

OPEN ACCESS

Full open access to this and thousands of other papers at <http://www.la-press.com>.

Diagnostic Performance of Ultrafast 3-Dimensional Ultrasound on the Small Bowel: Single Center Experience

Salah Elwagdy¹, Mokhtar Ragab Ramadan¹, Mohamed A. Farag¹, Manal Farag², Sahar Eladawy³, Hosni A-Karim³, Gamal M. Soliman³, Ali Ibrahim³, Shabban Salah³ and Abdel Hamid Elgargani⁴

¹Radiology Department, Azhar University, Cairo, Egypt. ²Internal Medicine Department, Azhar University, Cairo, Egypt.

³Tropical Medicine Department, Azhar University, Cairo, Egypt. ⁴Department of Radiology, Omar Almokhtar University, Libya. Corresponding author email: salah_elwagdy@yahoo.com

Abstract

Background: Increased speed and resolution of ultrasound have made it a first-line modality for the abdominal examination. During the last 5 years trans-abdominal ultrasonography has been used increasingly, for assessment of patients with small bowel (SB) diseases. Around 350 such examinations are performed annually in the diagnostic imaging department at Azhar University Hospital. Hence, the aim is to determine if the ultrafast three-dimensional ultrasound (U3D US) is potent for optimal examination of SB diseases.

Patients and methods: Tap-water intake has been used to distend the SB. All patients have been examined in supine position. The U3D US data of 198 patients with SB diseases were assessed. The proximal and distal SB image quality along with the evaluation of bowel distention, motility and lesions were reported.

Results: Image quality was good in all examinations. Adequate demonstration of the proximal and distal SB was obtained in all of U3D US examinations. The inclusive diagnostic accuracy of U3D US was precise in 92.3%. Proximal SB was, however, less frequently involved, particularly in patients below the age of 30 years ($P = 0.050$).

Conclusion: The diagnostic accuracy of U3D US enterography is valuable for detecting SB lesions. This modality is widely available, inexpensive and easy technique, can be used as an initial investigation in the evaluation of patients with SB disorders.

Keywords: small bowel disease—ultrafast threedimensional Ultrasonography—Diagnostic performance

Clinical Medicine Insights: Gastroenterology 2011:4 45–51

doi: [10.4137/CGast.S8143](https://doi.org/10.4137/CGast.S8143)

This article is available from <http://www.la-press.com>.

© the author(s), publisher and licensee Libertas Academica Ltd.

This is an open access article. Unrestricted non-commercial use is permitted provided the original work is properly cited.



Introduction

The advent of endoscopy has increased the diagnostic possibilities of small bowel (SB) disorders. Wireless capsule video-endoscopy is the most recent method, which may allow for excellent visualization of the SB mucosa and any luminal abnormalities, but it does not clearly localize the area of the SB where lesions are identified or demonstrate beyond the mucosal surface; therefore its specificity is lower than other methods.¹⁻³ In addition, there is a possibility of capsule retention where SB strictures are present.⁴

Due to the variable sensitivity of barium follow-through (23%–80%) for the detection of SB lesions,⁵ much research has been directed toward the potential of cross-sectional imaging modalities for the diagnosis and evaluation of SB diseases, as with these techniques the bowel lumen, the bowel wall and the extra-intestinal abdomen including the visceral fat, the lymph nodes and the vascular structures feeding and draining the bowel can be visualized.⁵⁻⁷

Minordi et al reported that Multi Detector Computed Tomography (MDCT) enteroclysis has been shown to be superior to small-bowel barium examinations, conventional CT, and complementary to capsule endoscopy in the elective investigation of small-bowel disease.⁸ However, the growing awareness of the risks of ionizing radiation exposure has prompted the exploration by Magnetic Resonance Enteroclysis (MRE) useful in assessing the quality and quantity of bowel. Advantages of MRE imaging include a lack of ionizing radiation and the ability to provide dynamic information regarding bowel distention and motility.⁹ The main value of enteral MDCT and MRI is that they permit detection of jejuna lesions that have escaped detection with conventional two-dimensional ultrasound (2D US) imaging.⁸⁻¹⁰ The reason is frequently because the surface visualization of ultrasound image contains many speckles, so that the interesting image parts and minute details of ultrasound anatomy are not definite.¹⁰⁻¹²

The recent advances of dynamic interactive speckle subtraction accompanying the introduction of three-dimensional ultrasound (3D US) have provided good quality display for proper tissue characterization and subsequently visualization of subtle lesions.¹³⁻¹⁶

During the last 5 years ultrafast three-dimensional ultrasonography (U3D US) has been increasingly used for assessment of patients with bowel disease.

Almost about 350 such examinations are performed annually in the diagnostic imaging department at Azhar University Hospital which is also the site for the management of bowel diseases.

The aim of this prospective study was thus to assess the quality of U3D US imaging in SB diseases and to confirm whether imaging of patients with this modality can provide a quality adjunct diagnosis.

To our knowledge, no previous studies addressing the ultrafast 3-dimensional ultrasound (U3D US) on the small bowel or explaining the small bowel U3D US's display techniques have been published before.

Patients and Methods

The study protocol, including review¹⁷ of the ultrasound normal figures for the SB, was approved by the local research ethics committee, who deemed that patient consent was not required for this study as both conventional and 3-dimensional ultrasound are considered to be standard examination methods.

We prospectively evaluated 189 patients; 102 male patients aged 17–72 years (mean age, 44.5 years) and 87 female patients aged 20–74 years (mean age, 40.3 years). All subjects were patients of Azhar University Hospital, Cairo, Egypt, which is also the site for the management of bowel diseases. All patients had undergone the necessary laboratory investigations. The clinical indication for U3D US test was mainly to assess reasons for recurrent episodes of abdominal pain with illness ($n = 187$), persistent or intermittent bouts of intestinal obstruction with cramping, chronic anemia, loss of appetite and weight loss ($n = 13$) and family history of bowel neoplasms ($n = 9$).

U3D US preparation

All patients drank tap-water for 15 minutes just prior to their U3D US test; 1200–1500 mL of pure tap-water was usually required for each to distend the SB, which varied depending on the patient's tolerance. There was no need for medications to reduce SB peristalsis or prolong SB distension. Patients were also asked to report any discomfort that they experienced after the procedure such as vomiting, diarrhea, or abdominal pain.

U3D US techniques

Patients were imaged in the supine position using a 3-dimensional ultrasound system (Accuvix V20,

Medison, South Korea) with a volume probe (V 4–8 MHz, 75 frames/second). Routine conventional 2D US was primarily obtained to ensure adequate SB distention. Patients were asked to drink more water if the small bowel was not adequately distended. Visual division of the abdominal field into 4 quadrants centered on the umbilicus was well-thought-out. Real-time 4 scan-volumes were then acquired dynamically, one volume for each quadrant, without breath-holding to cover the entire abdomen. Additional volume or more were occasionally required when targeting any lesion was essential. The time of U3D US examination varied from 5 to 15 minutes (mean 10 minutes), depending upon how many additional volumes were required.

Image analysis

Each real time U3D US volume was reviewed twice: first to confirm proper volume acquisition, distensibility of the SB loops, motility and lesion detection. The U3D US volumes were then archived at a workstation (Sonoview_Pro 1.5.1).

After the patient left the examination room, the stored volumes were displayed and analyzed by a committee of well-trained specialists at least of 5 years' experience, so as to evaluate U3D US modality, specifically for the presence of SB wall thickening, panoramic viewing of the mucosal aspect, and SB masses. Surface rendering was routinely viewed in sagittal, coronal, transverse and oblique contiguous images. Then, the multislice extended capability (XI MR) was performed to obtain very thin (0.5 mm) contiguous slices targeting the SB lesion at any overlap point.

The laboratory data for all patients ($n = 182$), and endoscopy ($n = 4$) and/or surgical ($n = 7$) findings and specimens for Crohn's disease (CD) and tumors, were blind during the U3D US assessments.

Statistical analyses

Were performed with the commercially available software (SPSS 19.0 for Windows). All P values ≤ 0.05 were considered to indicate statistical significance.

Results

We used the previously reported ultrasound parameters for normal personnel presented in the report of Sporea et al¹⁷; calibers = less than 3.0 and 2.0 cm for

the jejunum and ileum, respectively and the normal wall thickness = less than 3.0 mm.

Data from 189 U3D US examinations of patients with SB disorders and their corresponding laboratory, enteroscopy and/or surgical data and their histologic findings were finally disclosed and scheduled. No significant difference was found in male to female sex ($P = 0.102$ vs. $P = 0.078$, respectively).

Tap-water intake was well tolerated in all the 189 patients in whom the examination was completed successfully, with good distention of the proximal and distal SB and good image quality (Fig. 1). No patient experienced side effects at the examination.

Table 1 shows the U3D US performance in proximal and distal SB diseases in consideration with patients' age and sex.

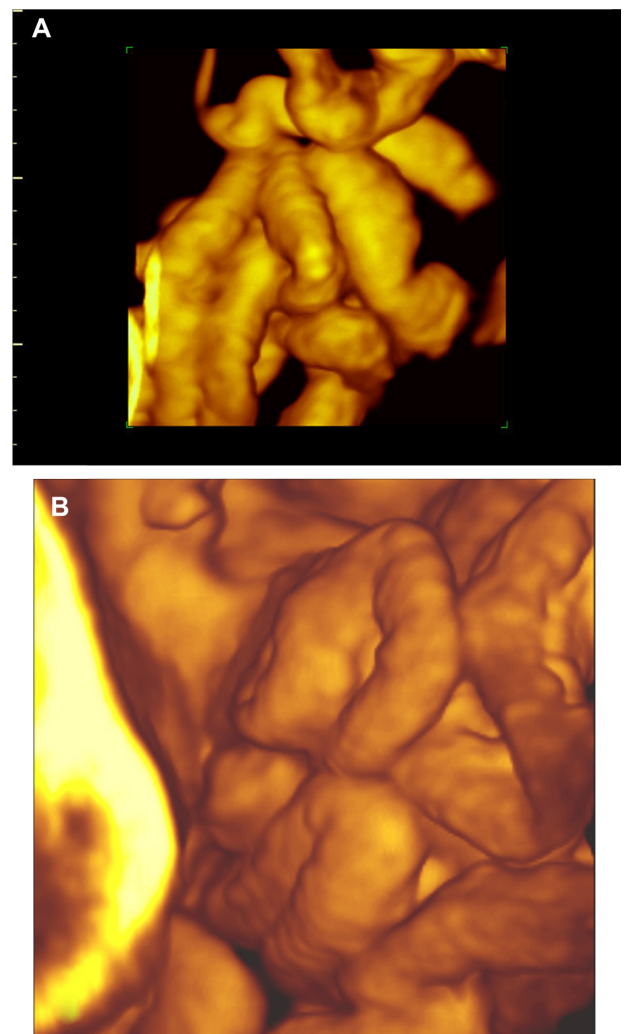


Figure 1. U3D UD showing the normal appearance of the small bowel; (A) proximal and (B) distal, with good distention of the bowel after sufficient tap-water intake.

Table 1. Performance of U3D US in SB disease, patient age and sex (M = 102, F = 87).

| | Patients (n) | SB disease | | P value |
|----------|--------------|---------------------|-------------------|---------|
| | | Proximal SB disease | Distal SB disease | |
| Male | 102 | 36.3% (37/102) | 63.7% (65/102) | 0.102 |
| Female | 87 | 25.3% (22/87) | 74.7% (65/87) | 0.078 |
| <30 yr | 84 | 25.0% (12/48) | 75.0% (36/48) | 0.057 |
| 30–50 yr | 53 | 30.2% (16/53) | 69.8% (37/53) | 0.050 |
| >50 yr | 88 | 44.3% (39/88) | 55.7% (49/88) | 0.110 |

Abbreviations: U3D US, Ultrafast three-dimensional ultrasound; SB, small bowel.

The diagnostic accuracy of U3D US was superior with use of the combined image-sequences (surface rendering and thin contiguous multislice viewing). In general, U3D US revealed 182 lesions of 189 (92.3%); 176 out of 182 (96.7%) for non-tumorous, 3 out of 4 patients (75%) for mass lesion, and 3 out of 3 patients for CD (100%). This means that 7 of our patients' showed false negative results; 6 with non-tumorous SB disease and one case of jejunal adenoma (Table 2).

U3D US revealed thickening of the SB wall and broadening of the mucosal pattern as the main diagnostic criteria for enteritis. No significant variance could be noted differentiating infectious enteritis from irritable bowel, either in SB motility or wall changes. However, for typhoid enteritis, surface oval-shaped bright patches were noted and well thought-out to be characteristics (Fig. 2). In case of intestinal tuberculosis, stenotic segments were considered discerning, and mostly seen involving the ileum than the jejunum (Fig. 3).

Crohn's disease in the present study was scheduled distinctly, as its pathogenesis is not yet known and has dissimilar diagnostic criteria. In CD, the U3D US

enterography was able to demonstrate the thickened wall of the terminal ileum in all cases of this category, with central string-sign and marginal jaggings representing infiltration of perivisceral fat (Fig. 4). However, one of them showed U3D US of early signs of abscess formation on coronal multislice sequence.

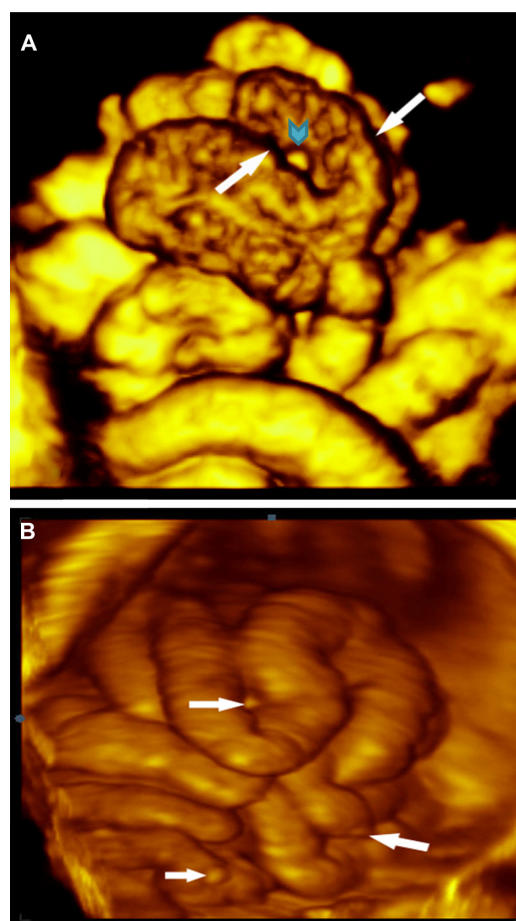


Figure 2. U3D US coronal cut-section image of a 37-year-old female patient with known inflammatory bowel disease (typhoid). (A) Image along the mucosal surface shows thickening of the intestinal wall (arrows) and broadening of the intestinal mucosa. A longitudinal depression is noted (arrow head) likely representing ulcer. (B) The small bowel outer surface shows few bright surface oval-shaped nodules, likely aggregated lymph follicles.

Table 2. U3D US imaging findings and accuracy on 189 patients with small bowel disorders.

| Findings | n | Accuracy (%) |
|--------------------------------|---------|--------------|
| Wall thickening | 176/182 | 96.7% |
| Infectious enteritis | 102/176 | 58.0% |
| Irritable bowel | 74/176 | 42.0% |
| Mass lesion | 3/4 | 75.5% |
| Chron's disease | 3/3 | 100% |
| Obstructive variants (minimal) | 9/9 | 100% |
| Mass lesion | 3/9 | 33.3% |
| Chron's disease | 3/9 | 33.3% |
| Tuberculosis (marked) | 2/9 | 22.2% |
| Mass lesion + intussusception | 1/9 | 1.2% |

Abbreviations: U3D US, Ultrafast three-dimensional ultrasound; n, number of diagnosed patients/out of total in each category.

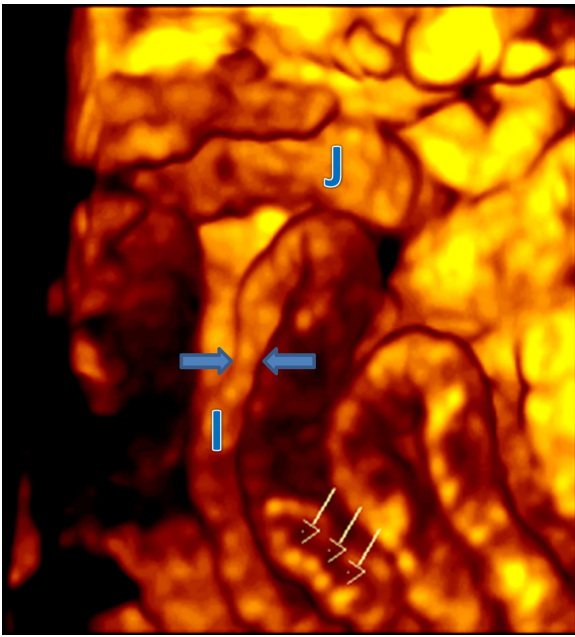


Figure 3. U3D US surface rendered image of a 17-year-old male patient with known intestinal tuberculosis. Image shows severe inflammation of the small bowel with dotted bright tiny (transversely aligned) spots involving the SB mucosal aspect (arrows), likely representing ulcers. Stenotic segments are noted (opposed arrows). The process is involving the ileum (I) more than the jejunum (J).

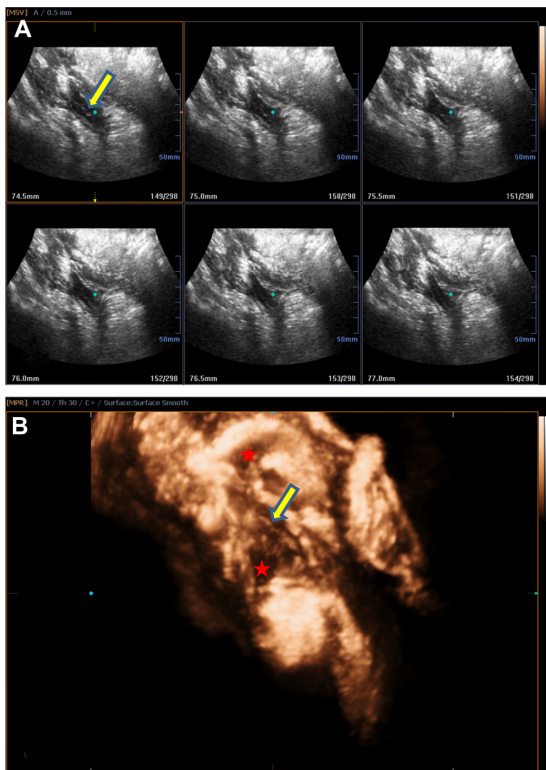


Figure 4. A 34-year female patient with intermittent abdominal pain and cramps. (A) U3D US multislice sequence shows the thickened wall of the terminal ileum, with string-sign (arrow). (B) Surface rendered image shows the string sign (arrow) with infiltration of the perivisceral fat (asterisks) located ventrally and cranially at the right iliac fossa.

From a total of 4 SB mass lesions, all of them were confirmed at surgery. U3D US enterography helped us to identify luminal and the extraluminal patterns in 3 out of them (Fig. 5). However, the missed case with SB mass lesion showed partial SB obstruction and the location could be suggested at the level of the proximal ileum, which proved adenoma at surgery. The diameters of the neoplasms in the three cases of SB adenocarcinoma ranged from 19 to 43 mm (mean diameter, 26.7 mm). The extraluminal disease in these patients was liver metastasis in two patients and enlarged mesenteric lymph nodes in one.

In the 7 patients who underwent surgery, there was perfect concordance with the findings detected at U3D US; demonstrated high-grade partial SB obstruction in one patient with SB adenocarcinoma inducing jejuno-jejunal intussusception (Fig. 6) and low grade partial small-bowel obstruction in six patients; three were due to mass lesion and the remaining three instances were due to CD.

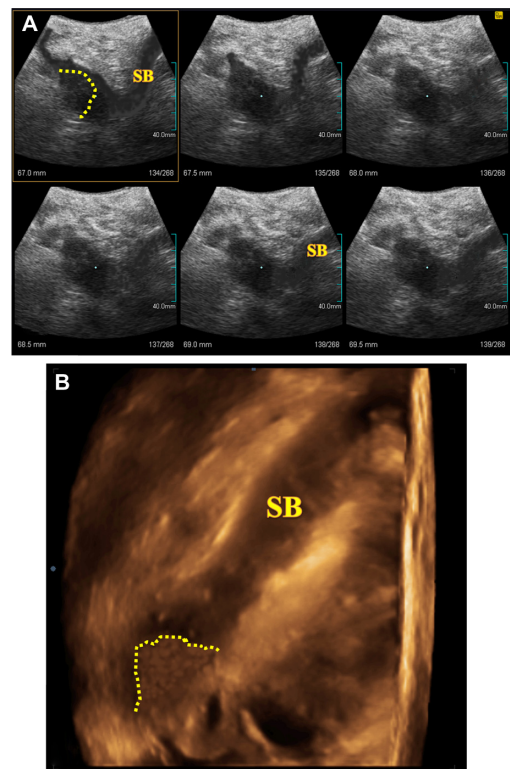


Figure 5. U3D US images of ileal adenocarcinoma in 70-year-old man with unexplained loss of weight, abdominal pain and cramps. (A) Coronal Multislice sequence (1.5 mm thickness) shows a luminal projecting mass (arrow) in lumen of distal ileum. This finding suggests a mucosal origin of the neoplasm. The mammilated surface is correlating with ulceration of the overlying normal mucosa. (B) Coronal surface rendered image (10 mm thickness) the mammilated-border mass (dashes) protruding into lumen of small bowel (SB) with dilated small bowel proximal to the mass.

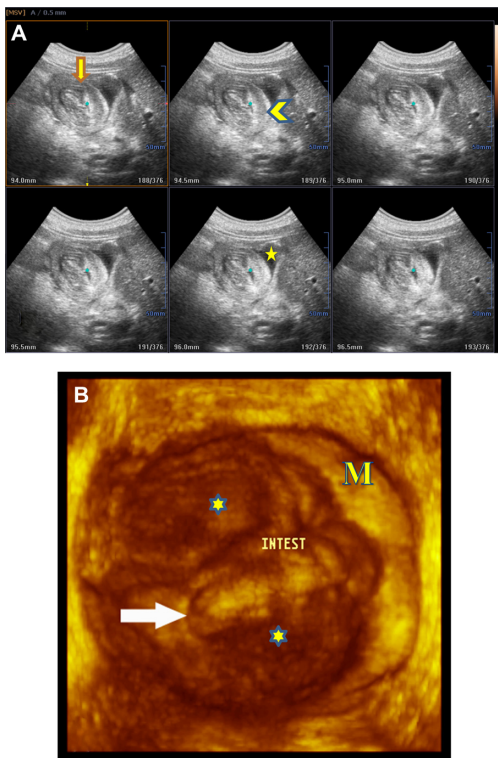


Figure 6. 38-year-old male with complaints of vomiting, abdominal distension and pain. U3D US-enterography to evaluate the small bowel revealed: **(A)** Coronal multislice sequence shows the intussusception of the small bowel (arrow), with marginal mass (arrow head) bordered by little collection (asterisk). **(B)** Surface rendered image in coronal plane revealing the intussusception, with marginal delineation of the mass (M). Intussusceptant (asterisks) and apex of the intussusceptum (arrow).

Discussion

Precise evaluation of SB lesions is difficult because of its curved course and overlapping folds. Currently, two major techniques are used: MDCT and MRI for the necessity to reveal the luminal, mural and extraluminal profile as well.¹¹

On the other hand, several reports mentioned that the role of sonography in the evaluation of SB neoplasms is similar to that of CT scan and comparable to MRI with oral contrast material administration. They mentioned that ultrasound is frequently performed early in the diagnostic work-up, which may lead to accurate recognition, localization and even staging of disease with the opportunity for directing appropriate further investigation, including sonography—guided aspiration biopsy.^{18–21}

In the present study, U3D US sequences yielded useful information in the evaluation of SB.

The advantages of ultrafast volume acquisition and interactive speckle reduction are combined in this modality to overcome motion artifacts due to SB motility and enable the detection of intraluminal, mural, and extramural SB disorders along with motility information comparable to that gleaned at current cross-sectional imaging modalities.

Optimal distention of the SB has also been shown to facilitate for correct SB evaluation because collapsed SB loops can hide or mimic lesions or confusing thickened bowel wall in collapsed segments. This proved significant in accurate delineation of mural changes in patients with enteritis and CD, and also particularly proved important in the detection of the luminal, mural and extraenteric patterns of SB neoplasms in the early stage.

Results of the present study on U3D US compared to the previous reports on conventional 2D US,^{15,22–24} has been shown to be more sensitive in detecting mural changes of the SB, and more potent in the detection of mucosal surface abnormalities due to the better soft-tissue characterization. Besides, our results are almost parallel to that performed on MDCT²⁵ in the evaluation of SB neoplasms.

Moreover, the U3D US test can be performed several times, as it is a cost-effective, office-based technique, with no ionizing radiation exposure.

Our study had a number of limitations. First, most of our patients relieved on medical treatment after the U3D US assessments; and thus, for ethical reasons, it was difficult to do further invasive examinations in such patients in whom symptoms resolved with proper treatment. On the other hand, the remaining patients in our study with small bowel CD or neoplasms were presented with partial or complete intestinal obstruction, have been subjected to surgical interventions just after the U3D US test. Second, this was a single-center trial and its design is not reliable on the inter-observers' variability and the disease prevalence or type in other populations. Nevertheless, our center covers a big population, hence, this attempt deemed feasible and more research is needed to establish the diagnostic effectiveness of this modality.

Conclusion

U3D US is widely available, inexpensive, and easy technique, can be used as an initial virtual



enterography in the evaluation of patients with SB disorders.

Disclosures

Author(s) have provided signed confirmations to the publisher of their compliance with all applicable legal and ethical obligations in respect to declaration of conflicts of interest, funding, authorship and contributorship, and compliance with ethical requirements in respect to treatment of human and animal test subjects. If this article contains identifiable human subject(s) author(s) were required to supply signed patient consent prior to publication. Author(s) have confirmed that the published article is unique and not under consideration nor published by any other publication and that they have consent to reproduce any copyrighted material. The peer reviewers declared no conflicts of interest.

References

1. Saurin JC, Delvaux M, Vahedi K, Gaudin JL, Villarejo J, Florent C, et al. Clinical impact of capsule endoscopy: 1-year follow-up study. *Endoscopy*. 2005;37:318–23.
2. Fork FT, Aabakken L. Capsule enteroscopy and radiology of the small intestine. *Eur J Radiol*. 2007;17:3103–11.
3. Jensen MD, Nathan T, Rafaelsen SR, Kjeldsen J. Diagnostic Accuracy of Capsule Endoscopy for Small Bowel Crohn's Disease is Superior to that of MR Enterography or CT Enterography. *Clin Gastroenterol Hepatol*. November 5, 2010. [Ahead of print.]
4. Sears DM, vots-Avotins A, Culp K, Gavin MW. Frequency and clinical outcome of capsule retention during capsule endoscopy for GI bleeding of obscure origin. *Gastrointest Endosc*. 2004;60:822–7.
5. Korman U, Kurugoglu S, Ogut G. Conventional enteroclysis with complementary MR enteroclysis: a combination of SB imaging. *Abdom Imaging*. 2005;30:564–75.
6. Masselli G, Vecchioli A, Gualdi GF. Crohn disease of the SB: MR enteroclysis versus conventional enteroclysis. *Abdom Imaging*. 2006;31:400–9.
7. Horsthuis K, Stokkers PC, Stoker J. Detection of inflammatory bowel disease: diagnostic performance of cross-sectional imaging modalities. *Abdom Imaging*. Jul–Aug 2008;33(4):407–16.
8. Minordi LM, Vecchioli A, Mirk P, Bonomo L. CT enterography with polyethylene glycol solution vs. CT enteroclysis in small bowel disease. *Br J Radiol*. 2011;84(998):112–9.
9. Tennyson CA, Semrad CE. Advances in small bowel imaging. *Curr Gastroenterol Rep*. 2011;13(5):408–17.
10. Aiyappan SK, Kalra N, Sandhu MS, Kochhar R, Wig JD, Khandelwal N. Comparison of neutral and positive enteral contrast media for MDCT enteroclysis. *Eur J Radiol*. January 14, 2011. [Ahead of print.]
11. Miao F, Wang ML, Tang YH. New progress in CT and MRI examination and diagnosis of small intestinal tumors. *World J Gastrointest Oncol*. 2010; 2(5):222–8.
12. Christensen AF, Nyhuus B, Nielsen MB. Interobserver and intraobserver variation of two-dimensional and three-dimensional anal endosonography in the evaluation of recurrent anal cancer. *Dis Colon Rectum*. 2009; 52(3):484–8.
13. Gravante G, Giordano P. The role of three-dimensional endoluminal ultrasound imaging in the evaluation of anorectal diseases: a review. *Surg Endosc*. 2008;22(7):1570–8.
14. Elwagdy S, Ramadan R, Sabry AF, Elhawary M, Nabil M, Shehata M, et al. Virtual gastroscopy: A preliminary study on the use of trans-abdominal, fast three-dimensional, colour-coded ultrasound in the evaluation of gastric mass lesions. *Arab J Gastroenterol*. 2010;11:90–5.
15. Park NH, Park SI, Park CS, et al. Ultrasonographic findings of SB intussusception, focusing on differentiation from ileocolic intussusception. *Br J Radiol*. 2007;80(958):798–802.
16. Nagi B, Rana SS, Kochhar R, Bhasin DK. Sonoenteroclysis: a new technique for the diagnosis of SB diseases. *Abdom Imaging*. 2006;31(4):417–24.
17. Sporea I, Popescu A. Ultrasound examination of the normal gastrointestinal tract. *Med Ultrason*. 2010;12(4):349–52.
18. Feuerbach S. MRI enterography: the future of small bowel diagnostics? *Dig Dis*. 2010;28(3):433–8.
19. Girtler MT, De Zordo T, Romagnoli C. Sonographic findings in a patient with neurofibromatosis type 1 and a gastrointestinal stromal tumor. *J Clin Ultrasound*. 2010;38(5):274–8.
20. Yang DM, Kim HC, Jin W, Ryu CW, Kim H. Imaging findings of idiopathic localized dilatation of the ileum. *Br J Radiol*. 2008;81(962):e48–9.
21. Onali S, Calabrese E, Petruzzello C, Zorzi F, Sica GS, Lolli E, et al. Endoscopic vs. ultrasonographic findings related to Crohn's disease recurrence: a prospective longitudinal study at 3 years. *J Crohns Colitis*. 2010;4(3):319.
22. Naevdal EF, Nylund K, Gilja OH. Transabdominal ultrasonography inflammatory intestinal syndrome. *Tidsskr Nor Laegeforen*. 2010;130(22):2230–4.
23. Pallotta N, Giovannone M, Pezzotti P, Gigliozzi A, Barberani F, Piacentino D, et al. Ultrasonographic detection and assessment of the severity of Crohn's disease recurrence after ileal resection. *BMC Gastroenterol*. 2010;10:69.
24. Benevento G, Avellini C, Terrosu G, Geraci M, Lodolo I, Sorrentino D. Diagnosis and assessment of Crohn's disease: the present and the future. *Expert Rev Gastroenterol Hepatol*. 2010;4(6):757–66.
25. Romano S, De Lutio E, Rollandi GA, Romano L, Grassi R, Maglente DD. Multidetector computed tomography enteroclysis (MDCT-E) with neutral enteral and IV contrast enhancement in tumor detection. *Eur J Radiol*. 2005; 15:1178–83.

Publish with Libertas Academica and every scientist working in your field can read your article

"I would like to say that this is the most author-friendly editing process I have experienced in over 150 publications. Thank you most sincerely."

"The communication between your staff and me has been terrific. Whenever progress is made with the manuscript, I receive notice. Quite honestly, I've never had such complete communication with a journal."

"LA is different, and hopefully represents a kind of scientific publication machinery that removes the hurdles from free flow of scientific thought."

Your paper will be:

- Available to your entire community free of charge
- Fairly and quickly peer reviewed
- Yours! You retain copyright

<http://www.la-press.com>