loops were displaced by graded compression and this also permitted bowel wall stiffness to be determined. Power Doppler was used for assessing intramural and adjacent mesenteric vascularity when considering abnormal loops of small bowel. For both ultrasound systems, the parameters were optimised toward low-volume flow while trying to avoid excessive flash artefact. A pulse repetition frequency (PRF) of 800 Hz was used, with a low-medium wall filter and the gain adjusted to just below the noise floor. Scans were performed or supervised by 2 experienced radiologists with a sub-specialty interest in ultrasonography (JP and RA).

*MRE*

Scans were performed in a Siemens 1.5T scanner with an 8-channel body coil. All patients attended 90 minutes prior to the scan and were asked to drink an oral contrast mix comprising 1 litre of water (to fill the bowel), 4 scoops of Vitaquick™ thickener and 5 mg of metoclopramide hydrochloride. Patients were instructed to drink the first cup quickly and the remainder gradually over 45 minutes. A drug history was taken to verify that there were no contraindications to the antimuscarinic hyoscine butylbromide (Buscopan®), given to reduce intestinal motility. Patients and/or their parents were also made aware of potential adverse effects of mannitol and asked to empty their bladder prior to scanning.

Patients were positioned prone to reduce peristalsis and the number of imaging slices required. The following 3 sequences were obtained to image the entire small bowel; localisers, coronal 2D FIESTA, coronal T2 Fat Sat, coronal lava, Axial T2, coronal lava post contrast 30 seconds, coronal lava post contrast 70 seconds, and axial lava post contrast. Coronal T2 fat saturation, and axial lava were also acquired to image the terminal ileum exclusively. MRE was reported by JV and other members of the department.

**Statistical analysis**

The sensitivity and specificity of SICUS in identifying CD were calculated according to the final clinical diagnosis (gold standard), determined by the treating gastroenterologist, taking into account clinical history, examination findings, biochemical results and imaging findings other than those of SICUS. Consistency between investigations was tested by Cohen’s kappa coefficient statistical analysis (κ) with 0-0.20 indicating slight agreement, 0.21-0.40 fair, 0.41-0.60 moderate, 0.61-0.80 substantial and 0.81-1 almost perfect agreement. CRP, ESR and FC were compared by paired Student’s *t*-test.

**Results**

Ninety-three patients underwent SICUS during the study period (median age 15 years, range 2-17, 49 male) with 58 having suspected and 35 established CD. Figure 2 illustrates small bowel complications identified by SICUS and MRE in a representative patient with CD.

*SICUS vs MRE*

Seventeen patients were assessed with both SICUS and MRE (median age 15.1 years, range 8-17, 10 male). No difference was found in markers of disease severity at the time of each radiological investigation; SICUS (CRP 24.4 ± 33.3, ESR 21.1 ± 22.8, FC 514.8 ± 830.5) and MRE (CRP 19.1 ± 18.4, ESR 26.9 ± 18.5, FC 1266.6 ± 1070.6), p = 0.18, 0.92 and 0.18, respectively. The mean interval between SICUS and MRE was 108.9 days ± SD 54.5. Comparative statistical data are provided in Table 1. Agreement between TUS and MRE was moderate (κ = 0.53) for the presence of lesions but substantial between SICUS and MRE (κ = 0.63). In our cohort, SICUS correctly identified 3/4 proximal bowel lesions and 9/10 distal small bowel lesions detected by MRE. Agreement between SICUS and MRE was substantial in detecting both strictures (κ = 0.77) and dilatation (κ = 0.68). SICUS identified 2 cases of small dilatation not identified by MRE.

*TUS vs SICUS*

When comparing sonographic findings before and after contrast administration, the sensitivity and specificity to detect CD small bowel lesions in those with suspected disease were 85.7% and 87.5% for TUS and 98.7% and 100% for SICUS. In patients with known CD, sensitivity and specificity of TUS were 80.0% and 100%, and for SICUS, 97.3% and 100%, respectively.

*SICUS vs IC*

Thirty-nine patients were evaluated with both TUS/SICUS and IC with a mean interval of 89.7 days ± SD 76.5 between investigations. Inflammatory markers at time of SICUS (CRP 24.4 ± 33.3, ESR 21.1 ± 22.8, faecal calprotectin 514.8 ± 830.5) and IC (CRP 21.1 ± 31.8, ESR 26.9 ± 23.3, faecal calprotectin 686.6 ± 949.4) were not significantly different (p = 0.39, 0.18 and 0.77, respectively). Agreement between SICUS and TUS with IC for the presence of terminal ileal lesions was substantial (κ = 0.73, 95% CI 0.43 – 1.0) and fair (κ = 0.31, 95% CI 0.09 – 0.71), respectively. Agreement between SICUS and IC was almost perfect for detecting strictures (κ = 0.84, 95% CI 0.54 – 1) with 100% sensitivity and 97.5% specificity.

*SICUS vs surgery*

Three patients underwent resective bowel surgery, all within 2 months of SICUS evaluation (range 24-60 days). At surgery, terminal ileal disease and wall thickening was noted in all 3 cases, corroborating SICUS findings. In one patient, a 5 cm ileo-colonic stricture was present at operation, and in another, a colo-vesical fistula was identified; SICUS correctly delineated both CD-related complications.

**Discussion**

As clinical symptoms and signs may lag behind intestinal mucosal disease activity in Crohn's disease, disease monitoring using biochemical markers, cross-sectional imaging and endoscopy is important.29,30 This approach aims to identify subclinical disease to allow timely diagnosis, medical therapy and monitor mucosal response to treatment with the aim of reducing the need for surgery. However, the requirement for more frequent imaging increases the potential risks of a high cumulative exposure to ionising radiation for the patient, when performing small bowel barium studies and CT imaging; this is particularly relevant in children and adolescents amongst whom there is a rising incidence.2,31 MRE has therefore emerged as the preferred imaging technique in evaluating small bowel CD, since it avoids this while offering high sensitivity and specificity in diagnosing CD.32 Its drawback is lack of availability, high relative cost and difficulty performing it in young children, who may be unable to lie still during image acquisition without general anaesthetic. Our study, the first to compare the use of SICUS with MRE in routine clinical practice in a paediatric cohort, suggests that SICUS offers a satisfactory alternative with comparable diagnostic yield. Agreement between SICUS and MRE was substantial for detecting small bowel lesions (κ = 0.63) and stricturing disease (κ = 0.77). Furthermore, SICUS had near perfect agreement with IC in detecting terminal ileal disease (κ = 0.87).

TUS is an inexpensive, readily available option in the assessment of paediatric Crohn’s disease, with a reported sensitivity of between 74%-88%.33-35 Some groups have demonstrated results comparable to MRE,36,37 but it can fail to detect proximal small bowel lesions reliably, with reported sensitivity as low as 50%.26 This has led to interest in administering oral contrast prior to ultrasonography to promote bowel loop distension to enhance the clarity of visualisation of adjacent bowel loops.38 In our cohort, SICUS proved to be superior in terms of both sensitivity and specificity when compared to TUS in defining small bowel lesions.

We found agreement between SICUS and MRE to be substantial in identifying small bowel lesions, stricturing disease and wall dilatation. In a prospective paediatric case series, Pallotta *et al* reported that SICUS correlated well with SBFT in both identifying small bowel lesions and assessing their length.26 They found agreement between SICUS and SBFT to be almost perfect in delineating both distal and proximal disease (κ = 0.93). In another recent Italian study,27 SICUS had a higher sensitivity than MRE in detecting jejunal disease (92% vs 75%), which occurs more commonly in paediatric Crohn’s disease.10 The sensitivity of MRE was slightly higher than SICUS in detecting lesions of the proximal and mid ileum (100 % vs 80%, respectively) and identical (94%) for detecting terminal ileal disease. They also reported that MRE and SICUS were both well tolerated. In our study, SICUS fared well when compared to MRE with substantial/almost perfect agreement for both proximal (κ = 0.78) and distal lesions (κ = 0.87).

Whilst we did not formally assess the tolerability of SICUS and MRE in this retrospective study, anecdotally clinicians, patients and parents reported that SICUS was well tolerated, sometimes better so than MRE. It appeared to be particularly suited to young patients who may otherwise struggle to lie still in the enclosed environment of an MR scanner. Indeed, MRE can be problematic in those under 8 years of age and a general anaesthetic is often required, which is not always straightforward. SICUS offers a promising alternative in the very young since it can be performed using a nasogastric tube without general anaesthetic in patients as young as 2 years, in our cohort.

Our study is limited by its retrospective design, small sample size and undertaken in a single regional centre. It is possible disease progression may have occurred in the interval between SICUS and other investigations. This was considered unlikely because the ESR, CRP and FC, all validated surrogate markers of disease activity, were not significantly different at the time of each investigation.39,40 All SICUS studies were performed independently by one of three radiologists, but the retrospective design did not allow assessment of inter-observer variability. Finally, the evaluation of SICUS as part of service development prevented masking of the multidisciplinary team from the results, a potential confounder, although SICUS was usually performed as the first investigation. In terms of training new personnel, it has been established in adults that SICUS performed by an inexperienced ultrasonographer can achieve better diagnostic accuracy over conventional TUS performed by an experienced sonographer in the detection of small bowel pathology in CD nevertheless there is clearly a learning curve.41 We chose not to re-evaluate and re-report MRE images since it was felt that firstly the study aimed to compare SICUS and MRE in routine clinical practice and secondly, since SICUS is a dynamic test which cannot easily be accurately reported retrospectively without defined and stored cine clips, it would favour MRE if additional features were identified on revaluation. Clearly the small size of this study means our findings must be interpreted cautiously but it is the first study to evaluate SICUS against MRE in a paediatric cohort in a real-world setting.

In conclusion, our findings provide preliminary evidence to suggest SICUS offers a comparable diagnostic yield to that of MRE and IC and performed better than TUS in a paediatric cohort with suspected or established CD. Our work comparing SICUS and MRE in routine clinical practice adds to the existing, albeit very limited evidence, that SICUS offers a radiation-free alternative to MRE for the evaluation of CD in children and adolescents. Our findings support its wider adoption in this age group. Further dedicated prospective comparative studies of SICUS and MRE, such as the UK-based MR Enterography or ulTrasound In Crohn’s disease (METRIC) trial in adults, are now needed in children.42

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**Table 1.** Comparing small intestinal contrast ultrasonography with the reference standard of magnetic resonance enterography in paediatric Crohn’s disease. TP = true positive, FN = false negative, TN = true negative, FN = false negative. 95% confidence intervals given in brackets.

**Figure 1.** Flow diagram showing the investigations that the study cohort underwent.

CD – Crohn’s disease, TUS – transabdominal ultrasound, SICUS – small intestine contrast-enhanced ultrasonography, MRE – magnetic resonance enterography

**Figure 2.** A 16-year-old male with Crohn’s disease. (a) Coronal MRE, Gradient Echo (GRE) sequence (2D FIESTA), demonstrating bowel wall thickening affecting the terminal ileum, caecum and appendix. (b) Coronal MRE, 3D, T1-weighted sequence with fat suppression and intravenous gadolinium contrast administration (LAVA), at 70sec post injection, demonstrating avid enhancement of the thickened segment of bowel. (c) Selected SICUS images demonstrating the same loop of terminal ileum, with bowel wall thickening, and oedema (hypoechoic change), decreased luminal diameter and (d) increased vascularity on Doppler imaging.