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Advances in the Measurement of Gastric Motility: A Review

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Abstract: The *motility of the gastric smooth muscle is an intricate process influenced by a variety of endogenous biochemical modulators, including meal content, hormones, nerves, muscles, and functional resistance of the duodenum. Therefore, the present manuscript focuses to review the techniques employed to measure gastric motility. The contrivances used include the following; scintigraphy, positron emission tomography, single positron emission computed tomography, magnetic resonance imaging, ultrasonography, stable isotope breath test, absorption kinetics of pharmaceutics and epigastric impedance. In conclusion, the breakthrough in biomedical engineering has revealed considerable details on gastric smooth properties that improve understanding of many unresolved or vague issues and has increased knowledge of pathophysiology of number gastric disorders.*

Keywords: *Advances, Measurement, Gastric, Motility, review*

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I. Introduction

Gastric motor function aids in milling, mixing and digestion of ingested food[1]. It facilitates nutrients, vitamins, minerals and water, transport and absorption for maintenance of homeostasis[2]. Gastric motility allows for growth of beneficial microorganism[3]. The motility of the gastric smooth muscle is a complex process influenced by a variety of endogenous biochemical modulators, including meal content, hormones, nerves, muscles, and functional resistance of the duodenum[4, 5].This elegant interplay between variety of neurogenic, myogenic and hormonal factors result in composite endpoint. The components of gastric motility are gastric emptying, myoelectric potentials, intraluminal pressure, contractions, motor patterns; luminal transit [6].The disease can affect the motor activity of the stomach leading to malfunction of the digestive process. Such maladies include the dumping syndrome characterized by rapid gastric emptying, hypovolemia with its associated cardiac disorders[7] or it may cause gastroparesis indicated by delay in gastric emptying, acid reflux, bloating, vomiting, diarrhoea or constipation, incontinence among others[8]. These changes are associated with subjective sensation of pain, fullness or urgency for bowel movement[8]. Other diseases that interfere with gastric motility may include diabetes mellitus, scleroderma, intestinal pseudo-obstruction, ileus, among others. It is necessary to measure gastric motility in health and in disease. The need to define normal gastric activities and the diagnoses of gastric disorders led to the discovery of a variety of methods used in gastric motility measurement. These techniques largely evaluate one parameter, but may overlap in certain activities. The techniques measures

1. Gastric emptying
2. intraluminal gastric pressure and
3. Gastric electrical activity.

The techniques used to quantify gastric emptying; include scintigraphy, positron emission tomography (PET), single positron emission computed tomography (SPECT), magnetic resonance imaging (MRI), ultrasonography, stable isotope breath test, absorption kinetics of pharmaceutics, epigastric impedance [2].
Intraluminal pressure component of gastric motility is monitored with manometry, ultrasonography, barostat, MRI, strain gauge transducer[9], strain rate imaging [10] among others. The electrical activity of the gastric smooth muscle is detected in electrogastrography[2, 6, 11].The various techniques for the gastric motility study are further classified as invasive or non- invasive. Each of the two methods is sub-divided into imaging and non-imaging

techniques. These innumerable techniques have undergone incredible technological breakthrough and refinement that reduces screening time, increase quality of result and improve the safety of the procedures used.
In this review, an attempt was made to look at

1. The functional anatomy of the motor region of the stomach
2. Physiological mechanism of gastric motility
3. Brief history of gastric motility measurements
4. The invasive and non-invasive techniques used to generate information on gastric motor function, their merits, challenges and advances in the 21st century.

1.1 Functional anatomy of the stomach

The human stomach is a sac- like, J-shaped elastic muscular structure that lies between oesophagus and the intestine. The stomach is located in the upper abdomen inferior to the diaphragm and lateral to the liver. It sometimes extends to the pelvis. The stomach is linked to the oesophagus at the lower oesophageal sphincter and terminates towards the duodenum at the pyloric sphincter. The anatomic regions of the stomach are the cardia, fundus, corpus, antrum and pylorus. The stomach has an outer arch called the greater curvature and a small inner depression referred to as lesser curvature[10].

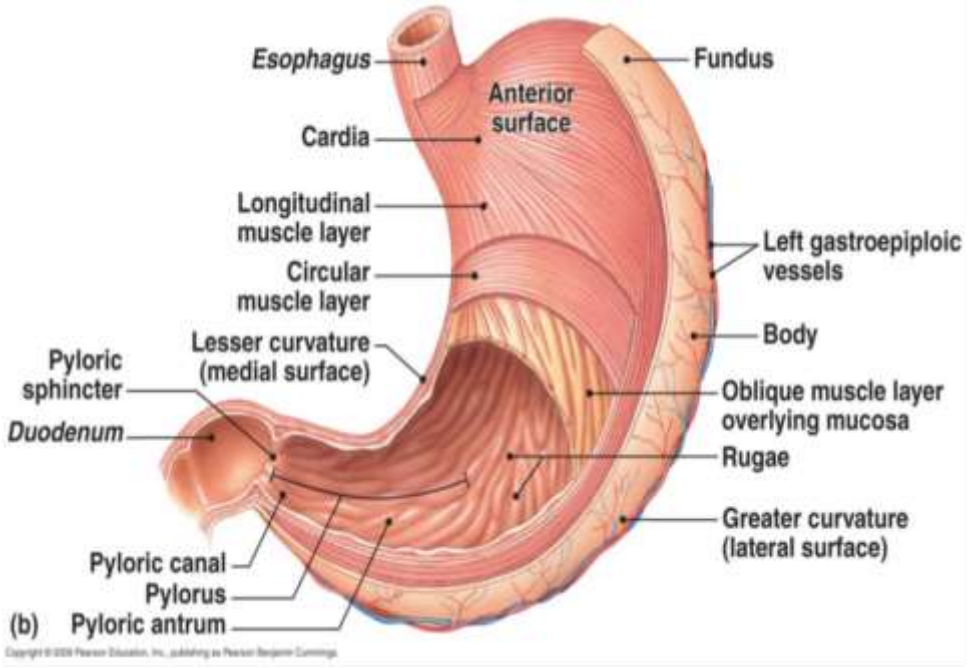

Figure1. The structure of the human stomach (adapted from Guyton and Hall, 2006)

The smooth muscle of the stomach has four distinct layers that include the mucosa, submucosa, mucosa externa and serosa. The gastric mucosa is composed of columnar epithelium that form the rugae, gastric pits, secreting cells and glands for production of hydrochloric acid, pepsin, mucus, hormones, enzymes, minerals and intrinsic factor[12-14].The gastric secretions aid in digestion and absorption of food. The intrinsic factor is essential for absorption of vitamin B_{12} in the small intestine, serve as precursors for erythropoiesis while the acidic medium of the stomach confers immunity against ingested microbe, and facilitate the growth of beneficial bacteria[13]. In addition, the stomach serves as temporary storage for ingested food; it mechanically breaks down ingested, disrupt chemical bonds in food material by acid and enzymes, mixes the chyme and convey it to the duodenum[13].The stomach seldom digests itself because of the gastric mucosal barrier arranged in a hierarchical manner analogous to the anatomic organization of the mucosa[14]. The mucosal defense is in pre-epithelial, epithelial and endothelial level. The first level comprised of lumen secretions such as acid, bicarbonate, mucus, immunoglobulins, antibacterial substances (lactoferrin) and phospholipids. Epithelium constitutes the second level of defense by forming a tight barrier to passive diffusion of acid and is continually being renewed with the older cells extruded to the lumen due to the action of gastrin and other gut hormones on mitotic cycle, cell renewal and mucosal growth. Microcirculation constitutes the third level of mucosal defense. It limits gastric mucosal damage by removing or diluting or neutralizes acid or toxic substances that diffuses into the mucosa from lumen and facilitate repair. Mucosal immune system forms the last component of defense by producing mast cells and macrophages that trigger an inflammatory response[16].

Functionally, the stomach is divided into gastric reservoir and the gastric pump[10]. The fundus and the proximal corpus constitute the gastric reservoir with a tonic activity that permit receptive relaxation triggered by swallowing reflex. A prolonged adaptive relaxation (accommodation) mediated by mechano-receptors in response to stretch of the gut wall is also observed as part activity of gastric reservoir. The intragastric and gastroduodenal pressure is kept constant due to sustained contraction of the proximal stomach regulated by slow waves from the interstitial cell of cajals[2]. The non- cholinergic, non- adrenergic neurotransmitters act on the oblique muscles of the stomach to modulate the receptive and adaptive relaxations[12].The distal part of the corpus and the antrum form the gastric pump. In this area, peristaltic waves (3cycles/minute) occur aborally with phasic activity on the pyloric valves [10].

1.2 Cellular and molecular mechanism of gastric motility

Gastric motility is an integrated process that has myoelectrical and contractile activity, tone, compliance and transit [17]. The gastric smooth muscle has interstitial cells of Cajal (ICC) located in the myenteric and submucosal plexuses to modulate ionic conductance expressed in gastric smooth muscle. The ICC are electrically coupled to smooth muscle cells, possess Ca^{2+} and voltage-dependent ion channels, tight junction, and forms syncytium with distinctive ionic conductance that trigger slow-wave generation, making ICC the pacemaker cells of the gut[17-18]. ICC may facilitate active propagation of electrical events, mediate neurotransmission and act as mechanoreceptors[19]. ICC is innervated by enteric neurons, respond to neurotransmitters, produce nitric oxide and amplify inhibitory neurotransmission by activating a dihydropyridine-resistant Ca^{2+} conductance[18, 20-21]. Entry of small amounts of Ca^{2+} into ICC entrains spontaneous pacemaker activity and produces cell-to-cell propagation of slow waves [19].Slow waves generated by the ICC elicit spike potentials in the stomach walls by depolarizing the smooth muscle cells from a resting membrane potential of between -75 and -55 to a peak potential of -40 and 25[22]. Acetylcholine released by the efferent enteric nervous system combine with G-protein coupled receptor (GPCR) on the muscuranic (M_4) cholinergic receptor to cause phosphorylation of guanosine diphosphate (GDP) subunit to guanosine triphosphate GTP. The GTP causes a conformational change, the cleavage of the $G\alpha_q$ subunit and its subsequent coupling to GTP. The activated $G\alpha_q$-GTP subunit trigger phospholipase Cβ (PLCβ), a lipase that cleaves the signalling phospholipids (inositol phosphatidyl, PIP_2) of the plasma membrane, generating several second messengers including inositol phosphate (IP_3) and diacylglycerol. The diacylglycerol activates phosphorylation by protein kinase C while the IP_3 combines with an IP3 receptor in the cytoplasm leading to release of calcium ion from endoplasmic reticulum[23].

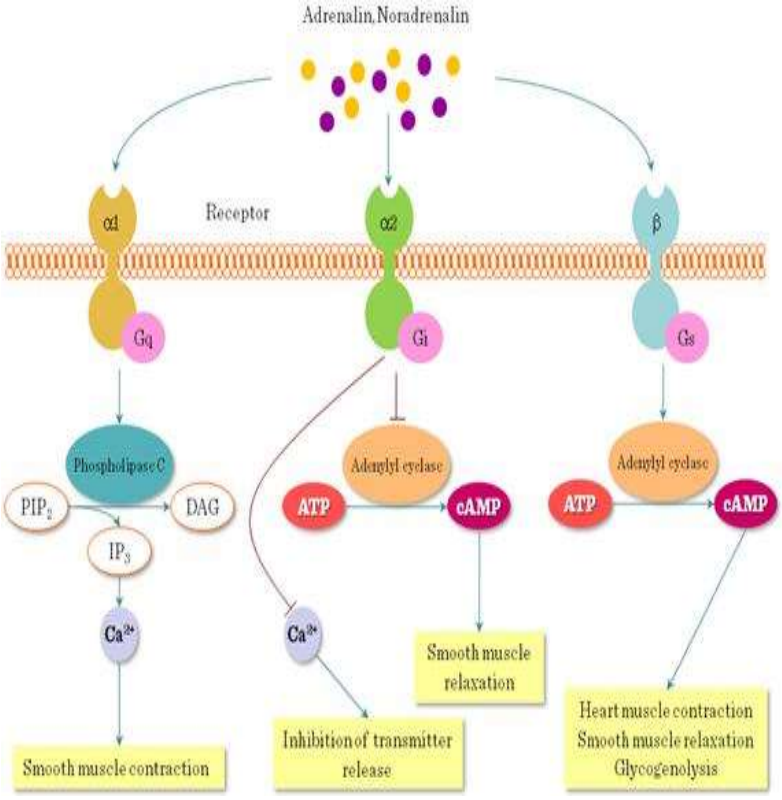

Figure 2. Activation of G- protein coupled receptor for gastric smooth muscle contraction (Eugene et al., 2014).

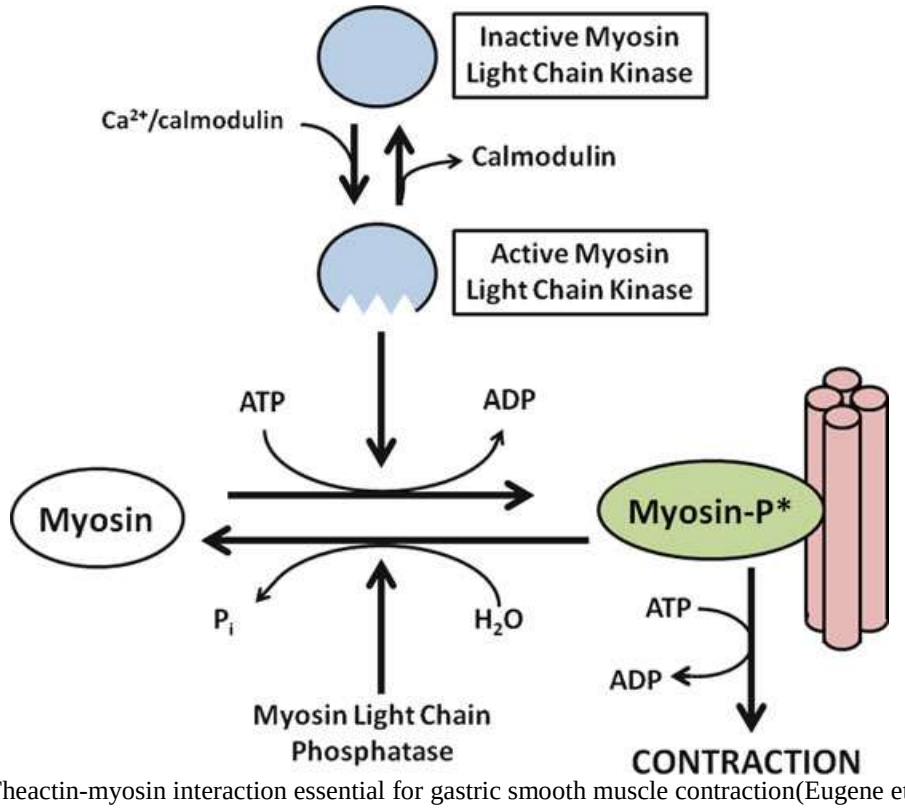

Figure 3. Theactin-myosin interaction essential for gastric smooth muscle contraction(Eugene et al., 2014)

1.3 Historical background of gastric motility measurements

Documented evidence of gastric motility recording began with the crude, cruel and inhuman work of Emperor Frederick II. His experiment was designed to establish the state of activity that aid digestion. Two able healthy men were fed with equal volume of fluid and the same quantity of food. The first conscript was asked to go for hunting while the second person was asked to rest at home. At an appointed time, the two men were sacrificed and their stomach content observed. It was concluded that the man who went on hunting had his stomach full while the person on sedentary activity had empty stomach[2]. Beaumont directly observed the to-and-fro movement of gastric contents in his patient with gastric fistula and concluded that the contractile activity of the stomach changes with psychological influences such as emotion and expectation of a meal. It was further confirmed in the same patient (Tom) that gastric hypomotility or hypermotility is dependent on the kind of emotion elicited. A refined gastric motor recording was obtained after the discovery of X-rays, X-rays images was used to describe segmented contractions, peristalsis, and changes in muscle tone as the basic patterns of gastric motility. The passage of bismuth-impregnated diet in cat with Crooke's tube placed beneath was traced on transparent papers. Coloured lead pencils were used to trace the outline of the shadows of bismuth cast on the fluorescent screen. The fluoroscopic examination evaluated stomach motility in cat during a rage, stress or fear[24].Seventy years after the pioneering work of Canon, new and safer X-ray equipment established the then famous cineradiography routine procedure and tape recordings of fluoroscopic images. It captures with good resolution oesophageal and gastric peristalsis, rhythmic segmentation, fast moving and gradually advancing peristalsis of the small intestine, and the mass movement contraction that empties the colon of its content [25].X- ray images on photographic plates at the beginning of the century were blurry and requires about 1,500 times more radiation dose than today's' X-ray. A more quantitative and reliable record of gastric motility was seen in the work of Canon and Washburn[25]. They used air-filled balloon in an intragastric tube connected to a Marey capsule, a pressure sensitive device that indicate contraction with rises in intragastric pressure. In the 1940's, the air filled balloons were replaced with water filled tubes. Catheters with mini pressure sensors were introduced in the 1950's, leading to present daylight-resolution manometry (HRM).Alvarez and Mahoney discovered and recorded the spontaneous electrical slow waves (electrogastrogram) in the smooth muscle walls of the stomach and small intestines. They placed a pair of electrodes on the abdominal surface of a very old woman that was small. They electrodes were connected to a galvanometer that depict a wave form similar to a sinusoid with a frequency of 3 cycles/min. A few years after this breakthrough, similar waves were observed in a five weeks old child, but the electrodes were placed on the limbs. Progress in this area continues to show that slow wave and spike potentials are the basis for electrogastrography and magnetogastrography[12, 26].

After these novel discoveries in physiology, confluence of research on smooth muscle physiology, anatomic/mechanical factors, flow dynamics, as well as basic molecular and cellular biology have led to many other technological innovations that were designed to capture various components of gastric motility[27]. Scintigraphy, CT scans, MRI, nuclear medicine(PET, SPET), finger photo plethysmography, high definition manometry, ultrasonography, breath test, electrogastrography, magnetogastrography, kymography, power lab, data capsule, mapping and modelling, etc. Are now extensively used to record the physiology and pathophysiology of gastric motility.

1.4 The ideal technique of gastric motility measurement

The ideal tools and techniques to be used in the assessment of the gastric motility in health and in disease conditions should be non-toxic, non-radiologic and non-invasive with a capacity to distinguish liquid meal from solid meal, monitor prandial and post prandial state, and differentiate between secretion and air in the lumen and to obtain information from subjects with minimum stress or discomfort[28]. The ideal technique is expected to have protocols that is not time consuming, safe and cost effective with capacity to determine many parameters at a time and has the ability for repeated tests.

1.5 Overview of techniques used in gastric motility measurement

Information on physiology and pathophysiology of gastric motility can be obtained from gastric emptying time, transit time, myoelectric potentials, intraluminal pressure, contractions, motor patterns, luminal transit, etc [6].The techniques of measuring gastric motility can be classified as invasive or non-invasive. The procedure become invasive when surgery or puncturing of the skin is involved or infiltration into body cavities, skin or natural orifice using needles, catheter or fine tubes is used during the test e.g. manometric methods. Conversely, the technique is referred to as non-invasive when intrusion into body cavities or piecing of the skin is not required in the test e.g. scintigraphy, X-ray, breadth test, magnetic resonance imaging (MIR), ultrasonography, finger photo plethysmography, longitudinal motion sensing, computed tomography (CT scan), gastroduodonojejunal manometry, impedance planimetry, etc. The method of recording gastric motility can also be classified as imaging or non-imaging practice. In imaging techniques, camera and scanners are used to obtain picture or image of the stomach. This classification encompasses most of the techniques found in the non- invasive categorization. The imaging technique detects, quantify and measure motility directly. They provide two or three-dimensional pictures of the stomach in a photographic plate or slices or digital recorder. The imaging practices include fluoroscopy, computed tomography (CT scan), digital radiography, magnetic resonance imaging (MRI), nuclear medicine, scintigraphy, ultrasonography etc. The imaging technique is further divided into radiologic and non-radiologic imaging techniques. The radiologic imaging include the use of X-rays and gamma radiation. The X-ray imaging techniques include radiography, CT scans, 3D CT scans, and electron-field emission (EFE) etc. The non-X-rays radiation technique that uses gamma radiation (radionuclide) are positron emission tomography (PET), SPECT and scintigraphy. They have for long being the gold standard in measuring gastric motility. The non-radiologic imaging techniques do not utilize the X- rays or gamma radiation to form the image on the screen. The protocols rely on magnetic field or electrical field or sound waves or radio signals to establish a spatial image of the stomach e.g. finger photo plethysmography[29], electrogastrography[30], magnetogastrography[31] and ingestible data capsule[32].Other techniques of measuring gastric motility do not rely on image presentation as their final output or readout. Kymograph, strain gauge force transducers in physiography, data capsule and power lab, present graphical or digital display of gastric changes observed. Additional non- imaging techniques are breath test, satiation or nutrient drink test[33], *in vitro*, *in vivo*, and *ex vivo* animal models that measures charcoal, magnesium, phenol, and pharmaceutics transit time. Measurement is represented in metric scale [34].Recently, mapping and modelling have been introduced as an aid in the measurement of gastric motility.

1.6 Techniques used in gastric motility measurement

1.7 Scintigraphy

This is a physiologic, non-invasive, radiologic method that quantitatively measure solid or liquid gastric emptying time. Gastric emptying is a complex end point that echoes a diverse array of gastric activities such as gastric accommodation, pressure gradient between the proximal and distal stomach, antropyloroduodenal contractility and coordination. Scintigraphy has become a gold standard in gastric emptying studies[6].Scintigraphic gastric emptying involve intake of radiolabelled solid or liquid meals after an overnight fast. At intervals of one, 2 and 4 hours, a one-minute image of the meal are taken anteriorly with a single headed camera or both anteriorly and posteriorly with dual headed camera in standing position. For individuals that cannot be in upright position, a single left anterior oblique image suffice. The images obtained are used to map out regions of interest manually. A computer program is then employed to outline the stomach and to determine an acquisition times. The normal times for gastric emptying are expressed as percent of meal remaining in the stomach. For first image immediately after meal ingestion at *time t* = 0, the total gastric counts are equal to 100%; at one hour (37–90%), two hours (30–

60%), and four hours (0–10%). Gastric emptying becomes delayed if 10% of meal is retained at four hours or more than 40% retained at two hours[6].Precautions: Individuals to do the test should fast overnight and suspend all medication (e.g., anticholinergics, narcotics, and prokinetics) forty-eight hours prior to the test. Diabetic subjects should have a glucose level of not more than 275mg/dl.

II. Disadvantages

Although, Scintigraphic imaging remains the gold standard in gastric emptying studies, it has the limitation of absence of standard test diet, duration of image acquisition varies, patient positioning differs, and gamma camera equipment and exposure to radiation reduces the value of the technique.

2.1 Barostat

Barostat is a gold standard in the measurement of proximal gastric tone, compliance, postprandial accommodation and visceral sensory perception. It monitors volume changes and maintain uniform pressure[35]. It uses pressure sensors placed in the lumen of the stomach. The barostat assembly comprised of a plastic balloon and an electronic regulator that determine the volume of air to be in the balloon in order to maintain constant pressure. During the test, an endoscope is used to insert a guide wire into the extreme of the duodenum. The barostat motility tube is placed on the guide wire and one of its end with balloon is affixed to the proximal segment of the stomach. The second end of the utility tube is connected to a computer to measure muscle functions (www.cmpc.org/sevice).This procedure is mainly used in research related to sensory threshold and altered visceral perception[33, 36].

2.2 Manometry

This is the measurement of intraluminal pressure of the hollow segments of the gastrointestinal tract e.g. the stomach-using catheter. The catheter can be solid-state or liquid-filled pressure transducer that is inserted through the mouth or anus into the lumen of the organ to be studied. A transducer is used to convert intraluminal pressure into electrical signal; the electrical signals generated are digitalized and recorded on a magnetic disk or portable data recorder. Manometry is done to evaluate motility disorders in patients in whom structural lesions have been ruled out by other studies. Manometry is used in the oesophagus, stomach and duodenum, sphincter of Oddi, and rectum. Aside from minor discomfort, complications are very rare. In gastric motility study, manometers measure phasic contraction of the antrum and the motility of the pylorus. Manometry may be of solid state or infusion. In solid-state manometry, the signal transformation is achieved within the body cavity through which a catheter equipped with miniature sensors that transduce 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 pressure transducer. This option responds to high frequency and has the possibility of ambulatory recording. On the other hand, a water-perfused catheter with external pressure transducer can be used. The major components of an infusion or water manometer are a pneumo-hydraulic pump, pressure transducers, a polygraph, and manometry catheters. The movement of water into the transducer from the catheter causes the displacement of diaphragm in the pressure transducer. The oscillation of the diaphragm is transformed into electric signal and read off on a polygraph[37]. This method has low frequency response; it records multiple channels from a small diameter catheter and is cheap for use.

2.3 High-resolution manometry

This is a non-invasive radiation free imaging technique that measures gastric filling and accommodation[31], intraluminal pressure and motor functions of the stomach and other hollow segments of the gastrointestinal tract. High-resolutionmanometer uses catheters with 36 solid state sensors placed at 1 cm interval along with computer hardware and software to capture, store and analyse data obtained from the segment of the GIT of interest e.g. the stomach[38].

2.4 Wireless motility ingestible capsule

The wireless motility ingestible capsuleis an orally ingested, non- digestible, non-radioactive, office-based, data recording device that enables the simultaneous assessment of regional and whole gut transit[32]. The wireless capsule system consists of a single-use, non-digestible, wireless transmitting capsule, and a receiver for acquiring and storing signals from the capsule and software for displaying data on a computer.

Figure 4.The wireless motility capsule (Saad, e*t al*., 2011)

The subject fasts for several hours before he drinks water and eat a standardised meal prior to swallowing the capsule. After oral intake of the capsule, the subject will fast for several more hours and is advised to avoid vigorous exercise. While in the body, the capsule survey the bowel contents and transmits data about pH, pressure and temperature to a portable receiver (worn by the volunteer) at regular intervals as it travels through the GI tract. The subject can record meals, sleep and bowel movements by pushing an event button on the receiver. The capsule is passed out of the bowel with the faeces. If not seen in the stool, loss of the recording signal or an abrupt pH or temperature drop on therecording profile confirm exit of the capsule from the body[32, 39].

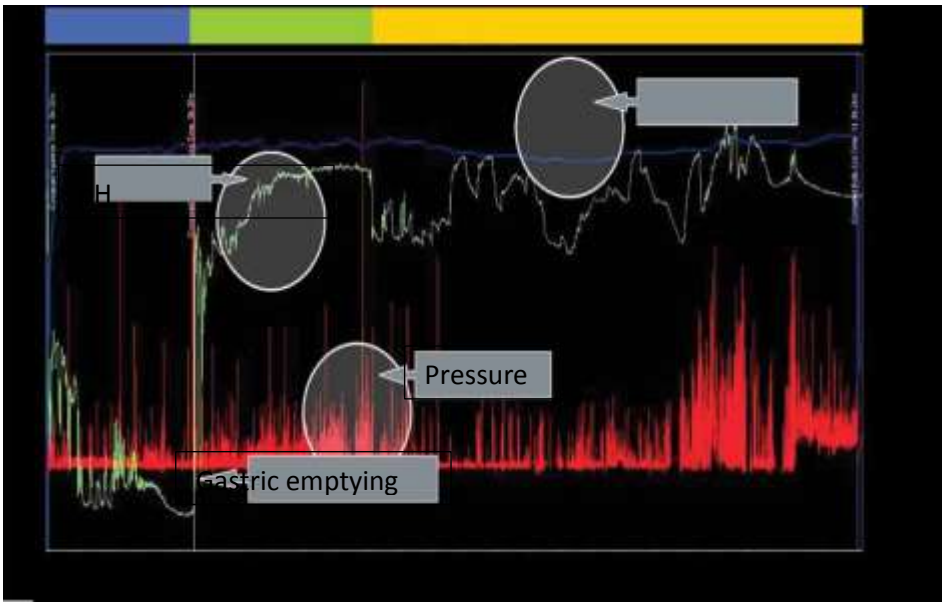

Figure 5. Graph showing data of motility from a wireless motility capsule. Temperature, pH, and pressure measurements (Saad and Hasler, 2011).

2.5 Breadth test

This is a non- invasive and non-radiologic gastric emptying test that utilizes stable isotope ^{13}C for solid meal or ^{14}C for liquid phase. The stable isotopes ^{13}C is combined with solid meal into the synthesis of the medium-chain fatty acid octanoic acid or by growing the blue-green algae *Spirulina platensis* in $^{13}CO_2$-enriched chambers. [^{13}C] acetate can also be included in a liquid meal to assess gastric emptying of liquids (Camilleri and Linden, 2016; Chan, 2016).During the test, *Spirulina platensis* in the ingested meal is digested in the stomach, absorbed in the duodenum, metabolized by the liver and expelled by the lungs. As a result, the level of exhaled $^{13}CO_2$ rises above baseline. The expelled $^{13}CO_2$ is collected and determined using desktop isotope ratio mass spectrometry.The $^{13}CO_2$ enrichment is expressed as the delta per millilitre difference between the $^{13}CO_2$ -to-$^{12}CO_2$ ratio of the sample and the limestone standard. The protocol assumes that the rate limiting factor in excretion of $^{13}CO_2$ is gastric emptying time of labelled test meal[33, 36].

2.6 X-ray imaging for gastric motility recording

Beams of X- rays from source[40], pass through the stomach where it is then absorbed or scattered by the internal structures. The unabsorbed X- rays are transferred to a film or computer for processing and storage.Fluoroscopy involve a steady stream of X- ray images that are captured in a monitor to allow for real time monitoring of a procedure or passage of a contrast dye. This requires extensive exposure of the individual to high radiation and its associated risks. The imaging technique uses contrast of single or double radiopaque material to fill the lumen of the stomach or any other part of the gastrointestinal tract. In most instances, high barium meal is administered orally in single contrast study or in combination with intrinsic or injected gas in a double contrast investigation. In both single and double contrast studies, fluoroscopy can be used to monitor the transition of the given barium or other contrast material using video or plain film.

2.7 CT scan in gastric motility study

Over the years, changes in machines using X-rays have advanced to the use of computed tomography or CT scans which was introduced in 1972. A non –invasive radiological techniqueuses X-rays from numerous angles to produce cross sectional, two dimension images of the stomach or other body tissues of interest. The X-ray tube is rapidly rotated (360^0) around the subject andthe transmitted radiation is measured by a ring of sensors on the gantry around the subject. These measurements are digitized, reconstructed, and viewed as cross-sectional images on a computer. In the past, sequential scanning (acquiring an image per slice at a time) was performed. At present, a new continuous motion (helical or spiral) CT with slip ring technology allows the X-ray tube to repeatedly rotate in a direction around the subject[41], to provide a three dimensional (3D) CT that offer a more detailed pictures of the stomach or other internal anatomy based on tissue density.It has the advantage of reduced X- ray emissions. Although, they still need high temperature of about 1,000ºC inside a vacuum tube.

Electron-Field Emission (EFE) in gastric motility measurement.

The most notable progress in the field of gastric motility recording that employs X-ray principle is the electron-field emission (EFE). The source of electron for EFE is a myriad of carbon nanotubes that can be built into an array as against the traditional single metal filament that discharges the electrons. CT scanners uses single X-ray tube to take pictures and is rotated around the area of interest in a fraction of a second. The overall image will be blurred if the patient moves. But, in EFE, arrays of field-emission devices take their exposures simultaneously, so the resulting image are always pin sharp[42].In addition, utilization of X-ray has transformed into digital radiography where digital sensors are used in forming image as against the traditional photographic film. A digital image-capture device records the image and makes it available as a digital file that can be viewed for interpretation, shared electronically or saved for reference

2.8 Magnetic Resonance Imaging (MRI) in gastric motility measurement

MRI is a non-invasive imaging technique that measures gastric motility without the use of ionizing radiation and the disadvantage of intra-gastric catheter. The general principle of Magnetic resonance imaging (MRI) is that it utilizes magnetic field, radio frequency pulses and a computer to produce detailed pictures of organs, soft tissues, bone and virtually all other internal body structures. MRI is based on the fact certain atomic nucleus particularly hydrogen atom in water and body fluid absorb and emit radio signals. The magnetic field in the scanner compel the hydrogen nuclei to align in the direction of the magnetic field of the scanner and be rotated by radio waves. The nuclei oscillate while returning to equilibrium and in the process emit radio signal that is sensed by the antenna. These radio signals (40-150 MHZ) provides detail image of the body tissue of interest for example the stomach. The images can be examined on a computer monitor, printed or copied to CD. MRI is sensitive to flow and diffusion, nuclear mobility and molecular structure, it can be used to measure structure and functions of tissues and organs such as gastric motility.MRI uses a high-speedtwo-dimensional dynamic scan such as Turbo field echo, turbo spin echo or echo planar imaging to measures gastric peristalsis by determining gastric diameters at equally distributed point's perpendicular to the stomach axis. Peristaltic contractions are recorded and their frequency is calculated based on the diameter measured[43]. MRI differs from other imaging technique because it provides anatomic details based on proton density and relaxation dynamics. The protocol is safe, expensive and time consuming but provides a better contrast than CT scan.

2.9 Positron Emission Tomography (PET) in gastric motility study

Positron emission tomography is a non-invasive, non-X-ray nuclear diagnostic imaging technique that quantitatively produces a 3D images of physiologicprocesses in the body e.g., gastric emptying time[44]. It is very useful in oncology, cardiology, neurology and musculo-skeletal system[45]. PET measures glucose, oxygen consumptions and blood flow by detection of radioactivity emitted by accumulated radiolabelled tracer injected into a peripheral vein. The positron-emitter-labelled biologic molecules arecarbon-11, oxygen-15, nitrogen-13,

and fluorine-18. The target structures of these molecules are e.g. glucose metabolism, receptor binding potential, catecholamine transport, amino acid transport, or protein synthesis[46](Ziegler, 2005)Positron emission occurs when the proton rich isotope decays and a Proton decays to a Neutron, a Positron and a Neutrino. After traveling a short distance (3-5mm), the positron emitted encounters an electron from the surrounding environment. The two particles combine and "annihilate" each other, resulting in the emission of two gamma rays in opposite directions with an energy of 0.511 MeV each.

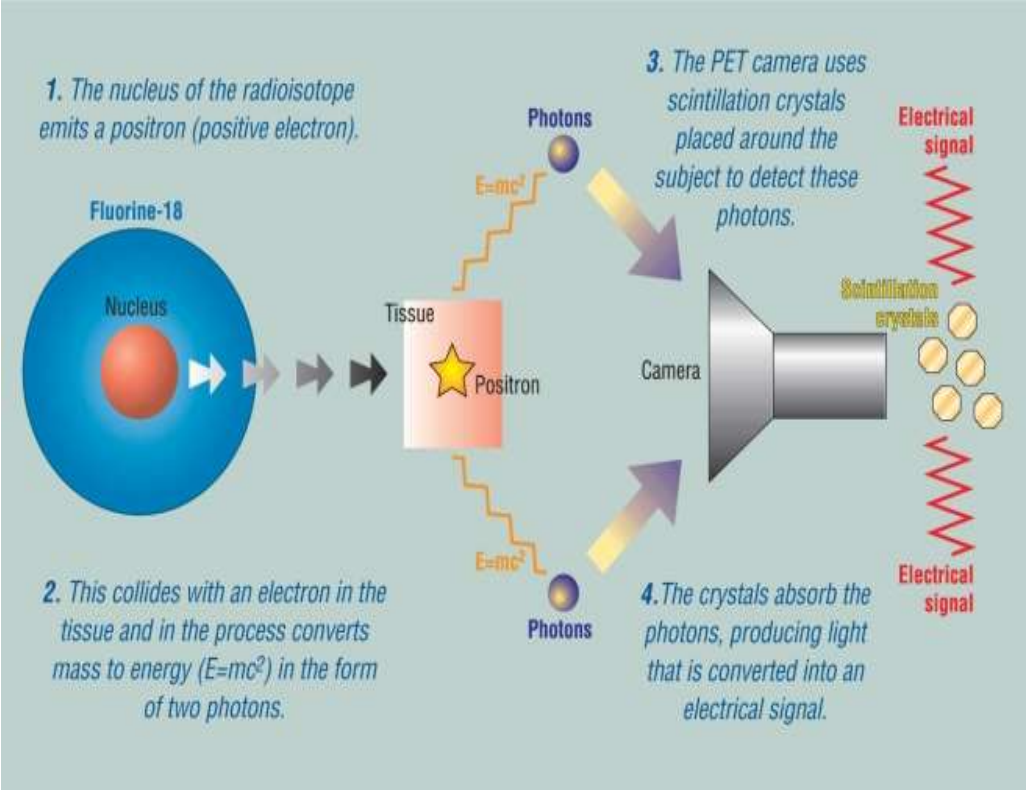

Figure 6. Positron annihilation event (Berger, 2003)

PET differs with other modalities because it deals with biochemistry and metabolic changes at molecular level.PET detect changes earlier than anatomic imaging modalities[45, 46]..

2.10 Electrogastrography

Electrogastrophy is the recording, analysis and interpretation of electric signals of the gastric smooth muscle. The myoelectrical signals measuredis called electrogastrogram. The electrical signals from the gastric smooth muscle can be measured on the serosa, intraluminally, or on cutaneous surface of the stomach. The signals are measured directly with electrodes placed on the serosa[47]. The intraluminal recording can be acquired by inserting a catheter with recording electrodes into the stomach. Suction is usually applied to assure a good contact between the electrodes and the stomach mucosal wall. The serosal and intraluminal electrodes can record both slow waves and spikes[47].Non-invasively, the gastric electrical activity can be measured with electrodes placed on the cutaneous surface of the body of the abdomen[47].

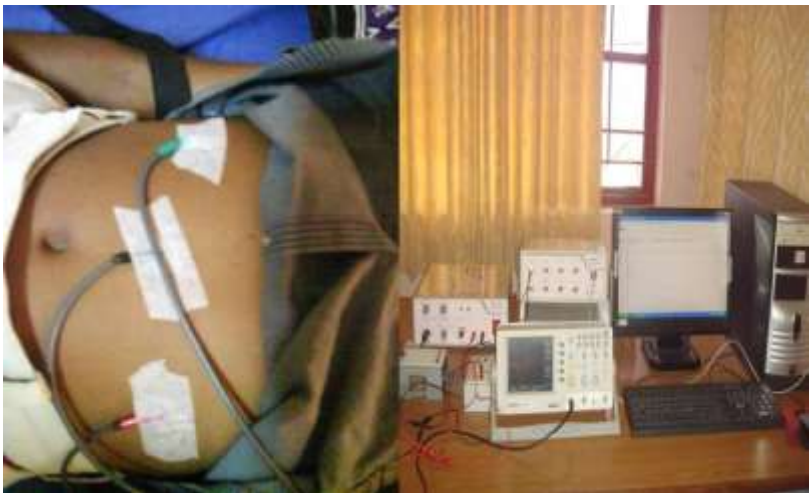

Figure 7. Set-up for the recording of electrical signals in man(Krusiec and Jonderko, 2008)

The recorded myoelectric signal may indicate normal waves with frequency of 3 contractions per minute, bradygastria with less than 2 contractions per minute, or dyspepsia suggesting vague feeling of discomfort in the upper belly or abdomen during or right after eating with 4-5 contractions per minutes. In tachygastria, the contractions per minutes is greater than 4. Other gastric disorders such as nausea, vomiting, gastric ulcer are differentiated based on their frequency, amplitude and contours.EGG provides information about the gastric myoelectric frequency and the amplitude or power of the EGG signal in the normal or abnormal frequency ranges.

2.11Magnetogastrography

Magnetogastrography is a non- invasive, non-radiologic biomagnetic technique that measures magnetic field arising from electrical activity of the gastric smooth muscle. It is based on the fact that ion movements in the stomach or when tiny magnets, iron chips and other magnetic active materials are introduced into the stomach, they induce magnetic field in the stomach that changes with gastric contractions. The motility is sensed by magnetometer, fluxgate or magnetoresistor. Peristaltic contraction is computed from gastric emptying time usually expressed as half emptying time (t ½)[48]. The magnetic field generated in human is from movement of ions, accumulated ferro-magnets in an organ eg. the stomach and tracer and marker. The magnetic field is weak with frequency below 0.050Hz[49]. Magnetic field generated by ion movement in the stomach is in the range of Femstosola and is detected by magnetosmeter in magnetically sheilded room. Other source of magnetic field is in nano –microtesla range and detected by fluxgate or magnetoresistor[50]. superconducting quantum interference device is required to sense magnetic field. A multiferrotic magnetoelectric-composite-based sensors that is compact, inexpressive and can transmit weak AC magnetic field into voltage over a wide range of temperature - 35^0C – 85^0C is in today[51].

2.12 Impedance Planimetry in gastric motility measurement

Impedance planimetry (IP) is an imaging technique that measures active (phasic and tonic contraction) and passive function of the stomach or other segment of the gastro intestinal tract. It records tension, stress and strain to provide insight into the elastic and mechanical properties of the gut wall. IP evaluate intraluminal pressure and estimate the cross sectional area of bag placed in a tube or hollow organ e.g. the stomach. Electrodes supplied with alternating current are placed in the fluid contained in a bag placed in a hollow visceral e.g. the stomach. The cross sectional area is derived from the inpedence of fluid inside a bag. The potential difference in the fluid is determined and used for estimation of cross sectional area.

2.13 Ultrasonography

It is a non-invasive, non-radiologic and atraumatic imagining technique. It is used to measure gastric volume[33] byscanning body structures based on their acoustic properties using ultrasound probe. The ultrasonic assembly has a pulse generator, transducer and an oscilloscope. The transducer converts electrical energy to high frequency sound that ranges from 2-15 hertz. The Sound waves or mechanical vibrations emitted by the electroacoustic transducer spread through tissues of interest before being refracted and reflected back to the transducer that further transforms the echoes into electrical signals to be processed and displayed as images on the screen. The images are displayed on the oscilloscope as A-mode (vertical deflections on a scale), or B-mode (dots of light that its brightness is proportional to reflected sound waves) or M-mode[52].

2.14 Ultrasonomicrometry

This method concurrently measures soft tissues motion directly at various locations of interest in the stomach or other segments of the gut. The techniquemeasures distance between piezoelectric crystals based on transmission time of ultrasound bursts. It utilizes transmitters and receivers that are directly linked to the structures whose motion is being analysed e.g. Stomach[53].The physical basis of ultrasonomicrometry is the measurement of the time required for an ultrasound signal to travel between a transmitter and a receiver each affixed to the tissue whose motion is to be studied. If the speed of propagation of the sound wave is known and is constant in the medium through which it travels, then the distance between the transmitter and the receiver can be calculated from this time measurement. On the basis of measurements from a number of mammalian soft tissues at physiological temperatures, a transit speed of 1.59 mm/s is typically used for this calculation. The transmitted signal is produced by energizing a piezoelectric crystal, which leads to physical distortion of the crystal, thereby producing an ultrasonic sound wave. This wave propagates through the aqueous (or soft tissue) medium and impinges on a second, receiving piezoelectric crystal, which is distorted by the sound and thus produces a corresponding voltage change. The time of arrival of the wave at the receiving crystal is taken as the time at which the voltage change produced by the receiver exceeds a user-adjustable threshold. The transmitting crystal is energized at a known time according to a fixed cycling rate, the time of arrival of the impulse at the receiving crystal is registered, and the distance between transmitter and receiver during that interval is calculated from the time difference. Typical sound frequencies used in modern devices are on the order of 1-3 MHz. Typical cycling rates used in cardiovascular, respiratory, and skeletal muscle studies range between 50 and 2,000 Hz/crystal. Distance measurements are made continuously between pairs of crystals affixed to the tissue(s) of interest. The dynamic resolution of these distance measurements can be as small as 0.016 mm.Crystals may be affixed by using cyanoacrylate tissue glue or with sutures manufactured into the epoxy bead surrounding

2.15 Finger Photo Plethysmography

Finger Photoplethysmography (PPG) is a non- invasive, simple and low-cost optical technique that serve as a source of gastric motility related information[29]. It measures the proportion of light that is either absorbed, reflected or scattered by haemoglobin density in underlying nail bed capillaries using appropriate wavelength. This procedure detects blood volume changes in the microvascular bed of tissues and in the skin surface of the fingertip. It uses an infrared beam to pass through the fingertip. Pulsatile arterial blood, venous blood and other absorbing tissues such as skin pigmentation and bone absorb the beam, and a photo detector[54] detects the transmitted or reflected beam. The PPG waveform comprises of pulsatile ('AC') physiological waveform attributed to cardiac synchronous changes in the blood volume with each heartbeat, and is superimposed on a slowly varying ('DC') baseline with various lower frequency components attributed to respiration, sympathetic nervous system activity and thermoregulation. Although the origins of the components of the PPG signal are not fully understood, it is generally accepted that they can provide valuable information about the cardiovascular system, the gastric contractions, etc.

2.16 Transit time in gastric motility

This is an *in vivo,* non-radiologic, imaging/non- imaging, *invasive* technique of measuring gastric motility. It involves oral consumption of one these agents: dye, charcoal, magnesium, phenol, or pharmaceutic that is not toxic and is not absorbed by the gastrointestinal smooth muscle. The distance travelled by the agent consumed provide an idea of the gastric emptying time of the compound. The test is usually conducted against a standard control largely involving laboratory animals such mice, rat and rabbit.

2.17 Kymography in gastric motility measurement

The kymograph records response against time. Laboratory animal is sacrificed humanely, dissected and stomach tissue is removed and placed in appropriate physiological saline prescribed for the animal used. Nutrients and temperature regulation for metabolic activity that will support gastric contractions are contained in the physiologic saline situated in tissue bath that is placed in organ bath. Transmission link is established between the tissue and the writing pen using cotton thread. The pen records gastric contraction on chart paper fastened on a rotating drum of the kymograph. Modern physiology recorders now use transducers to convert biologic responses into electrical signals to be displayed on graph paper or on oscilloscope or as digital output or a combination of the above. Example of physiograph include Data capsule by Hugo Basile, Power lab etc.

2.18 Advances in the measurement of gastric motility

Techniques used in the measurement of gastric motility have undergone significant and substantial transition, changes and modification that reduced investigation time and have also become less intensive, less hazardous and safer. The present day procedures are largely non- invasive, more informative with better precision, accuracy and reliability.

2.19 Advances in X-rays Imaging Techniques

Technical advances in X- ray imaging is aimed at improving image acquisition and contrast resolution amidst the risk associated with ionising radiation. Emphasis were placed on refining the source of X-rays, optical components of the X-ray assembly, detectors and the imaging technology [55]. These changes have now allowed for real time monitoring of the stomach and other body segments which permit the inspection of a subject's anatomy without the use of the surgical blade.X-rays are now sourced from synchrotron light source in a new low dose method called diffraction enhanced imaging. It provides a greater image details than the conventional X-rays. The method is safer with less exposure to radiation hazard and does not require contrast agent even in soft tissues imaging.The conventional beams of X-ray from a single large source is further modified in yet another technique that produce the desired X-rays from micro-point source in a nanostructured surface that bears electrons that exit through micro-structured plate to emit beam of X-rays [56].The presence of multi-detector scanners in todays' imaging devices has increased the anatomical coverage with thinner section which produce a high quality multi- plane images with less motion artefacts. CT scan has a detector that move around the individuals' body to provide a multitude of images that are recorded contrary to single image in fluoroscopy. These images are reconstructed into slices or cross-sectional images [57]. The present day X-ray imaging technique uses neutral contrast in place of the traditional positive contrast. The new innovation has enhanced visualization. Recent advances in X- ray imaging also include replacement of X-ray films with solid state digital detectors, development of high speed powerful computers that support advanced image processing and analysis. Invention of new technologies and more sensitive materials for detection and capture of radiation is an added armament in the new technique of gastric measurement. These have eliminated dark-room, chemical handling and processing error associated with image acquisition in X-ray imaging.

2.20 Technical advances in non- X-rays imaging Techniques

Improvements in computer technology that include both hardware and software, miniaturization of working instruments, robust detectors and revolution in image acquisition, transmission and manipulation has made non-X-ray imaging technique to provide a spatial details of gastric motor function and dysfunctions that were not readily available in the past.Advances in the MRI technology have enhanced gastric motility measurement with more spatial resolution, multi-planar facility and reduction in hazard associated with the use of radiation. These improvements include the development of super conducting magnets that overcome resistance by increasing static field strength and homogeneity. Improvements in computer and digital technologies with integrated circuit that provide high-speed signal and allow instant access to images also added to the MRI innovation. Similarly, elaborate radio frequency coils and amplifiers that avert long imaging time using faster pulse sequences such as fast spin echo sequence, echo planar imaging, and ultra-fast single shot method modulate magnetic field gradients to improve signal sensing and produce compressed parallel images for a more informed decision. Gating and saturation bands prevents signals arising from artefacts while surface coils are replaced with refined phase array coils and circular polarized bird cage coils to enhance transmission and signal reception (Bandhu and Berry).Utilization of multi- contrast in the latest MRI technology has made data acquisition faster and providesspatial and temporal resolutions of images that cannot be achieved with conventional MRI.

2.21 Technical advances in nuclear imaging of gastric motor function

Modern changes in nuclear imaging techniques for gastric motility include a notable transition from single photon emission computed tomography (SPECT) to positron emission tomography (PET) that captures 3D images of labelled compounds with camera [58].

2.22 Technical advances in gastric motility study using manometry

High-resolution manometry and high definition manometry are the most recent improvement in the manometry technology. The pressure sensors in high-resolution manometry are placed at approximately 1 cm apart as against 3-5 cm apart in the water or solid-state manometers. The number of pressure sensors used in high-resolution manometry is 32 as against 2-4 in the classical manometry. This placement strategy has the advantage of capturing images that were otherwise lost in the traditional approach. The spacing of the sensors leads to improve data acquisition, seamless, dynamic presentation of pressure pattern. The increase in the number of detectors, transducer technology, computerization and graphic data presentation has enhanced the image quality and provided greater details for efficient analysis of the result obtained [59].In high definition manometry, 128 pressure sensors confined within a radius of 4.8 cm are used to provide more spatial details of gastric motor function and dysfunctions. The introduction of fibre optic technique in place of sensors allow for installation of 72 sensors or more. This approach has offered better spatio-temporal plots compared to what is obtainable with high-resolution manometry.

2.2 3Technical advances in wireless capsule for gastric motility recording

Conventional wireless monitoring devices such as smartpill only sense and transmit signals as peristaltic activity moves it around. The innovation added to the technology is that it is now suitable for ambulatory recording of a specific segment in the stomach. In Bravo pills, a needle affixation is provided and it allows for anchoring the capsule in a determined position. A more robust magnetic affixing capsule now replaces the needle type. Magnet is placed on the collar or at the neck region to immobilize the capsule to keep it in a fixed position for a desired period.

III. Conclusion

Breakthrough in biomedical engineering through development of high speed mini computers, high resolution micro sensors, oscillating nano-tubes as source of X-rays, and neutral contrast for better resolution of image with spatio-temporal plots have revealed considerable details on gastric smooth properties that improve understanding of many unresolved or vague issues. It has increased knowledge of pathophysiology of number gastric disorders.These astonishing discoveries has greatly enhanced researches into pathophysiology of the gastric smooth muscle.

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Competing Interests

The author declares no conflicting interests in the preparation or content of this review.

References

[1]. Poscente MD, Gwang DF, Ninova P, Pecht Y, Andrew CN, Mintcher MP. Gastric Emptying, Food Transit, Intragastric Pressure. Physiological Measurements. 2014; **35**: 217-29. doi: 10.1088/0967-3334/35/2/217.
[2]. Stevens JA. Studies of Gastric Motility in Health and Disease. A ThesisSubmitted for the Degree of Doctor of Philosophy, University of Adelaide. 2009; https://digital.library.adelaide.edu.au/dspace/bitstream
[3]. Kim JW. Contribution of Gut Microbes to Gastrointestinal MotilityDisorders. Practical Gastroenterology. 2007;**31**:51–60.
[4]. Jung IS, Kim J, Lee HY, Lee, SI. Endoscopic Evaluation of Gastric Emptying and Effect of Mosapride Citrate on Gastric Emptying. Yonsei Med J. 2012; **51**: 33–38.
[5]. Quini CC, Americo MF, Cora LA, Cabresi MFF, Alvarez M, Oliveira RB, Mirando JA. Employment of Non-invasive Magnetic Method for Evaluation of Gastrointestinal Transit in Rats. Journal of Biological Engineering. 2012; **6**:http://www.jbioleng.org/content/6/1/6
[6]. Szarka LA, Camilleri M. Methods for Measurement of GastricMotility. Am J Physiol Gastrointest Liver Physiol 2009; 296: G461–G475.
[7]. Furness JB. The enteric nervous system and neurogastroenterology. Nat. Rev. Gastroenterol. Hepatol. 2012; 9:286–294.
[8]. Camilleri M, Parkman HP, Shafi MA, Abell TL, Gerson L. Clinical Guideline: Management of Gastroparesis. Am J Gastroenterol. 2013; 108:18–37.
[9]. Meile T, Zieker D, Königsrainer A, Glatzle J. () New TelemetryDevice for the Measurement of Gastrointestinal Motility in Rats and Comparison with Standard Equipment. Int Surg. 2015; 100:755-760.
[10]. Schemann M, Ehrlein HJ, Sahyoun H: Computerized method for pattern recognition of intestinal motility: Functional significance of the spread of contractions. Med Biol Eng Comput. 1985; 23:143–149.
[11]. Ahmed AB, Gilja OH, Hausken T, Gregersen H, Matre K. StrainMeasurement during Antral Contractions by Ultrasound Strain Rate Imaging: Influence of Erythromycin. Neurogastroenterology & Motility. 2009; 21: 170–179.
[12]. Qin S, Ding W, Miao L, Xi N, Li N, Yang C. SignalReconstruction of the Slow Wave and Spike Potential from Electrogastrogram. Bio-Medical Materials and Engineering2015; 26: S1515–S1521.
[13]. Guyton AC, Hall JE. Textbook of Medical Physiology 2006; (11th Ed).Elsevier: Philadelphia.
[14]. Bray JJ, Cragg PA, Macknight ADC, Mills RG. Lecture Notes on Human Physiology. 2009; (4th Ed). Blackwell Science.
[15]. Barrett KE, Barman SM, Boitano S, Brooks, HL. Ganong's Review of Medical Physiology 2010; (23rd Ed). McGraw Hill: New York.
[16]. Wallace JL, Granger N. The Cellular and Molecular basis of GastricMucosal Defence. The FASEB Journal. 1996; 10:731-740.
[17]. Hansen MB. Small Intestinal Manometry. Physiol. Res. 2002; 51: 541-556.
[18]. Horowitz B, Ward SM, Sanders KM. Cellular and Molecular Basis forElectrical Rhythmicity in Gastrointestinal Muscles. Annu. Rev Physiol. 1999; 61:19-43.
[19]. Sanders, KM. A case for Interstitial Cells of Cajal as Pacemakers andMediators of Neurotransmission in the Gastrointestinal Tract. Gastroenterology. 1996; 111:492-515.
[20]. Huizinga JD. Physiology and Pathophysiology of the Interstitial Cellof Cajal: From Bench to Bedside II. Gastric Motility: Lessons from Mutant Mice on Slow Waves and Innervation. Am J Physiol Gastrointest Liver Physiol. 2001; 281: G1129–G1134.
[21]. Takayama I, Huriguchi k, Daigo Y, Mine Y, Fujino MA, Ohno S. The interstitial Cells of Cajal and a Gastroenteric Pacemaker System. Arch. Histol. Cytol. 2002; 65:1-26.
[22]. Sanders KM, Koh SD, Ordög T, Ward SM. Ionic Conductanceinvolved in Generation and Propagation of Electrical Slow Waves in Phasic Gastrointestinal Muscles. Neurogastroenterol Motil. 2004; 1:100-5
[23]. Eugene B, Chang EB, Leung PS. Gastrointestinal Motility. In:Leung, P.S. ed. 2014. Gastrointestinal, Nutritional and Hepatobiliary Physiology. http://www.springer.com/2014; 978-94-017-8770-3.
[24]. Szurszewski JH. A 100-year perspective on gastrointestinalmotility.Am. J. Physiol. 1998; 274: G447–G453.
[25]. Cannon WB. Cited in: Szurszewski, JH. A 100-year Perspective onGastrointestinal Motility. Am. J. Physiol. 1922; 274: G447–G453.
[26]. Yin J, Chen JDZ. Electrogastrography: Methodology, Validationand Applications. J Neurogastroenterol. Motil, 2013; 19:5-17.

[27]. Thor P J, Laskiewicz J. History Traces of Gastrointestinal Motilityin Poland. Journal of Physiology and Pharmacology. 2003; 54:145-154.
[28]. Schwizer W, Fox M, Steingotter A.Non-invasive investigation of gastrointestinal functions with magnetic resonance imaging: towards an "ideal" investigation of gastrointestinal function. Gut. 2003; 52: 34-39.
[29]. Yacin SM, Manivannan M, Chakravarthy VS. On non-invasiveMeasurement of Gastric Motility from Finger Photoplethysmographic Signal. Ann Biomed Eng. 2010; 38:3744-55.
[30]. Jieyun Y, Jiande DZC. Electrogastrography: Methodology, Validation and Applications. J Neurogastroenterol Motil. 2013; 19: 5–17.
[31]. Herbella FA, Aprile LR, Patti MG. High Resolution Manometryfor the Evaluation of Gastric Motility. Surg. 2014; 66:177-81.
[32]. Saad RJ, Hasler WI. A Technical Review and Clinical Assessmentof the Wireless Motility Capsule. Gastroenterol Hepatol. 2011; 7:795-804.
[33]. Camilleri M, Linden DR. Measurement of Gastrointestinal andColonic Motor Functions in Humans and Animals. Cellular and Molecular Gastroenterology and Hepatology 2016; 2:413-428.
[34]. Tanaka R, Inui A, Asakawa A, Atsuchi K, Ataka K, Fujimiya M. New Method of Manometric Measurement of Gastroduodenal Motility in Conscious Mice: Effects of Ghrelin and Y2 Depletion. Am J Physiol Gastrointest Liver Physiol2009; 297: G1028–G1034.
[35]. Van der Scaar PJ, Lamers CBHW, Masclee AAM. The Role of Barostat in Human Research and Clinical Practice. Scandinavian Journal of Gastroenterology. 2009; 34(230).
[36]. Chan WW. Manometry. 2016; http://www.merckmanuals.com/
[37]. Dumitrascu DL, Barnert J, Kirschner T, Wienbeck M. Antral emptying of semisolid meal measured by real-time ultrasonography in chronic renal failure. Digestive Diseases and Sciences. 1995; 40: 636–644.
[38]. Rao SS, Camilleri M, Hasler WL, Evaluation of gastrointestinal transit in clinical practice: position paper of the American and European Neurogastroenterology and Motility Societies. Neurogastroenterol Motil. 2011, 23:8–23.
[39]. Farmer AD, Scott SM, Hobson AR. () Gastrointestinal MotilityRevisited the Wireless Motility Capsule.United European Gastroenterol, J.1:413-421.
[40]. Seiberads JA. X-Ray Imaging Physics for Nuclear Medicine Technologists. Part 1: Basic Principles of X-Ray Production. Journal of Nuclear Medicine Technology2004, 32:139-147
[41]. Das BK. Basic Principles of CT Imaging: Das, B. K. (ed.), PositronEmission Tomography: A Guide for Clinicians. Springer, India. 2015,
[42]. The Economist. Modern X-ray technology: Another look insidehttp://www.economist.com/node/14119801. 2009,
[43]. De Zwart IM, De Roos. MRI for the Evaluation of GastricPhysiology. Eur Radiol. 2010, 20:2609-2616.
[44]. Berger A. How does it work? Positron Emission Tomography. BMJ. 2003, 326: 49.
[45]. Baghae H, Wang W, Uribe J. Clinical Positron Emission Tomography. In Principles of Positron Emission Tomography Imaging. Springer: NY. 2012,
[46]. Ziegler, S.I. Positron Emission Tomography: Principles, Technology and Recent Developments. Nuclear Physics A. 2005, 752: 679c–687c.
[47]. Roca-Chiapas JMD, Cordova-Fraga T, Reynaga G, Solorio S, SosaM, Rivera Cisneros AE, Bernal JJ, Vargas-Luna M. Scintigraphy Vs. Mechanical Magnetogastrography: Gastric emptying Analysis. Med. Bio. Eng. Comp. 2010, 48:727-729.
[48]. Wu KL, Rayner CK, Chuah SK, Changchien CS, Lu SN, Chiu YC, Chiu KW, Lee CM. Effects of ginger on gastric emptying and motility in healthy humans. Eur J Gastroenterol Hepatol. 2008; 20:436-40. doi: 10.1097/MEG.0b013e3282f4b224.
[49]. Mores ER, Troncon LES, Baffa Oba-Kunyioshi AS, Wakai R,Leuthola A. Adaptive, Autoregressive Spectral Estimation for Analysis of Electrical Signal of Gastric Origin, 2003.
[50]. De La Rocha-Chiapas JM, Cardova-Fraga T. Biomagnetic Techniques for Evaluating Gastric Emptying, Peristaltic Contraction and Transit Time.World Journal of Gastrointes Pathophysiology. 2011, 255:65-71.
[51]. Main Hu J, Nan T, Nian XS, Chen L. Multiferroic Magneto electric Nano structures for Novel Device Applications. MRS Bulletin. 2015, 40:728733. www.mrs.org/bulletin.
[52]. Hassani NMD. Ultrasonic Evaluation of Ovarian Teratoma Simulating Pregnanc. Journal of the National Medical Association. 1974; 66: 468-471.
[53]. Adelson DW, Million M. Tracking the Moveable Feast:Sonomicrometry and Gastrointestinal Motility. Physiology. 2004, 19:27-32.
[54]. Allen J. Photoplethysmography and its Application in Clinical Physiological Measurement. Physiological Measurement. 2007, 28:
[55]. Ahn S, Jung SY, Lee SJ. Gold Nano Particle Contrast Agents in Advanced X-ray Imaging Technologies. Molecules. 2013; 8:3858-5890.
[56]. Chandler DL. A Leap forward in X-ray Technology. MIT News.2013; http://news.mit.ed
[57]. Yu Chen, Chia-PL, Yang L, Andrew HF, Anil VP, Liron P. Review of advanced imaging techniques. J Pathol Inform 2012; 3:22
[58]. Kahrilas, P. J., Ghosh, S.K. and Pondolfino, J. E. Imaging andTechnology: challenging the Limits of Esophageal Manometry. Gastroenterology. 2008; 134:16-18.
[59]. Erlandsson K, Dickson J, Arridge S, Atkinson D, Ourselin S, Hutton BF. Magnetic resonance imaging-guided partial volume correction for positron emission tomography in PET/MRI. PET Clinics 2015 http://dx.doi.org/10.1016/j.cpet.2015.09.002.

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