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Original Research

Electrical Impedance Tomography (EIT) in The Gastrointestinal Tract: Ultrasonography, Medical Imaging and Using EIT for Paediatric Applications

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Abstract:

Glass rods and balloons can have their volume changes measured precisely in a phantom using EIT in an in vitro setting. Under controlled laboratory settings, EIT reliably measures experimentally induced changes in stomach volume (balloons) in humans. Electrodes placed on the ninth costal cartilage provide precise stomach EIT readings. While a little misalignment won't throw off the results, it's better to be on the high side than the low side if you want to measure the antral/duodenal area. There is a strong relationship between dye dilution and stomach emptying time (EIT) when measuring liquid meals. Because gastric secretions are removed, it is not apparent how closely this represents gastric emptying under normal circumstances. There is a correlation between scintigraphy and non-nutritive liquid meals. Suppressing acid is necessary for EIT measurements of semi-solid and solid meals to correlate with scintigraphy. When measuring stomach acid suppression, the lag phase assessed by EIT is substantially shorter than observed by scintigraphy, and the time to reach gastric emptying t1=2 measured by EIT always takes longer than measured by scintigraphy. Therefore, unlike scintigraphy, which only measures stomach emptying of the radio-labeled portion of the meal, EIT is more likely to quantify gastric volume, including secretions. While scintigraphy has been utilised to validate EIT and is considered the "gold standard" for measuring stomach emptying, it does have certain limitations: Although most studies only utilise one marker, solid meals actually consist of complex mixes or particles with both solid and liquid components. The stomach emptying of the other meal components—fat, carbohydrates, and liquid—is not tracked since the most popular marker binds solely to the protein portion. Incorrect findings might be produced if radionuclide markers detach from the meal's solid phase and then empty into the liquid phase. Although they gradually dilute both solid and liquid markers, gastric secretions have a substantial impact on gastric emptying patterns and contribute significantly to stomach volume throughout meals. Since the volume of gastric secretion within or emptied from the stomach cannot be measured by external gamma counting, this crucial element of gastric emptying is not observed. It is important to compare EIT with the 'gold standard,' however disagreements may be due to methodological differences, such as scintigraphy's failure to detect stomach secretions.

Keywords: Electrical Impedance Tomography (EIT), Ultrasonography, Medical Imaging, Paediatric, Applications

Introduction:

In humans, the gastrointestinal tract (GIT) is a lengthy, hollow tube that starts at the mouth and ends at the anus [1]. An integral part of every living thing, the gastrointestinal tract (GIT) processes and transports nutrients into the body so they can be used as fuel. In humans, it's a network of interconnected tubes that undergoes a number of intricate biological reactions. These reactions take place in compartments, and they work in a highly specialised fashion to transform nutrients that we intake into molecules that can be carried into our bloodstream. All of the other systems in the body receive their energy from the bloodstream. The physiological process can be boiled down to its essential three steps: digestion [2], absorption, and transit. There are a number of distinct sections that make up the human gastrointestinal tract (GIT), as illustrated in figure 1. In order to regulate movement both within and between the various compartments, sphincters (also known as biological valves) are installed. The function of a given compartment has a significant impact on the resident time in that compartment. It takes around 6 seconds to travel down the oesophagus. The amount of time that ingesta spends in the stomach varies greatly from meal to meal, ranging from 5-10 minutes to 6-8 hours. The time needed to optimise nutrient absorption processes is controlled by these significantly variable periods, making them crucial. The physiology of normal stomach motility explains this considerable range in gastric residence time [3].

There are two primary roles for the stomach: first, to store food (since our bodies can absorb nutrients at a faster rate than they can be broken down) and second, to change the consistency of food through physical and chemical disruptions to create chyme, a thick fluid containing finely powdered nutrients. In the small intestine, this partially digested food is given a consistency that is optimal for digestion and absorption. During digestion, the stomach goes through three stages of motility. The first is receptive relaxation, when it can hold a lot of food [4]. The second is mixing, when the contents of the stomach are stirred up with acid and enzymes. Lastly, there's emptying, when the antrum grinds the food and releases the partially digested chyme into the small intestine. Due to the time required to break down solids into a texture that the small intestine can handle, solid meals have a longer emptying period compared to liquids. It is also important to empty high-calorie and high-fat foods in a regulated manner so that they don't overwhelm the small intestine. The gastric emptying half-time for water and other non-nutritive liquids is around 20 minutes, for nutritive liquids like milk it's around 90 minutes, and for big, complicated meals like beefburgers it can take up to 360 minutes. It is not uncommon to see food leftovers in the stomach even after 8 hours of intake. Using EIT, changes in resistivity within thick sections of human tissue can be detected. In order to research normal physiology, pathology [5], and the effects of transit modifying agents used to treat gut transit disorders, this principle is employed to monitor the passage of luminal materials through distinct compartments of the GIT. For this kind of motion, the word "motility" is employed. Measuring gastric residence and emptying times of consumed meals, the stomach has been the most extensively researched part of the GIT utilising EIT. Other passages, including the rectum, the small and large intestines, and others, have been explored, but so far, with little result.

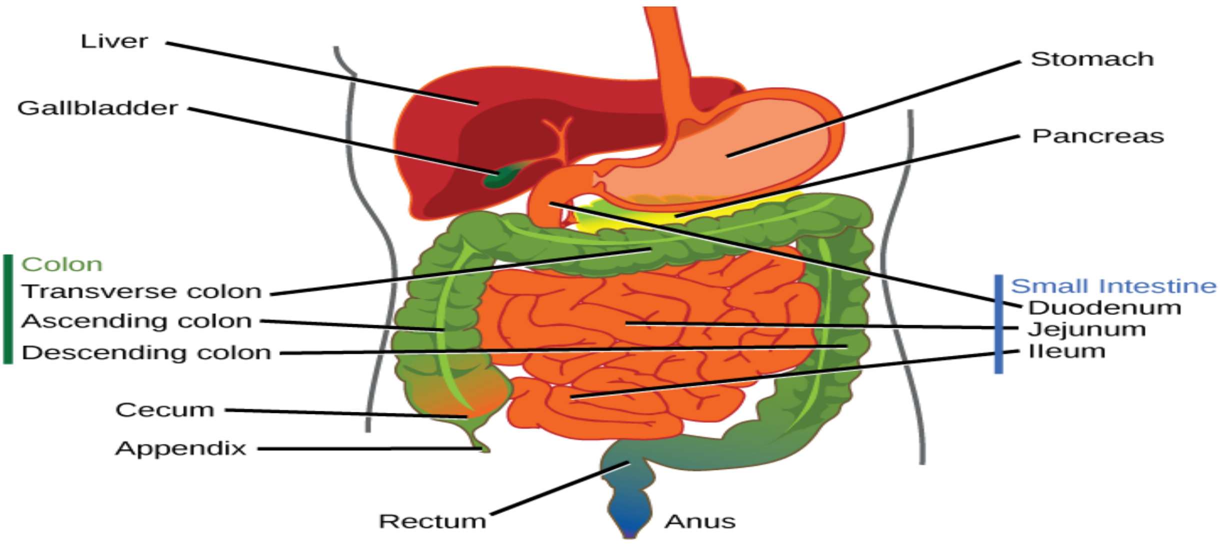

Figure 1. The structure of the human GIT.

Radiology (Barium Contrast) Approaches to Assessing Gastric Emptying:

Radiography is highly effective in detecting mechanical obstruction or mucosal illness, however it provides far less information when it comes to gastrointestinal motility [6]. A follow-through or contrast swallow can only tell you so much about the digestive tract because it follows the movement of barium-based liquids from one region of the body to another, but it can give you an approximate idea of how fast the stomach is moving relative to the others [7]. The density of the liquids and solids that comprise a typical meal is closer to water, in contrast to the thick and heavy barium, therefore this is relatively nonphysiological. Furthermore, because to the high levels of radiation used to see the contrast material, this approach is not appropriate for some people or repeated tests conducted over short periods of time.

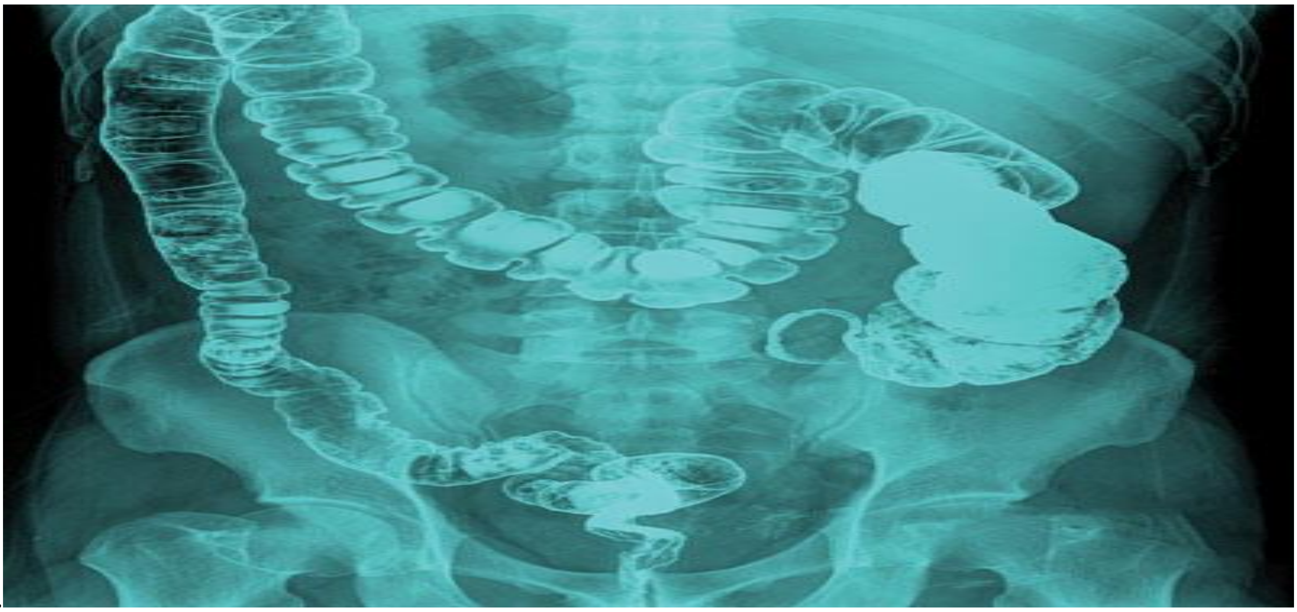

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Figure 2. Human intestinal tract, as imaged via double-contrast barium.

Gamma Scintigraphy:

Using a gamma camera to follow a radionuclide-labeled test meal as it exits the stomach, gamma scintigraphy can assess gastric emptying [8]. A gastric emptying curve is generated by changes in gastric radionucleotide counts, which represent the amount of food left in the stomach [9]. You can use it to see how quickly your stomach empties of solid and liquid foods. For accurate measurements of stomach emptying, it is recommended to take photos every 10 minutes to determine the lag time, and to keep recording for 3 to 4 hours after eating to detect gastric stasis. Currently, gamma scintigraphy is considered the "gold standard" for assessing stomach emptying; it has validated alternative, less invasive technologies like EIT. When evaluating the EIT validation studies, it is important to keep in mind that gamma scintigraphy [10], while often hailed as the "gold standard," does have a few drawbacks. Gastric emptying can be monitored using gamma scintigraphy by following the movement of a radioactive marker that is physically attached to a portion of the meal. Gastric secretions and other portions of the meal are not included in this measurement. In individuals who are routinely fed, gastric secretions make up to 188 ml/h of gastric volume. Since most meals contain complex combinations of protein, carbohydrates, and lipid emulsions, the stomach is likely to empty at varying rates for different parts of the meal [11]. The gastric emptying of the other components (fat, carbs, and fluids) cannot be monitored with the use of a single marker that binds to the protein molecules. It is possible for markers to detach from the protein phase and empty as a non-nutritive liquid, leading to inaccurate results. Standard isotopes can lose 2-5% of their binding strength from the solid phase every hour. A mixed test meal can have its solid and liquid components monitored at the same time, but they need to be labelled with distinct isotopes. A stomach emptying curve is generated when measurement studies are evaluated. It is feasible to determine the function of the antrum and fundus regions of the stomach independently by calculating their half-emptying times (t1=2) and lag times from this.

Figure 3. Gamma Scintigraphy Imaging Services

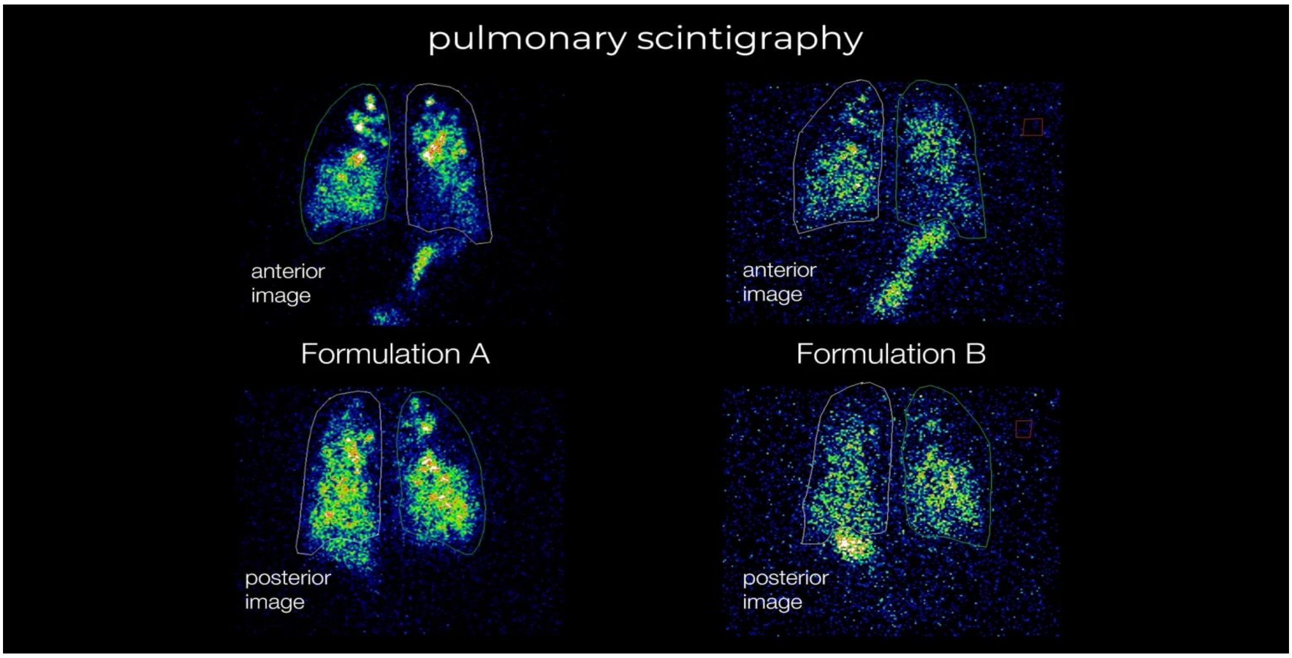

Figure 4. Gamma Scintigraphy Imaging Services

Chemical:

By timing how long it takes for non-gastrically absorbed medications or indicators to reach the bloodstream or the breath, this technique evaluates gastric emptying [12]. These substances are quickly absorbed from the small intestine. Time spent digesting, absorbing, and metabolising, in addition to time spent emptying the stomach, is what is actually assessed. It is assumed that gastric emptying is the rate limiting step in these approaches, which [13] are often called indirect. Some chemical markers have been used to simulate gastric emptying, such as paracetamol or acetophamine in blood tests, or carbon labelled breath tests (acetate, bicarbonate, octanoin, and spirulina) in which the marker's appearance in the breath is used as a surrogate for gastric emptying. A few years ago [14], there was some curiosity about paracetamol absorption as a potential approach for usage with sensitive people, like critically ill patients, because to its non-invasive nature. Unfortunately, it isn't really useful for anything other than measuring stomach emptying during the non-nutritional liquid portion of a meal. approach for the majority of cases where stomach emptying measurements are required [15]. Verified CO2 breath tests with labels: As a substitute for gamma scintigraphy [16], breath tests utilising stable isotopes have been created. You can measure solids and liquids independently or all at once. Since the method's introduction in the early 1990s [17], several validation studies have been conducted. The authors described breath testing as a stomach emptying test done in an office setting after refining the technique and including a basic muffin lunch. Sure enough, carbon-labeled breath testing is simple to do and causes patients very little pain. Patients in critical illness, pregnant women [18], and toddlers can all benefit from breath tests since they minimise or eliminate [14C] radiation exposure compared to gamma scintigraphy [19].

Ultrasonography:

Assessing transpyloric flow and distal stomach attenuation of diameter is done using ultrasonography [20]. A 3D method that sequentially captures pictures of the entire stomach has only recently been created. A gadget is used to capture the position and orientation of the images as the ultrasonic transducer is spun through 908 degrees. Computerised picture processing creates a three-dimensional model of the stomach [21], which allows for the determination of gastric volume and the distribution of meals within the stomach. But it takes a lot of time and an expert ultrasonographer to do this approach [22].

Impedance Spectroscopy in Real-World Applications:

Electrical impedance tomography (EIT) uses voltage-current data taken at the domain boundary to rebuild the object's conductivity or resistivity distribution within a volume conductor. In EIT [23], surface electrodes measure border potentials while a continuous sinusoidal current signal is delivered into the object. with the use of EIT gear or EIT instruments [24]. A computer programme called an image reconstruction algorithm is used to recreate the conductivity or resistivity distribution from the boundary potential data. Before putting the system to use in real-world scenarios [26], EIT relies on practical phantoms—models of specific objects used in the field of actual application—to investigate, calibrate, and assess it. Practical phantoms in EIT are created using a variety of conductivity-varying materials [27], some of which are biological and some of which are not. In order to measure the boundary voltage and inject a constant current in EIT, electronic instruments are needed. The phantom border is injected with a low-frequency [29], constant-amplitude sinusoidal current from a constant current source, and the potential differences between the two are then monitored. To obtain the tomographic images [30], the EIT invers issue is solved using boundary voltage-current data, and the impedance image reconstruction is carried out. One example of an illposed inverse issue is the EIT. receives weak signals compared to background noise. with limited geographical detail. Since this is the case [31], the EIT method cannot compete with the spatial resolution of more traditional tomographic imaging methods like CT and MRI. Despite its potential, EIT has not yet been the go-to technology for medical and clinical imaging due to pictures' subpar quality (particularly the special resolution) compared to CT and MRI. Due to its many benefits, including its portability[32], low cost, lack of radiation, lack of ionising radiation, and high temporal resolution, EIT has garnered a great deal of interest and attention from a wide range of disciplines, including but not limited to: medical imaging [30–38], material engineering, nanotechnology and microelectromechanical systems (MEMS), civil engineering, chemical engineering, biotechnology [33], and many more. For the benefit of future scholars, this article provides a concise overview of the many uses of EIT across disciplines. We start with a quick overview of the operating principle, instrumentation, and benefits, then move on to a detailed examination of the applications in many fields, including their limitations [34].

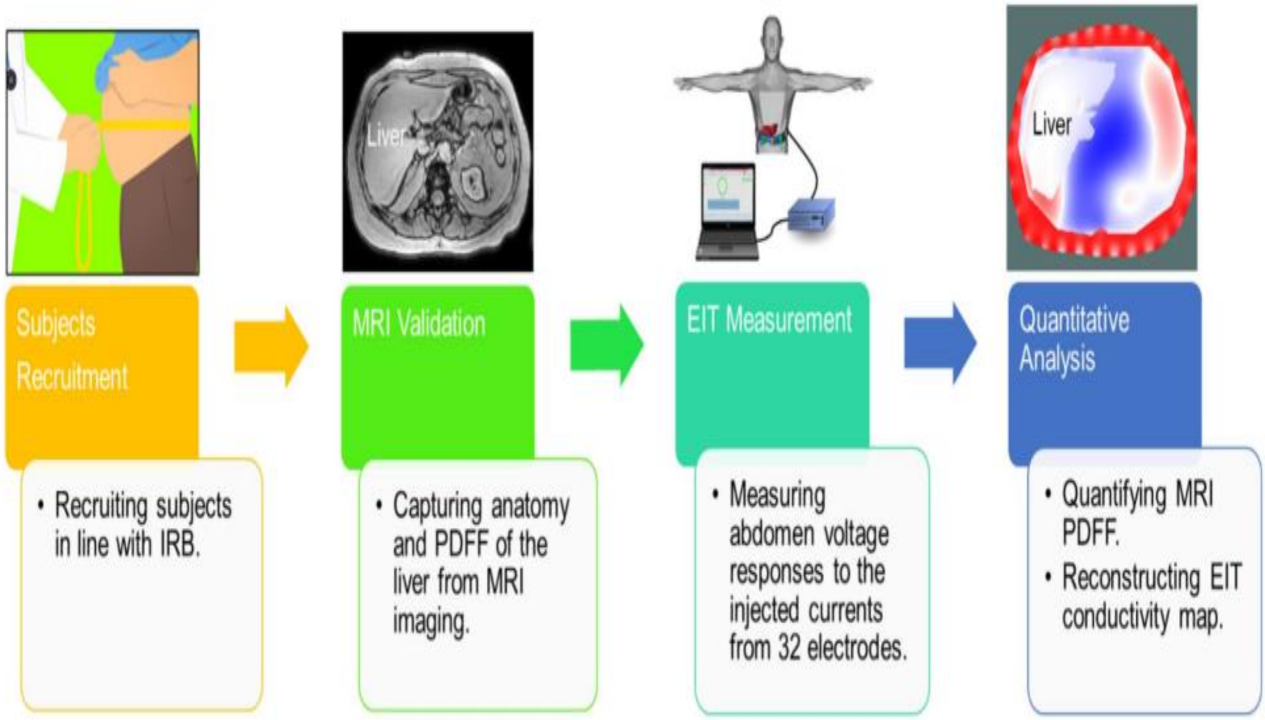

Figure 5. A schematic depicting the process of validating and comparing the MRI and EIT. In accordance with the guidelines set out by the UCLA Institutional Human Subjects Protection Committee, volunteers were sought after. Prior to the EIT measurements, the liver's anatomy and proton density fat fraction (PDFF) were determined using multi-echo MRI scans.

An Introduction to EIT Technology:

By injecting a constant voltage signal or current signal from a constant voltage source [35], EIT is able to reconstruct the electrical impedance of the object under test from a collection of voltage current data obtained at the border. is a source of steady current. applying the electrodes to the surface. Connected to the EIT apparatus, the surface electrodes are fastened to the test domain's perimeter. A single frequency EIT system measures the boundary potentials by injecting a continuous current pulse at a specific frequency (ω), while a multifrequency EIT system measures them at many frequencies. Typically, a four-electrode setup is used for both current injection and voltage monitoring. to stay away from the contact impedance or electrode-skin interaction issue. working in EIT. In the EIT data collecting technique that is based on the four-probe approach, the red electrodes represent the current electrodes and the driving electrodes, which are used to inject the alternating current signal (I(ϋ)). measuring the induced potential (V(ϋ)) across additional two-electrodes (referred to as sensing electrodes or voltage electrodes in blue) in

Use Cases for EIT Software:

Researchers in various fields have attempted to solve their many research problems using the EIT technology, thanks to the method's many unique advantages. These fields include medical imaging, material engineering, nanotechnology and microelectromechanical systems (MEMS), civil engineering, chemical engineering, biotechnology, and many more [36].

Health-Related Imaging:

Below are a few of the medical uses of EIT that have been determined to be appropriate for tomographic imaging in the medical field, which allows for the visualisation of the anatomy, physiology, and various illness conditions:

Diagnostic Imaging of the Lungs:

Recent research on EIT lung imaging has shown promising results. In a study by Meier et al., the technique was tested in animal models of acute lung injury using EIT experimental studies on six pigs with saline-lavage-induced acute lung injury. The aim was to determine if EIT could be used to monitor regional lung recruitment and collapse. The researchers used incremental and decremental positive end-expiratory pressure (PEEP) trials at ten pressure levels, automatically recording ventilatory, gas exchange, and hemodynamic parameters. We compare the results of concurrent EIT and CT scans of the same slice taken at each PEEP level. The authors concluded that EIT is a good tool for tracking the localised changes in tidal volume as a function of dynamic PEEP oscillations. Also, EIT studies pulmonary edoema. Reference: Harris et al., 1987. asserted that APT was utilised. can capture photos of the changes in the distribution of resistivity within the chest in a cross-sectional format. The scientists came to the conclusion that the APT might be utilised to identify ventilatory problems in specific forms of lung disease, to identify high-risk patients before pulmonary edoema develops, and to track the edema's progression after treatment. The year 1995 was mentioned by Adler and colleagues. have performed a battery of EIT tests on canines to determine the technology's ability to assess fluid content and lung tidal volume. There was a strong correlation between the authors' results from the canine experiments and those from the usual reference methods, according to their paper. Additionally, it was found to be challenging to achieve long-term electrode stability on both the subject and the instrumentation [37].

Treatment with Hyperthermia:

Additionally, EIT has been utilised for hyperthermia treatment thermal monitoring. (Conway et al., 1985). 1987, with Conway. displayed the induced temperature gradients during hyperthermia treatment using an impedance imaging approach. Results from in vitro and in vivo experiments using the EIT approach were presented. A temporal sequence of conductivity pictures revealed the dispersion of heat changes and hinted at a temperature resolution superior to 1 °C. According to their findings [38], the 104 separate readings from the 16 electrodes utilised in the EIT system restricted the spatial resolution to about 10% of the circumference of the circular array [39].

Childhood Bronchitis:

Paediatric lung illness is another area where EIT has found use. (Pham et al., 1994–). investigated the distribution of regional ventilation in paediatric and neonatal lung disorders using the EIT method. During their non-rapid eye movement sleep, EIT was applied to infants who were breathing on their own during the newborn period, at 3 and 6 months of age, and data on the distribution of ventilation and filling characteristics in different regions were acquired [40] . The amplitudes of regional impedances are said to grow. the pattern of regional ventilation did not alter with age in babies, and the posterior (dependent) lung was consistently better ventilated. During the first six months of life, the authors also noted that regional filling characteristics and ventilation distribution stayed the same, and that the results on ventilation distribution with EIT were quite comparable to those in adults [41].

Imaging of the Breast:

Several research groups have examined breast imaging with EIT. In 2014, Zain and Chelliah used the EIT method on 150 women who had mammograms and were beyond the age of 40. The breast imaging - electrical impedance (BI-EIM) classification was used to visually evaluate the pictures and find anomalies. We used Chi-square to find correlations with the radiologist's visual evaluation of the pictures and compared the average electric conductivity of the breasts to the norm for quantitative assessment. We compared the groups' mean electrical conductivity using one-way analysis of variance (ANOVA), and we compared it with pre-existing Caucasians data using a t-test [42]. The authors found a strong correlation between the visual interpretation of breast images and the quantitative assessment of electrical impedance tomography.

Imaging of the Brain:

(Holder et al., 1996). published their research on EIT as a means of visualising the tens of seconds-long, several-percent impedance changes known to occur during triggered cortical activity. This study's findings suggest that EIT could one day be useful for imaging human subjects' evoked responses or epilepsy [43], and it also shows that EIT images taken during functional brain stimulation can reveal reproducible impedance variations of a few percent.

Advanced Materials Science:

EIT has also been investigated in the fields of manufacturing technology, material engineering, and semiconductor production, among others. Kruger and Michiel (2003). investigated semiconductor production using the EIT method [44]. As a function of film thickness, the author evaluated the conductivity distribution of a conductive polysilicon thin film across a wafer using the conventional EIT technique. Findings demonstrated that EIT is a good tool for visualising the conductivity changes brought about by physical and chemical processes occurring within a semiconductor wafer during manufacture. The author found a strong correlation between optical thickness measurements and differential thickness measurements taken by the EIT-based prototype etch rate sensor. In addition, the author put out a new EIT-based sensor that could record the surface potential of wafers in space and time as they were being processed by plasma. The simulation experiments performed on the prototype sensor [45], which used depletion mode NMOSFETs as transduction elements, produced encouraging findings and provided support for the appropriateness of the EIT based metrology technique.

Multi-Elements Structures and Nanotechnology:

EIT has been investigated in nanotechnology and thin film technology, for example, imaging of CNT composite thin films. Using EIT, Hou et al. 2007 [46] were able to see the structural flaws in CNT thin films and how they changed in response to different pH conditions by reconstructing the spatial conductivity distribution. The EIT's capacity to capture images of the conductivity distribution in CNT thin films was deemed useful for creating multifunctional sensing skins based on CNTs.

Building Construction:

Several research studies have reported on EIT's use in civil engineering, including one that images leaks from subterranean pipes (Jornadat al., 2001) and another that images brick walls (Hola et al., 2008). Citation: Jordana et al., 2001. used EIT to find pipes that were leaking underground. surface linear electrode arrays positioned perpendicular to the pipe axis are used to detect leaks in pipelines. The author conducted laboratory testing of their suggested system with a rubber-sleeved, stainless steel tube submerged in water to mimic a non-conductive leak. Additionally, the system has been investigated using field tests that included simulating water leaks from a plastic tube that was buried in a farm field. An EIT-based pipe leakage detection system was able to accurately identify the simulated leak, according to the author. (Hola et al., 2008). investigated if EIT could be useful for detecting the presence of moisture in brick walls in actual buildings. The moisture of test brick walls was determined using an EIT setup on a custom-built laboratory test rig. The results from the EIT-based investigations were compared to those from the conventional destructive dry-weight approach. The results and future studies that attempt to implement the EIT approach in building engineering practice were determined to be in satisfactory agreement, according to the author.

The Field of Biotechnology:

The microelectrodes used in EIT-based cell culture imaging are created using microtechnology. These are then housed in a tiny domain where the cell culture is processed and monitored. The object is a biological culture medium containing live cells or tissue. A little quantity of electrical current is delivered into the medium, and data is captured along the boundaries. By inputting the gathered boundary data into a reconstruction technique, the computer is able to generate impedance images. In 2008, Linderholm et al. introduced a new, low-cost [47], and quick microimpedance tomography system that could take four-electrode readings from a culture chamber equipped with sixteen planar microelectrodes, allowing enabling two-dimensional imaging of cell and tissue cultures. An Agilent 4294A impedance analyser and front-end amplifier are used to measure impedance, and a reconstruction method is employed to create 2D pictures. Human epithelial stem cells (YF 29) grown on the surface of the device are examined in relation to the object's shape and location, which produces vertical cross sections. The EIT system has the potential to be utilised in electroporation research as it can monitor the quick reduction in resistance generated by permeabilized cell membranes. (Sun et al., 2008) [48]. in 2010, and Sun et al. demonstrated a miniature EIT device capable of imaging the distribution of electrical conductivity in a two-dimensional cell culture. Physarum Polycephalum, a multi-nuclear single-cellular organism, is subjected to current injection and spatial voltage measurement using a PCB-fabricated chip that has a circular 16-electrode array. To acquire the voltage-current data, a four-electrode impedance analyser is employed, and EIDORS, an open-source programme, is utilised to rebuild the impedance images. The author asserted that the system's non-invasive lab-on-a-chip (LOC) technology will greatly benefit diagnostic and clinical applications by measuring the spatial distribution of electrical characteristics of individual cells.

Researchers across many disciplines are turning to EIT as a solution to their challenges because of its many benefits. The EIT technique has several benefits, however it has low spatial resolution and signal-to-noise ratio. Although spatial resolution improves with more electrodes, it isn't usually feasible to house so many in practical settings. Although the picture quality is improved with an increase in the number of elements in the FEM mesh, the computation time and cost may go up. The majority of the time, surface electrodes are what you'll see when doing medical imaging. Soldering or penetrating the item is another option for attaching electrodes in other fields. For medical EIT, the injected current amplitude and frequency must be carefully selected, however for EIT imaging of non-biological samples, the amplitude can be raised. Most EIT applications find contact impedance to be a critical concern, which is why the four electrode approach is recommended. Because it is an ill-posed inverse issue, the EIT makes a lot of noise at the output for a very tiny amount of input noise or error. An appropriate regularisation technique is also required for the inverse issue solution procedure in order to provide an improved solution. That is why it is crucial to plan the system's architecture thoroughly so that we may obtain the best possible photos for a given task. So, there's still a lot of research that has to be done to address all the problems with sensor design, new instrumentation, and reconstruction.

Tools and Methodology:

A computer, a video display device, and a data collection unit make up the Sheffield Mark 1 EIT system (Medical Physics, Sheffield) apparatus. It all started with the idea of using a 128 x 128 impedance tomogram back-projection on a cross-sectional slice of the abdomen, right around the electrodes that are transmitting and receiving signals from the abdominal wall [49]. Regular intervals (often 1 minute for the stomach) are used to take serial measurements. These measurements are taken against the reference frame both before and after a test meal is consumed. By using back-projection, the software is able to plot the filling and emptying of the meal against the initial reference frame.

Scientific procedures:

The location of the EIT electrodes:

With the help of 19 healthy individuals, we looked at whether the eighth costal cartilage was a good spot to put electrodes for EIT stomach resistivity measurements. The subject was given a 100 mCi 99mTc-tin colloid-containing soup drink after three electrodes were marked with a 57Co marker. A -camera was utilised for the imaging of gastric radioactivity. All nineteen participants had their electrodes placed at either the body level or the fundus of the stomach. The impact of electrode location was also investigated in a separate study that used six male participants. The stomachs of five subjects were scanned the day before EIT using 200 ml of orange juice tagged with 1MBq 99mTc-DTPA to determine their shape and position. After the scintigraphy the day before, EIT electrodes were inserted at what was thought to be the stomach antrum level the next day. with order to find out where the electrodes should be with respect to the stomach, a 57Co marker was applied to the subject's back at the EIT level. After the pre-meal EIT baseline was obtained, a 500 ml Oxo liquid meal tagged with 2MBq 99mTc-DTPA was administered, and scintigraphy and EIT were recorded simultaneously, with scintigraphy taking place at 8 minute intervals and EIT at 1 minute intervals. When the scintigraphy-determined marker concentration in the stomach dropped below 30%, the trial was deemed a success. Two patients had their electrodes put low, three had them at the antral level; of the latter three, one had their electrodes positioned high. Those whose electrodes were placed low showed a delay in emptying as measured by EIT, which may have been caused by duodenal filling.

Intragastric Balloon Volume Measurement with EIT:

Using intragastric balloons, six people were tested to determine how accurately EIT measured changes in volume. A nasogastric tube with a balloon placed 10 cm distal to the gastro-oesophageal junction was given to each volunteer so that they may swallow it. Inflating the balloon was done in batches of 50 ml until either the participant felt pain or 250 ml of air had been introduced. There was constant aspiration of gastric secretions. A reference image was captured with the tube in place and the balloon deflated, and this image was compared with the images produced at each volume. There was a direct relationship between the EIT readings and the air volume in the stomach balloon ($r = 0.999$).

Standard Deviation At EIT,

After 90 minutes of consuming cimetidine, four healthy volunteers who had fasted were evaluated for baseline variation. The EIT frames were recorded every minute for 45 minutes. At that point, 500 millilitres of Oxo were consumed by the participants. As a percentage of the maximum EIT value, which was acquired immediately after the Oxo drink was consumed, the fasting variation in the areas of interest according to the stomach position was displayed. Values obtained after consuming the Oxo drink typically showed baseline differences of little more than 10%, while deviations of up to 20% were rarely seen [50].

Dissimilarities Between Dye Dilution and Gastric Emptying as Measured by EIT for Liquid Meals:

Ten healthy subjects had their EIT and dye dilution rates monitored simultaneously to determine the pace of emptying a 750 ml 5% sucrose solution. A double lumen tube was inserted into the stomach of the subjects in order to intubate them. After aspirating the stomach contents, the abdominal cavity was flushed with 200 ml of water that contained 0.6 mg of phenol red dye. Inject 20 ml of a solution containing 6.25 mg of phenol red dye per 100 ml into the tube and mix the gastric contents completely ten minutes after consuming the sucrose. To ensure that the stomach was completely empty, this process was repeated every 10 minutes while increasing the dye concentration by a factor of 2. Before and after each dye addition, spectrophotometry was used to detect the quantity of phenol red in 10 mls of gastric contents. A correlation coefficient of 0.83 ($p < 0{:}001$) was used to describe the link between the two approaches' half-times. Infants were given 25 ml/kg of either Cow & Gate or SMA formula milk or Dioralyte via the naso-gastric tube for the liquid meal in 20 cases. In the end, the researchers matched the results from EIT with those from aspirating gastric contents to determine what proportion of the meal remained. Asymptomatic newborns were not subjected to scintigraphy or dye dilutions because their use was deemed unnecessary. Out of the twenty infants that were breastfed, sixteen had stomach residuals that agreed well with EIT. Distinct variations were observed in the other four newborns. Again, agreement was high for 24 of the 27 newborns given Dioralyte, while three showed significant discrepancies. Evaluation of Gastric Emptying Time (EIT) as Compared to Scintigraphy for a Semi-Solid Meal The gastrointestinal emptying of porridge was evaluated by Wright (1995) [51]. EIT and scintigraphy were compared in eight volunteers twice, at least 14 days apart. The subjects were either in the control group, which did not undergo acid inhibition, or they had received 400 mg of cimetidine two hours before the trial. The experiment included recording EIT at 1-minute intervals and scintigraphy at 10-minute intervals after a pre-meal baseline recording. The semi-solid meal consisted of 500 ml of salty porridge that had 3 MBq of 99mTc-DTPA added to the fluid before cooking. The study lasted no more than two hundred minutes. It was possible to analyse the data from ten investigations. A significant difference was found between stomach emptying evaluated by scintigraphy and EIT (p ½ 0:04), and the study in the EIT control group concluded before half-time for gastric emptying was reached. In the group that had acid inhibited, no discernible difference was found. In the scintigraphy group, the half-time was more prolonged after cimetidine administration (p ¼ 0:04).

Evaluation of Gastric Emptying vs Scintigraphy for Solid Meals:

Eight healthy volunteers had their EIT and single-camera readings compared simultaneously using a Pho/Gamma III, model 1201, Nuclear Chicago, Europa, NY. The meal's solid component was 85 grammes of instant mashed potato combined with 300 millilitres of water that included 100 millicuries of 99mTc-tin colloid. The radioactive distribution was imaged for two hours, with images taken every two minutes for the first forty minutes and every five minutes for the last eighty minutes [52]. Finding the stomach-related ROI, then calibrating the local radioactivity and accounting for isotope decay, yielded the gastric emptying profile. We compared these with EIT profiles that were obtained every 1 minute. The cimetidine was given 90 minutes and 15 minutes before the meal was to be eaten, respectively. The two approaches had a correlation value of 0.73 ($p < 0.05$).

The Impact of Different H2 Blocker Types on Gastric Emptying Rate:

Mushambi et al. (1992) used a crossover design to examine the effects of ranitidine and cimetidine on stomach emptying as determined by EIT in a group of 10 healthy adults. The presence of unrestricted acid was not observed in any of the control groups. After ranitidine was given, stomach emptying was significantly slower than after cimetidine (p < 0:04). Wright (1995) studied 16 healthy participants and compared solid and liquid meals. The semi-solid meals consisted of 500 ml of porridge with 4.5 g of salt, while the liquid meals were made with one Oxo cube diluted in 500 ml of water. Six independent studies were conducted on each subject. After taking an oral dose of 400 mg cimetidine 2 hours before the trial or 40 mg of omeprazole at 12 hours (20 mg) and 2 hours before the study, subjects were observed without acid suppression while they consumed the liquid and semi-solid meals. There was no significant difference in the rate of liquid emptying between the sexes when it came to the liquid meal. When compared to the control group, individuals taking acid suppressed studies had faster gastric emptying times (p ¼ 0:06 cimetidine, p ¼ 0:09 omeprazole). In both the control (p ½ 0:01) and cimetidine (p ½ 0:02) groups, it was found that males emptied their semi-solid meal containers more quickly than females. The order of elimination was omeprazole first, then controls, and finally cimetidine in both guys. When compared to the control group, the females exhibited a faster elimination of both cimetidine and omeprazole. The lag phases for semi-solids were longer in males compared to females (p ¼ 0:002). The lag phase was noticeably lengthier in the semisolid and liquid groups compared to the controls, for both males (p ½ 0:04) and females (p ½ 0:04). The percentage lag phase for solids and liquids was comparable when acid was blocked.

Acid Secretion and Its Impact on EIT-Liquid Meal Reproducibility:

Eight healthy volunteers participated in a randomised blind trial that demonstrated how cimetidine affected stomach emptying. Every single volunteer underwent a total of two sets of tests. On two separate days, participants took 800 mg of cimetidine or a sugar pill simultaneously. A 500 cc solution of warm water with one Oxo cube served as the experimental meal. Between the first and second studies, there was a considerable association between half-emptying times when cimetidine was given (r ½ 0:90), but no significant correlation (r ½ 0:19) when acid secretion was not stopped.

Impact of Acid Secretion on EIT-Solid Meal Reproducibility:

Another study that examined a beef burger meal used a single-camera system (Pho/Gamma III, model 1201, Nuclear Chicago, Europa, NY) to do scintographic and EIT measurements concurrently. A 160-gram radio-labeled beefburger with 137 millilitres of water, 20 grammes of fat, 23 grammes of protein, 8 grammes of carbohydrates, and 2.5 grammes of sodium chloride was given to the experimental subjects. Before being mixed with the raw meat, the 100 mCi 99mTc-sulphur colloid was beaten into the egg and then added to the beefburger. Twelve volunteers had their gastric acid secretion suppressed by taking 400 mg of cimetidine 60 minutes before the test and 800 mg at the beginning; eight subjects did not experience any inhibition of acid secretion during scintigraphy. Starting before the food was consumed, images of the radioactivity distribution were taken for 4 hours at 5-minute intervals. EIT readings were taken every 2 minutes for 10 minutes before and 4 hours after the meal was consumed. Although stomach filling was not observed in one patient, images were obtained in nineteen out of twenty subjects. For half and quarter time, there was a substantial correlation between the two approaches (r ½ 0:713, $p < 0{:}02$), but for the lag period when stomach acid was suppressed, the results did not reach significance (r ½ 0:585). There was no correlation for half-time ($r = 0.058$) or lag phase ($r = 0.376$) when gastric acid secretion was not stopped, and in 5 out of 8 experiments, EIT was slower than scintigraphy. In just 2 out of 8 trials did the half-time fall within 10% of the value achieved by scintigraphy.

Research in Paediatrics It is particularly desirable to use EIT for paediatric applications due to operational and safety concerns. Paediatricians have embraced EIT as a way to evaluate stomach function in babies and children with suspected foregut dysfunction since it is completely non-invasive and does not involve exposure to ionising radiations of any type. Hypertrophic pyloric stenosis was the subject of an investigation by Lamont et al. (1988). In a study conducted by Milla and Ravelli (1994), stomach stasis and GOR were found in children who had reflux and vomiting as well as in the large-scale investigations conducted by Nour et al (1994, 1995). The restrictions of EIT in adults also apply to youngsters. Furthermore, there are additional issues that arise from the subjects' size and general compliance, such as:. the challenge of fitting 16 electrodes onto a small subject's abdomen;. the fact that certain electrodes, like ECG electrodes, do not provide very good conductivity in children;. the length of time needed to record solid test meals;. the impact of movement artefacts on recording;. the importance of maintaining a stable position for the extended monitoring period;. the acceptance of validated test meals;. the absence of 'normal' paediatric data with varying ages on test meals.

When administering a continuous nasogastric feed, the use of EIT to gauge gastric emptying is essential.

Soulsby et al., who are currently awaiting publication, created the procedure as a way to study and monitor enteral feed tolerance, especially in critically ill patients. Typically, a continuous naso-gastric infusion is used to give enteral nutrition in a hospital setting. Aspirating the stomach contents through the nasogastric tube and monitoring the volume aspirated, also called the gastric residual volume, is a way to monitor enteral feed tolerance. The patient is said to be tolerating the feed if the stomach residual volume is below a threshold amount, often between 150 and 200 ml. Many have voiced their disapproval of this method, claiming that it relies on assumptions that lack physiological support. Actually, other from what may be predicted using mathematical models, no actual data on gastric emptying patterns during continuous infusion is available. We have created a method to study the effects of naso-gastric infusion on gastric emptying patterns in both critically ill patients (Soulsby et al., awaiting publication) and healthy volunteers, as well as on continuous enteral feed infusion.

Conclusion:

EIT has found use in many branches of the technical and applied sciences. We have summarised the research that has been done on the use of EIT in several engineering fields, including biotechnology, civil engineering, micro and nanotechnology, material engineering, and medical imaging. With a few other benefits and drawbacks, EIT technology is a low-cost, portable, and quick tomographic imaging modality that is used in all industries. A variety of benefits make EIT applicable to a wide range of research issues. In this paper, we review and evaluate a variety of studies that have looked at EIT in various contexts. This article gives a brief overview of EIT's uses, and reading about those uses could spark ideas for new areas to apply the technology in that haven't been explored or used before. A new non-invasive technique for measuring volume transit through certain human hollow visci is electrical impedance tomography. Its primary application is in gastroenterology, where it has replaced radionuclide studies—the "gold standard" according to clinicians—in determining the rate of ingesta transit through the stomach. There should be no correlation between it with gamma scintigraphy because it measures gastric volume instead of gastric residence time (emptying). This holds true even when all physiological secretions into the gastric lumen are blocked. Despite its appealing features, EIT is not commonly utilised for stomach emptying measures in the UK or anywhere else. The new technology has not been widely used in normal clinical settings in the UK healthcare system due to the challenges in transferring it to staff and infrastructure. The following issues are detailed: Marketing, production, and service/technical support all suffer from ineffective commercialisation. Institutions that teach medical professionals how to make the most of medical equipment. Establishing uniform procedures for use in healthcare facilities. Physiologically normal levels for several test foods established. Adoption of the method by medical professionals. Also, gastric emptying isn't often asked to be used in clinical settings. A lack of knowledge about foregut pathology and symptoms contributes to this, but failing to acknowledge the importance of such an enquiry in patient diagnosis and care also plays a role. With a little creativity and vision from medical professionals and researchers in this area, EIT may make a big splash. Lack of finance has prevented effective commercialisation and future development of EIT, which is currently being used by a handful of centres for research purposes. This condition will remain unchanged until there is a significant improvement compared to current diagnostic procedures in gastroenterology.

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