Thieme

EFSUMB Recommendations and Guidelines for Gastrointestinal Ultrasound

Part 1: Examination Techniques and Normal Findings (Long version)

EFSUMB-Empfehlungen und Leitlinien des Gastrointestinalen Ultraschalls

Teil 1: Untersuchungstechniken und Normalbefund (Langversion)

Authors

Kim Nylund[1], Giovanni Maconi[2], Alois Hollerweger[3], Tomas Ripolles[4], Nadia Pallotta[5], Antony Higginson[6], Carla Serra[7], Christoph F. Dietrich[8], Ioan Sporea[9], Adrian Saftoiu[10], Klaus Dirks[11], Trygve Hausken[12], Emma Calabrese[13], Laura Romanini[14], Christian Maaser[15], Dieter Nuernberg[16], Odd Helge Gilja[17]

Affiliations

1 National Centre for Ultrasound in Gastroenterology, Haukeland University Hospital, Bergen, Norway
2 Gastroenterology Unit, Department of Biomedical and Clinical Sciences, "L.Sacco" University Hospital, Milan, Italy
3 Department of Radiology, Hospital Barmherzige Brüder, Salzburg, Austria
4 Department of Radiology, Hospital Universitario Doctor Peset, Valencia, Spain
5 Department of Internal Medicine and Medical Specialties, Sapienza University of Rome, Roma, Italy
6 Department of Radiology, Queen Alexandra Hospital, Portsmouth Hospitals NHS Trust, Portsmouth, United Kingdom of Great Britain and Northern Ireland
7 Department of Digestive System, Sant'Orsola-Malpighi Hospital and University of Bologna, Italy
8 Department of Internal Medicine 2, Caritas Krankenhaus, Bad Mergentheim, Germany
9 Dept. of Gastroenterology and Hepatology, "Victor Babes", University of Medicine and Pharmacy Timisoara, Romania
10 Research Center of Gastroenterology and Hepatology, University of Medicine and Pharmacy of Craiova, Romania
11 Gastroenterology and Internal Medicine, Rems-Murr-Klinikum Winnenden, Germany
12 Department of Clinical Medicine, University of Bergen, and Department of Medicine, Haukeland University Hospital, Bergen, Norway
13 Gastroenterology Unit, Department of Systems Medicine, University of Rome Tor Vergata, Roma, Italy
14 Dept. of Radiology, Radiologia 1, Spedali Civili di Brescia, Italy
15 Outpatients Department of Gastroenterology, University Teaching Hospital Lueneburg, Germany
16 Department of Internal Medicine and Gastroenterology, Brandenburg Medical School, Neuruppin, Germany
17 National Centre of Ultrasound in Gastroenterology, Department of Medicine, Haukeland University Hospital, and Department of Clinical Medicine, University of Bergen, Norway

Key words
guideline, ultrasound, gastrointestinal, examination technique, normal variants

received 24.06.2016
accepted 09.08.2016

Bibliography
DOI https://doi.org/10.1055/s-0042-115853
Published online: September 07, 2016 | Ultraschall in Med 2017; 38: e1–15 © Georg Thieme Verlag KG, Stuttgart · New York, ISSN 0172-4614

Correspondence
Dr. Kim Nylund
National Center of Ultrasound in Gastroenterology, Haukeland University Hospital, Jonas Lies vei 65, 5021 Bergen, Norway
Tel.: ++ 47/55 97 30 79
Fax: ++ 47/ 55 97 29 50
kim.nylund@med.uib.no

ABSTRACT

In October 2014 the European Federation of Societies for Ultrasound in Medicine and Biology formed a Gastrointestinal Ultrasound (GIUS) task force group to promote the use of GIUS in a clinical setting. One of the main objectives of the task force group was to develop clinical recommendations and guidelines for the use of GIUS under the auspices of EFSUMB. The first part, gives an overview of the examination techniques for GIUS recommended by experts in the field. It also presents the current evidence for the interpretation of normal sonoanatomical and physiological features as examined with different ultrasound modalities.

ZUSAMMENFASSUNG

Im Oktober 2014 bildete die „European Federation of Societies for Ultrasound in Medicine and Biology“ einen Arbeitskreis „Gastrointestinaler Ultraschall“ (GIUS), um den Einsatz des GIUS in der klinischen Praxis voranzutreiben. Eines der Hauptziele des Arbeitskreises war die Erarbeitung klinischer Empfehlungen und Leitlinien für den Einsatz des GIUS unter der Schirmherrschaft des EFSUMB. Der erste Teil gibt einen Überblick über die Untersuchungsmethoden des GIUS, wie er von Experten auf diesem Gebiet empfohlen wurde. Außerdem wird die derzeit aktuelle Evidenz für die Interpretation normaler sonoanatomischer und physiologischer Merkmale, wie sie mit unterschiedlichen Ultraschallmethoden untersucht wurden, präsentiert.

Introduction

Transabdominal gastrointestinal ultrasound (GIUS) offers the unique opportunity to examine non-invasively and in physiological condition the bowel including extra-intestinal features such as the splanchnic vessels, mesentery, omentum and lymph nodes. For properly trained users, GIUS has been shown to have good accuracy and repeatability not only in a primary work up, but also in the follow up of chronic diseases [1, 2].

Although there is an extensive documentation for the usefulness of GIUS in clinical practice it has only been fully implemented in some European countries and expert centres. Furthermore, the lack of standardization of the examination technique, and of guidelines, makes it hard to properly train physicians.

This was the motivation behind establishing the GIUS Task Force Group in 2014 under the umbrella of the European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) which previously have published several guidelines and recommendations [3 – 11]. The group consists of a team of international experts of GIUS and the objective is to promote the use of GIUS in a clinical setting. This will be achieved by publishing clinical guidelines and recommendations on indications and use of GIUS for the gastrointestinal (GI) tract and by stimulating the development of training networks.

A guideline-series of altogether 7 papers are in the pipeline: examination techniques and normal findings, inflammatory bowel disease, transrectal and perineal ultrasound, other inflammatory disorders, functional disorders, upper GI ultrasound and miscellaneous pathologies.

In the making of this first document the GIUS task force group agreed on the scope of the document and then assigned a responsible author to select a panel of authors from the group based on their previous publications in the relevant fields of interest and their reputation as international experts in research and in teaching GIUS. Finally, a consensus meeting was held April 2016 to discuss important aspects of the guidelines and to vote on actual recommendations.

This document is mainly focused on presenting the examination techniques for performing GIUS and the normal ultrasound (US) features of the bowel, bowel wall and surrounding structures. Examination techniques and normal ultrasound findings for the perineal region and stomach are not included, but will be addressed in upcoming guideline papers. The recommendations are based on an extensive literature review. Based on the literature a recommendation level was suggested for each guideline. The Oxford Guidelines for reporting medical evidence was used specifying the level of evidence (LoE) and the grade of recommendation (GoR) [12]. Since many of the themes in these guidelines have not been subjected to systematic studies these recommendations often have a level of evidence 4 or 5, the latter simply being expert opinion. Therefore this document also includes the level of consensus of the members in the GIUS task force group. In April 2016 members of the Task Force Group participated in a consensus meeting in Gargnano, Italy. Each recommendation was discussed, adjusted and subjected to vote by members in the GIUS task force group. Recommendations 14 and 15 were not ready before the consensus meeting and were put to the vote during the review process. Degree of consensus was graded as follows: Strong consensus = > 95 %, broad consensus = 95 – 76 %, majority consensus 75 – 50 % and dissent < 50 %.

Equipment and examination modalities

B-mode

Ultrasound scanners should have sufficient quality and screen resolution to be able to delineate the structures in the gastrointestinal wall. The resolution of an US transducer is dependent on the frequency, the speed of sound in tissue and the number of cycles in the US pulse. Since the thickness of the bowel wall layers usually is less than 1 mm [13, 14], the frequency of a transducer must be at least 5 megahertz (MHz) for wall layers to be well discriminated [15 – 17]. No head-to-head studies have been published comparing the diagnostic performance of regular low frequency range abdominal probes (frequency range around 1 – 6 MHz), mid-frequency range transducers (frequency range around 5 – 10 MHz) and high frequency range transducers (frequency range around 10 – 18 MHz) for the detection of the intestines and intestinal disease. However, according to their specifications most mid-frequency range transducers offer the investigator a good compromise between resolution and depth penetration. While a mid -frequency range transducer can have a depth penetration of about 8 – 10 cm a high-frequency range transducer rarely penetrates beyond 4 cm. At the same time the resolution of a mid-frequency range transducer is quite adequate for separating individual layers in the GI wall [15 – 17]. A low-frequency range transducer is still needed for overview for reaching deeper lying bowel segments, such as the rectum and in obese patients. Harmonic imaging should be activated when available as this may improve the delineation of bowel wall layers [18, 19]. To document longer areas of involved intestines panoramic imaging may be helpful [20, 21].

RECOMMENDATIONS:

1. For a complete examination of the bowel both a low and high resolution probe are needed, LoE 5, GoR C, Strong consensus 13/13
2. A probe with a frequency above 5 MHz should be used when measuring wall thickness, LoE 4, GoR B, Strong consensus 13/13

Doppler techniques

Doppler US can assess both the signal from the visceral vessels that supply the gastrointestinal tract and directly smaller vessels of the intestinal wall, but cannot detect capillary flow.

Analysis of superior and inferior mesenteric inflow by pulsed Doppler scanning (systolic and diastolic velocities, resistance index, blood flow volume) provides several quantifiable parameters [22 – 25]. The best place to position the sample area is 2 – 3 cm distally to the origin of the vessel, in a longitudinal section as it runs parallel to the aorta, proximal to any side branches [26 – 28]. The examiner should tilt the probe to obtain an angle < 60°. A high-pass filter of 100 – 200 KHz should be used to eliminate low frequencies related to vessel wall movement [28, 29].

Colour or Power Doppler can both be used to evaluate bowel wall vascularity [30]. Colour or Power Doppler flow parameters should be optimized to maximize the sensitivity for the detection of vessels with low-velocity flow in the bowel wall. Although specific technical characteristics depend on the equipment, in general it is recommended that persistence of colour be set at "medium," the wall filter adjusted to the lowest setting, and a combination of the lowest velocity scale with the colour sensitivity at high level to maximize visualization of vessels avoiding colour blooming [30 – 34]. This special preset optimized for slow flow detection should be programmed, and be kept constant for the follow-up studies for each patient in cases of therapy monitoring [30, 31, 33]. Finally, colour Doppler gain should be turned up until flash artefacts occur and then turned down until they disappear before assessing vascularity.

The information obtained from colour Doppler images is semi-quantitative. It is recommended to measure bowel wall vascularity according to the number of vessels detected per square centimetre [30 – 33, 35]. According to previously published data, vascularity is subjectively assigned a grade as follows: grade 0 = no vessels; grade 1 or barely visible flow = fewer than two signals per square centimetre; grade 2 or moderate flow = three to five signals per square centimetre; and grade 3 or readily visible flow = more than five signals per square centimetre [30 – 33, 35].

Colour Doppler flow is considered present when colour pixels persist throughout the observation period and/or reoccur in the same location. Pulsed Doppler obtaining an arterial or venous signal at the location of the colour pixel should be used when there is doubt, to confirm that colour signals are originated from blood vessels and not from movement artefacts [31, 33, 36, 37].

If vascularity is not detected in the pathologically thickened intestinal wall this might be due to insensitivity of the equipment, inadequate chosen Doppler parameters, high body mass index or depth penetration > 40 mm with loss of sensitivity.

RECOMMENDATIONS:

3. Colour Doppler imaging should be used to evaluate the vascularisation of pathological bowel wall, LoE 2b, GoR B, Broad consensus 12/13

Contrast-enhanced ultrasound

Contrast-enhanced ultrasound (CEUS) is performed after the injection of stabilized microbubbles with gaseous content into the blood stream.

The bubbles oscillate when subjected to US and the size and stiffness of the microbubbles affects the resonance frequency. Resonating microbubbles give rise to more intensely reflected signals which are easier to separate from tissue signals [38]. The most commonly used microbubble in Europe, Sonovue, is on average 2.5 µm and has a size distribution of 1 – 10 µm[39]. With high frequency probes a full vial of Sonovue (4.8 ml) is commonly used while it is usually sufficient with half a vial or less with low frequency probes. Due to the broad size distribution the higher dose will make more bubbles available for imaging at the higher frequencies needed for examining the intestinal wall [39].

There are several ways of interpreting contrast-enhancement in the bowel wall: pattern of enhancement [40 – 43], contrast quantification at peak intensity [44 – 46] and dynamic contrast-enhanced ultrasound where intensity changes over time are analysed [47 – 51].

CEUS can be used to quantify vascularity [44, 45, 52], but also be used to separate vascular from avascular tissue which is particularly useful when trying to differentiate a phlegmon from an abscess [53, 54].

Pattern of enhancement after a bolus injection is used as a qualitative parameter. For instance, patients with no enhancement can be separated from those with enhancement or the patients can be categorized according to where in the GI-wall the enhancement is detectable [42, 43, 55, 56]. The operators' interpretation and the sensitivity of the US equipment may, however, affect the results [57].

Since there is a linear relationship between microbubble concentration and US intensity within a certain range [58] it is possible to quantify contrast-enhancement to make the method more objective. This does not reflect pathophysiological changes. Therefore attempts have been made to use an internal reference to reduce the variability [44, 45].

Finally, the contrast-enhancement can be analysed over time. This method is called dynamic contrast-enhanced ultrasound (DCE-US) and the values obtained from these analyses are closely related to perfusion in the GI wall. There are two main methods practiced, the bolus tracking and the burst-replenishment technique [48].

Bolus tracking is performed by injecting a dose of contrast followed by a flush of saline and analysing the development of the time intensity curve after the recording has been saved to the

scanner. The development of such a curve is complex however and there are several ways of modelling it [48]. Since the curve development is also profoundly affected by other factors such as injection speed, injection site and vascular architecture it does not compare very well to the local perfusion [50]. Even though most commercial scanners offer some sort of analysis tool for DCE-US for post-processing of contrast data, most studies on DCE-US have been performed on exported datasets. So even if the method has shown some promising results it is not so easy to introduce in daily practice.

In the burst-replenishment technique a burst with high mechanical index is given after the contrast has reached a steady state in the bloodstream. The development of the burst-replenishment curve is simpler to model [48]. Another advantage of such a technique is that repeated measurements are possible during the same injection reducing variability and/or enabling sampling from several imaging planes. However, this warrants the use of a specialized infusion pump which mixes the microbubbles continuously while performing the injection. A combination of the two, the bolus and burst technique [50, 51], in which the microbubbles are burst at a given time after the injection when the contrast level has reached a pseudo-steady-state, enables an estimation of the local perfusion without using a pump. Currently this is also only available as an off-board method. All these methods are also dependent on internal scaling to reduce variability.

RECOMMENDATIONS:

4. Contrast-enhanced ultrasound of the bowel can be used to separate vascular from avascular intestinal or perintestinal lesions including abscesses. EL 3b, GoR B, Strong consensus 12/12

Elastography

Elastography is a relative new technique that depicts the stiffness of tissues and is already used in clinical practice. An overview of the different techniques and applications has been published by EFSUMB [3, 5]. Recently, elastography has also been suggested as a tool for assessing diseases in the gastrointestinal tract [59, 60].

The bowel wall is thin, surrounded by serosa and with a lumen containing gas and chyme or fecal contents. This does not make it the ideal organ to be studied with elastography. However, pathology of the GI tract such as inflammation or tumour causes bowel wall thickening and often reduces motility and luminal contents in the affected area which may facilitate sonoelastography. There is good evidence for the use of elastography in endorectal ultrasonography [61 – 64], but the evidence for transabdominal elastography of the bowel is sparse. Some recent studies suggest that it can be used to differentiate between fibrotic and inflammatory stenosis in Crohn's disease [65, 66].

RECOMMENDATIONS:

5. Ultrasound elastography can be used to evaluate the stiffness of pathological thickened bowel. LoE 4, GoR C, Broad consensus 11/12

Investigator training and learning curve

It is important to set standards for performance of GIUS and for EFSUMB to secure high quality US education and professional standards. Previously, EFSUMB defined three levels of training recommendations in its release of minimal training requirements. Appendix 5 is specifically addressing gastroenterology [67]. EFSUMB recommends that GI US should mainly be performed by operators that have considerable experience and have passed the first competence level. However, also on level 1 the operator should be able to recognise the small and large bowel, and major focal intestinal abnormalities including obstruction. On level 2, the investigator should be able to perform a comprehensive examination of the GI tract: evaluation of the small bowel for focal or diffuse disease, the large bowel for the presence of diverticular disease and its complications (tumours and obstruction), the peritoneal cavity, its mesenteries, compartments and the omentum for the presence of infectious or malignant diseases. A level 3 practitioner should spend the majority of their time undertaking gastrointestinal US or teaching, research and development and be an expert in this area.

RECOMMENDATIONS:

6. Dedicated training in bowel ultrasound is necessary and should preferably be performed following training in general abdominal ultrasound, LoE 5, GoR C, Broad consensus 11/12

Preparation

In principle, no preparation of the patient is needed to perform a GIUS. Fluid installation, laxatives, and anti-flatulent preparations do not improve results [68, 69]. There is also no clinically relevant difference in wall thickness in the small and large bowel after a meal [14].

To reduce the amount of food and air in the small bowel a fasting period of at least 4 hours is recommended, however, fasting may not significantly improve visibility except in male patients [70, 71]. Also the presence of food in the stomach and small bowel will increase the flow in the splanchnic vessels which will vary with the size, composition and time since the last meal [72 – 76]. An overnight fast (> 8 hours) will include both the effect of improved visibility and minimize the effect of the previous meal.

Activity also affects splanchnic flow and thus the patients should refrain from extensive physical activity in the period before the examination [77].

RECOMMENDATIONS:

7. A standard examination of the intestine does not need specific preparation, LoE 4, GoR B, Strong consensus 12/12
8. Fasting > 6 hours is recommended before measuring splanchnic blood flow, LoE 4, GoR B, Strong consensus 12/12
9. Overnight fasting is recommended before assessing gastrointestinal motility, LoE 5, GoR C, Strong consensus 12/12

Techniques

Scanning

The scanning technique for evaluating the bowel may vary according to the clinical problem [28, 78, 79]. The investigative approach will, for instance, differ between abdominal trauma, suspected intestinal obstruction [80] or appendicitis and chronic complaints such as longstanding diarrhoea. For surgical disorders a faster, targeted approach is used whereas for other complaints a full examination is performed. In this document, however, a general approach on how to perform the examination is described. There are no comparative studies where one GIUS scanning technique has been compared with another. As such these recommendations are mostly LoE meaning they are a matter of expert opinion.

After examining the parenchymal organs in the abdomen using the low frequency abdominal US probe the gastrointestinal tract is scanned systematically. First the abdominal US probe is used to get an overview before switching to a mid-range to high-frequency probe for a detailed examination.

The rectum can be scanned behind the urinary bladder with the abdominal US probe. The normal rectum may be difficult to display if the urinary bladder is empty.

The investigator should use a combination of internal and external references to describe the findings in the gastrointestinal tract. Since the cecum, ileocecal valve and terminal ileum very often are found and identified with certainty lying over the iliopsoas muscle in the right iliac region this is a convenient location to start the scan of both the large and small intestine.

When scanning the large bowel the probe is moved to the right iliac fossa in a transverse direction to identify the cecum. The probe should then be oriented in the longitudinal direction of the large bowel to identify haustrations more easily. After the cecum has been identified in the right iliac fossa the bowel is followed in the distal direction through the ascending colon, right flexure, transverse colon, left flexure, descending colon and sigmoid colon and final the rectum. By sweeping back and forth in the transverse direction the examiner gets an overview of the pathology while at the same time tracing the path of the colon. The flexures are located high in the abdomen. The right flexure can be seen both intercostally and subcostally while the left flexure is found intercostally in the region of the spleen and left kidney.

If the examiner loses track of the colon the recommendation is to return to a known location and try again or identify a more distal area and backtrack. Segments that are easy to use as reference points are the ascending colon in the right flank, the descending colon in the left flank and the proximal sigmoid colon as it crosses the left iliopsoas muscle. The transverse colon can also be easily found by moving the probe from the epigastrium caudally, until typical haustrations are recognized.

The small bowel scan starts by returning the probe to the right iliac fossa and identifying the terminal ileum. The examiner should then trace the terminal ileum as far as possible proximally. The rest of the small bowel is difficult to trace and to ensure most parts of the small bowel have been included in the examination a systematic scanning approach must be adopted. The abdomen should be scanned in parallel overlapping lanes cranially and caudally ("mowing the lawn") while applying sufficient probe pressure so the dorsal wall of the abdominal cavity can be identified. This way the examiner is certain that all bowel segments between the probe and the dorsal wall are included in the scan. If the dorsal wall is not seen, such a claim cannot be made. In addition, scanning in a horizontal direction is recommended for a complete examination of all intestines. It is particularly important to look carefully at the small bowel segments in the pelvic region as it is harder to push away overlying bowel segments. A well filled urinary bladder may help in this regard as it will tend to push the small bowel loops in the hypogastric region up towards the umbilical region.

RECOMMENDATIONS:

10. The scanning of the intestines must involve a systematic approach, LoE 5, GoR C. Strong consensus 12/12

Graded compression

Graded compression is performed by using the US probe much in the same way as when performing palpation with the fingertips. The probe is used to compress the abdomen while following the respiratory movements. This can push away overlying bowel segments with gas or intraabdominal fat and in this way enable the examiner to reach deeper with high frequency probes such as for instance in the pelvis. The concept of graded compression was introduced by Puylaert [81] for the diagnosis of appendicitis [82 – 84]. Surgeons use the technique with good results [85]. Graded compression has been used for detection of bowel wall thickening [86] and for specific diagnoses such as diverticulitis [87, 88] and polyp detection [89].

Fluid use

Luminal gas and the variable and unpredictable presence of contents in the gastrointestinal tract may interfere with its visualization and with detailed evaluation of wall structure and intraluminal lesions. This can be improved by filling the lumen with an anechoic fluid. The ingestion of adequate amounts of water en-

hances the contrast and facilitates the assessment of the stomach wall if the gastric lumen has been properly distended [90]. The distention of the colonic lumen with instillation of water into the colon, hydrocolonic ultrasound [91], and with oral administration of hyperosmotic solutions [92] allows the visualisation of the colon with US from the rectosigmoid transition to the cecum in 97 % of patients studied, making the detailed examination of the architecture of colonic wall and surrounding structure possible. Unlike the stomach and the large bowel, water and osmotic solution are not appropriate to distend the lumen of the small bowel lumen. Water and hypo-osmolar solutions containing digestible or absorbable solutes are rapidly absorbed in the proximal small intestine, so that the lumen of the distal small bowel is not distended. Hyperosmolar solutions with indigestible contents, delay gastric emptying and, stimulating the intestinal peristaltic activity, hinder the appropriate lumen distension of the entire small bowel. It is thus unlikely that the entire small bowel can be visualized using hypo-osmolar, hyperosmolar, water or caloric fluid. The examination of the small bowel after ingestion of small (250 – 500 ml) amounts of iso-osmolar polyethylene glycol (PEG) 3350 – 4000 (macrogol) solution analogous to CT- or MR-enterography is called US-enterography or Small Intestine Contrast US (SICUS). With this technique the entire small bowel from the duodenal-jejunal angle to ileo-cecal valve can be visualized [93]. After ingestion the iso-osmolar and non-caloric macrogol solution is rapidly delivered from the stomach into the duodenum, since its gastric emptying is not opposed by osmotic and caloric-sensitive duodenal receptors [94]. The relatively constant gastric emptying rate induces gradual small bowel distension irrespective of the amount of the ingested solution. The PEG solution being non-digestible and non-absorbable links the waters molecules and thus retaining fluid within the lumen distends the intestinal wall. The luminal distension induces wall contractility and the PEG solution is displaced aborally, sequentially distending every single loop of the entire small bowel. SICUS used in healthy controls independent from the amounts of oral contrast used, results in values of wall thickness (≤ 3 mm) and lumen diameter (≤ 25 mm). These normative values help to discriminate normal from abnormal findings [93]. Safety and tolerability of PEG solution have been reported to be satisfactory previously, in studies using larger solution amounts than those administered in SICUS studies, and thereafter by several studies performed also in paediatric patients [95]. US enteroclysis has also been performed after instillation of PEG solution through a nasojejunal tube, placed in the duodenum using gastroscopy [96]. However, an excellent visualization of the small bowel was achieved only for the distal part of the ileum.

Hydrocolon examination with retrograde installation of fluids has also been used to improve visualization of colon pathology [91]. However, this technique has not gained widespread acceptance in clinical practice.

RECOMMENDATION:

11. Oral fluid contrast can improve visualisation of small bowel disease, LoE 1b, GoR A, Strong consensus 12/12

Safety

Diagnostic US should be performed according to the EFSUMB clinical safety statement [97].

Ultrasound is generally considered a very safe procedure and there are no data showing harmful effects of diagnostic US in adults. However, US may cause bio-effects with cavitation and tissue heating. The risk for causing such effect increases with the acoustic output (Pulse wave Doppler> Colour Doppler> B-mode), tissue transitions with large differences in acoustic impedance such as between soft tissue and bone and exposure time, but also between soft tissue and gas which is commonly encountered when examining bowel and exposure time. One should therefore limit examination time to what is necessary for diagnostic purposes [98].

Ultrasound contrast agents (UCA) have a low incidence of side effects. Serious anaphylactoid reactions occur in less than 0.002 % of the examinations [99, 100]. As they are excreted via the lungs and through breakdown in the liver they can be used in patients with kidney failure. When combining US with a high mechanical index and UCA's, microvascular damage has been found resulting in small haemorrhages in animal models, but in these studies both higher MI and longer exposure times are used than in diagnostic US [10].

The benefit in using UCA's should outweigh the risks. To avoid complications resuscitation facilities should be available, off-label use in areas where small haemorrhages may have serious clinical consequences should be avoided, long exposure and high mechanical indexes should be avoided and caution should be exercised when used in patients with severe coronary heart disease or pulmonary hypertension.

Anatomy and sonographic findings

Bowel wall

Wall thickness

In vitro measurements of GI wall thickness with high frequency US correlate well with histological sections [101]. However, studies have shown that devitalization of tissue and tissue preparation with formalin as well as histological sectioning can cause changes in tissue dimensions. Also differences in tissue texture and temperature can cause variability in the tissue impedance thus complicating the comparison between in vivo and in vitro measurements [17, 102].

There are several studies where wall thickness in different parts of the gastrointestinal tract has been measured with GIUS without a reference standard. In recent publications of studies performed with equipment comparable to present standards the common

finding is that both the normal small and large intestine is < 2 mm when distended [13, 14, 103 – 107]. The exceptions are the duodenal bulb and rectum which are smaller than 3 and 4 mm, respectively [14, 106]. Since collapsed bowel loops probably lead to higher wall thickness measurements it should be reported if the measurements were made on these.

The normal appendix can be identified in about 50 % of healthy subjects using graded compression [108, 109], but experience plays a significant role. Maximum wall thickness in healthy volunteers is 2 ± 0.5 mm or less than 3 mm [110]. In clinical practice usually the maximum overall appendiceal diameter is measured, which should be less than 6 mm.

RECOMMENDATIONS:

12. A bowel wall thickness less than 2 mm (not the cut-off value for pathology) could be considered as normal, when measured in the normal filling state except in the duodenal bulb and rectum, LoE 4, GoR B, Majority consensus 9/12

Wall layers

The gastrointestinal wall consists of 5 distinct sonographic layers when examined with a high frequency probe in the range of 5 – 15 MHz in vitro. The echo layers are a combination of interface echoes and the echo properties of the histological layers [101, 111, 112]. When imaged in the anterior wall of a bowel loop starting from the lumen the hyperechoic layer 1 corresponds to the interface between the mucosa and the lumen and is not a part of the actual GI wall. The hypoechoic layer 2 corresponds to the mucosa without the intergface between the submucosa and mucosa, the hyechoic layer 3 to the submucosa including this interface echo, the hypoechoic layer 4 to most of the proper muscle and layer 5 to the hyperechic interface echo between the proper muscle and the serosa

Since interface echoes are hyperechoic and located distally to the actual tissue interface, the correspondence between histology and sonographic layers differ slightly in the dorsal wall. Notably, the interface between lumen and mucosa (layer 1) is a part of the actual mucosa and layer 2 represents the rest of the mucosa without muscularis mucosae which normally is covered by an interface echo and add thickness to layer 3. Furthermore, the interface between submucosa and the proper muscle adds thickness to layer 3 and reduces the thickness of layer 4. The interface between the propermuscle and serosa (layer 5) extends beyond the actual serosa [15, 16, 113].

During in vivo scanning it is not always possible to discern all the layers. The interface echo from the serosa is mixed in with the interface from the peritoneum and the interface between the mucosa and the lumen can be difficult to distinguish without the presence of bowel air or luminal debris. Also the posterior bowel wall often is not possible to see due to air in the lumen. The measurements should therefore be made in the anterior wall. Since the interface from the serosa is difficult to delineate the measurement should be made from the start of the hypoechoic layer of the proper muscle to the end of the hypoechoic layer of the mucosa. Compression of the bowel wall with the transducer will reduce thickness and can make it difficult to separate the wall layers [114, 115]. However, some operators practice mild compression suggesting that this improves reproducibility of measurements [103]. The examiner should also be aware of interpretation difficulties du to mucosal folds and haustrations and keep the probe angled perpendicular to the GI wall to avoid tangential measurements.

RECOMMENDATIONS:

13. Bowel wall thickness should be measured perpendicular to the wall from the interface between the serosa and proper muscle to the interface between the mucosa and the lumen. LoE 4, GoR B, Strong consensus 10/10

Superior and inferior mesenteric artery

The normal fasting flow in the superior mesenteric artery (SMA) has been assessed in a large number of studies where the healthy volunteers mostly have been added as a control group while there is clearly less data found on the flow parameters in the inferior mesenteric artery (IMA) [26].

The mean peak systolic velocity of the SMA varies between 93 to 146 cm/s in published literature, but there is considerable inter-individual variability suggesting a normal range between 80 to 220 cm/s [116 – 122]. Resistive index ranges from 0.80 to 0.89 and blood flow from 380 to 640 ml/min in the SMA [23, 72, 116 – 118, 120 – 129]. Some of the variability could be caused by the difficult angle between the SMA and abdominal surface. In the IMA the blood flow is between 80 – 130 ml/min and the RI 0.9[24, 26, 130].

RECOMMENDATION:

14. A resistive index in the superior mesenteric artery between 0.80 and 0.89 should be considered normal. LoE 4, GoR B, Strong consensus 17/17
15. A peak systolic velocity of the SMA between 80 and 220 cm/s should be considered normal. LoE 4, GoR B, Broad consensus 16/17

Intramural vessels

Vessel assessment in the GI wall is relevant with regards to diseases causing changes in vascularity such as for instance tumours, ischemia and inflammatory bowel disease. In vitro studies have shown that small vessels in the gastrointestinal wall can be identified using high frequency US [131]. More common is the use of colour Doppler to detect flow in the vessels of the GI wall. Due to the comparatively slow flow and small dimensions of these vessels the velocity range of the colour Doppler has to be set very low between 2 to 5 cm/s [31, 36, 122, 132, 133]. This increases the risk of flash artefacts and the patients need to hold their breath during the acquisition. Also, due to the PRF needed to perform this exam-

ination the depth where this flow can be detected is quite limited. Colour and power Doppler provide a semi-quantitative description of vessel density in the bowel wall. In the healthy bowel wall it is uncommon to detect more than one or two vessel signals with colour or power Doppler [36, 122].

Pulse wave measurements of individual arteries in the GI wall can provide indirect quantitative measurements of the local vascularity. Since the angle of a vessel in the GI wall is difficult to see the resistive index is used [36, 122, 134]. Unfortunately, the measurements are difficult to perform and the technique is not commonly used in clinical practice.

Local perfusion

DCE-US provides non-invasive measurements of the perfusion in the gastrointestinal wall. To date only one study reports absolute blood flow values from healthy volunteers with a median and range of 44.5 (6.6 – 91.2) ml/min/100 ml tissue and 39.4 (2.2 – 111.4) ml/min/100 ml of tissue[51]. The method requires much post-processing and has quite a substantial variability which is currently not useful in clinical practice, but seems in line with current literature [135 – 139].

Small and large bowel

Location

The duodenum passes into the small bowel at the ligament of Treitz. The small bowel has a tortuous course and is very moveable due to the mesenteric leaves. The jejunum is usually located in the left upper- and mid-abdomen, and the ileum in the right mid- and lower abdomen. The right iliac vessels are a landmark of the ileocecal region. As a result of malrotations the different parts of the small bowel can also be found in other positions.

The colon is located like a picture frame more in the periphery of the abdomen. The ascending and descending colon are usually fixed to the retroperitoneum dorsolaterally on the right and on the left side, respectively. The transverse and the sigmoid colon may have a more variable course owing to the different length of the mesocolon [140]. The transverse colon may descend down to the lower abdomen in case of an elongated mesocolon or may be located behind the stomach in case of a very short mesocolon [141]. The sigmoid colon on the other hand may have an elongated course and can cross the midline to the right iliac fossa or even extend up to the liver. The rectum is visible in its predominantly extraperitoneal position behind the urinary bladder.

Sometimes the cecum and ascending colon may be located intraperitoneal with the cecum in variable positions or the whole colon is located on the left side of the abdomen. This is important for diagnostic US because of possible misinterpretations of pathologic findings and because of allocation of findings to the wrong bowel segment. Such variations are better detected with CT or MRI than with US.

The appendix arises from the cecum about 3 cm below the ileocecal valve at the point where the three taeniae converge. It has a highly variable position such as the typical medial course over the iliopsoas muscle, a medial or lateral elevation or a retro-caecal course and it also varies with the position of the cecum [142].

Appearance

The small bowel has a length of 3 – 6 metres and is characterised by the valvulae conniventes. They decrease in number and height from the proximal jejunum to the distal ileum and are best visualised when the bowel loops are fluid-filled. In a collapsed condition bowel loops may have a predominant hypoechoic appearance or in case of intraluminal gas a hyperechoic appearance. Usually we can find both conditions side by side. Usually only high-frequency transducers allow the visualisation of the valvulae conniventes of collapsed loops.

The colon is characterised by its haustration, which is best visible on US in longitudinal sections if the colon is filled with stool and gas and thus has a hyperechoic appearance. In a contracted condition – which is more frequently seen at the left hemicolon – the haustration is not adequately demonstrable. The semilunar folds protrude to the lumen between the haustra and are only visible after cleansing preparation of the colon which allows the best visualisation of the colonic wall [143]. If the colon is distended and filled with stool, bowel wall layers are hardly visible even with high-frequency transducers. When we look for the colon with the abdominal probe, we are usually guided by the typical location and by the hyperechoic luminal content and not by the aspect of the colonic wall itself. The numerous epiploic appendages of the colon can only be differentiated from adjacent fatty tissue if fluid is present in the peritoneal cavity.

When examined with a high-frequency probe, the appendix usually appears as a target structure with different wall layers [144]. If the lumen is completely filled with gas, a predominant hyperechoic appearance may result. Sometimes this can be helpful to find a normal appendix even with the abdominal probe if higher frequencies cannot be applied.

Motility

The normal transit time for the small bowel ranges from 2 – 6 hours [145]. Knowledge on motility of the small bowel motility is still limited due to complex interaction between the central and enteric nervous system, sensory and motor functions and multiple gastrointestinal hormones influencing peristaltic activity [143].

After overnight fasting the motility of the small bowel is reduced [146, 147], but intake of food or fluids will induce contractility. To-and-fro movements in the bowel improves the contact between contents and the mucosa for absorption of nutritional components and is significantly more easily seen in patients with coeliac disease [143].

Even during transit of colonic contents such a to-and-fro movement is present [148]. But this is usually not noticeable on US because of the long transit time in the colon (20 – 72 hours) with very slow peristaltic movement. It is usually only under pathological conditions such as enterocolitis or bowel obstruction that contractions in the colon are visible on US. The peristalsis of the appendix is also not noticeable during examination.

Blood supply

The whole small bowel is supplied by the SMA with its jejunal and ileal branches. The blood supply of the colon occurs on the one hand via branches of the SMA and on the other hand via the IMA. The watershed between the SMA and IMA is in the transverse colon near the splenic flexure. The rectum has its arterial supply from the IMA and the internal iliac artery. This explains the typical affection of the colon from the left colonic flexure to the sigmoid colon in ischaemic colitis.

The superior mesenteric vein accompanies the superior mesenteric artery and the inferior mesenteric vein runs vertically upward and enters the splenic vein or its junction with the superior mesenteric vein to form the portal vein.

Collateral pathways are important to protect the bowel wall from potential ischaemia if arterial supply is compromised. In case of severe stenosis or occlusion at the origin, the one pathway connects the three mesenteric vessels. The other collateral pathway is formed by multiple interconnecting arterial arcades between the branches in order to warrant adequate blood supply in cases of segmental arterial occlusion [149].

Lumen

After overnight fasting, the lumen of the small bowel is frequently collapsed. Usually only small amounts of intraluminal fluid and some gas are present. Depending on nutritional components a more or less hyperechoic liquid content and more gas is visible after a meal. Small bowel obstruction and oral intake of fluids or application through a feeding tube result in hypoechoic luminal content. The normal maximum diameter of small bowel loops ranges from 2 – 2.5 cm [147, 150, 151].

At the level of the ileocecal valve, where the ileal content passes over to the colon, a still liquid content of mixed echogenicity may be visible. The faecal material gradually solidifies as it moves along in the colon and thus becomes hyperechoic. The diameter of the colon usually measures up to 5 cm, whereas that of the cecum may exceed this width [80, 152]. The width of the left hemicolon slightly decreases in an aboral direction. The colon is usually filled with stool and gas but the descending and sigmoid colon sometimes present in a mainly contracted condition which could make detection of these bowel segments more difficult.

The lumen of the normal appendix may be collapsed or contain some stool and gas. The lumen rarely exceeds a width of 4 – 5 mm. At times we can see that the lumen of a distal segment is obliterated and the hyperechoic submucosa is the predominant layer[142].

RECOMMENDATIONS:

16. Transabdominal ultrasound can be used to assess the normal bowel anatomy, the vascularisation and luminal width, LoE 2b, GoR B, Broad consensus 9/10
17. The anatomical location of the bowel, peristalsis and luminal content can be assessed by GIUS, LoE 5, GoR C, Majority consensus 7/10

Peri-intestinal features

Peri-intestinal sonographic findings provide relevant elements, as an adjunct to the features of bowel wall to suspect, diagnose or exclude digestive diseases. Therefore, mesentery and lymph nodes should always be assessed during routine bowel investigation.

Mesentery and omentum

Mesentery extends laterally to the aorta, from the left hypochondrium to right iliac fossa. It is scanned with both regular abdominal and mid-range to high-frequency probes, depending on size of the patient, as visceral fat determines increase in attenuation thus limiting the use of high-frequency probes [153]. The normal mesentery appears at US as a series of mildly hypoechoic parallel layers, 7 – 12 mm in thickness, alternated by hyperechoic strips, resembling thickened bowel walls in a longitudinal scan. Mesentery is easily seen when ascites is present, appearing as a series of hyperechoic folds, which arise from the posterior wall of the peritoneal cavity and extend to the bowel loops, visible at their extremities.

Mesentery may be affected by several systemic and gastrointestinal diseases. As it reflects the overall visceral adiposity, increased mesenteric fat thickness (> 1 cm) may correlate with metabolic syndrome and cardiovascular diseases [154]. More important, chronic and acute inflammatory disorders (e. g. Crohn's disease, appendicitis and diverticulitis) and some neoplastic diseases affecting the bowel may show mesenteric hypertrophy, also named fat wrapping or creeping fat presenting as a firm, abundant hyperechoic tissue, surrounding the bowel loops [155 – 159].

Despite the accuracy of US in the description and detection of mesenteric abnormalities, it is limited by inferior panoramic view compared to CT and MRI.

Lymph nodes

The detection of enlarged or even normal mesenteric lymph nodes is a common and often incidental finding of abdominal and bowel US, in particular in children and young adults [160]. The sonographic detection of regional mesenteric lymph nodes may be a normal or physiologic condition or suggest a past or ongoing, mainly inflammatory or neoplastic, disease of the abdomen.

In adults normal mesenteric lymph nodes appear as oval, elongated or U-shaped hypo- or mild hypo-echoic nodules with the shorter diameter < 4 mm and larger diameter usually < 17 mm [161 – 164]. In children, due to an activated immune response and as a result of previous intestinal infections, normal mesenteric lymph nodes may have a shorter axis with a diameter up to 10 mm, but preserved regular shape ad echogenicity [160, 165, 166].

In enlarged mesenteric nodes, the size, number, site, shape and echogenicity are not specific for the underlying diseases [167]. However, the analysis of all these features may help in discriminating between infectious, inflammatory or potential neoplastic causes [168]. Enlarged mesenteric lymph nodes may sug-

gest intestinal and systemic inflammatory conditions as well as neoplastic diseases. In particular if associated with sonographic changes of the bowel and mesenteric hypertrophy [161, 169 – 172].

RECOMMENDATIONS:

18. Ultrasound can assess lymph nodes and mesenteric tissue. LoE 4, GoR B, 4, Strong consensus 10/10

Reporting on the examination

There are published standards for the reporting of US examinations [173]. In addition there are specific requirements of reporting for GIUS examinations which may be focused and limited to an assessment of the intestine.

If oral bowel preparation has been used (SICUS) this should be stated in the report.

It is of particular importance to document in the report where there has been a failure to identify a structure which may influence the sensitivity of the examination, in particular identification of the ileocecal junction and appendix.

It may be necessary to state which segments of the colon, in particular the rectum and sigmoid have been evaluated when relevant to the clinical question being addressed. As the jejunal and ileal loops cannot be assessed in a contiguous fashion it may also be relevant to state the confidence with which the operator has technically assessed the small bowel.

When describing findings in GIUS the most discriminatory parameters include bowel wall thickness, length and distribution of bowel wall thickening, an assessment of the preservation of layering and symmetry of any changes present. The presence of fat wrapping and fat creep is a highly specific finding in Crohn's disease and should be included in the report when present.

The presence of relevant identified complications such as fistulae, strictures and collections are a useful guide to management of intestinal disease together with functional findings such as enteric content and the presence of bowel dilatation and peristalsis.

An assessment of the presence of lymphadenopathy and free fluid is a useful statement within a report including an assessment for free air when clinically appropriate.

More advanced techniques such as elastography, Doppler assessment and CEUS should be included in the report when used.

RECOMMENDATION:

19. The report should state degree of bowel visualisation, specific technical aspects and sonographic findings relevant to the clinical context of the examination. LoE 5, GoR C, Strong consensus 10/10

Clinical applications

Intestinal US is often suggested as the first imaging tool in patients with acute abdomen [88]. Systematic reviews and meta-analyses have shown that US is highly accurate in detecting acute appendicitis, although not as high as CT [174, 175]. However, as their positive predictive value is quite similar, US can be used as the first imaging tool in a conditioned US-CT strategy where patients with US positive for appendicitis, are sent directly to surgery, avoiding CT, while those with inconclusive or negative sonographic results are submitted to CT. This strategy has been proven to be as effective as immediate CT for all patients, and although potentially burdened by more false positive results, it halves the number of CTs needed, without any impact on length of hospital stay, saving radiation exposures and costs [176 – 178].

The diagnosis of acute colonic diverticulitis can be made in patients only by clinical evaluation [179]. However, additional imaging is usually required to establish the diagnosis and assess complications. Systematic reviews and meta-analyses have shown that US and CT have high and comparable accuracy in diagnosing acute diverticulitis [88, 180]. Despite the advantage of CT due to higher specificity, panoramic view and the ability to identify alternative diagnoses, a conditional strategy with CT performed after an inconclusive or negative US, is the preferable approach, endorsed also by national guidelines [179, 181].

Intestinal US accurately detects ileus, showing as dilated (> 3 cm) and fluid-filled small bowel loops. Real-time US evaluation enables also to assess the nature of ileus, if mechanic or dynamic, and may suggest the causes and severity. In particular, the reported sensitivities and specificities of US in detecting ileus is high in most prospective studies published so far both in consecutive series of patients and in selected population of Crohn's disease patients [182 – 184].

Besides acute conditions, one of the most common uses of intestinal US is the detection and follow-up of inflammatory bowel diseases, in particular Crohn's disease along with disease complications such as strictures, fistulas, abscesses and extra-intestinal complications. Several systematic reviews and meta-analyses have shown that US is able to detect signs of Crohn's disease and, like CT and MRI, has a high and comparable diagnostic accuracy at the initial presentation of terminal ileal CD, as well as in monitoring the disease by assessing its activity and abdominal complications [1, 2]. US has proven to be of value in the follow up of IBD patients irrespective of symptoms [185].

Finally, when used as preliminary imaging investigation in patients with abdominal symptoms, such as abdominal pain or changes in bowel habits, US can identify abnormal intestinal findings or lesions that suggest intestinal diseases which may not primarily have been suspected [186] In particular, US can detect signs suggesting malabsorption and celiac disease such as enlarged mesenteric lymph nodes, dilated small bowel loops with increased fluid content, and increased peristalsis with high sensitivity. The overall accuracy and the place of US in the diagnostic algorithm of celiac disease may vary upon the probability of the disease in the considered population [169, 187]. The detection of these signs in patients with abdominal complaints and changes in bowel habit can adequately drive further investigations.

Finally, intestinal US can detect masses and neoplastic lesions of the gastrointestinal tract, in particular when in advanced stage[188]. In contrast, the role of US in detecting or suggesting gastrointestinal functional disorders is not established and needs further investigation.

References

[1] Panes J, Bouzas R, Chaparro M et al. Systematic review: the use of ultrasonography, computed tomography and magnetic resonance imaging for the diagnosis, assessment of activity and abdominal complications of Crohn's disease. Aliment Pharmacol Ther 2011; 34: 125 – 145

[2] Panes J, Bouhnik Y, Reinisch W et al. Imaging techniques for assessment of inflammatory bowel disease: joint ECCO and ESGAR evidence-based consensus guidelines. J Crohns Colitis 2013; 7: 556 – 585

[3] Bamber J, Cosgrove D, Dietrich CF et al. EFSUMB guidelines and recommendations on the clinical use of ultrasound elastography. Part 1: Basic principles and technology. Ultraschall in Med 2013; 34: 169 – 184

[4] Claudon M, Dietrich CF, Choi BI et al. Guidelines and good clinical practice recommendations for Contrast Enhanced Ultrasound (CEUS) in the liver – update 2012: A WFUMB-EFSUMB initiative in cooperation with representatives of AFSUMB, AIUM, ASUM, FLAUS and ICUS. Ultrasound Med Biol 2013; 39: 187 – 210

[5] Cosgrove D, Piscaglia F, Bamber J et al. EFSUMB guidelines and recommendations on the clinical use of ultrasound elastography. Part 2: Clinical applications. Ultraschall in Med 2013; 34: 238 – 253

[6] Dietrich CF, Lorentzen T, Sidhu PS et al. An Introduction to the EFSUMB Guidelines on Interventional Ultrasound (INVUS). Ultraschall in Med 2015; 36: 460 – 463

[7] Jenssen C, Brkljacic B, Hocke M et al. EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part VI – Ultrasound-Guided Vascular Interventions. Ultraschall in Med 2015; Nov 18. DOI: 10.1055/s-0035-1553450

[8] Jenssen C, Hocke M, Fusaroli P et al. EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part IV – EUS-guided interventions: General Aspects and EUS-guided Sampling (Short Version). Ultraschall in Med 2016; 37: 157 – 169

[9] Lorentzen T, Nolsoe CP, Ewertsen C et al. EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part I. General Aspects (Short Version). Ultraschall in Med 2015; 36: 464 – 472

[10] Piscaglia F, Nolsoe C, Dietrich CF et al. The EFSUMB Guidelines and Recommendations on the Clinical Practice of Contrast Enhanced Ultrasound (CEUS): Update 2011 on non-hepatic applications. Ultraschall in Med 2011; 33: 33 – 59

[11] Sidhu PS, Brabrand K, Cantisani V et al. EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part II. Ultraschall in Med 2015; 36: E15 – E35

[12] Howick J, Chalmers I, Glasziou P et al. The Oxford Levels of Evidence 2. OCEBM Levels of Evidence Working Group, Oxford Centre for Evidence-Based Medicine. 2009. Available from: http://www.cebm.net/index.aspx?o=5653

[13] Haber HP, Stern M. Intestinal ultrasonography in children and young adults: bowel wall thickness is age dependent. J Ultrasound Med 2000; 19: 315 – 321

[14] Nylund K, Hausken T, Odegaard S et al. Gastrointestinal wall thickness measured with transabdominal ultrasonography and its relationship to demographic factors in healthy subjects. Ultraschall in Med 2012; 33: E225 – E232

[15] Aibe T, Fuji T, Okita K et al. A fundamental study of normal layer structure of the gastrointestinal wall visualized by endoscopic ultrasonography. Scand J Gastroenterol Suppl 1986; 123: 6 – 15

[16] Boscaini M, Moscini PL, Montori A. Transrectal ultrasonography: interpretation of normal intestinal wall structure for the preoperative staging of rectal cancer. Scand J Gastroenterol Suppl 1986; 123: 87 – 98

[17] Kimmey MB, Martin RW, Haggitt RC et al. Histologic correlates of gastrointestinal ultrasound images. Gastroenterology 1989; 96: 433 – 441

[18] Rompel O, Huelsse B, Bodenschatz K et al. Harmonic US imaging of appendicitis in children. Pediatr Radiol 2006; 36: 1257 – 1264

[19] Schmidt T, Hohl C, Haage P et al. Phase-inversion tissue harmonic imaging compared to fundamental B-mode ultrasound in the evaluation of the pathology of large and small bowel. Eur Radiol 2005; 15: 2021 – 2030

[20] Ying M, Sin MH. Comparison of extended field of view and dual image ultrasound techniques: accuracy and reliability of distance measurements in phantom study. Ultrasound Med Biol 2005; 31: 79 – 83

[21] Troger J, Darge K. SieScape–a new dimension of ultrasound imaging in pediatric radiology. Radiologe 1998; 38: 417 – 419

[22] Giovagnorio F, Diacinti D, Vernia P. Doppler sonography of the superior mesenteric artery in Crohn's disease. Am J Roentgenol 1998; 170: 123 – 126

[23] Maconi G, Parente F, Bollani S et al. Factors affecting splanchnic haemodynamics in Crohn's disease: a prospective controlled study using Doppler ultrasound. Gut 1998; 43: 645 – 650

[24] Mirk P, Palazzoni G, Gimondo P. Doppler sonography of hemodynamic changes of the inferior mesenteric artery in inflammatory bowel disease: preliminary data. Am J Roentgenol 1999; 173: 381 – 387

[25] Van Oostayen JA, Wasser MN, van Hogezand RA et al. Activity of Crohn disease assessed by measurement of superior mesenteric artery flow with Doppler US. Radiology 1994; 193: 551 – 554

[26] Dietrich CF, Jedrzejczyk M, Ignee A. Sonographic assessment of splanchnic arteries and the bowel wall. Eur J Radiol 2007; 64: 202 – 212

[27] Ignee A, Boerner N, Bruening A et al. Duplexsonography of the mesenteric vessels – a critical evaluation of inter observer variability. Z Gastroenterol 2016; 54: 304 – 311

[28] Nylund K, Hausken T, Gilja OH. Ultrasound and inflammatory bowel disease. Ultrasound Q 2010; 26: 3 – 15

[29] Van Oostayen JA, Wasser MN, Griffioen G et al. Activity of Crohn's disease assessed by measurement of superior mesenteric artery flow with Doppler ultrasound. Neth J Med 1998; 53: S3 – S8

[30] Ruess L, Blask AR, Bulas DI et al. Inflammatory bowel disease in children and young adults: correlation of sonographic and clinical parameters during treatment. Am J Roentgenol 2000; 175: 79 – 84

[31] Spalinger J, Patriquin H, Miron MC et al. Doppler US in patients with crohn disease: vessel density in the diseased bowel reflects disease activity. Radiology 2000; 217: 787 – 791

[32] Patriquin HB, Garcier JM, Lafortune M et al. Appendicitis in children and young adults: Doppler sonographic-pathologic correlation. Am J Roentgenol 1996; 166: 629 – 633

[33] Ripolles T, Simo L, Martinez-Perez MJ et al. Sonographic findings in ischemic colitis in 58 patients. Am J Roentgenol 2005; 184: 777 – 785

[34] Drews BH, Barth TF, Hanle MM et al. Comparison of sonographically measured bowel wall vascularity, histology, and disease activity in Crohn's disease. Eur Radiol 2009; 19: 1379 – 1386

[35] Neye H, Voderholzer W, Rickes S et al. Evaluation of criteria for the activity of Crohn's disease by power Doppler sonography. Dig Dis 2004; 22: 67 – 72

[36] Esteban JM, Maldonado L, Sanchiz V et al. Activity of Crohn's disease assessed by colour Doppler ultrasound analysis of the affected loops. Eur Radiol 2001; 11: 1423 – 1428

[37] Ripolles T, Martinez MJ, Morote V et al. Appendiceal involvement in Crohn's disease: gray-scale sonography and color Doppler flow features. Am J Roentgenol 2006; 186: 1071 – 1078

[38] Cosgrove D. Ultrasound contrast agents: an overview. Eur J Radiol 2006; 60: 324 – 330

[39] Greis C. Technology overview: SonoVue (Bracco, Milan). Eur Radiol 2004; 14 (Suppl. 8): 11 – 15

[40] Rapaccini GL, Pompili M, Orefice R et al. Contrast-enhanced power doppler of the intestinal wall in the evaluation of patients with Crohn disease. Scand J Gastroenterol 2004; 39: 188 – 194

[41] Robotti D, Cammarota T, Debani P et al. Activity of Crohn disease: value of Color-Power-Doppler and contrast-enhanced ultrasonography. Abdom Imaging 2004; 29: 648 – 652

[42] Serra C, Menozzi G, Labate AM et al. Ultrasound assessment of vascularization of the thickened terminal ileum wall in Crohn's disease patients using a low-mechanical index real-time scanning technique with a second generation ultrasound contrast agent. Eur J Radiol 2007; 62: 114 – 121

[43] Incesu L, Yazicioglu AK, Selcuk MB et al. Contrast-enhanced power Doppler US in the diagnosis of acute appendicitis. Eur J Radiol 2004; 50: 201 – 209

[44] Kratzer W, Schmidt SA, Mittrach C et al. Contrast-enhanced wideband harmonic imaging ultrasound (SonoVue): a new technique for quantifying bowel wall vascularity in Crohn's disease. Scand J Gastroenterol 2005; 40: 985 – 991

[45] Pauls S, Gabelmann A, Schmidt SA et al. Evaluating bowel wall vascularity in Crohn's disease: a comparison of dynamic MRI and wideband harmonic imaging contrast-enhanced low MI ultrasound. Eur Radiol 2006; 16: 2410 – 2417

[46] Schreyer AG, Finkenzeller T, Gossmann H et al. Microcirculation and perfusion with contrast enhanced ultrasound (CEUS) in Crohn's disease: first results with linear contrast harmonic imaging (CHI). Clin Hemorheol Microcirc 2008; 40: 143 – 155

[47] Cui XW, Ignee A, Jedrzejczyk M et al. Dynamic Vascular Pattern (DVP), a quantification tool for contrast enhanced ultrasound. Z Gastroenterol 2013; 51: 427 – 431

[48] Dietrich CF, Averkiou MA, Correas JM et al. An EFSUMB introduction into Dynamic Contrast-Enhanced Ultrasound (DCE-US) for quantification of tumour perfusion. Ultraschall in Med 2012; 33: 344 – 351

[49] Frohlich E, Muller R, Cui XW et al. Dynamic contrast-enhanced ultrasound for quantification of tissue perfusion. J Ultrasound Med 2015; 34: 179 – 196

[50] Jirik R, Nylund K, Gilja O et al. Ultrasound perfusion analysis combining bolus-tracking and burst-replenishment. IEEE Trans Ultrason Ferroelectr Freq Control 2013; 60: 310 – 319

[51] Nylund K, Jirik R, Mezl M et al. Quantitative contrast-enhanced ultrasound comparison between inflammatory and fibrotic lesions in patients with Crohn's disease. Ultrasound Med Biol 2013; 39: 1197 – 1206

[52] Romanini L, Passamonti M, Navarria M et al. Quantitative analysis of contrast-enhanced ultrasonography of the bowel wall can predict disease activity in inflammatory bowel disease. Eur J Radiol 2014; 83: 1317 – 1323

[53] Esteban JM, Aleixandre A, Hurtado MJ et al. Contrast-enhanced power Doppler ultrasound in the diagnosis and follow-up of inflammatory abdominal masses in Crohn's disease. Eur J Gastroenterol Hepatol 2003; 15: 253 – 259

[54] Ripolles T, Martinez-Perez MJ, Paredes JM et al. Contrast-enhanced ultrasound in the differentiation between phlegmon and abscess in Crohn's disease and other abdominal conditions. Eur J Radiol 2013; 82: e525 – e531

[55] Liu C, Xu XR, Xu HX et al. Conventional ultrasound and contrast-enhanced ultrasound in evaluating the severity of Crohn's disease. Int J Clin Exp Med 2015; 8: 123 – 134

[56] Migaleddu V, Scanu AM, Quaia E et al. Contrast-enhanced ultrasonographic evaluation of inflammatory activity in Crohn's disease. Gastroenterology 2009; 137: 43 – 52

[57] Zink F, Kratzer W, Schmidt S et al. Comparison of Two High-End Ultrasound Systems for Contrast-Enhanced Ultrasound Quantification of Mural Microvascularity in Crohn's Disease. Ultraschall in Med 2016; 37: 74 – 81

[58] Lampaskis M, Averkiou M. Investigation of the relationship of nonlinear backscattered ultrasound intensity with microbubble concentration at low MI. Ultrasound Med Biol 2010; 36: 306 – 312

[59] Havre R, Gilja OH. Elastography and strain rate imaging of the gastrointestinal tract. Eur J Radiol 2014; 83: 438 – 441

[60] Giannetti A, Biscontri M, Matergi M. Feasibility of real-time strain elastography in colonic diseases. J Ultrasound 2014; 17: 321 – 330

[61] Waage JE, Leh S, Rosler C et al. Endorectal ultrasonography, strain elastography and MRI differentiation of rectal adenomas and adenocarcinomas. Colorectal Dis 2015; 17: 124 – 131

[62] Waage JE, Bach SP, Pfeffer F et al. Combined endorectal ultrasonography and strain elastography for the staging of early rectal cancer. Colorectal Dis 2015; 17: 50 – 56

[63] Allgayer H, Ignee A, Zipse S et al. Endorectal ultrasound and real-time elastography in patients with fecal incontinence following anorectal surgery: a prospective comparison evaluating short- and long-term outcomes in irradiated and non-irradiated patients. Z Gastroenterol 2012; 50: 1281 – 1286

[64] Allgayer H, Ignee A, Dietrich CF. Endosonographic elastography of the anal sphincter in patients with fecal incontinence. Scand J Gastroenterol 2010; 45: 30 – 38

[65] Baumgart DC, Muller HP, Grittner U et al. US-based Real-time Elastography for the Detection of Fibrotic Gut Tissue in Patients with Stricturing Crohn Disease. Radiology 2015; 275: 889 – 899

[66] Fraquelli M, Branchi F, Cribiu FM et al. The Role of Ultrasound Elasticity Imaging in Predicting Ileal Fibrosis in Crohn's Disease Patients. Inflamm Bowel Dis 2015; 21: 2605 – 2612

[67] Gilja OH. Education and Practical Standards Committee, EFSUMB. Minimum Training recommendations for the practice of medical ultrasound. Ultraschall in Med 2006; 27: 79 – 105

[68] Pinto PN, Chojniak R, Cohen MP et al. Comparison of three types of preparations for abdominal sonography. J Clin Ultrasound 2011; 39: 203 – 208

[69] Heldwein W, Sommerlatte T, Hasford J et al. Evaluation of the usefulness of dimethicone and/or senna extract in improving the visualization of abdominal organs. J Clin Ultrasound 1987; 15: 455 – 458

[70] Sinan T, Leven H, Sheikh M. Is fasting a necessary preparation for abdominal ultrasound? BMC Med Imaging 2003; 3: 1

[71] Ehrenstein BP, Froh S, Schlottmann K et al. To eat or not to eat? Effect of fasting prior to abdominal sonography examinations on the quality of imaging under routine conditions: A randomized, examiner-blinded trial. Scand J Gastroenterol 2009; 44: 1048 – 1054

[72] Dauzat M, Lafortune M, Patriquin H et al. Meal induced changes in hepatic and splanchnic circulation: a noninvasive Doppler study in normal humans. Eur J Appl Physiol Occup Physiol 1994; 68: 373 – 380

[73] Matheson PJ, Wilson MA, Garrison RN. Regulation of intestinal blood flow. J Surg Res 2000; 93: 182 – 196

[74] Qamar MI, Read AE. Effects of ingestion of carbohydrate, fat, protein, and water on the mesenteric blood flow in man. Scand J Gastroenterol 1988; 23: 26 – 30

[75] Sidery MB, Macdonald IA, Blackshaw PE. Superior mesenteric artery blood flow and gastric emptying in humans and the differential effects of high fat and high carbohydrate meals. Gut 1994; 35: 186 – 190

[76] Stubbs TA, Macdonald IA. Within- and between-day variability in transcutaneous Doppler ultrasound measurements of superior mesenteric artery blood flow (SMABF) in the fasted state. Physiol Meas 1998; 19: 181 – 187

[77] Qamar MI, Read AE. Effects of exercise on mesenteric blood flow in man. Gut 1987; 28: 583 – 587

[78] Hollerweger A, Dirks K, Szopinski K. Transabdominal ultrasound of the gastrointestinal tract. In: Dietrich CF, editor EFSUMB Course Book on Ultrasound.2012: 233 – 271

[79] Maconi G, Rigazio C, Ercole E. Bowel Ultrasound: Investigation Technique and Normal Findings. In: Maconi G, Bianchi Porro G, editors. Ultrasound of the Gastrointestinal tract. 2nd ed Springer; 2014: 7 – 17

[80] Hollerweger A, Wustner M, Dirks K. Bowel Obstruction: Sonographic Evaluation. Ultraschall in Med 2015; 36: 216 – 235

[81] Puylaert JB. Acute appendicitis: US evaluation using graded compression. Radiology 1986; 158: 355 – 360

[82] Puylaert JB, Rutgers PH, Lalisang RI et al. A prospective study of ultrasonography in the diagnosis of appendicitis. N Engl J Med 1987; 317: 666 – 669

[83] Jeffrey RB Jr, Laing FC, Lewis FR. Acute appendicitis: high-resolution real-time US findings. Radiology 1987; 163: 11 – 14

[84] Niekel RA, Lampmann LE. Graded compression sonography in acute appendicitis. Rofo 1986; 145: 441 – 445

[85] Carroll PJ, Gibson D, El-Faedy O et al. Surgeon-performed ultrasound at the bedside for the detection of appendicitis and gallstones: systematic review and meta-analysis. Am J Surg 2013; 205: 102 – 108

[86] Siegel MJ, Friedland JA, Hildebolt CF. Bowel wall thickening in children: differentiation with US. Radiology 1997; 203: 631 – 635

[87] Schwerk WB, Schwarz S, Rothmund M. Sonography in acute colonic diverticulitis. A prospective study. Dis Colon Rectum 1992; 35: 1077 – 1084

[88] Lameris W, van RA, Bipat S et al. Graded compression ultrasonography and computed tomography in acute colonic diverticulitis: meta-analysis of test accuracy. Eur Radiol 2008; 18: 2498 – 2511

[89] Parra DA, Navarro OM. Sonographic diagnosis of intestinal polyps in children. Pediatr Radiol 2008; 38: 680 – 684

[90] Worlicek H, Dunz D, Engelhard K. Ultrasonic examination of the wall of the fluid-filled stomach. J Clin Ultrasound 1989; 17: 5 – 14

[91] Limberg B. Diagnosis and staging of colonic tumors by conventional abdominal sonography as compared with hydrocolonic sonography. N Engl J Med 1992; 327: 65 – 69

[92] Hirooka N, Ohno T, Misonoo M et al. Sono-enterocolonography by oral water administration. J Clin Ultrasound 1989; 17: 585 – 589

[93] Pallotta N, Baccini F, Corazziari E. Ultrasonography of the small bowel after oral administration of anechoic contrast solution. Lancet 1999; 353: 985 – 986

[94] Schiller LR, Santa Ana CA, Porter J et al. Validation of polyethylene glycol 3350 as a poorly absorbable marker for intestinal perfusion studies. Dig Dis Sci 1997; 42: 1 – 5

[95] Pallotta N, Civitelli F, Di NG et al. Small intestine contrast ultrasonography in pediatric Crohn's disease. J Pediatr 2013; 163: 778 – 784

[96] Folvik G, Bjerke-Larssen T, Odegaard S et al. Hydrosonography of the small intestine: comparison with radiologic barium study. Scand J Gastroenterol 1999; 34: 1247 – 1252

[97] European Commitee for MEdical Ultrasound Safety (ECMUS). EFSUMB clinical safety statement for diagnostic ultrasound (2015). European Commitee for Medical Ultrasound Safety (ECMUS). 2015. Available from: http://www.efsumb.org/guidelines/ss2015clinical.pdf

[98] ter Haar G. Ultrasound bio-effects and safety considerations. Front Neurol Neurosci 2015; 36: 23 – 30

[99] Piscaglia F, Bolondi L. The safety of Sonovue in abdominal applications: retrospective analysis of 23188 investigations. Ultrasound Med Biol 2006; 32: 1369 – 1375

[100] ter Haar G. Safety and bio-effects of ultrasound contrast agents. Med Biol Eng Comput 2009; 47: 893 – 900

[101] Wiersema MJ, Wiersema LM. High-resolution 25-megahertz ultrasonography of the gastrointestinal wall: histologic correlates. Gastrointest Endosc 1993; 39: 499 – 504

[102] Goldstein NS, Soman A, Sacksner J. Disparate surgical margin lengths of colorectal resection specimens between in vivo and in vitro measurements – The effects of surgical resection and formalin fixation on organ shrinkage. Am J Clin Pathol 1999; 111: 349 – 351

[103] Chiorean L, Schreiber-Dietrich D, Braden B et al. Transabdominal ultrasound for standardized measurement of bowel wall thickness in normal children and those with Crohn's disease. Med Ultrason 2014; 16: 319 – 324

[104] Dialer I, Hundt C, Bertele-Harms RM et al. Sonographic evaluation of bowel wall thickness in patients with cystic fibrosis. J Clin Gastroenterol 2003; 37: 55 – 60

[105] Haber HP, Busch A, Ziebach R et al. Bowel wall thickness measured by ultrasound as a marker of Crohn's disease activity in children. Lancet 2000; 355: 1239 – 1240

[106] Huh CH, Bhutani MS, Farfan EB et al. Individual variations in mucosa and total wall thickness in the stomach and rectum assessed via endoscopic ultrasound. Physiol Meas 2003; 24: N15 – N22

[107] Sandek A, Bauditz J, Swidsinski A et al. Altered intestinal function in patients with chronic heart failure. J Am Coll Cardiol 2007; 50: 1561 – 1569

[108] Ferri E, Bonvicini U, Pisani M. Ultrasonography of normal vermiform appendix. Chir Ital 2001; 53: 231 – 238

[109] Simonovsky V. Sonographic detection of normal and abnormal appendix. Clin Radiol 1999; 54: 533 – 539

[110] Simonovsky V. Normal appendix: is there any significant difference in the maximal mural thickness at US between pediatric and adult populations? Radiology 2002; 224: 333 – 337

[111] Kimmey MB, Hwang JH. Assessment of the Layered Structure of the Gastrointestinal Tract. In: Ødegaard S, Gilja OH, Gregersen H, editors Basic and New Aspects of Gastrointestinal Ultrasonography. Singapore: World Scientific; 2005: 167 – 188

[112] Odegaard S, Kimmey MB. Location of the muscularis mucosae on high frequency gastrointestinal ultrasound images. Eur J Ultrasound 1994; 1: 39 – 50

[113] Silverstein F, Kimmey M, Martin R et al. Ultrasound and the intestinal wall: experimental methods. Scand J Gastroenterol Suppl 1986; 123: 34 – 40

[114] Jorgensen CS, Dall FH, Jensen SL et al. A new combined high-frequency ultrasound-impedance planimetry measuring system for the quantification of organ wall biomechanics in vivo. J Biomech 1995; 28: 863 – 867

[115] Odegaard S, Kimmey MB, Martin RW et al. The effects of applied pressure on the thickness, layers, and echogenicity of gastrointestinal wall ultrasound images. Gastrointest Endosc 1992; 38: 351 – 356

[116] Cosar S, Oktar SO, Cosar B et al. Doppler and gray-scale ultrasound evaluation of morphological and hemodynamic changes in liver vascualture in alcoholic patients. Eur J Radiol 2005; 54: 393 – 399

[117] Erden A, Cumhur T, Olcer T. Superior mesenteric artery blood flow in patients with small bowel diseases: evaluation with duplex Doppler sonography. J Clin Ultrasound 1998; 26: 37 – 41

[118] Gentile AT, Moneta GL, Lee RW et al. Usefulness of fasting and postprandial duplex ultrasound examinations for predicting high-grade superior mesenteric artery stenosis. Am J Surg 1995; 169: 476 – 479

[119] Kalantzis N, Rouvella P, Tarazis S et al. Doppler US of superior mesenteric artery in the assessment of ulcerative colitis. A prospective study. Hepatogastroenterology 2002; 49: 168 – 171

[120] Schaberle W, Seitz K. Duplex ultrasound measurement of blood flow in the superior mesenteric artery. Ultraschall in Med 1991; 12: 277 – 282

[121] Sigirci A, Baysal T, Kutlu R et al. Doppler sonography of the inferior and superior mesenteric arteries in ulcerative colitis. J Clin Ultrasound 2001; 29: 130 – 139

[122] Sjekavica I, Barbaric-Babic V, Krznaric Z et al. Assessment of Crohn's disease activity by doppler ultrasound of superior mesenteric artery and mural arteries in thickened bowel wall: cross-sectional study. Croat Med J 2007; 48: 822 – 830

[123] Dinc H, Sari A, Resit GH et al. Portal and splanchnic haemodynamics in patients with advanced post-hepatitic cirrhosis and in healthy adults. Assessment with duplex Doppler ultrasound. Acta Radiol 1998; 39: 152 – 156

[124] Ludwig D, Wiener S, Bruning A et al. Mesenteric blood flow is related to disease activity and risk of relapse in Crohn's disease: a prospective follow-up study. Am J Gastroenterol 1999; 94: 2942 – 2950

[125] Piscaglia F, Zironi G, Gaiani S et al. Relationship between splanchnic, peripheral and cardiac haemodynamics in liver cirrhosis of different degrees of severity. Eur J Gastroenterol Hepatol 1997; 9: 799 – 804

[126] Qamar MI, Read AE, Skidmore R et al. Transcutaneous Doppler ultrasound measurement of superior mesenteric artery blood flow in man. Gut 1986; 27: 100 – 105

[127] Ray-Chaudhuri K, Ryder SA, Thomaides T et al. The relationship between blood flow and pulsatility index in the superior mesenteric artery at rest and during constrictor stimuli in normal subjects. J Clin Ultrasound 1994; 22: 149 – 160

[128] Sato S, Ohnishi K, Sugita S et al. Splenic artery and superior mesenteric artery blood flow: nonsurgical Doppler US measurement in healthy subjects and patients with chronic liver disease. Radiology 1987; 164: 347 – 352

[129] Ergun T, Lakadamyali H. Doppler ultrasound evaluation of morphological and hemodynamical changes of hepatic and mesenteric structures in end-stage renal disease patients on regular hemodialysis. Int Urol Nephrol 2010; 42: 205 – 210

[130] Sigirci A, Senol M, Aydin E et al. Doppler waveforms and blood flow parameters of the superior and inferior mesenteric arteries in patients having Behcet disease with and without gastrointestinal symptoms: preliminary data. J Ultrasound Med 2003; 22: 449 – 457

[131] Odegaard S, Kimmey MB, Cheung AHS et al. High frequency endosonography of gastrointestinal arteries: potential and limitations in vitro. Eur J Ultrasound 1995; 2: 313 – 319

[132] Heyne R, Rickes S, Bock P et al. Non-invasive evaluation of activity in inflammatory bowel disease by power Doppler sonography. Z Gastroenterol 2002; 40: 171 – 175

[133] Scholbach T, Herrero I, Scholbach J. Dynamic color Doppler sonography of intestinal wall in patients with Crohn disease compared with healthy subjects. J Pediatr Gastroenterol Nutr 2004; 39: 524 – 528

[134] Yekeler E, Danalioglu A, Movasseghi B et al. Crohn disease activity evaluated by Doppler ultrasonography of the superior mesenteric artery and the affected small-bowel segments. J Ultrasound Med 2005; 24: 59 – 65

[135] Ahn H, Lindhagen J, Nilsson GE et al. Assessment of blood flow in the small intestine with laser Doppler flowmetry. Scand J Gastroenterol 1986; 21: 863 – 870

[136] Ahn H, Lindhagen J, Lundgren O. Measurement of colonic blood flow with laser Doppler flowmetry. Scand J Gastroenterol 1986; 21: 871 – 880

[137] Hulten L, Jodal M, Lindhagen J et al. Blood flow in the small intestine of cat and man as analyzed by an inert gas washout technique. Gastroenterology 1976; 70: 45 – 51

[138] Hulten L, Jodal M, Lindhagen J et al. Colonic blood flow in cat and man as analyzed by an inert gas washout technique. Gastroenterology 1976; 70: 36 – 44

[139] Tateishi S, Arima S, Futami K. Assessment of blood flow in the small intestine by laser Doppler flowmetry: comparison of healthy small intestine and small intestine in Crohn's disease. J Gastroenterol 1997; 32: 457 – 463

[140] Hollerweger A. Colonic diseases: the value of US examination. Eur J Radiol 2007; 64: 239 – 249

[141] Oldfield AL, Wilbur AC. Retrogastric colon: CT demonstration of anatomic variations. Radiology 1993; 186: 557 – 561

[142] Hollerweger A. Acute appendicitis: sonographic evaluation. Ultraschall in Med 2006; 27: 412 – 426

[143] Gilja OH, Braden B, Piscaglia F et al. Functional ultrasound of the gastrointestinal tract. In: Dietrich CF, editor EFSUMB Course book on ultrasound. 1 ed London: EFSUMB; 2015: 597 – 620

[144] Rettenbacher T, Hollerweger A, Macheiner P et al. Outer diameter of the vermiform appendix as a sign of acute appendicitis: evaluation at US. Radiology 2001; 218: 757 – 762

[145] Lee YY, Erdogan A, Rao SS. How to assess regional and whole gut transit time with wireless motility capsule. J Neurogastroenterol Motil 2014; 20: 265 – 270

[146] Nylund K, Odegaard S, Hausken T et al. Sonography of the small intestine. World J Gastroenterol 2009; 15: 1319 – 1330

[147] Rettenbacher T, Hollerweger A, Macheiner P et al. Adult celiac disease: US signs. Radiology 1999; 211: 389 – 394

[148] Phillips SF. Functions of the large bowel: an overview. Scand J Gastroenterol Suppl 1984; 93: 1 – 12

[149] Walker TG. Mesenteric vasculature and collateral pathways. Semin Intervent Radiol 2009; 26: 167 – 174

[150] Schmutz GR, Benko A, Fournier L et al. Small bowel obstruction: role and contribution of sonography. Eur Radiol 1997; 7: 1054 – 1058

[151] Pallotta N, Baccini F, Corazziari E. Small intestine contrast ultrasonography. J Ultrasound Med 2000; 19: 21 – 26

[152] Jaffe T, Thompson WM. Large-Bowel Obstruction in the Adult: Classic Radiographic and CT Findings, Etiology, and Mimics. Radiology 2015; 275: 651 – 663

[153] Taniguchi DK, Martin RW, Myers J et al. Measurement of the ultrasonic attenuation of fat at high frequency. Acad Radiol 1994; 1: 114 – 120

[154] Liu KH, Chan YL, Chan WB et al. Mesenteric fat thickness is an independent determinant of metabolic syndrome and identifies subjects with increased carotid intima-media thickness. Diabetes Care 2006; 29: 379 – 384

[155] Gottschalk U, Nitzsche C, Felber J et al. Enteroscopy and imaging in sclerosing mesenteritis. Z Gastroenterol 2012; 50: 1013 – 1017

[156] Maconi G, Greco S, Duca P et al. Prevalence and clinical significance of sonographic evidence of mesenteric fat alterations in Crohn's disease. Inflamm Bowel Dis 2008; 14: 1555 – 1561

[157] Puylaert JB. Ultrasound of colon diverticulitis. Dig Dis 2012; 30: 56 – 59

[158] Roson N, Garriga V, Cuadrado M et al. Sonographic findings of mesenteric panniculitis: correlation with CT and literature review. J Clin Ultrasound 2006; 34: 169 – 176

[159] Vanhoenacker F, Vanwambeke K, Jacomen G. Amyloidosis: an unusual cause of mesenteric, omental and lymph node calcifications. JBR -BTR 2014; 97: 283 – 286

[160] Schreiber-Dietrich D, Braden B, Chiorean L et al. Sonografische Darstellung mesenterialer Lymphknoten bei gesunden Kindern. Endo heute 2015; 28: 149 – 152

[161] Macari M, Hines J, Balthazar E et al. Mesenteric adenitis: CT diagnosis of primary versus secondary causes, incidence, and clinical significance in pediatric and adult patients. Am J Roentgenol 2002; 178: 853 – 858

[162] Sivit CJ, Newman KD, Chandra RS. Visualization of enlarged mesenteric lymph nodes at US examination. Clinical significance. Pediatr Radiol 1993; 23: 471 – 475

[163] Watanabe M, Ishii E, Hirowatari Y et al. Evaluation of abdominal lymphadenopathy in children by ultrasonography. Pediatr Radiol 1997; 27: 860 – 864

[164] Dietrich CF, Zeuzem S, Caspary WF et al. Ultrasound lymph node imaging in the abdomen and retroperitoneum of healthy probands. Ultraschall in Med 1998; 19: 265 – 269

[165] Karmazyn B, Werner EA, Rejaie B et al. Mesenteric lymph nodes in children: what is normal? Pediatr Radiol 2005; 35: 774 – 777

[166] Lucey BC, Stuhlfaut JW, Soto JA. Mesenteric lymph nodes: detection and significance on MDCT. Am J Roentgenol 2005; 184: 41 – 44

[167] Cui XW, Jenssen C, Saftoiu A et al. New ultrasound techniques for lymph node evaluation. World J Gastroenterol 2013; 19: 4850 – 4860

[168] Chiorean L, Barr RG, Braden B et al. Transcutaneous Ultrasound: Elastographic Lymph Node Evaluation. Current Clinical Applications and Literature Review. Ultrasound Med Biol 2016; 42: 16 – 30

[169] Fraquelli M, Colli A, Colucci A et al. Accuracy of ultrasonography in predicting celiac disease. Arch Intern Med 2004; 164: 169 – 74

[170] Hollerweger A, Macheiner P, Neureiter D et al. Uncommon cystic appearance of lymph nodes in malignant lymphoma. Ultraschall in Med 2008; 29: 308 – 310

[171] Maconi G, Di SA, Ardizzone S et al. Prevalence and clinical significance of sonographic detection of enlarged regional lymph nodes in Crohn's disease. Scand J Gastroenterol 2005; 40: 1328 – 1333

[172] Tarantino L, Giorgio A, De SG et al. Disseminated mycobacterial infection in AIDS patients: abdominal US features and value of fine-needle aspiration biopsy of lymph nodes and spleen. Abdom Imaging 2003; 28: 602 – 608

[173] Standards for the provision of an ultrasound service. The Royal College of Radiologists, The society and college of Radiographers. 2014. Available from: https://www.rcr.ac.uk/sites/default/files/documents/BFCR(14)17_Standards_ultrasound.pdf

[174] Terasawa T, Blackmore CC, Bent S et al. Systematic review: computed tomography and ultrasonography to detect acute appendicitis in adults and adolescents. Ann Intern Med 2004; 141: 537 – 546

[175] van Randen A, Bipat S, Zwinderman AH et al. Acute appendicitis: meta-analysis of diagnostic performance of CT and graded compression US related to prevalence of disease. Radiology 2008; 249: 97 – 106

[176] Le J, Kurian J, Cohen HW et al. Do clinical outcomes suffer during transition to an ultrasound-first paradigm for the evaluation of acute appendicitis in children? Am J Roentgenol 2013; 201: 1348 – 1352

[177] Parker L, Nazarian LN, Gingold EL et al. Cost and radiation savings of partial substitution of ultrasound for CT in appendicitis evaluation: a national projection. Am J Roentgenol 2014; 202: 124 – 135

[178] Atema JJ, Gans SL, van RA et al. Comparison of Imaging Strategies with Conditional versus Immediate Contrast-Enhanced Computed Tomography in Patients with Clinical Suspicion of Acute Appendicitis. Eur Radiol 2015; 25: 2445 – 2452

[179] Andeweg CS, Wegdam JA, Groenewoud J et al. Toward an evidence-based step-up approach in diagnosing diverticulitis. Scand J Gastroenterol 2014; 49: 775 – 784

[180] Andeweg CS, Mulder IM, Felt-Bersma RJ et al. Guidelines of diagnostics and treatment of acute left-sided colonic diverticulitis. Dig Surg 2013; 30: 278 – 292

[181] Kruis W, Germer CT, Leifeld L. Diverticular disease: guidelines of the german society for gastroenterology, digestive and metabolic diseases and the german society for general and visceral surgery. Digestion 2014; 90: 190 – 207

[182] Gasche C, Moser G, Turetschek K et al. Transabdominal bowel sonography for the detection of intestinal complications in Crohn's disease. Gut 1999; 44: 112 – 117

[183] Grunshaw ND, Renwick IG, Scarisbrick G et al. Prospective evaluation of ultrasound in distal ileal and colonic obstruction. Clin Radiol 2000; 55: 356 – 362

[184] Unluer EE, Yavasi O, Eroglu O et al. Ultrasonography by emergency medicine and radiology residents for the diagnosis of small bowel obstruction. Eur J Emerg Med 2010; 17: 260 – 264

[185] Hirche TO, Russler J, Schroder O et al. The value of routinely performed ultrasonography in patients with Crohn disease. Scand J Gastroenterol 2002; 37: 1178 – 1183

[186] Dietrich CF, Lembcke B, Jenssen C et al. Intestinal Ultrasound in Rare Gastrointestinal Diseases, Update, Part 2. Ultraschall in Med 2015; 36: 428 – 456

[187] Dietrich CF, Brunner V, Seifert H et al. Intestinal B-mode sonography in patients with endemic sprue. Intestinal sonography in endemic sprue. Ultraschall in Med 1999; 20: 242 – 247

[188] Maconi G, Radice E, Bareggi E et al. Hydrosonography of the gastrointestinal tract. Am J Roentgenol 2009; 193: 700 – 708