PAPER

Non-invasive investigation of gastrointestinal functions with magnetic resonance imaging: towards an "ideal" investigation of gastrointestinal function

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Gastrointestinal (GI) function is complex and physiological measurements are subject to a variety of technical difficulties and practical limitations. The ideal technique would be non-invasive, widely available, convenient, and reliable and would not expose the subject to ionising radiation. It would permit direct assessment of GI function in the postprandial as well as the resting state, and be able to differentiate between food, secretion, and air in the lumen. GI structure and function are interdependent and the ideal technique would permit simultaneous assessment of these factors. Finally, the bowel operates as a functional whole and assessment of the GI tract proximal and distal to the area of interest is desirable. In this article the authors summarise the development and validation of magnetic resonance imaging techniques that overcome many of the deficiencies of existing methods, and have many characteristics of the "ideal" investigation of GI function.

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Over the past 10 years high performance clinical magnetic resonance imaging (MRI) has become widely available around the globe. Continuous improvement of MR gradient strength and speed (fields and slew rates up to 60 mT/m and 150 mT/m/ms, respectively) together with dedicated coils permit rapid, high resolution, and artefact free MRI of the human abdomen and pelvis. Innovative sequencing and parallel imaging, a recently introduced imaging method, has the potential to further increase imaging speed and/or image quality for MRI of organ function. Simultaneous development and application of various MR contrast agents enabled significant improvements in image contrast and delineation of organs and vessels. These factors have improved the spatial resolution of MRI and brought acquisition speed into the physiological range of most gastrointestinal (GI) events. Image acquisition in GI studies must be rapid because the bowel is in constant movement. Spatial resolution must be high to delineate thin walled, convoluted GI structures from other abdominal structures. These advances have stimulated investigation of MRI techniques for the study of GI function as well as structure and promise much for future applications in the clinic.

The first reports of MRI in the study of GI function were for the assessment of gastric emptying.[1 2] Further studies have validated MRI for the measurement of gastric accommodation, gastric motility, small bowel, colonic, and anorectal function. With the application of paramagnetic contrast agents luminal contents, gaseous, solid, and liquid phases, can be resolved. Gastric secretion can also be assessed and recent studies have also demonstrated that MRI can be used in the functional assessment of the exocrine pancreas. In addition MRI provides exciting new opportunities in the assessment of visceral sensation.

OESOPHAGUS

Oesophageal function has been observed using a recently developed rapid MRI sequence true fast imaging with steady state precession (TrueFISP).[3] However, maintaining spatial and temporal resolution during the very rapid sequence of motor events that characterise deglutination remains a limiting factor and at present MRI provides no advantages over barium studies that accurately depict the swallowing process and delineate oropharyngeal abnormalities.

STOMACH

The evaluation of gastric motility and emptying disorders remains a difficult and somewhat inexact science.[4] Current methods for the assessment of gastric function are both technically challenging and have important limitations. Gastric physiology is highly complex and depends on the appropriate interplay of gastric accommodation, gastric contractile activity, and distal resistance. Interactions between these processes determine the rate of gastric emptying. Abnormal function of any individual process may have decisive effects on the whole. For example, in diabetic gastropathy impaired gastric accommodation may increase the rate of liquid gastric emptying, whereas weak trituration slows the emptying of solids.[5] The fine control exerted by this integrative mechanism is highlighted by the high day to day intraindividual variation in gastric emptying of 10% to 20%.[6–9] There is also a high inter individual variation in gastric emptying. These effects are

Abbreviations: GI, gastrointestinal; MRI, magnetic resonance imaging; SPECT, single photon emission computed tomography; EPI, echo planar imaging; fMRI, functional MRI physiological, seen with all investigation modalities and do not represent measurement artefact. Standard measurements of gastric physiology either assess global function (gastric emptying) or individual components of gastric physiology. A single test rarely gives a full account of gastric function; rather combining investigations provides complementary information. The unique advantage of MRI is that it may permit simultaneous measurement of multiple physiological variables.

Gastric emptying

Gastric emptying is a compound function; gastric tone and contractile activity together with pyloric function and duodenal resistance determine the rate at which ingested material is delivered to the small bowel. Measurement of gastric emptying is the only test of gastric physiology available to most clinical practitioners. Gastric scintigraphy provides the standard, direct, non-invasive measurement of gastric emptying. However, this test involves radioactive isotopes and is not suitable for children and pregnant mothers, or when repeated measurements are required. Different radioactive isotopes are available to label the solid and liquid components of a meal. The results are quantitative and generally expressed by two summary statistics: half time ($t_{1/2}$) for the stomach to empty 50% of the test meal, and lag time (t_{lag}) the period after a meal before significant emptying begins. Grossly abnormal intragastric distribution of a meal[10] and gastric motility[11] can also be assessed by scintigraphy. However, low temporal and spatial resolution precludes any but the most general comments about gastric motor function and errors may arise related to changes in shape, position, and distribution of gastric contents during emptying.[12 13] Alternatives include intubation techniques, such as the double indicator method, and stable isotope ^{13}C breath tests. The first is invasive, technically demanding, and rarely applied in clinical practice. The second is non-invasive, non-radioactive, and shows a good correlation with results determined by scintigraphy in health and disease, however breath tests provide only an indirect measurement of gastric emptying and optimal algorithm for analysis remains controversial.[14] In addition, neither technique provides any information about gastric accommodation or contractile activity.

The assessment of gastric emptying using MRI involves the repeated acquisition of transaxial image stacks covering the gastric region after a test meal. The most widely applied method uses a multislice turbo spin echo (TSE) technique. Imaging is performed during breath holds to minimise movement artefacts. Other respiratory compensation techniques such as gated acquisition to thoracic diameter or diaphragm position have also been attempted. For analysis the total gastric volume and meal volume are identified by distinct positive contrast and are outlined on the images. The volumes are then determined by multiplying the sum of these areas by the slice thickness. With positive paramagnetic contrast markers (for example, gadolinium-DOTA) gastric volume can be corrected for gastric secretions by reference to the signal intensity of an external standard. In conclusion, a time plot of corrected gastric volume provides a direct assessment of $t_{1/2}$ and t_{lag}. Semi-automatic analysis now in development will greatly reduce the time required for image processing.

MRI measurement of gastric emptying has been validated against a double indicator intubation technique[2] and against gastric scintigraphy for liquid and solid meals.[13 15–17] The results correlate closely for patients over a wide range of gastric emptying times in health[2] and disease, including diabetic gastroparesis.[18] The technique is also sensitive to pharmacological interventions that modulate the rate of gastric emptying.[19]

MRI studies have also investigated the mixing of foods with gastric secretions and the distribution of liquid and solid gastric contents within the gastric lumen. These studies have shown that rapid and complete mixing only occurs for liquid meals; with gastric secretions able to penetrate a solid bolus only slowly.[20] Moreover the more peripheral components of the meal empty more rapidly from the stomach, probably because of the action of gastric contractions on the surface of the bolus and moving fluid distally.[20] In addition using T1 weighted imaging sequences; layering of fat separate to the aqueous phase can be resolved. Fat layering above the aqueous phase also influences gastric function.[21] Depending on position relative to the pyloric outlet the fat layer either emptied early or late leading to differential effects on gastric emptying, presumably because of the timing of feedback from duodenal receptors.

Gastric accommodation

Gastric accommodation describes the reduction in gastric tone and increase in compliance observed (predominantly) in the proximal stomach following meal ingestion. Accommodation comprises at least two responses, receptive relaxation that enables a volume increase without a rise in gastric pressure and adaptive relaxation that adapts the gastric tonic response to the physicochemical properties of the ingested meal. The first response provides an appropriate reservoir, the second is probably important in determining the rate of gastric emptying. Gastric accommodation is important because reduced postprandial relaxation of the stomach is considered a likely cause of symptoms in non-ulcer dyspepsia[22 23] and postvagotomy syndromes. Conversely increased gastric accommodation might be a cause of gastro-oesophageal reflux.[24]

Considerable technical difficulties are faced in measuring the accommodation process. Gastric barostat studies are the best established method and entail the introduction of a balloon into the gastric fundus. Isobaric or isovolumic expansion of the balloon is then performed with continual, independent monitoring of intra-balloon volume or intra-balloon pressure respectively. However, the gastric barostat is invasive, uncomfortable, difficult to use with solid food, changes the intra-gastric distribution of a meal, and may exaggerate the relaxation of the stomach wall because of the direct stimulus of the balloon.[25] It remains however the only technique that measures intra-gastric tone and visceral sensitivity. Ultrasound imaging permits the non-invasive measurement of gastric accommodation. The technique is indirect and based on 2D measurements of gastric antral diameter.[26] Gastric ultrasound imaging is user dependent and the images produced are often of poor quality and difficult to independently verify.[27] Combined with a position and orientation measurement device[28 29] ultrasound can improve visualisation of the proximal stomach and allows 3D reconstruction of the images to provide a volumetric assessment of gastric accommodation. Nevertheless, assessment of accommodation by ultrasound and barostat do not correlate well.[30] This may be attributable to measurement error or because different components of the accommodation response are measured by the different techniques.[28] Moreover the costal margin and the presence of air in the abdomen limit ultrasound images and solid meals cannot be used because sonographic artefacts obscure the gastric dimensions. Singlephoton emission computed tomography (SPECT) provides simultaneous assessment of gastric accommodation and gastric emptying by radioactively imaging the gastric mucosa.[9] Repeated multiorbit tomographic studies are acquired with a dual head gammacamera system. Transaxial images of the stomach are produced and measurements of gastric volume and accommodation are calculated. The technique has not been validated against the barostat, however it has been shown to be sensitive to pharmacological modulation of the accommodation process.[31] Reduced accommodation in non-ulcer dyspepsia has also been observed with this technique.[32] SPECT has important limitations however, it entails significant exposure to ionising radiation, does not assess gastroduodenal motility, the extensive image reconstruction and filtering techniques are time consuming, and the spatial and temporal resolution is not comparable to MRI.

MRI measurements of gastric accommodation are acquired in a similar manner to gastric emptying. Transaxial image stacks are acquired at regular time intervals covering the gastric region. Proximal and distal stomach volume are identified on the MRI images and analysed as described for gastric emptying. The measurement of gastric accommodation with MRI has been validated against the gastric barostat. Barostat volume correlates accurately with MRI measurements during phasic pressure changes after meal ingestion and tonic relaxation induced by glucagon.[19] Preliminary studies also demonstrate the effects of fat and carbohydrate meals on gastric accommodation. For a given volume initial changes are identical as the stomach adapts by receptive relaxation. As gastric emptying progresses however, differential effects of the macronutrients on gastric accommodation and emptying are observed, presumably reflecting different feedback from duodenal receptors.[33]

Gastroduodenal motility

Gastroduodenal motility exists in distinct fasting and postprandial states. In the postprandial state rhythmic contractions migrate distally towards the pylorus, the sphincter narrows as contraction approaches, forcing the gastric contents back into the body of the stomach. This process of trituration mixes and grinds ingested food and together with chemical and enzymatic digestion solid matter is broken down into a homogenous mixture (chyme) ready for passage through the pylorus into the small bowel. Duodenal contractile activity occurs at a higher frequency distal to the pylorus and is not coordinated with gastric contractions.[34] In contrast during the fasting state intense, coordinated gastroduodenal contractile activity (phase III of the migrating motor complex (MMC)) clears the stomach of debris and prevents bacterial overgrowth

Gastroduodenal manometry provides a quantitative measure of intraluminal pressure activity, however in the postprandial period peristaltic contractions are not often occlusive and not reliably associated with intraluminal pressure changes or "peristaltic", forward flow.[34,35] Therefore manometry does not provide an accurate picture of postprandial gastric activity; rather it is used to record normal phase III MMC activity and appropriate changes between the fasting and the fed state. In addition catheter placement is invasive, positioning can be difficult, and catheter migration is a common occurrence. Electrogastrography (EGG) is used to measure the electric activity generated by gastric muscle by using surface electrodes. However, although arrhythmias in the gastric slow wave may predict gastric dysmotility, unlike the QRS complex on the electrocardiogram, slow wave activity recorded by the surface electrogastrogram does not correlate with the presence of gastric contractions.[34,36] Gastric ultrasound documents antral contractile activity (occlusive and non-occlusive) and transpyloric flow. Simultaneous measurement of these factors is difficult however and, as noted above, the technique is associated with various potential sources of error.

Oblique coronal MRI images along the long axis of the stomach are used to assess gastric motility. Rapid imaging of a single slice at approximately 1/second using a dynamic gradient echo sequence is applied for image acquisition.[16,17] This time scale allows gastric contractions to be followed closely as they progress distally towards the pylorus. Analysis of the MRI images can quantify frequency and depth (occlusion) of gastric pressure waves at pre-defined positions of the stomach. Combined with volume sequences the rate of gastric emptying can be assessed at the same time. Measurement of phasic gastroduodenal motility with MRI is more difficult than anatomical and volume studies for practical and technical reasons. Gastric position can change with posture, respiration, and intrinsic muscular activity. Gastric contractions are neither high frequency nor regular and, in contrast with the heart, phase locking to GI myoelectrical events is not possible. Peristaltic contractions produce lateral movement and shortening of the stomach as well as contraction that impairs image quality especially in the antropyloroduodenal region. These issues make imaging the pylorus extremely difficult. Validation studies have compared MRI with gastroduodenal manometry. Similar to ultrasound imaging, MRI appears to under-detect propagated events, whereas manometry detected a greater number of isolated duodenal pressure waves.[37,38] Non-invasive tests remain unable to measure gastric tone or intraluminal pressure events. However, MRI flow measurements can be acquired across a single axial slice at any point along the gastric long axis. This technique uses a velocity sensitive echo planar imaging (EPI) sequence and has been used to show that antral activity is associated with substantial forward and backward flow rather than peristaltic bolus transport.[35]

Combining volume, motility and potentially velocity sequences provides unique insights into the mechanisms that control gastric emptying. Early studies revealed changes in antral motility with glucose loads of different concentrations, however the association of antral activity to gastric emptying was not strong.[39,40] Combining MRI with manometry provides gastric volume, space-time pressure, and contraction wave histories. This work suggests that gastric emptying of nutrient liquids is unrelated to contractile activity; rather fluid appears to follow the small positive gastroduodenal pressure gradient and suggests that gastric emptying may be controlled by gastric tone rather than peristaltic action.[41] Thus, MRI demonstrates significant advantages over existing techniques for the measurement of gastric emptying, accommodation, and contractility. Combined with pressure measurements it also provides a "global view" of gastric function.

Gastric secretion

The assessment of gastric secretion is a further application of MRI. In the past this aspect of GI function has only been investigated by intubation techniques that are invasive, unpleasant, and may influence the production of GI secretions, especially saliva.[42] There is an exponential correlation between the dilution of a labelled liquid meal and the resulting signal intensity in the MRI image. With solid meals a linear correlation is obtained.[13] By comparison with the intensity of an external standard and the labelled gastric content the volume of gastric secretions can be calculated.[2,13] Alternatively the effects of gastric secretion on the viscosity of polysaccharide solutions can be used; viscosity is reduced by dilution and affects the transverse nuclear relaxation process (T2 relaxation time) of polysaccharide molecules measured by MRI. With this information meal dilution and hence the volume of gastric secretion can be calculated from measured changes in meal viscosity.[43] These measurements were initially developed to correct total gastric volumes for gastric secretion,[2] however the potential exists for studies into the relation of gastric secretion, meal viscosity, and the influence of these factors on GI function.

EXOCRINE PANCREATIC FUNCTION

Magnetic resonance cholangiopancreatography (MRCP) shows promise as a replacement for diagnostic endoscopic retrograde cholangiopancreatography (ERCP), for example in the diagnosis of chronic pancreatitis.[44,45] However, the diagnosis of pancreatic insufficiency is not reliably predicted by the typical ectatic changes in the pancreatic ducts.[46,47] The reference standard investigation for exocrine pancreatic function, the secretin test, entails collection of duodenal secretion through nasoduodenal catheters after hormonal stimulation of the pancreas. The process is time consuming, technically demanding, and expensive. Secretin has been used to improve the visualisation of stenotic and irregular pancreatic ducts on MRCP. Developments in MR technology including the use of surface coils and single shot, T2 weighted MR sequences has allowed researchers to quantify the pancreatic duct and duodenal filling after administration of secretin.[48 49] These measurements correlate with duodenal filling and biochemical parameters determined by invasive intubation methods in health and disease, detecting patients with abnormal pancreatic exocrine function with high sensitivity and specificity.[49 50] Other workers have not found a robust difference in duodenal filling and consider the T2 weighted signal of the pancreas as a better marker of pancreatic insufficiency.[51] Nevertheless, once the best measure has been established, secretin MRCP may provide a simple, non-invasive quantitative test of pancreatic exocrine function. Potential also exists for the development of similar tests for the assessment of biliary function and secretion from other exocrine glands.

SMALL BOWEL AND COLON

Clinical studies of small bowel and colonic function are technically difficult and, with the exception of transit tests, rarely performed in clinical practice outside research centres. Investigations of small bowel function include manometry, marker tests, scintigraphic transit time, and the hydrogen (lactulose) breath test. Gastroduodenal or small bowel manometry provide quantitative pressure data. As in the stomach propulsive peristalsis is clearly demonstrated only during phase III of the MMC. Otherwise complex intraluminal pressure events are seen in health that can be difficult to correlate to bolus movement. Scintigraphic transit and breath tests use orocaecal transit time as a proxy for foregut (stomach and small bowel) transit time.

MRI can observe transit, volume changes and peristaltic contractions in the small bowel and colon, however practical and technical factors make formal measurement of motility difficult. In the postprandial period motor function includes propulsive contractions and segmental contractions, serving both to move chyme forward and ensure effective contact of the absorptive mucosa with the luminal contents. In addition quantitative assessment of small bowel and colonic function is difficult because of unpredictable movement, the comparatively small diameter of the lumen, and the complex 3D structure formed by the bowel.

Nevertheless the analysis of small gut function has been shown to be feasible. Distension of the small bowel can be produced by ingestion of ispaghula (Metamucil) in aqueous solution that forms a voluminous, non-absorbable, viscous hydrogel within the small bowel lumen.[52] Labelled with a positive paramagnetic contrast agent this enabled the measurement of not only small bowel anatomy but also contractility as assessed by repeated measurements of small bowel diameter during breath holds. The sensitivity of the functional measurements has been demonstrated by pharmacological modulation, scopolamine butyl bromide (Buscopan) inhibited and metoclopramide (Paspertin) stimulated jejunal contractility.[53] Thus MRI provides not only an alternative to transit tests in the small bowel but also an opportunity to measure small bowel contractility. Modifications of the technique may permit the assessment of bolus movement through sections of bowel. In addition, measurements of GI secretion and fluid absorption may be possible by reference to the signal intensity of external standards.

In the colon, "virtual colonography" using MRI has been proposed as a possible alternative to endoscopic investigation.[54 55] Colonic distension and contrast is achieved with a gadolinium enema and fast T1 weighted 3D gradient echo sequences are obtained in the prone and supine positions. MR colonography combines the volumetric data obtained in this manner with 2D and 3D image processing to create images of the intraluminal appearance of the bowel. Unfortunately, although the lower spatial resolution required for functional studies decreases acquisition time compared to MR colonography, 3D imaging (that is, on several planes) with fast gradient echo techniques still requires at least 20–30 seconds. Thus, the acquisition speed required for tracking a peristaltic contraction through the colon remains beyond the capabilities of current technology. However, simple measurements of contractility are possible using the same technique as in the small bowel.

ANORECTUM

Defecation involves the action of anorectal and pelvic floor muscles to evacuate stool from the rectum. The process involves the integrity of structural factors such as the pelvic floor musculature and the coordinated function of voluntary and autonomic muscular function. A wide variety of complaints can be referred to damage, disease or abnormal function of defecation including chronic constipation, obstructed or incomplete evacuation, rectal prolapse, and pelvic pain syndromes. Clinical examination and endoscopy are essential in the investigation of abnormal defecation but are often non-diagnostic. Fluoroscopic defecography is a valuable technique in the diagnosis of anatomical changes during evacuation and anismus, however it is limited by poor visualisation of the pelvic floor and overlapping of structures, and the comparatively high radiation dose (up to 4.9 mSv) required to visualise the pelvis.

With the advent of open configuration MRI systems, enabling image acquisition in the vertical or sitting patient position, dynamic MRI defecography has become possible. The rectum is filled with a semi-solid labelled with a positive contrast marker. The patient sits on a commode between two magnet rings and based on axial localising images a sequence of MRI images is acquired in the sagittal plane during contraction of the pelvic floor and defecation. The stack of images acquired is then analysed on a workstation. This technique provides a "global view" of the pelvic viscera and musculature, permitting analyses of the anorectal angle, opening of the anal canal, functioning of the puborectal muscle, and descent of the pelvic floor during defecation. The rectal walls are well delineated, permitting visualisation of intussusceptions, and rectoceles. The concomitant depiction of structures surrounding the anorectal canal is helpful in the assessment of the pelvic floor and the descending perineum syndrome and in permitting visualisation of enteroceles.[56] MR imaging has been validated against fluoroscopic defecography with excellent agreement for all variables.[57 58] Moreover, in a comparison of MR defecography against standard clinical investigations, including proctography, a high level of agreement was demonstrated and further significant abnormalities were detected in one third of patients.[58] The clinical utility of MRI defecography is evidenced by the fact that it is the only MRI measurement of GI function that, where available, is routinely used in clinical practice.

VISCERAL SENSITIVITY

In GI disease symptoms are often poorly correlated with the presence of gastric motor dysfunction. Especially in functional bowel disease the intake of food or the occurrence of visceral events that usually go unnoticed in controls frequently causes unpleasant symptoms. Thus, hypersensitivity to normal GI events may be an important potential cause of abdominal symptoms. However, the acquisition and interpretation of sensations during visceral stimulation is difficult because of the dynamic relation between gastric function and sensation. MRI offers the opportunity to correlate visceral sensations with natural, physiological events rather than experimental stimuli such as barostat balloon dilatation. For example, using polysaccharide test meals, high viscosity and high nutrient content were found not only to delay the rate of gastric emptying and increase gastric secretion, but these effects could be related to increased post-prandial satiety. In a similar fashion we are currently using MRI to investigate the relation of abdominal pain, nausea, and earlier satiety with impaired gastric motor function in patients with non-ulcer dyspepsia.

Another use of MR technology in the investigation of visceral sensitivity involves functional MRI (fMRI) of the brain to provide objective measurements of neural activity in response to GI events or stimulation. The blood oxygen level dependent (BOLD) MRI technique can differentiate between oxyhaemoglobin and deoxyhaemoglobin. On GI stimulation blood flow increases in several areas of the brain. Recent evidence from BOLD fMRI seems to offer objective evidence that CNS activity in response to visceral stimulation is altered in functional bowel disease. Several studies in patients have shown that although the areas of the brain associated with discriminative function respond in a generally appropriate fashion to GI stimulation, the emotional cortex responds in an abnormal, exaggerated fashion.[59 60] At present although these findings are intriguing, the true meaning of these effects is difficult to assess and the whole technique has been playfully compared with phrenology. In addition methodological problems exist, in particular the difference between basal and activated measurements on fMRI is only of the order of 1%–5% and various techniques must be used to improve the signal to noise ratio. Looking to the future however, fMRI offers the opportunity for the objective measurement of visceral sensation. Still further in the future magnetic resonance spectrography (MRS) may allow us to monitor the metabolism of specific neurotransmitters in the brain and, potentially, in the enteric nervous system as well. However, the spatial resolution of MRS will have to improve by an order of magnitude before this becomes possible.

CONCLUSION

Gastric MRI has many of the properties of an ideal investigation for GI function. The images themselves are remarkable in their clarity. The preliminary findings provide insights into previously inaccessible visceral events. The technique is non-invasive, reliable, and does not expose the subject to harmful radiation. It permits direct assessment of GI function in the postprandial as well as the resting state, and differentiates between food, secretion, and air in the lumen. The anatomy as well as the function is visualised and multiple visceral processes can be observed simultaneously.

Despite those advantages MRI is not without important limitations. The technique remains expensive, programming the special imaging sequences requires the skills of specially trained personnel, the analysis and interpretation of the images requires specialist knowledge, and the reconstruction of gastric volume is time consuming. Moreover, the lack of a true standard of reference for comparison makes validation with existing techniques more difficult. At issue is not the "reality" of the images but the mathematical analysis and interpretation of the functional information provided by MRI.

As yet MRI measurements of GI function have been applied almost exclusively in the study of basic physiology. However, the techniques described could be valuable in the clinical setting for diagnosis and for monitoring response to treatment. Disturbances of gastrointestinal function are common in many systemic disorders and are considered important in the development of common visceral sensations such as nausea, early satiety, abdominal pain, bloating, and constipation. Standard imaging procedures and endoscopy are frequently unrevealing, however the increased sensitivity of MRI may provide us with the means to define the clinical significance of a variety of motility disorders in a wide range of patients. Moreover, if these techniques prove to be accurate and reproducible, it may be possible to separate clearly normal function from abnormal function by stressing the system under study by mechanical or pharmacological means. By assessing the functional response to a stressor, the range of what would be considered normal may narrow. Thus the technique would not only have high sensitivity, but high specificity as well.[4] Talley has called for the treatment of motility and functional GI disease to be aimed at correcting pathophysiological abnormalities.[61] MRI may identify relevant functional abnormalities, and allow us to select specific treatments for the correction of these disorders and the alleviation of symptoms.

In summary, there is a large potential for the application of MRI techniques in the evaluation of GI physiology and a variety of motility disorders. Growing evidence demonstrates that MRI is sensitive to the changes seen in disease states and to the effects of various therapeutic and physiological challenges. We believe that MRI represents the future in the measurement of GI function in humans.

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