Measurements of GI Motility

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Introduction

Although the morphology of the alimentary tract can simplistically be described as a muscular tube extending from the mouth to the anus the motility of the gastrointestinal tract is organized in a complex way. The diameter of the tube is not the same throughout its length. There are widenings and narrowings so that different compartments are formed, which are more or less separate from each other. The contractions of the gastrointestinal tract can be divided into two types. ***Tonic contractions*** are long lasting. Tone is a state of stable and protracted contraction of the smooth muscle. Tonic contractions form sphincters and haustral indentations of the colon. They are prominent in the proximal stomach and the gallbladder. ***Phasic contractions*** are short and (more and less) rhythmic. They predominate in the tubular esophagus, the distal stomach and the small intestine. Peristaltic phasic contractions transport a bolus aborally, simultaneous contractions mix and grind the intestinal content, and for example in the colon retropulsive contractions even propagate orad.

Apart from recording contractions motility can be tested by measuring the transport of a marker in the alimentary tract. Gastric emptying studies are performed in this way as well as measurements of transport in the small or large intestine.

Motility studies are not only done in scientific research but are also useful in assessing patients and guiding their treatment. Measurement of gastrointestinal motility needs not to be complicated but it is sometimes difficult in the clinical setting to choose the appropriate test and to interpret its results.

Combined measurement of contractions and passage

Radiology

Radiography is the oldest method of examining the movements of many parts of the gastrointestinal tract. The first observations of gastric and colonic motility were done using radiography with barium contrast. But radiology has a major disadvantage especially in humans: The dose of radiation it delivers makes prolonged observations impossible. In addition the contrast media are not physically and chemically comparable to food which often provokes the patient’s symptoms. Nowadays radiography is performed only in a special dynamic technique called ***cineradiography*** (1-3) in patients with swallowing or defecation disorders.

Defecography makes the defecation process visible. The rectum is filled with a barium paste which should have the same viscosity as normal feces. The patient sits on a radiolucent commode following the rectal injection of the contrast medium. The radiological examination is done by taking the lateral pelvic view at rest, during straining and during defecation. A slow motion film is recorded and afterwards analyzed. Attention is paid to the anorectal angle, the lowering of the pelvic floor, anatomical changes like a rectocele, a prolapse or an intussusception, the opening of the anal canal and the expulsion of the contrast medium.

Deglutition disorders can also be analyzed by means of slow motion or frame-by-frame analysis of ***cinefluorographic or videotape recordings*** (Fig.1). This method is a helpful clinical tool especially for patients with oropharyngeal dysphagia and dyskinesia of the upper esophageal sphincter. ***Esophagograms*** are performed using either a semi-solid barium suspension or a solid barium-containing marshmallow. Cineradiography can identify altered patters of deglutition, defective closure of the laryngeal vestibule, immobility of the epiglottis and cricopharyngeal dysfunction but also defective peristaltic motor function of the esophageal body, dilation of the esophageal lumen and ineffective relaxation of the lower esophageal sphincter. At the same time other causes of dysphagia like malignancy, peptic stricture, rings, webs or Zenker's diverticulum can be excluded.

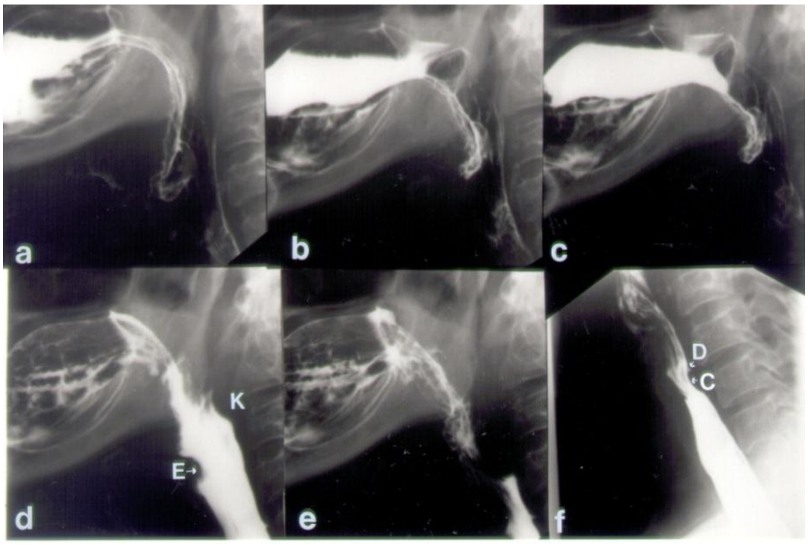

Fig. 1 ***Cineradiography:*** *Normal radiological sequence of deglutition. From the onset of swallowing (a) to the passage of the upper esophageal sphincter (f) every detail of the deglutition can be visualized. E= epiglottis K= pharyngeal contraction D= small Zenker's diverticulum C= cricopahryngeal muscle (upper esophageal sphincter)*

Plain films of the abdomen may also be helpful especially in patients with suspected pseudo-obstruction. Abdominal radiographs reveal in these patients marked dilatations of the small intestinal loops filled with air and fluid, and a variable degree of colonic distension. The presence of large amounts of air throughout the whole gastrointestinal tract distinguishes this motility problem from an obstructive ileus and helps to avoid an unnecessary laparotomy. A plain film of the abdomen may also be used to assess the degree of fecal accumulation in the colon in patients suffering from constipation.

The speed of passage through the alimentary tract can be measured by having the patient swallowed ***radio-opaque pellets*** or tiny rings which can then be seen on X-ray pictures. The mouth to anus time is normally 1-3 days whereas the passage from mouth to the large bowel accounts only for 1-6 hours. In practice the measured passage time is mainly determined by the ***colonic transit time*** of the markers. The radio-opaque markers can be ingested either as a bolus or on a daily basis followed by interval radiography of the abdomen (4, 5). A number of methods has been described. The method preferred in our institution is to give 20 pellets daily for six days and to carry out a plain film of the abdomen on the seventh day. Using this method the counted number of the markers on the X-ray picture (Fig. 2) has to multiplied by 1.2 to obtain the hours of total colonic transit time. Values exceeding 60 hours confirm objectively the diagnosis of constipation. Radio-opaque markers can also be used to study ***gastric emptying***. In the method proposed by *Feldman* (6) small pieces of gastric tubing were ingested together with a test meal. After 6 hours all markers should have emptied from the stomach. Changes in the rate of emptying of pellets according to the composition of the meal suggest that the emptying of the marker reflects emptying of the meal and not emptying of the marker alone. But it must be emphasized that in contrast to studies using barium swallows or enemas pellet tests can give no information about contractions.

Fig. 2 ***Colonic transit time:*** *The x-ray picture shows a large amount of radio-opaque markers retained in the colon of a patient with constipation. Lines are drawn to enable calculation of segmental transit times of the right hemicolon, the left hemicolon and the rectosigmoid.*

Ultrasonography

The movements of stomach, pylorus and duodenum can be observed by ultrasonography after the subject has ingested a liquid or semiliquid test meal (7, 8). At the same time the gastric emptying of the test meal can be measured by calculating the antral cross-sectional area over time. However such an examination requires a certain experience and is time-consuming. So, this method is not used in daily clinical practice.

Pressure recordings

Manometry

Manometry is a technique to measure intraluminal pressures in the gastrointestinal tract either using water-filled catheters or electronic miniature pressure devices called microtransducers. For ***infusion manometry*** (9-11) the essential elements are a pneumohydraulic pump, pressure transducers, a polygraph, and manometry catheters (Fig. 3). The pressure transducers used in this technique are volume transducers. The displacement of water from the catheter into the transducer causes movement of the diaphragm in the pressure transducer. This movement of the diaphragm is transduced into an electric signal using sophisticated electronics, and this electrical signal can be shown on the polygraph. The accuracy of pressure measurements requires all three elements – infusion pump, pressure transducer and catheters - to be minimally compliant (i.e. hardly deformable). The usually used pneumohydraulical pump must be able to deliver a constant amount of water in order that the flow of the water in the catheter is constant. The catheters used for side-hole manometry (Fig. 4) are made of polyvinyl material to ensure a low compliance. These open-tip catheters incorporate various lumina, each of which is connected to a pressure sensor and is perfused with water (0.2 – 0.3 mL/min).

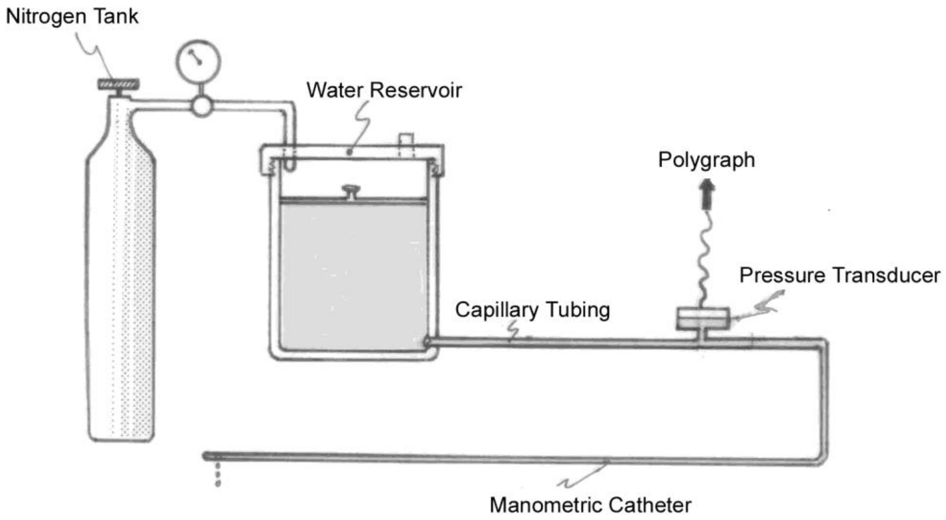

Fig. 3 ***Essential elements of infusion manometry*** *(scheme).*

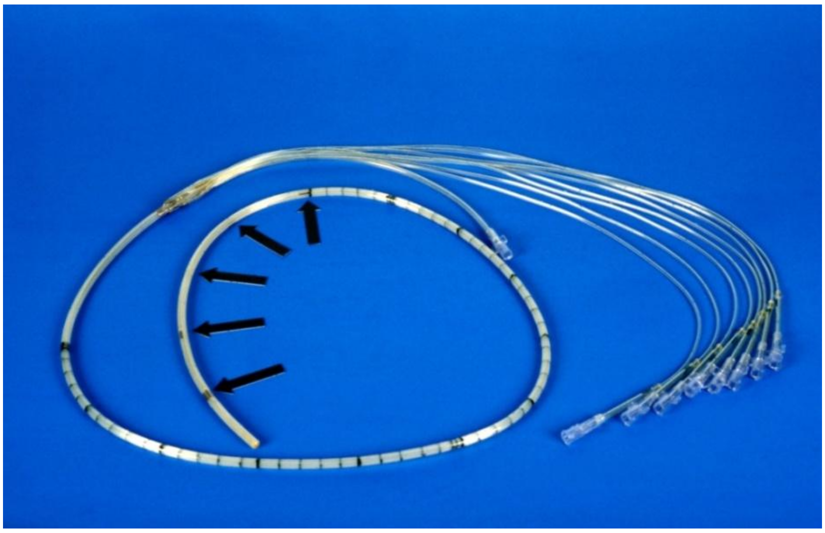

Fig. 4 ***Side-hole polyvinyl catheter for water-perfusion manometry****: This catheter is used for esophageal manometry*

Dent (12) developed in 1976 a ***sleeve*** device (Fig. 5) that uses a long pressure sensor instead of the point sensor of the side-hole manometry. A short or long membrane is used, depending on the sphincter of interest. The sleeve was designed to overcome the relative motion between for example the lower esophageal sphincter and the pressure sensor during respiration as well as swallowing. Therefore the sleeve allows continuous recording of the sphincter pressure for long periods without motion artifacts.

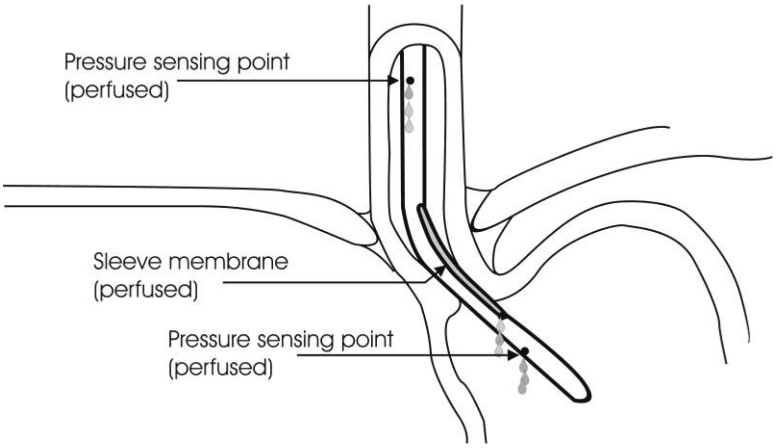

Fig. 5 ***Dent sleeve*** *(scheme): The sensor consists of a thin silicon rubber membrane under which water is perfused. The sensor measures the highest pressure exerted on the membrane.*

Instead of perfused catheters, catheters with incorporated electronic ***minitransducers*** are also used (13). These sensors transform the intraluminal pressure into an electric signal. This makes it unnecessary to have a system which continuously pumps a strictly controlled flow of water through the catheter. Thanks to this technique prolonged (ambulatory) manometric studies can be performed on outpatients.

Manometric studies can be done in various parts on the gastrointestinal tract. In the ***esophagus*** manometry allows us to assess various motor disorders causing dysphagia or non-cardiac chest pain like diffuse spasms, nutcracker esophagus, achalasia, and involvement of the esophagus in scleroderma and other systemic disorders. It is also done before performing antireflux surgery. ***Antroduodenal manometry*** is performed only in some tertiary centres as well as ***jejunal manometry***. Antroduodenal manometry may be helpful in same cases of gastroparesis; jejunal manometry is essential in diagnosing chronic intestinal pseudo-obstruction (CIPO) and helps in differentiating myopathic and neurogenic causes. The pressure in the bile tract and the ***sphincter of Oddi*** can also be assessed by using infusion or microtransducer manometry. In the recent years it has been shown that sphincter of Oddi dyskinesia can be responsible for biliary pain and impeded bile flow. Pressure measurement in the spincter of Oddi was shown to be helpful in deciding whether endoscopic sphincterotomy can be useful in these patients. ***Anorectal manometry*** is performed in patients suffering from anal incontinence and to rule out Hirschsprung’s disease or incomplete relaxation of the anal sphincter in patients with rectal constipation.

But it must be emphasized that there are also same drawbacks for manometry. First only lumen obliterating contractions can be assessed. Secondly this method is invasive and causes discomfort to the patients. Thirdly standardisation of many procedures is poor and reference values show a great variability. Last not least manometry requires skilled and experienced investigators and an established motility laboratory.

Barostat

Manometry can not measure the gut tone. This is only possible by using a so called barostat which is a pneumatic pump connected to an intraluminal flaccid bag made from polyethylene (14, 15). This instrument maintains constant pressure inside the bag. By injecting and withdrawing air isobaric volume changes can be recorded. Thus the barostat can measure relaxation or contraction of a hollow viscus (Fig. 6). By correlating pressure and volume the compliance and in consequence the ***tone of the intestinal wall*** can be calculated. The barostat is also useful for visceral sensitivity testing in patients with functional gut disorders. Although barostat studies have been done in the esophagus, stomach, small intestine, colon and rectum this is still a scientific tool for research which has no proper place in clinical practice.

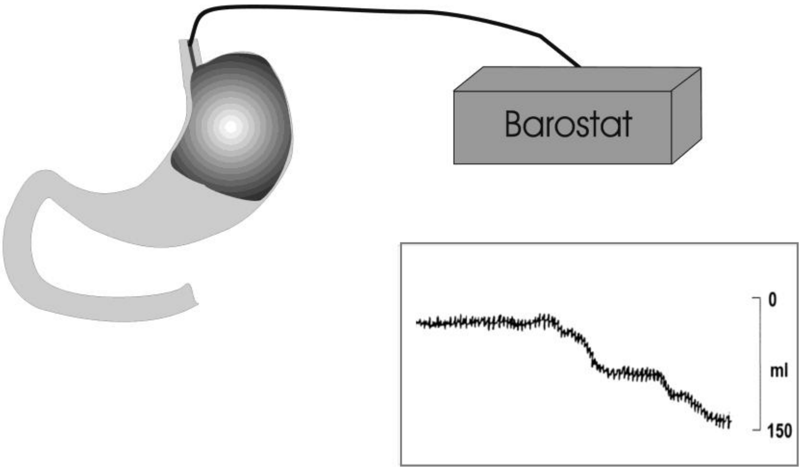

Fig. 6 ***Barostat:*** *The gastric fundus is relaxing in this example indicated by the increasing volume of the intraluminal barostat bag.*

Measurement of transit time

Scintigraphy

There are different ways of introducing radioactive tracers into the gastrointestinal tract in order to study their transport (16). The great advantage of scintigraphy is that transit through the alimentary tract can be observed for prolonged periods placing little strain on the patient. In addition different physiological test meals can be used. In clinical practice scintigraphy is mainly used for gastric emptying studies and is now considered to be the gold standard for this purpose. A whole range of test meals is used, ranging from liquid to solid. As tracers ^{99m} Technetium (half-life: 6 hrs.) and ^{113}Indium (half-life: 1,5 hrs.) are used. Gastric emptying of a liquid and a solid test meal can be measured simultaneously where the liquid meal is labeled with ^{113} Indium and the solid phase with ^{99m}Technetium (Fig. 7) (17). Both isotopes can be separately monitored by a scintillation camera (Fig.8). Gastric filling and emptying can be measured over time by this method. Special tracers can be used to observe bile transport, for example iminodiacetic acid (IDA). This substance is selectively filtered and excreted from the blood into the bile. This method is called HIDA scan (hepatobiliary IDA). Scintigraphic measurement of the transport time can also be performed in the small intestine and the colon. In the latter the tracer is introduced into the cecum either by using a catheter or specially coated tablets.

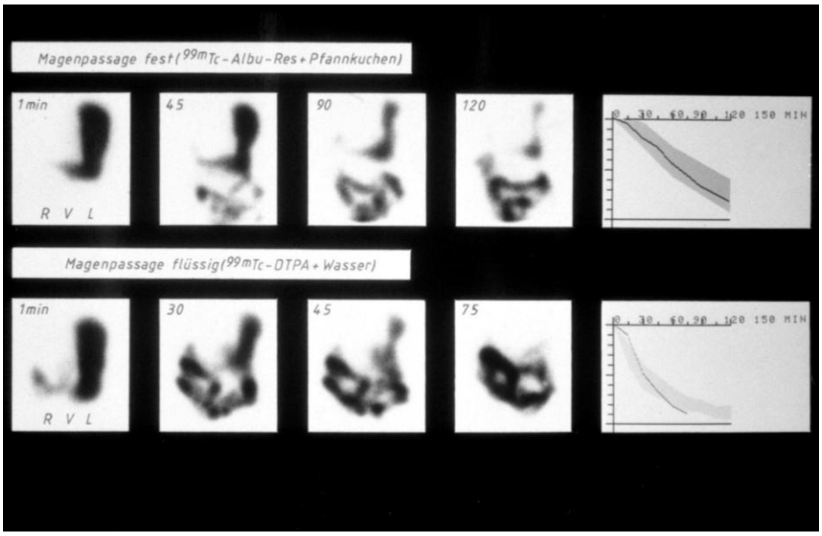

Fig. 7 ***Gastric emptying measurement by scintigraphy:*** *In the upper row an example of a solid test meal is shown and in the lower row gastric emptying of a liquid test meal (tap water) is displayed. In both cases* ^{99m}*Technetium was used as tracer.*

Fig. 8 ***Scintillation camera:*** *Photograph of the set-up for scintigraphic examination using a scintillation camera.*

^{13}C breath test

Gastric emptying can now be measured by a non-radioactive method using ^{13}C as marker. ^{13}C is a stable isotope of carbon and forms a safe medium for non-invasive diagnosis. Being non-radioactive, it can be used without any radiation hazard with everybody, including children and pregnant women. Mixed to the test meal ^{13}C is quickly resorbed, metabolized (mainly in the duodenal wall) and exhaled whereas carbon dioxide is the final product. With its quick time response, ^{13}C is appropriate for the use in exact kinetic studies. By measuring the ^{13}C/^{12}C isotope ratio at CO_2 in breath the ***gastric emptying*** rate of the labelled test meal can be calculated (18). For measuring the $^{13}C/^{12}C$ isotope ratio in the exhaled air a mass spectrograph or an infrared spectrometer are used. The latter method is less expensive and less time consuming to perform. The stable isotope ^{13}C is either incorporated into octanoic acid in solid test meals or into acetic acid in liquid test meals. Measuring gastric emptying by using ^{13}C as marker has shown to be accurate when compared to scintigraphy (18).

Hydrogen (H_2) breath test

The small intestine in humans is unable to break down some carbohydrates like the synthetic lactulose, a disaccharide comprised of the sugars D-galactose and D-fructose. Bacteria in the large intestine are able to ferment lactulose, releasing hydrogen (H_2) as one of the final products. The gaseous hydrogen is quickly absorbed into the blood and exhaled from the lungs. After ingestion of lactulose and measurement of hydrogen in the exhaled breath, we can assess how long it takes for the test meal to reach the cecum. After reaching the colon a sharp peak of hydrogen concentration will appear in the exhaled breath (Fig. 9). Bacterial overgrowth of the small intestine should be excluded for example by a hydrogen breath test with glucose as test substrate. Otherwise bacteria in the stomach or small intestine would pretend a too short orocecal transit time. The ***orocecal transit time*** is a good indicator for the speed of the small intestine passage (19). Lactulose can be given with water or mixed into a test meal. Alternatively a meal which contains a source of unresorbable carbohydrate such as baked beans can be used instead of lactulose. The test can be helpful in patients with unexplained diarrhea or constipation.

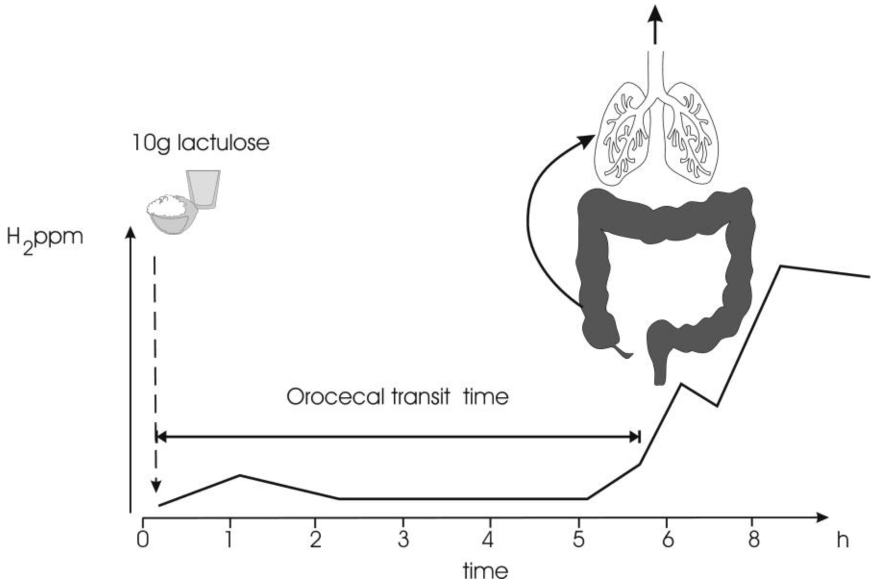

Fig 9 ***Measurement of orocecal transit time with the hydrogen breath test:*** *The diagram illustrates the principle of this technique. In this case 10 g of lactulose has been mixed to a test meal and then ingested by the patient. About 6 hours later there is a sudden rise in the quantity (ppm) of hydrogen (H_2) in the exhaled breath. This is the time when the lactulose arrives in the cecum.*

Pellet tests (radiology)

As already mentioned radio-opaque pellets can be used for assessing ***colonic transit time*** or ***gastric emptying***.

Impedance measurement

Impedance have long be established for monitoring the volume of various organs. The current frequency used does not influence sensitive neuronal synapses. Impedance measurement was used for non-invasive gastric emptying studies (20)
Multichannel impedance is a new technique designed to detect intraluminal bolus movement (21-23). The principle is based on measurement of changes in resistance to alternating electrical current when a bolus passes by a pair of metallic rings mounted on a catheter. Liquid boluses contain an increased number of ions exhibiting a higher conductivity. Thus they will lower the impedance. The impedance stays at its nadir as long as the bolus is present in the segment, returning to baseline once the bolus is cleared by a contraction (Fig. 10). In contrast gas will show a high impedance. In consequence gas passing will produce a transient rapid rise in the impedance since it has a poor electrical conductance. The direction of bolus movement can be seen by temporal differences in bolus entry and exit. A bolus progressing from proximal to distal indicates an antegrade movement whereas bolus entries progressing from distal to proximal indicate retrograde movement. The clinical value of this new technique is under debate. But first results and ongoing studies rise the expectation that this method could be helpful in functional dysphagia and in evaluating patients with gastroesophageal reflux disease and persistent symptoms on proton pump inhibitor therapy (24). It seems also to identify patients who may profit best from antireflux surgery (25). But further studies must be awaited.

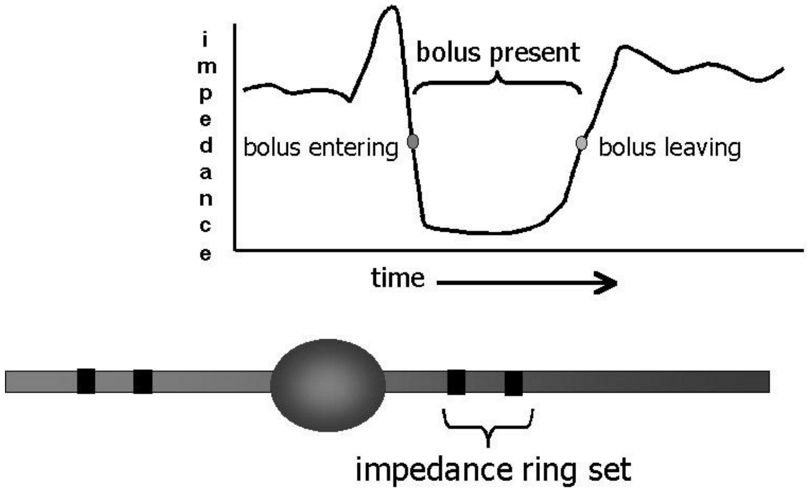

Fig 10. ***Impedance measurement:*** *This diagram illustrates the principle of impedance measurement: A bolus with a high conductivity (many ions) is passing the impedance ring set mounted on a catheter. As a consequence impedance between the two rings will be lowered. When the bolus has passed the ring set impedance will increase again.*

Conclusions

For direct and indirect measurements of gastrointestinal motility various techniques and methods are available. In clinical practice the physician has to choose the best test or combination of tests sufficiently specific and effective to analyze and identify the supposed individual motor disorder of the gastrointestinal tract. The current available motility tests have clear limitations and our knowledge about physiology and pathophysiology of gastrointestinal motility is incomplete. But this should not demoralize us. Advances in available instrumentarium, increase of our knowledge about gastrointestinal motility in health and disease and development of new gut-selective drugs will make our diagnoses more precise and our treatment more specific and effective. We always should remember the sentence *N.W. Read* wrote in 1989 (26): Science is never cast in stone, and ideas are written with a finger on shifting sand.

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