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Functional ultrasound of the gastrointestinal tract

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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

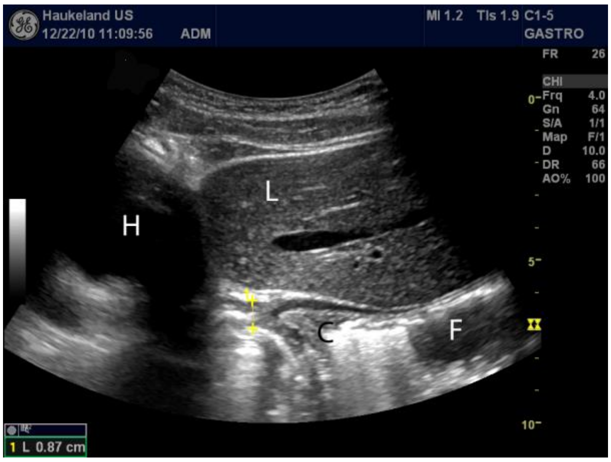
The cervical oesophagus is traceable left to the trachea in almost all patients. Starting from the left lower pole of the thyroid, the transducer can be positioned over the oesophagus while swallowing facilitates the identification. Osophageal motility can be sonographically monitored during swallowing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

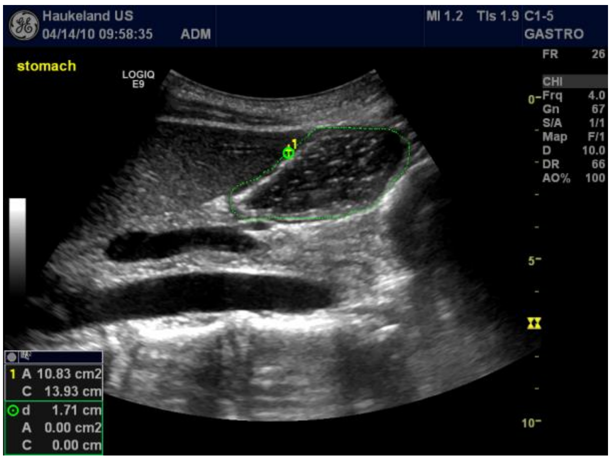
Gastric Emptying

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].