EFSUMB – European Course Book

Editor: Christoph F. Dietrich

Functional ultrasound of the gastrointestinal tract

Odd Helge Gilja[1], Barbara Braden[2], Fabio Piscaglia[3], Christoph F. Dietrich[4]

[1]Odd Helge Gilja (corresponding author). [2]John Radcliffe Hospital Oxford. [3]University of Bologna. [4]Caritas-Krankenhaus Bad Mergentheim

Corresponding author[1]:

Prof. Odd Helge Gilja, M.D., Ph.D.

National Centre for Ultrasound in Gastroenterology

Department of Medicine

Haukeland University Hospital

N-5021 BERGEN

NORWAY

Tel: +47 55972133

Fax: +47 55972950

E-mail: Odd.Gilja@uib.no

Introduction

Ultrasonography is a widely used and indispensable method for the non-invasive investigation of intraabdominal organs. It depicts the normal and pathological anatomy of the biliopancreatic as well as of the gastrointestinal tract [(1)]. The focus of interest has most frequently been morphology while functional processes and disorders have usually been disregarded.

However, ultrasound can offer more; it is superior to any other imaging method in visualising motion-sequences in a real-time mode [(2)]. In contrast to conventional imaging of anatomic structures and organ morphology, functional ultrasonography (f-US) aims at imaging and assessing organ function. For instance, (f-US) can provide information on motility, biomechanics, flow, perfusion, peristalsis, organ filling and emptying [(3)]. Compared to other imaging methods (CT, MRI, and PET) ultrasonography offers the highest temporal resolution combined with also very high spatial resolution. The full potential of ultrasound and its applications is not widely known; this led to establishing an EFSUMB task force group that aims to publish guidelines on gastrointestinal ultrasound (GIUS) (1).

Due to its non-invasiveness and high repeatability, the ultrasound technique is most helpful for investigations of functional processes which often have a high intra-individual variability. As ultrasound is also free of radiation, widely available and inexpensive, it is most suitable for functional studies.

In this chapter, the authors outline applications of functional ultrasound for the investigation of gastrointestinal and intra-abdominal organ function and discuss its practical relevance.

Functional ultrasound of the gastrointestinal tract

Functional ultrasound of the tongue

The movements of the tongue during speech and the oropharyngeal phase of swallowing can be monitored non-invasively in real-time by placing an ultrasound probe under the chin.[(2)] This has been used as visual feedback in dysphagia and dysphasia rehabilitation following partial glossectomy for cancer [(3, 4)] and in speech and dysphagia training for stroke patients as well as in childhood apraxia [(5, 6)].

The back of the mandible and the hyoid bone can be visualised by their acoustic shadows when the ultrasound probe is placed in a longitudinal axis under the chin. The submental ultrasonography can measure the hyoid bone displacement as a change in the distance to the mandible; a weak hyoid bone displacement correlates with the amount of pharyngeal residue [(7)] Hyoid bone displacement and larynx elevation are essential components in the swallowing process to protect the airways. The anterior movement of the hyoid bone (reduced distance to mandible) and the larynx-to-hyoid approximation initiates the larynx elevation and down-folding of the epiglottis.

Submental functional ultrasonography can visualise the bolus transport of normal food in real time. It enables reliable measurement of the hyoid bone displacement in the pharyngeal phase and can evaluate changes in tongue thickness. Hyoid bone displacement of less than 15 mm and changes in tongue thickness of less than 10 mm indicate poor swallowing function and risk of aspiration [(8-13)].

Functional ultrasound of the oesophagus

In the majority of patients, the cervical and distal oesophagus can be visualised ultrasonographically. This allows sonographic real-time investigations of the anatomical oesophageal structure as well as motility studies which might be of interest in patients with dysphagia, gastroesophageal reflux disease, and motility disorders, e.g. scleroderma, Parkinson disease and other causes of functional impairment.

Cervical oesophagus

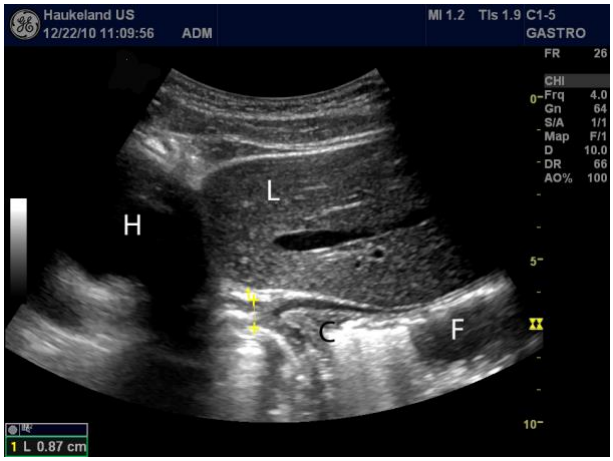
The cervical oesophagus is traceable left to the trachea in almost all patients. Starting from the left lower pole of the thyroid, the transducer can be positioned over the oesophagus while swallowing facilitates the identification. Osophageal motility can be sonographically monitored during swallowing in real time.

Distal esophagus

Sliding hiatal hernia

The distal 4-5 cm of the oesophagus at the level of the diaphragm can usually be visualised from the epigastrium using the left liver lobe as an acoustic window and tilting the transducer cranially while the patient is asked for a deep inspiration [Figure 1].

Figure 1 **Using the liver (L) as acoustic window the lower part of the oesophagus (between yellow markers) and cardia (C) can be visualised. In the left part of the image is the heart (H) and at the lower right end the fundus (F) can be seen.**



In this transducer position with a longitudinal orientation to the aorta, the oesophagus can be visualised above and below the diaphragm in a longitudinal view; a hiatal hernia at the cardia might be seen ventral to the aorta. This sonographic investigation of the oesophagogastric junction can confirm or exclude the presence of a (large) sliding hiatal hernia. The sonographic assessment of hiatal hernias has been evaluated in children and seemed to be comparable or even superior to the barium swallow [(7, 8)]. If the gastro-oesophageal junction cannot be visualised sonographically the size of the hernia is assumed to be > 16 - 20 mm [(9)].

The repeatability is an advantage of the method as well as the real time visualisation of ingested physiological meals. In addition to the functional evaluation, ultrasonography also

depicts the anatomy and morphology of the oesophagogastric junction. Disadvantages of the sonographic assessment of hiatal hernia include the requirements of time and video documentation. Due to available alternatives, the technique does not play a role in adults. However, particularly important is the sonographic assessment of the oesophagogastric junction in paediatrics; in children under the age of 5 years it is the method of choice [(10, 11)].

Gastrooesophageal reflux disease (GERD)

Standard techniques for diagnosing gastro-oesophageal reflux disease are oesophagogastroduodenoscopy and 24h pH-metry which is mostly performed in combination with manometry. Videofluoroscopic imaging after ingestion of a suspension of barium sulfate as contrast allows for imaging of the swallowing process. The barium swallow might also detect refluxing of the liquid contrast from the stomach back into the oesophagus. Naik and Moore [(12)] introduced ultrasound to investigate gastro-oesophageal reflux disease. Subsequently, the method has also been expanded [(14)], also to include CEUS [(15)]. Ultrasound of the oesophagus has also demonstrated increased reflux in high volume liquid meals compared to lower volumes [(14)] and other authors conclude that transabdominal US could be a useful modality for diagnosing GERD [(15)].

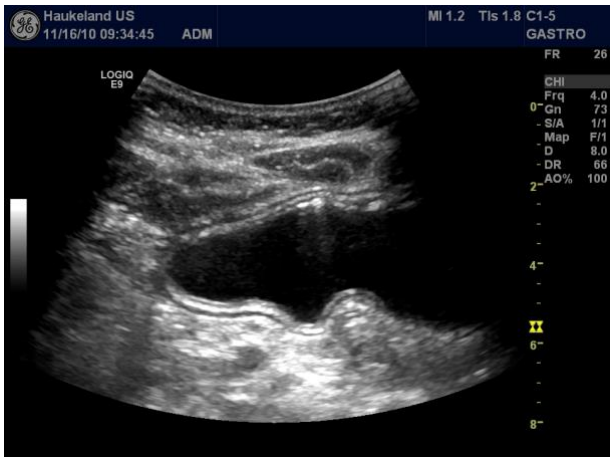
Functional ultrasound of the stomach

Ultrasonography of the human stomach allows to detect and investigate structural diseases of the gastric wall [(16-18)]. Furthermore, ultrasonography enables to study gastric motor function in humans as it provides valuable quantitative and qualitative information about gastric motility, both fasting and postprandial. The advantages of the sonographic methods are its safety, non-invasiveness, lack of radiation, and wide availability [(2)]. However, limited visualisation of the gastric wall due to obesity, intestinal gas and gastric resection present drawbacks of gastric functional ultrasound.

Contractile Activity

Ultrasonography can visualize and monitor gastric contractions and propagation of waves both, in fasting and postprandial state [(19-24)]. Frequency and amplitude of contractions are easily measured quantitative parameters; the amplitude is defined as the maximal reduction of the antral area induced by a contraction, it can be expressed as the difference of the contracted and relaxed area. High resolution ultrasound using transducer frequencies in the range 7-15 MHz permits detailed observation of gastric wall layer involvement during peristalsis [Figure 2].

Figure 2 The image shows a contracting gastric antrum where five wall layers can be observed using 4 MHz transducer frequency.



As ultrasound also detects non-occlusive contractions, it is more sensitive than manometry in detecting antral contractions [(25)]. Acute stress reduces postprandial antral motility in healthy controls, but not in patients with functional dyspepsia as shown in a study inducing acute mental stress by a video game in which the subjects were virtually driving a car trying to avoid collisions on a crowded highway [(26)].

Gastric Emptying

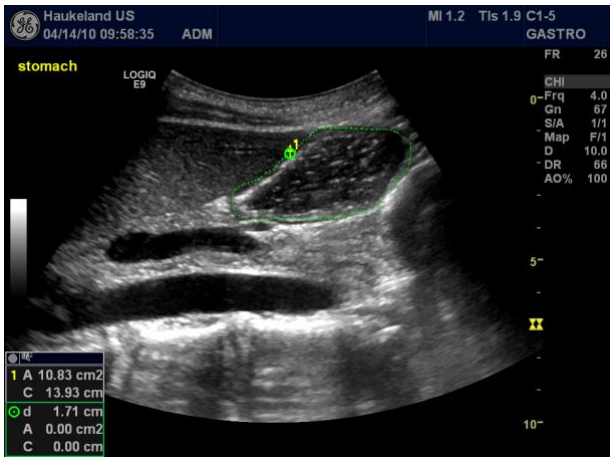
Indications for the measurement of gastric emptying are symptoms of delayed food transport as early satiety, fullness and dyspepsia as well as therapy control studies for

motility affecting drugs. Medication with numerous drugs, acute hyperglycaemia, polyneuropathy (caused by alcoholism or diabetes mellitus), congenital and acquired neuromuscular diseases can cause delayed gastric emptying.

Gastric emptying is a highly complex process with multifactorial influences. The subtle coordination of contraction and relaxation, propulsive and inhibitory impulses results in a concerted interaction of the proximal and distal stomach. Ultrasound permits evaluation of many aspects of gastric function: gastric emptying, antral contractility, transpyloric flow, gastric configuration, intragastric distribution of liquid and solid meals, gastric accommodation and strain measurement of the gastric wall.

Ultrasonography has become a widely applied method to determine gastric emptying rates [(27-33)] with good correlation to radionuclide methods [(29, 34, 35). In the most frequently used protocol, a standardized section of the antrum in a sagittal section using the aorta and superior mesenteric vein as landmarks, is planimetrically measured before and after ingestion of a test meal [Figure 3]. In a recent review, it was concluded that functional ultrasonography brings insight into gastric emptying both in healthy individuals and in gastrointestinal disorders [(19)].

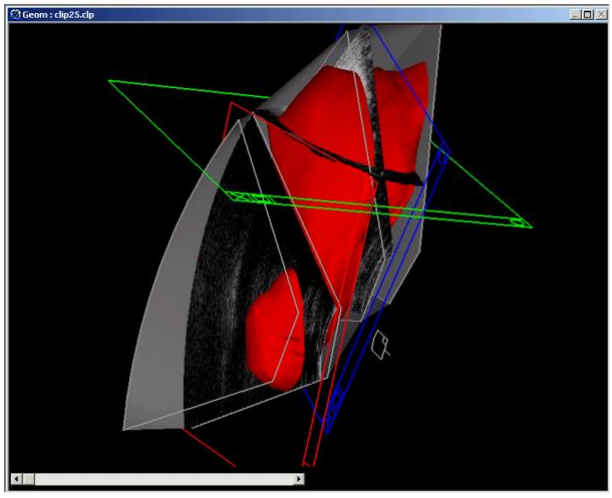
Figure 3 **A standardised section of the gastric antrum in a sagittal section in which the aorta and the superior mesenteric vein are visualised simultaneously. A measurement of the antral area is most often performed using this ultrasound section.**



3D ultrasound

For better visualization of the total stomach and improved calculation of gastric volumes, 3D ultrasound imaging of the gastric compartments was developed [(36-38)]. In our lab (Bergen), we have utilized two different systems for acquisition of 3D ultrasound images and both systems have been validated *in vitro* and *in vivo*. First, we used a mechanical system, which demonstrated excellent accuracy and precision *in vitro* [(39, 40)] and good agreement with MRI *in vivo [(41)]*. Subsequently, we developed a method based on a magneto-based system that enabled greater flexibility during scanning and larger volumes to be captured [Figure 4].

Figure 4 **3D volume reconstruction based on ultrasound acquisition with a magneto-based position- and orientation measurement system (POM). The 3D image is intersected by 3 ordinary grey scale ultrasonograms.**



The magnetic system also showed excellent accuracy *in vitro* [(42-45)] and in volume measurement of a fluid filled bag in the human stomach the agreement with true volumes was excellent [(46)]. This system of 3D acquisition was also highly correlated to scintigraphic measurements [(47)], also in a patient population [(48)]. Accordingly, 3D ultrasonography delivers high resolution, is accurate in volume estimation and is a well-suited tool to monitor

volume changes of the stomach. The method has also been validated and applied by other groups around the world [(46-48)].

Gastric accommodation

Gastric accommodation is a key mechanism for the understanding of the pathophysiology in functional dyspepsia [(49, 50)] and may also be relevant for symptom generation in other disorders [(51-54)]. Several methods can be used to assess gastric accommodation [(55)]. The gastric accommodation *process* is a complex phenomenon that describes how the size of the gastric compartment changes in response to a meal [(56)]. It involves both intra- and extragastric reflexes. The extragastric reflexes comprise both receptive relaxation and intestino-gastric reflexes elicited by balloon distension or nutrient infusion in the duodenum [(57, 58)]. The intragastric reflexes embrace at least adaptive relaxation and relaxation of the proximal stomach induced from antral reflexes [(59-61)]. The gastric meal accommodation *process* has two components: Passive meal distension of the gastric compartments and active muscle relaxation of the gastric wall. The first component is best measured with imaging methods whereas the barostat is best suited for studying the second component.
Simply because functional disorders are so strongly associated to psychological factors, the examination should be performed in a quiet and relaxing atmosphere with a minimum of distress. Ultrasonography satisfies these criteria as it is non-invasive and does not by itself distort the physiological response in stress-responsive individuals. Moreover, due to gravity playing a central role in the propulsion of gastric content, the study of meal accommodation should preferably be performed in a “natural position” such as sitting in a chair. Therefore, methods that enable patients to be seated have an advantage over methods requiring patients to be in supine position during the examination. Ultrasonography, a clinical method that is widely available, has shown applicability and validity for the study of gastric accommodation [(2)]. The 2D method developed by Gilja et al [(59)] has been used to study gastric accommodation in functional dyspepsia [(62, 63)], diabetes [(64)], in patients with reflux oesophagitis [(64-66)], in liver cirrhosis [(67)], and in children with recurrent abdominal pain [(68)]. This 2D method has also been applied to study pharmacological intervention [(69)] and the effect of a barostat bag in the stomach [(70)]. Another advantage with 2D ultrasonography is its clinical applicability; it can easily be performed at the bedside

and can be repeated numerous times in the same subject. This opportunity has also been utilized by Asian groups to study accommodation using ultrasound [(16-20)]. At Haukeland University Hospital we have for 20 years used The Ultrasound Meal Accommodation Test (U-MAT) for the work-up of patients with dyspepsia [Table 1].

Table 1 **The Ultrasound Meal Accommodation Test (UMAT) was developed at Haukeland University Hospital on the basis of close interaction between scientific and clinical work in patients with dyspepsia. Before entering the protocol, the patients have been carefully worked-up regarding history, physical examination, blood tests, testing for *H. pylori*, and upper endoscopy. In many cases, additional examinations are also performed to rule out organic causes for their symptoms. The protocol presented here is the mainstream *clinical* protocol. A 500 ml liquid meal of commercial meat soup (Toro® clear meat soup, Rieber & Søn A/S, Bergen, Norway) containing 1.8 g protein, 0.9 g bovine fat, and 1.1 g carbohydrate (20 kcal) is ingested over a period of 4 min (intentionally, as many patients needs more time). The soup is preheated and then cooled to 37º C to improve imaging quality by reducing the amount of air bubbles. Psychometric evaluation is also performed.**

Time	Protocol
Fasting	Ordinary ultrasound examination of the liver, gallbladder, biliary tract, spleen, pancreas, kidneys, and large vessels.
Fasting	Evaluation of symptoms by VAS.
Fasting	Assessment of motility pattern (interdigestive phase 1-3) by observing the pattern of contractility in the antrum.
Fasting	Measurement of area of the distal stomach (AA).
Fasting	Visualisation of the proximal stomach to explore whether it has content.
Meal ingestion	500 ml of preheated meat soup is ingested in 4 min at a constant speed.
2 min pp.	Measurement of the sagittal area (SA), the oblique frontal diameter (OFD), and the antral area (AA).

5 min pp.	Postprandial symptom evaluation.
10 min pp.	SA, OFD, and AA measurement.
20 min pp.	SA, OFD, and AA measurement.

Our mainstream *clinical* protocol consists of a standard soup meal (500 ml), ultrasound scanning of the proximal and distal stomach using predefined scan sections [Figure 5 and 6], calculation of size and volumes of the gastric compartments, evaluation of symptoms and psychological assessment. In our experience, ultrasonography used in this context can add valuable clinical information to the management of these patients.

Figure 5 **Ultrasonogram showing a sagittal section of the proximal stomach (S) in a patient with dyspepsia referred for Ultrasound Meal Accommodation Test (UMAT). The liver (L), the pancreas (P) and the left kidney (K) are used as internal landmarks. The area of the proximal stomach is measured indicating the postprandial size, hence indirectly the degree of accommodation of the proximal stomach to a meal.**

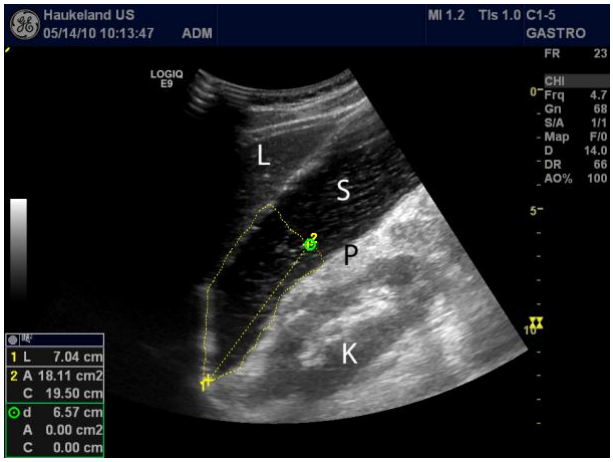
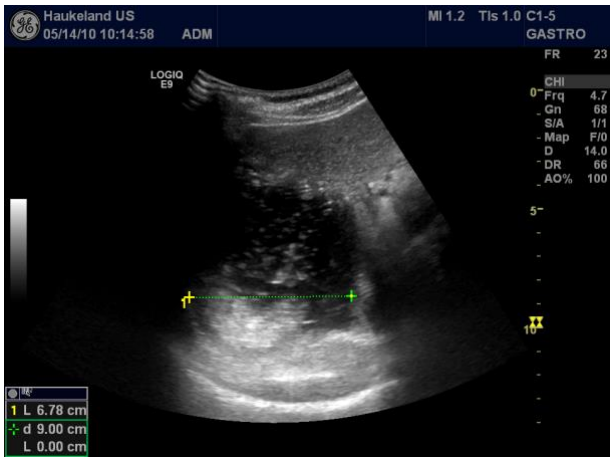


Figure 6 **Ultrasonogram showing an oblique frontal section of the proximal stomach in a patient with dyspepsia referred for Ultrasound Meal Accommodation Test (UMAT). The transversal diameter is measured indicating the size of the**

postprandial proximal stomach and hence indirectly degree of accommodation. The left hemidiaphragm is seen as a white, curved line at the bottom of the image.



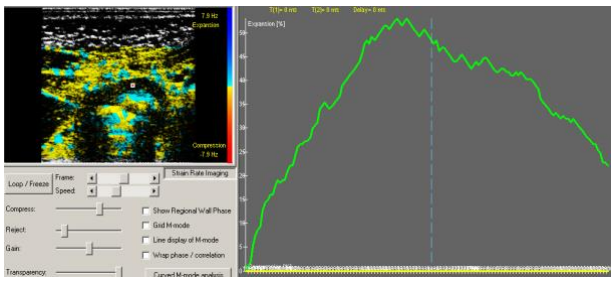
There are few methods that are capable of measuring all parameters of gastric motility simultaneously. However, several authors have demonstrated that ultrasonography can be used in a versatile manner to evaluate many aspects of gastric function.

Strain Rate Imaging

A Doppler method based on strain rate imaging (SRI) and estimation of relative strain was developed to enable differentiation between actively contracting and passively following tissue. In general terms, strain means tissue deformation as a function of applied force (stress) [(71)]. The temporal derivative of strain, i.e., the strain rate, is a measure of the rate of deformation.

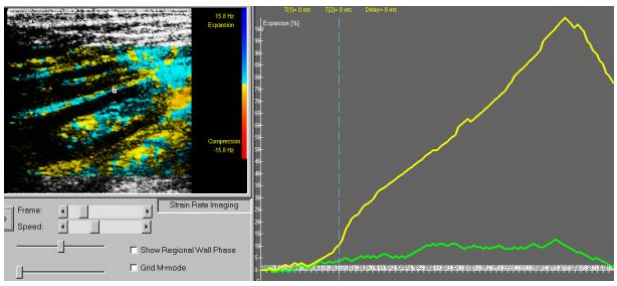
Doppler SRI was evaluated in vitro using a silicone strip phantom mimicking slowly moving tissue [(72)]. SRI in measuring strain in the porcine antral wall in vitro gave accurate measurement of radial strain [(73)]. Estimation of relative strain of the muscle layer of the gastric wall by Doppler ultrasonography is feasible [Figure 7] and enabled detailed mapping of local strain distribution [(74-76)].

Figure 7 **Strain Rate Imaging of a contracting gastric antrum where the sample volume (red dot) is positioned in the circular muscle layer of the antral wall. The color code is displayed in bar at the right image border; blue means expansion of tissue and yellow means compression of tissue. The right panel shows the curve of the strain evolving in the pre-pyloric antral wall reaching a level of 50% expansion.**



SRI is capable of distinguishing contractile activity of the longitudinal and circular muscle layers, even though the two layers cannot be separated visually in the 2D images [Figure 8].

Figure 8 **The figure demonstrates Strain Rate Imaging of a contracting gastric antrum where 2 sample volumes (dots) are located in the muscle layers of the gastric wall. The color code is displayed in the bar at the right image border; blue means expansion of tissue and yellow means compression of tissue. The right panel shows the curve of the strain differences between the inner circular (yellow line) and the outer longitudinal (green line) muscle layer evolving as the antrum contracts in the pre-pyloric region.**



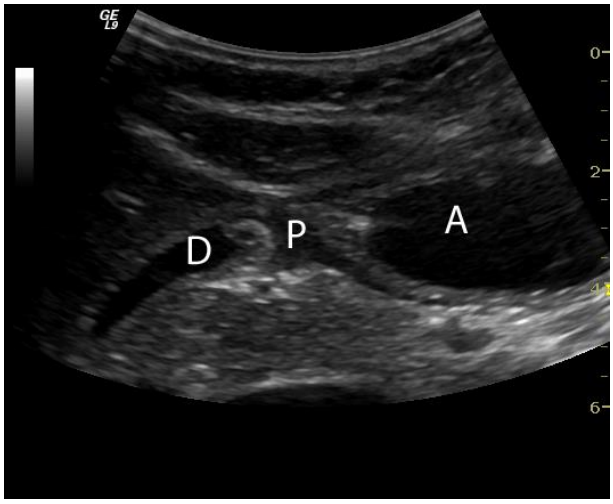
During balloon distension of the antrum, we found a significant inverse correlation between pressure and strain in the GI wall measured by SRI (r=-0.87). In patients with functional dyspepsia, SRI enabled distinction between subgroups showing that patients with epigastric pain syndrome had a totally different strain level in the antral wall compared to patients with postprandial distress [(77)]. However, SRI has mainly been used for research purposes.

Functional ultrasound of pylorus and duodenum and gastroduodenal flow

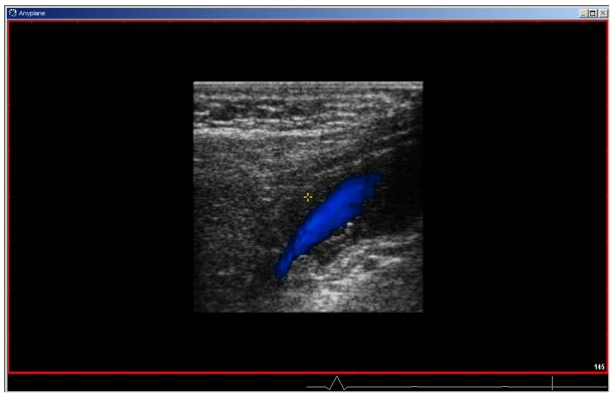
The movements of gastroduodenal contents [Figure 9a] and velocity curves of transpyloric flow can be synchronously visualized by duplex ultrasound, that is combination of Doppler measurement and B-mode scanning [(78, 79)]. By use of duplex scanning, it was revealed that, in the fed state, a short gush of duodenogastric reflux normally precedes the peristaltic closure of the pylorus [(79)]. An antral contraction can be defined as an indentation of the gastric wall greater than the antral wall thickness, and which is not due to respiration, pulsation transmitted from the aorta or heart, or to movements of adjacent intestine, and which was observed to propagate in space and time. An episode of gastric emptying is defined as flow across the pylorus with a mean velocity of more than 10 cm/sec lasting more than 1 sec. During maximal contractions transpyloric flow can be seen passing back and forth through the open pylorus [Figure 9b].

Figure 9 **Ultrasonogram showing the transition between the gastric and the intestinal compartment. The pylorus (P) is situated between the antrum (A) and the bulb of the duodenum (D) (i). Flow across the pylorus can easily be visualised and measured using Doppler methods. Flow across the pylorus is visualised using color Doppler and the blue color indicates that retrograde flow of duodenal content into the gastric antrum is present (ii).**

i



ii



Non-peristaltic-related transpyloric emptying can be defined as transpyloric emptying of gastric contents, without contractions detected on ultrasound or manometry. Using this Doppler method, timing of postprandial dyspeptic symptoms and transpyloric passage of gastric contents can be studied with high temporal and spatial resolution [(80)], also after pharmacological intervention [(81)].

A method was also developed to evaluate transpyloric flow and duodenogastric reflux stroke volumes using a three-dimensional guided digital color Doppler imaging model [(82)]. High intra- and inter-individual variations of the stroke volumes of transpyloric flow episodes during the initial gastric emptying were found. The duodenogastric reflux episodes lasted on average 2.4 seconds with average volume of 8.3 ml.

Sonographic technique

The ingestion of 500 ml warm (37°C) orange juice with standardised bread components or a meat soup will enable adequate visualisation of transpyloric flow. The idiopathic hypertrophic pyloric stenosis (IPHS) in infants can reliably be diagnosed using ultrasound. The hypertrophy of the circular antropyloric muscle is characteristic leading to recurrent vomiting and retardation in weight increase predominantly in male infants. A length of the pylorus > 17 mm and a muscle thickness > 3mm indicate pathological values. The volume of the pyloric muscle is an even more discriminative parameter [(7)]:

$V = (\pi * \text{diameter}^2 * \text{length})/4.$

The pyloric muscle index (PMI) is related to the body weight of the child.
PMI = Length * Thickness * π * (Diameter – Thickness)/ body weight
Normal children have a PMI of 0.19, while the PMI is > 0.24 in patients with IPHS.

The investigation should be performed under fasting condition in supine position using high frequency transducers. The marked separation of the gastric wall layers is characteristic in IPHS. A residual gastric volume > 10 ml determined by a nasogastric tube is typically found in IPHS. After intake of fluids the pyloric function is registered sonographically under stimulated peristalsis. About 2 - 3 hours after fluid intake the stomach should be empty in a normal infant, while patients with IPHS still have a residual gastric volume even after repeated vomiting [(7)].

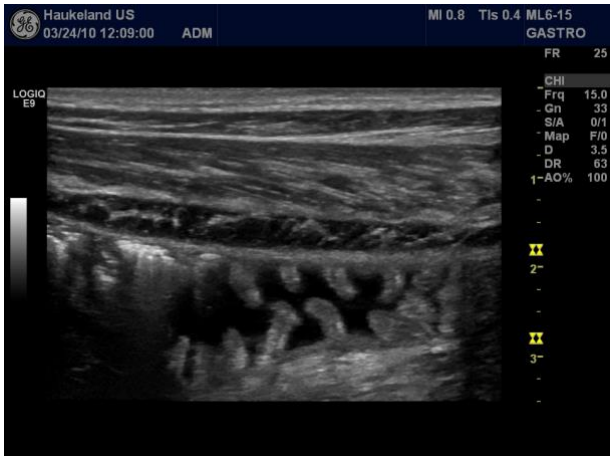
Functional ultrasound of the small bowel

Until recently, the diagnosis of small bowel diseases relied on spare information from small bowel enteroclysis and small bowel follow through. In both methods, patients are exposed to radiation. Advanced imaging methods such as capsule endoscopy and MR enteroclysis now enable better imaging of the small intestine without radiation. Balloon enteroscopy enables investigation of the complete length of the small bowel in most cases, but it is cumbersome and requires sedation. Ultrasonography using high resolution transducers provides small bowel image data of both high temporal and spatial resolution [Figure 10]. It

is probably the patient-friendliest method making it a useful tool in the diagnostics of small intestinal diseases [(83-85)] including small bowel motility disorders.

Our knowledge on small bowel motility is still limited due to the complexity of the interaction between the central and enteric nervous system, sensory and motoric functions, and multiple gastrointestinal hormones which all affect the intestinal smooth muscle and other intestinal cells resulting in peristalsis, secretion and absorption.

Figure 10 This high-frequency (15 MHz) ultrasonogram shows a fluid-filled loop of jejunum with highly visible valvula conniventes as fingerbuds protruding into the lumen.



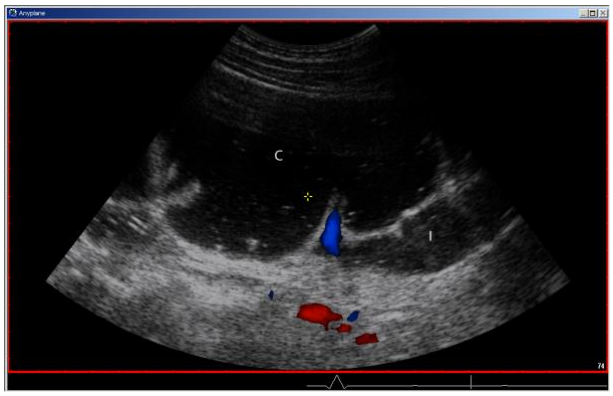
Familial GUCY2C diarrhea syndrome

Familial GUCY2C diarrhea syndrome (FGDS) is explained by an activating mutation in the GUCY2C gene encoding the receptor guanylate cyclase C in enterocytes. Activation leads to increased fluid secretion into the intestinal lumen. The condition resembles irritable bowel syndrome with diarrhea and some appear to develop Crohn's disease. FGDS is characterised by multiple, fluid-filled small bowel loops with incomplete contractions and fluid stagnation in fasting state, easily observed by ultrasound [(86)].

Hydrosonography

High-resolution transabdominal ultrasound for imaging the small intestine is often hampered by intestinal gas. Because the lumen of the small bowel frequently is collapsed, significant intraluminal pathology can be missed. Moreover, separation of different bowel loops can be difficult. Hydrosonography of the small intestine is a method where an echo-poor contrast liquid is used for distending the bowel and removing intestinal air, and thereby improving imaging [Figure 11].

Figure 11 Hydrocolon sonography demonstrating retrograde flow (blue color jet) from the coecum (C) into the terminal ileum (I)



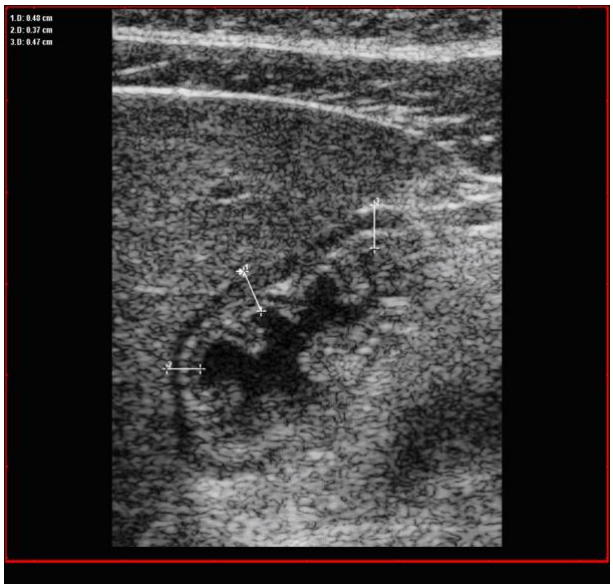
Most often an isotonic polyethylene glycol solution is used (PEG solution, Laxabon®). Because the PEG solution is indigestible and non-absorbable, it gives a predictable amount of luminal fluid and intestinal distension. In principle, any echo-poor fluid can be used. The amount of PEG solution used in different studies varies between 200 and 2000 ml. Oral intake of PEG solution (small intestine contrast ultrasonography or SICUS) is the least invasive way of giving the contrast liquid, and probably the most preferred method by most patients [(87)]. However, in patients having trouble drinking large amounts of PEG solution, a nasojejunal feeding tube can be used. The tube is placed at the duodenojejunal flexure either by endoscopy, fluoroscopy or by ultrasound guidance. These procedures are more time consuming than regular transabdominal ultrasonography, and the average examination time vary between 30 and 40 min in different studies (range 10-90 minutes). Examination time is

very much dependent on the passage of contrast fluid to the terminal ileum. Sensitivities for diagnosing a suspected disorder in the small intestine in patients referred for a barium study vary as much as 64 to 100%, while generally a near 100% specificity is found [(88-91)]. In patients with known CD the sensitivity for detecting a lesion in the small intestine varies between 96 and 100% [(92, 93)]. Hydrosonography of the small intestine is safe. As opposed to enteroclysis and CT-studies, the method can be used for examining the small intestine in patients where radiation should be avoided. Particularly, it is useful in the follow up of patients with inflammatory bowel disease where repeated examinations often are necessary.

Coeliac disease

The diagnosis of coeliac disease is based on the presence of villous atrophy and increased intraepithelial lymphocytosis in duodenal biopsies. However, several ultrasonographic signs which have been reported in coeliac disease might support the diagnosis and initiate the confirming oesophagogastroduodenoscopy. In one study, increased intraluminal fluid content and presence of a moderate small bowel dilatation was described [(94-99)]. Often, increased peristalsis and moderate bowel wall thickness [Figure 12] is also observed [(100, 101)].

Figure 12 Adjacent to the liver a transverse section of the duodenum is shown in a patient with celiac disease. The luminal folds are clearly visible and the wall thickness (0.37-0.48 cm) is slightly increased.



The typical sonographic appearance of untreated coeliac disease is the constant to and fro movements of luminal air and chymus within the bowels seen as whirling hoarse luminal echoes which resembles the laundry in a washing machine ("The washing machine phenomenon"). However, this is an unspecific finding and can also be observed in secretory diarrhoea and in other forms of enteropathies [(102, 103)].

Intestinal obstruction

Intestinal obstruction and ileus can result from incarcerated hernias, adhesions, tumours, invaginations, volvulus, foreign bodies (but also gall stones), and inflammatory bowel disease. A careful ultrasound investigation combined with clinical history and physical examination can often help to identify the cause of the ileus. The sonographic assessment of bowel diameter and motility patterns of bowel segments in all four quadrants can localise and further characterise the obstruction, Typical sonographic findings of intestinal obstruction include dilated bowel loops which appear as thin-walled round cross sections.

Patients with intestinal obstruction show alterations in peristalsis which can be visualised and quantified using Duplex ultrasound. Although the motility pattern is variable and,

therefore, unspecific in early phases of obstruction [(104, 105)], hyperperistalsis and back and forth peristalsis is often found in the beginning of the condition. In later stages, hypo- and aperistalsis, bowel atony and thickened oedematous bowel walls can be demonstrated. While proximal to the stenosis (”transition point”) the bowel loops are dilated and fluid filled, the empty bowel distal to the stenosis (“starving bowel”) has a typical sonographic appearance of the mesenterial layers close together. Ultrasound is also helpful to detect signs of peritoneal carcinomatosis which needs to be excluded when searching for the causes of the ileus [(98, 99, 106-110)].

Allergosonography

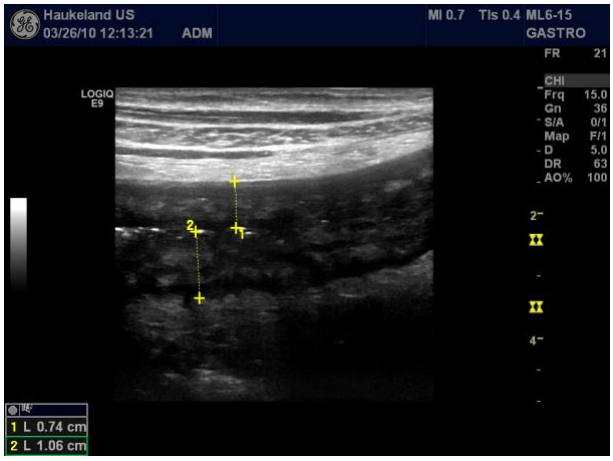
Food hypersensitivity reactions, including GI reactions due to allergy against food items, can be visualised by advanced imaging and visualization modalities such as endosonography [(111)], transabdominal ultrasound, and MRI. In Western countries, the rate of perceived food hypersensitivity is around 25% in the general population [(112)]. Conversely, a diagnosis of "true" food allergy in adults is confirmed in only 1-4 % of the cases. Not only mucosal swelling, but also luminal fluid can be visualised by ultrasonography [(113)]. Sonographic changes were observed after challenge in 44% of patients. A positive sonographic response (increased wall thickness, diameter, peristalsis and/or luminal fluid) was significantly related to positive skin prick test (p=0.008) and positive Double-Blind Placebo-controlled Food Challenge (p=0.03).

Inflammatory Bowel Disease

Crohn’s disease (CD) is the most common reason for performing ultrasonography of the small intestine. The typical US findings are discontinuous and consist of wall thickening [Figure 13], ulcerations, infiltrations, flow alterations, and changes in stratification [(114-119)]. Increased wall thickness, often with fibrosis, often leads to impaired motility of the affected GI segment and this hypomotility can easily be visualised with real-time ultrasound [(108, 118, 119)].

Figure 13 The descending colon showing markedly thickening of the bowel wall in a patient with Crohn’s disease. Note the disturbed architecture of the wall

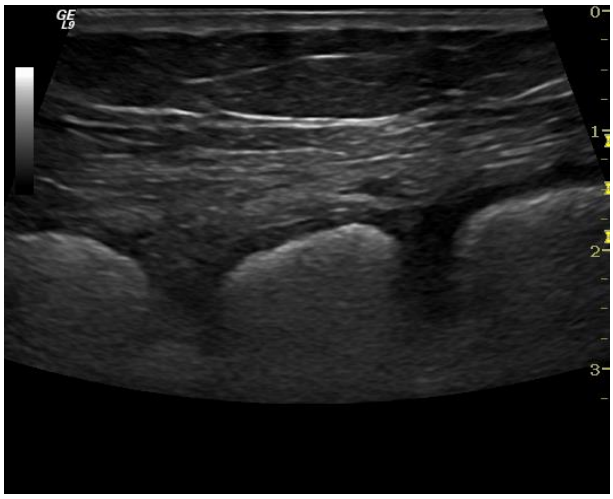
layering, a feature contributing to the impaired motility often observed in these patients.



Functional ultrasound of the colon

To examine the colon the examiner usually starts in the right iliac fossa and follows the colon systematically in distal direction ending with a transvesical view of the rectum. It is recommended to start with a transducer frequency of 3-5 MHz to obtain a good overview of the bowels and its surroundings, but subsequently use high-frequency linear probes (7.5-15 MHz) for detailed imaging of the GI wall and focus on pathology [(107)]. The colon very often contains air that is either lying close to the anterior wall blocking further penetration or is mixed in with faecal content causing a gradual decay of image quality [Figure 14]. Motility of the colon is quite rarely observed.

Figure 14 A typical appearance of the colonic wall in a healthy subject showing the haustration between loops of gas-filled bowels. The distinct interface between luminal gas and the dark GI wall enables precise measurements of wall thickness.



To improve visualisation of the colonic wall, colon hydrosonography was primarily developed to study polyps and inflammation but it can also be used to investigate the colonic peristalsis and function [(120, 121)]. 1.5 to 2 l of water at body temperature is installed through the rectum and a smooth muscle relaxant is given intravenously to obtain good distension of the colon and prevent urgency of rectal water emptying. Hydrosonography achieves excellent visualisation of the colonic wall, however, the cumbersome bowel preparation and the rectal water instillation renders it an unpractical technique which has not gained wide-spread clinical acceptance for colon imaging, particularly due to recent advances in radiologic colon imaging methods and standard ultrasonography.

Ultrasound assessment of bowel transit

The colon transit time contributes most (>90%; 20-72 hours) to the transit time of solids through the gastrointestinal tract, while oesophageal transit (30 seconds), gastric emptying time (10 minutes up to 3 hours), small bowel transit (2-3 hours) are relatively short.

A water filled 10-25 mm latex balloon containing 5 mm sized metal particles is sonographically traceable during its gastrointestinal passage and can be followed through

the stomach, small bowel and colon [(122)]. However, this method has not become an established diagnostic tool.

Rectal ultrasonography

The controlled retention and rectal discharge of gas, solid and liquid stool require a fine regulation and muscle coordination. An insufficiency as well as a lack of relaxation of the internal anal sphincter muscle can result in functional disorders. Rectal endosonography (or rectal ultrasound) can support the diagnosis of rectal incontinence as it is able to visualise defects in the sphincter muscle. Rectal and perirectal inflammation (abscess, fistula, tumor) can also be depicted. The perianal or perineal ultrasound is particularly helpful in case of rectal stenosis [(109, 113, 114, 123, 124)].

References

1. Nylund K, Maconi G, Hollerweger A, Ripolles T, Pallotta N, Higginson A, Serra C, et al. EFSUMB Recommendations and Guidelines for Gastrointestinal Ultrasound. Ultraschall Med 2017;38:273-284.

2. Odegaard S, Gilja OH, Gregersen H: Basic and New Aspects of Gastrointestinal Ultrasonography. In: Odegaard S, ed. Advanced Series in Biomechanics. Singapore: World Scientific, 2005; 1-502.

3. Gilja OH. Ultrasound in gastroenterology. Expert.Rev Gastroenterol Hepatol 2008;2:5-8.

4. Kansy K, Hoffmann J, Mistele N, Shavlokhova V, Bendszus M, Heiland S, Krisam J, et al. Visualization and quantification of tongue movement during articulation: Is ultrasound a valid alternative to magnetic resonance imaging? J Craniomaxillofac Surg 2018;46:1924-1933.

5. Gilja OH, Hatlebakk JG, Odegaard S, Berstad A, Viola I, Giertsen C, Hausken T, et al. Advanced imaging and visualization in gastrointestinal disorders. World J Gastroenterol 2007;13:1408-1421.

6. Kwak HJ, Kim L, Ryu BJ, Kim YH, Park SW, Cho DG, Lee CJ, et al. Influence of Nasogastric Tubes on Swallowing in Stroke Patients: Measuring Hyoid Bone Movement With Ultrasonography. Ann Rehabil Med 2018;42:551-559.

7. Gomes H, Lallemand A, Lallemand P. Ultrasound of the gastroesophageal junction. Pediatr.Radiol. 1993;23:94-99.

8. Naik DR, Bolia A, Moore DJ. Comparison of barium swallow and ultrasound in diagnosis of gastro-oesophageal reflux in children. Br.Med J (Clin Res Ed) 1985;290:1943-1945.

9. Naik DR, Moore DJ. Ultrasound diagnosis of gastro-oesophageal reflux. Arch.Dis.Child 1984;59:366-367.

10. Aliotta A, Rapaccini GL, Pompili M, Grattagliano A, Cedrone A, Trombino C, de Luca F, et al. Ultrasonographic signs of sliding, gastric, and hiatal hernia: their prospective evaluation. J Ultrasound Med 1994;13:665-669.

11. Westra SJ, Wolf BH, Staalman CR. Ultrasound diagnosis of gastroesophageal reflux and hiatal hernia in infants and young children. J Clin Ultrasound 1990;18:477-485.

12. Farina R, Pennisi F, La Rosa M, Puglisi C, Mazzone G, Riva G, Foti PV, et al. Contrast-enhanced colour-Doppler sonography versus pH-metry in the diagnosis of gastro-oesophageal reflux in children. Radiol.Med 2008;113:591-598.

13. Oh EH, Seo JS, Kang HJ. Assessment of Oropharyngeal Dysphagia in Patients With Parkinson Disease: Use of Ultrasonography. Ann Rehabil Med 2016;40:190-196.

14. Walls WJ. The evaluation of malignant gastric neoplasms by ultrasonic B-scanning. Radiology 1976;118:159-163.

15. Mascatello VJ, Carrera GF, Telle RL, Berger M, Holm HH, Smith EH. The ultrasonic demonstration of gastric lesions. J Clin Ultrasound 1977;5:383-387.

16. Lutz HT, Petzoldt R. Ultrasonic patterns of space occupying lesions of the stomach and the intestine. Ultrasound Med Biol. 1976;2:129-132.

17. Bateman DN, Leeman S, Metreweli C, Willson K. A non-invasive technique for gastric motility measurement. Br.J Radiol. 1977;50:526-527.

18. Holt S, McDicken WN, Anderson T, Stewart IC, Heading RC. Dynamic imaging of the stomach by real-time ultrasound--a method for the study of gastric motility. Gut 1980;21:597-601.

19. Hausken T, Berstad A. Wide gastric antrum in patients with non-ulcer dyspepsia. Effect of cisapride. Scand.J Gastroenterol 1992;27:427-432.

20. Hausken T, Odegaard S, Berstad A. Antroduodenal motility studied by real-time ultrasonography. Effect of enprostil. Gastroenterology 1991;100:59-63.

21. Ahluwalia NK, Thompson DG, Mamtora H, Troncon L, Hindle J, Hollis S. Evaluation of human postprandial antral motor function using ultrasound. Am.J Physiol 1994;266:G517-G522.

22. Wedmann B, Adamek RJ, Wegener M. [Ultrasound detection of gastric antrum motility--evaluating a simple semiquantitative method]. Ultraschall Med 1995;16:124-126.

23. Hveem K, Svebak S, Hausken T, Berstad A. Effect of mental stress and cisapride on autonomic nerve functions in functional dyspepsia. Scand.J Gastroenterol 1998;33:123-127.

24. Hveem K, Sun WM. Insights into stomach mechanics from concurrent gastric ultrasound and manometry. Gastroenterology 1995;107:1236.

25. Bateman DN, Whittingham TA. Measurement of gastric emptying by real-time ultrasound. Gut 1982;23:524-527.

26. Bolondi L, Bortolotti M, Santi V, Calletti T, Gaiani S, Labo G. Measurement of gastric emptying time by real-time ultrasonography. Gastroenterology 1985;89:752-759.

27. Holt S, Cervantes J, Wilkinson AA, Wallace JH. Measurement of gastric emptying rate in humans by real-time ultrasound. Gastroenterology 1986;90:918-923.

28. Duan LP, Zheng ZT, Li YN. A study of gastric emptying in non-ulcer dyspepsia using a new ultrasonographic method. Scand.J Gastroenterol 1993;28:355-360.

29. Ricci R, Bontempo I, Corazziari E, La Bella A, Torsoli A. Real time ultrasonography of the gastric antrum. Gut 1993;34:173-176.

30. Desaga JF, Hixt U. [Sonographic determination of gastric emptying]. Ultraschall Med 1987;8:138-141.

31. Gerards C, Tromm A, May B. [Optimizing antrum planimetry for ultrasound determination of gastric emptying using emptying function reference lines]. Ultraschall Med 1998;19:83-86.

32. Marzio L, Giacobbe A, Conoscitore P, Facciorusso D, Frusciante V, Modoni S. Evaluation of the use of ultrasonography in the study of liquid gastric emptying. Am.J Gastroenterol 1989;84:496-500.

33. Tympner F, Feldmeier J, Rosch W. [Study of the correlation of sonographic and scintigraphic results in measuring stomach emptying]. Ultraschall Med 1986;7:264-267.

34. Berstad A, Hausken T, Gilja OH, Thune N, Matre K, Odegaard S. Volume measurements of gastric antrum by 3-D ultrasonography and flow measurements through the pylorus by duplex technique. Dig Dis.Sci. 1994;39:97S-100S.

35. Gilja OH, Hausken T, Odegaard S, Berstad A. Three-dimensional ultrasonography of the gastric antrum in patients with functional dyspepsia. Scand.J Gastroenterol 1996;31:847-855.

36. Gilja OH, Detmer PR, Jong JM, Leotta DF, Li XN, Beach KW, Martin R, et al. Intragastric distribution and gastric emptying assessed by three-dimensional ultrasonography. Gastroenterology 1997;113:38-49.

37. Thune N, Hausken T, Gilja OH, Matre K. A practical methode for estimation of enclosed volumes using 3D ultrasound. Ultrasound Med Biol. 1994;20,S1.

38. Gilja OH, Thune N, Matre K, Hausken T, Odegaard S, Berstad A. In vitro evaluation of three-dimensional ultrasonography in volume estimation of abdominal organs. Ultrasound Med Biol. 1994;20:157-165.

39. Gilja OH, Smievoll AI, Thune N, Matre K, Hausken T, Odegaard S, Berstad A. In vivo comparison of 3D ultrasonography and magnetic resonance imaging in volume estimation of human kidneys. Ultrasound Med Biol. 1995;21:25-32.

40. Detmer PR, Bashein G, Hodges T, Beach KW, Filer EP, Burns DH, Strandness DE, Jr. 3D ultrasonic image feature localization based on magnetic scanhead tracking: in vitro calibration and validation. Ultrasound Med Biol. 1994;20:923-936.

41. Leotta DF, Detmer PR, Gilja OH, Jong JM, Martin R. Three-dimensional ultrasound imaging using multiple magnetic tracking suystems and miniature magnetic sensors. Seattel WA, USA: Proc IEEE Int Ultrasonic Symp, 1995.

42. Gilja OH, Hausken T, Olafsson S, Matre K, Odegaard S. In vitro evaluation of three-dimensional ultrasonography based on magnetic scanhead tracking. Ultrasound Med Biol. 1998;24:1161-1167.

43. Tefera S, Gilja OH, Olafsdottir E, Hausken T, Hatlebakk JG, Berstad A. Intragastric maldistribution of a liquid meal in patients with reflux oesophagitis assessed by three dimensional ultrasonography. Gut 2002;50:153-158.

44. Gentilcore D, Hausken T, Horowitz M, Jones KL. Measurements of gastric emptying of low- and high-nutrient liquids using 3D ultrasonography and scintigraphy in healthy subjects. Neurogastroenterol.Motil. 2006;18:1062-1068.

45. Stevens JE, Gilja OH, Gentilcore D, Hausken T, Horowitz M, Jones KL. Measurement of gastric emptying of a high-nutrient liquid by 3D ultrasonography in diabetic gastroparesis. Neurogastroenterol.Motil. 2011;23:220-224.

46. Gilja OH, Hausken T, Wilhelmsen I, Berstad A. Impaired accommodation of proximal stomach to a meal in functional dyspepsia. Dig Dis.Sci. 1996;41:689-696.

47. Tack J, Piessevaux H, Coulie B, Caenepeel P, Janssens J. Role of impaired gastric accommodation to a meal in functional dyspepsia. Gastroenterology 1998;115:1346-1352.

48. Oliveira RB, Troncon LE, Meneghelli UG, Padovan W, Dantas RO, de Godoy RA. Impaired gastric accommodation to distension and rapid gastric emptying in patients with Chagas' disease. Dig Dis.Sci. 1980;25:790-794.

49. Undeland KA, Hausken T, Gilja OH, Aanderud S, Berstad A. Gastric meal accommodation studied by ultrasound in diabetes. Relation to vagal tone. Scand.J Gastroenterol 1998;33:236-241.

50. Tefera S, Gilja OH, Hatlebakk JG, Berstad A. Gastric accommodation studied by ultrasonography in patients with reflux esophagitis. Dig Dis.Sci. 2001;46:618-625.

51. Olafsdottir E, Gilja OH, Aslaksen A, Berstad A, Fluge G. Impaired accommodation of the proximal stomach in children with recurrent abdominal pain. J Pediatr.Gastroenterol Nutr. 2000;30:157-163.

52. De Schepper HU, Cremonini F, Chitkara D, Camilleri M. Assessment of gastric accommodation: overview and evaluation of current methods. Neurogastroenterol.Motil. 2004;16:275-285.

53. Gilja OH. Functional dyspepsia studied by two- and three-dimensional ultrasonography. Significance of gastric meal accommodation University of Bergen, 1997.

54. Azpiroz F, Malagelada JR. Intestinal control of gastric tone. Am.J Physiol 1985;249:G501-G509.

55. Azpiroz F, Malagelada JR. Isobaric intestinal distension in humans: sensorial relay and reflex gastric relaxation. Am.J Physiol 1990;258:G202-G207.

56. Abrahamsson H. Vagal relaxation of the stomach induced from the gastric antrum. Acta Physiol Scand. 1973;89:406-414.

57. Caldarella MP, Azpiroz F, Malagelada JR. Antro-fundic dysfunctions in functional dyspepsia. Gastroenterology 2003;124:1220-1229.

58. Lunding JA, Tefera S, Bayati A, Gilja OH, Mattsson H, Hausken T, Berstad A. Pressure-induced gastric accommodation studied with a new distension paradigm. Abnormally low accommodation rate in patients with functional dyspepsia. Scand.J Gastroenterol 2006;41:544-552.

59. Gilja OH, Hausken T, Odegaard S, Berstad A. Monitoring postprandial size of the proximal stomach by ultrasonography. J Ultrasound Med 1995;14:81-89.

60. Gilja OH, Hausken T, Bang CJ, Berstad A. Effect of glyceryl trinitrate on gastric accommodation and symptoms in functional dyspepsia. Dig Dis.Sci. 1997;42:2124-2131.

61. Izbeki F, Kiss I, Wittmann T, Varkonyi TT, Legrady P, Lonovics J. Impaired accommodation of proximal stomach in patients with alcoholic liver cirrhosis. Scand.J Gastroenterol 2002;37:1403-1410.

62. Mundt MW, Hausken T, Samsom M. Effect of intragastric barostat bag on proximal and distal gastric accommodation in response to liquid meal. Am.J Physiol Gastrointest.Liver Physiol 2002;283:G681-G686.

63. Gregersen H, Barlow J, Thompson D. Development of a computer-controlled tensiometer for real-time measurements of tension in tubular organs. Neurogastroenterol.Motil. 1999;11:109-118.

64. Matre K, Stokke EM, Martens D, Gilja OH. In vitro volume estimation of kidneys using three-dimensional ultrasonography and a position sensor. Eur J Ultrasound 1999;10:65-73.

65. Ahmed AB, Gilja OH, Gregersen H, Odegaard S, Matre K. In vitro strain measurement in the porcine antrum using ultrasound doppler strain rate imaging. Ultrasound Med Biol. 2006;32:513-522.

66. Vingerhagen S, Hausken T, Gilja OH, Berstad A. Influence of a 5HT1 receptor agonist on gastric accommodation and initial transpyloric flow in healthy subjects. Neurogastroenterol.Motil. 2000;12:95-101.

67. Gilja OH, Heimdal A, Hausken T, Gregersen H, Matre K, Berstad A, Odegaard S. Strain during gastric contractions can be measured using Doppler ultrasonography. Ultrasound Med Biol. 2002;28:1457-1465.

68. Ahmed AB, Gilja OH, Hausken T, Gregersen H, Matre K. Strain measurement during antral contractions by ultrasound strain rate imaging: influence of erythromycin. Neurogastroenterol.Motil. 2009;21:170-179.

69. Heimdal A, Gilja OH: Strain Rate Imaging - A new tool for studying teh GI tract. In: Odegaard S, Gilja OH, Gregersen H, eds. Basic and new aspects of gastrointestinal ultrasonography. Singapore: World Scientific, 2015; 243-263.

70. Ahmed AB, Matre K, Hausken T, Gregersen H, Gilja OH. ROME III subgroups of functional dyspepsia exhibit different characteristics of antral strain measured by strain rate imaging. Gastroenterology 2008;134:A531.

71. King PM, Adam RD, Pryde A, McDicken WN, Heading RC. Relationships of human antroduodenal motility and transpyloric fluid movement: non-invasive observations with real-time ultrasound. Gut 1984;25:1384-1391.

72. Hausken T, Odegaard S, Matre K, Berstad A. Antroduodenal motility and movements of luminal contents studied by duplex sonography. Gastroenterology 1992;102:1583-1590.

73. Hausken T, Gilja OH, Undeland KA, Berstad A. Timing of postprandial dyspeptic symptoms and transpyloric passage of gastric contents. Scand.J Gastroenterol 1998;33:822-827.

74. Hausken T, Gilja OH, Odegaard S, Berstad A. Flow across the human pylorus soon after ingestion of food, studied with duplex sonography. Effect of glyceryl trinitrate. Scand.J Gastroenterol 1998;33:484-490.

75. Hausken T, Li XN, Goldman B, Leotta D, Odegaard S, Martin RW. Quantification of gastric emptying and duodenogastric reflux stroke volumes using three-dimensional guided digital color Doppler imaging. Eur J Ultrasound 2001;13:205-213.

76. Bhisitkul DM, Listernick R, Shkolnik A, Donaldson JS, Henricks BD, Feinstein KA, Fernbach SK. Clinical application of ultrasonography in the diagnosis of intussusception. J Pediatr. 1992;121:182-186.

77. Bozkurt T, Richter F, Lux G. Ultrasonography as a primary diagnostic tool in patients with inflammatory disease and tumors of the small intestine and large bowel. J Clin Ultrasound 1994;22:85-91.

78. Fraquelli M, Colli A, Colucci A, Bardella MT, Trovato C, Pometta R, Pagliarulo M, et al. Accuracy of ultrasonography in predicting celiac disease. Arch.Intern.Med 2004;164:169-174.

79. Pallotta N, Baccini F, Corazziari E. Small intestine contrast ultrasonography. J Ultrasound Med 2000;19:21-26.

80. Cittadini G, Giasotto V, Garlaschi G, de Cicco E, Gallo A, Cittadini G. Transabdominal ultrasonography of the small bowel after oral administration of a non-absorbable anechoic solution: comparison with barium enteroclysis. Clin Radiol. 2001;56:225-230.

81. Folvik G, Bjerke-Larssen T, Odegaard S, Hausken T, Gilja OH, Berstad A. Hydrosonography of the small intestine: comparison with radiologic barium study. Scand.J Gastroenterol 1999;34:1247-1252.

82. Pallotta N, Baccini F, Corazziari E. Small intestine contrast ultrasonography (SICUS) in the diagnosis of small intestine lesions. Ultrasound Med Biol. 2001;27:335-341.

83. Pallotta N, Tomei E, Viscido A, Calabrese E, Marcheggiano A, Caprilli R, Corazziari E. Small intestine contrast ultrasonography: an alternative to radiology in the assessment of small bowel disease. Inflamm.Bowel.Dis. 2005;11:146-153.

84. Calabrese E, La Seta F, Buccellato A, Virdone R, Pallotta N, Corazziari E, Cottone M. Crohn's disease: a comparative prospective study of transabdominal ultrasonography, small intestine contrast ultrasonography, and small bowel enema. Inflamm.Bowel.Dis. 2005;11:139-145.

85. Parente F, Greco S, Molteni M, Anderloni A, Sampietro GM, Danelli PG, Bianco R, et al. Oral contrast enhanced bowel ultrasonography in the assessment of small intestine Crohn's disease. A prospective comparison with conventional ultrasound, x ray studies, and ileocolonoscopy. Gut 2004;53:1652-1657.

86. von Volkmann HL, Nylund K, Tronstad RR, Hovdenak N, Hausken T, Fiskerstrand T, Gilja OH. An activating gucy2c mutation causes impaired contractility and fluid stagnation in the small bowel. Scand J Gastroenterol 2016;51:1308-1315.

87. Riccabona M, Rossipal E. [Value of ultrasound in diagnosis of celiac disease]. Ultraschall Med 1996;17:31-33.

88. Riccabona M, Rossipal E. Sonographic findings in celiac disease. J Pediatr.Gastroenterol Nutr. 1993;17:198-200.

89. Rettenbacher T, Hollerweger A, Macheiner P, Huber S, Gritzmann N. Adult celiac disease: US signs. Radiology 1999;211:389-394.

90. Dietrich CF, Brunner V, Seifert H, Schreiber-Dietrich D, Caspary WF, Lembcke B. [Intestinal B-mode sonography in patients with endemic sprue. Intestinal sonography in endemic sprue]. Ultraschall Med 1999;20:242-247.

91. Nuernberg D, Ignee A, Dietrich CF. [Current status of ultrasound in gastroenterology--bowel and upper gastrointestinal tract--part 1]. Z Gastroenterol 2007;45:629-640.

92. Bedi DG, Fagan CJ, Nocera RM. Sonographic diagnosis of bowel obstruction presenting with fluid-filled loops of bowel. J Clin Ultrasound 1985;13:23-30.

93. Derchi LE, Bazzocchi M, Brovero PL. Sonographic diagnosis of obstructed afferent loop. Gastrointest.Radiol. 1992;17:105-107.

94. Seitz K, Merz M. [Ultrasound ileus diagnosis]. Ultraschall Med 1998;19:242-249.

95. Arslan G, Odegaard S, Elsayed S, Florvaag E, Berstad A. Food allergy and intolerance: response to intestinal provocation monitored by endosonography. Eur J Ultrasound 2002;15:29-36.

96. O'Leary PF, Shanahan F. Food allergies. Curr.Gastroenterol Rep. 2002;4:373-382.

97. Dietrich CF, Brunner V, Seifert H, Schreiber-Dietrich D, Caspary WF, Lembcke B. [Intestinal B-mode sonography in patients with endemic sprue. Intestinal sonography in endemic sprue]. Ultraschall Med 1999;20:242-247.

98. Dietrich CF, Lembcke B, Jenssen C, Hocke M, Ignee A, Hollerweger A. Intestinal Ultrasound in Rare Gastrointestinal Diseases, Update, Part 2. Ultraschall Med 2015;36:428-456.

99. Dietrich CF, Lembcke B, Jenssen C, Hocke M, Ignee A, Hollerweger A. Intestinal ultrasound in rare gastrointestinal diseases, update, part 1. Ultraschall Med 2014;35:400-421.

100. Arslan G, Gilja OH, Lind R, Florvaag E, Berstad A. Response to intestinal provocation monitored by transabdominal ultrasound in patients with food hypersensitivity. Scand.J Gastroenterol 2005;40:386-394.

101. Allgayer H, Dietrich CF. [Celiac sprue and malignancies: analysis of risks and prevention strategies]. Med Klin (Munich) 2008;103:561-568.

102. Holt S, Samuel E. Grey scale ultrasound in Crohn's disease. Gut 1979;20:590-595.

103. Dietrich CF. Significance of abdominal ultrasound in inflammatory bowel disease. Dig Dis. 2009;27:482-493.

104. Nylund K, Hausken T, Gilja OH. Ultrasound and inflammatory bowel disease. Ultrasound Q. 2010;26:3-15.

105. Nylund K, Odegaard S, Hausken T, Folvik G, Lied GA, Viola I, Hauser H, et al. Sonography of the small intestine. World J Gastroenterol 2009;15:1319-1330.

106. Limberg B, Osswald B. Diagnosis and differential diagnosis of ulcerative colitis and Crohn's disease by hydrocolonic sonography. Am.J Gastroenterol 1994;89:1051-1057.

107. Dirks K, Calabrese E, Dietrich CF, Gilja OH, Hausken T, Higginson A, Hollerweger A, et al. EFSUMB Position Paper: Recommendations for Gastrointestinal Ultrasound (GIUS) in Acute Appendicitis and Diverticulitis. Ultraschall Med 2019.

108. Maconi G, Nylund K, Ripolles T, Calabrese E, Dirks K, Dietrich CF, Hollerweger A, et al. EFSUMB Recommendations and Clinical Guidelines for Intestinal Ultrasound (GIUS) in Inflammatory Bowel Diseases. Ultraschall Med 2018;39:304-317.

109. Atkinson NSS, Bryant RV, Dong Y, Maaser C, Kucharzik T, Maconi G, Asthana AK, et al. How to perform gastrointestinal ultrasound: Anatomy and normal findings. World J Gastroenterol 2017;23:6931-6941.

110. Atkinson NS, Bryant RV, Dong Y, Maaser C, Kucharzik T, Maconi G, Asthana AK, et al. WFUMB Position Paper. Learning Gastrointestinal Ultrasound: Theory and Practice. Ultrasound Med Biol 2016;42:2732-2742.

111. Limberg B. [Diagnosis of colonic tumors and chronic inflammatory colonic diseases by hydrocolonic sonography]. Radiologe 1993;33:407-411.

112. Amend M, Greiner L. [The sono-capsule: a new method for measuring gastrointestinal motility]. Ultraschall Med 1996;17:274-276.

113. Barreiros AP, Hirche TO, Ignee A, Nurnberg D, Dietrich CF. Indications and limitations of perineal ultrasound examination. Scand.J Gastroenterol 2010;45:764-765.

114. Dietrich CF, Barreiros AP, Nuernberg D, Schreiber-Dietrich DG, Ignee A. [Perianal ultrasound]. Z Gastroenterol 2008;46:625-630.

115. Braden B, Ignee A, Hocke M, Palmer RM, Dietrich C. Diagnostic value and clinical utility of contrast enhanced ultrasound in intestinal diseases. Dig.Liver Dis. 2010;42:667-674.

116. Dietrich CF, Braden B. Sonographic assessments of gastrointestinal and biliary functions. Best.Pract.Res.Clin.Gastroenterol. 2009;23:353-367.

117. Nuernberg D, Braden B, Ignee A, Schreiber-Dietrich DG, Dietrich CF. [Functional ultrasound in gastroenterology]. Z.Gastroenterol. 2008;46:883-896.

118. Schreiber-Dietrich D, Chiorean L, Cui XW, Braden B, Kucharzik T, Jungert J, Kosiak W, et al. Particularities of Crohn's disease in pediatric patients: current status and perspectives regarding imaging modalities. Expert Rev Gastroenterol Hepatol 2015;9:1313-1325.

119. Chiorean L, Schreiber-Dietrich D, Braden B, Cui XW, Buchhorn R, Chang JM, Dietrich CF. Ultrasonographic imaging of inflammatory bowel disease in pediatric patients. World J Gastroenterol 2015;21:5231-5241.

120. Shawker TH, Sonies B, Stone M, Baum BJ. Real-time ultrasound visualization of tongue movement during swallowing. J Clin Ultrasound 1983;11:485-490.

121. Blyth KM, McCabe P, Madill C, Ballard KJ. Ultrasound in dysphagia rehabilitation: a novel approach following partial glossectomy. Disabil Rehabil 2017;39:2215-2227.

122. Preston JL, Leece MC, Maas E. Intensive Treatment with Ultrasound Visual Feedback for Speech Sound Errors in Childhood Apraxia. Front Hum Neurosci 2016;10:440.

123. Hsiao MY, Chang YC, Chen WS, Chang HY, Wang TG. Application of ultrasonography in assessing oropharyngeal dysphagia in stroke patients. Ultrasound Med Biol 2012;38:1522-1528.

124. Yabunaka K, Sanada H, Sanada S, Konishi H, Hashimoto T, Yatake H, Yamamoto K, et al. Sonographic assessment of hyoid bone movement during swallowing: a study of normal adults with advancing age. Radiol Phys Technol 2011;4:73-77.