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Acoustic and Intraluminal Ultrasonic Technologies in the Diagnosis of Diseases in Gastrointestinal Tract: A Review

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ABSTRACT

Gastrointestinal (GI) auscultation (listening to sounds from stomach and bowel) has been applied for abdominal physical assessment for many years. This article evaluates the technique involved in listening to both bowel and stomach sounds and the significance of both normal and abnormal GI auscultation findings. Moreover, intraluminal ultrasonic techniques have been widely used for gastrointestinal disease diagnosis by providing intraluminal images since 1980s, this article also reviews the existing intraluminal ultrasonic technology for diagnosing of GI disorders.

Keywords: Auscultation; Gastrointestinal Diseases; Sound; Intraluminal Ultrasonic

1. Introduction

Sonic signals generated from both stomach and the bowels during the peristalsis could be clinically useful for the diagnosis of gastrointestinal diseases. In addition, intraluminal ultrasonic techniques provide clear images to visually monitor stomach and bowel anatomy and function in real time. Both sonic and ultrasonic technologies are relatively cheap and non-invasive by nature. In this paper, we will discuss both technologies, with an emphasis on the medical devices related to them and the associated methods for clinical applications.

2. Acoustic Technology

2.1. Why Acoustic Technology?

For centuries, clinicians performed auscultation by placing a stethoscope, an acoustic device, on patient's skin to listen to the sounds coming from adjacent internal organs in order to make a diagnosis. For example, lung and heart auscultation is now a routine clinical practice to exclude certain pulmonary and cardiac diseases. Cannon [1] pioneered abdominal auscultation for investigating sounds originally from GI organs more than a century ago. Due to its low cost and non-invasiveness compared to other modalities such as manometry and X-ray imaging [2], abdominal auscultation became attractive and was once a popular part of any clinical examination. However, due to the lack of scientific support, clinicians gradually turned away from abdominal auscultation [3].

Thanks to the advances in electronics and computer science, computerized analysis the abdominal sounds become possible [4,5].

2.2. Contemporary Acoustic Technology Devices

Earlier investigators wore acoustic stethoscope to listen to the abdominal sounds and manually recorded the data. Their data logging carried limited information and the data could be erroneous due to low sound levels. Further, the clinical criteria were generally considered subjective [6].

The introduction of the electronic stethoscope allowed amplification of the weak body sound signals [7]. More importantly, the signals could now be digitized and stored for offline computer-aided analysis. The electronic stethoscope further incorporated skin-adhesive and sealing features [8]. The advantages are twofold: Firstly, the sealing can effectively prevent the stethoscope from environmental interferences transmitted through air. Second, the adhesion permits long and unsupervised auscultation for hours [8].

Campbell *et al* [9] introduced what they referred to as "surface vibration analysis" device, the technology behind which is transferred from industrial applications. Rather than utilizing a diaphragm that transforms body vibrations to an acoustic signal, it utilizes a piezoelectric transducer, which has a minimal response to acoustic signals but is very sensitive to vibrational energy transmitted from internal organs through the abdominal wall.

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2.3. Acoustic Applications in GI Diseases

Computerized acoustic technologies in the diagnosis of diseases in the GI tract can be classified according to the GI organs they target.

Extensive research has been going on to understand bowel sounds [10-12]. With CASAS, an advanced signal processing software, Sugrue and Redfern [10] explored bowel sounds in controls and patients with several acute abdominal conditions, including appendicitis, cholecystitis and intestinal obstruction. They recorded the abdominal sounds for 10 minutes for each patient and defined five different acoustic parameters: a) sound length, b) number of sounds over a unit time, c) sound amplitude, d) interval between sounds and e) sound to silence ratio. Several interesting differences between controls and patients with various acute abdominal disorders are observed. However, the experiments failed to offer a reliable scientific explanation about the origins of the bowel sounds.

Later studies tried to correlate bowel sounds related to drug-induced episodes with simultaneous manometry findings. Tomomasa *et al* [11] compared bowel sound index (*i.e.* sound amplitude) to small intestinal transit time in subjects that were intraduodenally administered lactulose that can change the duodenal motility for 15 minutes. The correlation of their sound recordings with manometry suggested that the stimulated contractions can increase bowel sounds and these sounds are more likely to reflect the movement of food content rather than the movement of the lumen wall.

Yuki *et al* [12] conducted two-minute recordings on controls, inflammatory bowel disease (IBD) patients and those with increased bowel motility that was induced by a prokinetic drug. After comparing the mean sound-sound interval and number of detectable sounds per minute among the groups, they failed to identify any statistical difference, suggesting that the 2-minute sampling period may not be long enough to capture the bowel sound alterations.

Dimoulas et al [13,14] proposed prolonged abdominal sound monitoring and processing using a wavelet-based method [13] and time-frequency features [14]. The methods they developed were able to classify abdominal sounds into intestinal bursts (IB), *i.e.* those abrupt sounds in a very short duration, and regularly sustained (RS), *i.e.* those clustered sounds in a long duration. Further, they could identify three type of interfering noises: silent period, respiration and snoring, as well as motion-related moving noises.

Acoustic studies from GI organs other than intestines were also studied. Tomomasa *et al* [16] conducted stomach sound measurements with a microphone placed 3 cm below the umbilicus on infants with pyloric stenosis before and after pyloromyotomy. Gastric emptying was measured simultaneously. Sound index (SI) was calculated. They found that there was a significant positive correlation between SI and gastric emptying, which is suggesting that SI was a useful indicator of gastric emptying after the surgery.

Yamaguchi et al [15] measured stomach sounds while monitoring the motility of the gastric antrum using ultrasonography. Sounds were classified as gastroduodenal sounds and intestinal sounds based on whether antral movement was observed using ultrasonography. Diabetic patients and controls underwent measurements after food intake. In diabetics, the SI of the gastroduodenal sounds was significantly lower after food intake compared to controls.

3. Intraluminal Ultrasonic Technology

3.1. Principle of Intraluminal Ultrasonic Technology

Intraluminal ultrasound imaging techniques were originally developed for the visualization of plaques when investigating cardiac valves and vessels [17,18]. They had been applied to study gastrointestinal diseases since the 1980s [19,20]. The technique is a derivative of B-mode and M-mode ultrasonography, which are able to provide high-resolution images for both linear and cross-sectional images. Typically, the radial resonant frequencies of ultrasonic transducers vary from 9 to 40MHz [21]. Since the ultrasonic technique records in real time and is noninvasive, it has been widely adopted to study the dynamics of the GI tract. In recent years, due to device miniaturization, it becomes feasible to incorporate fine needle aspiration (FNA) biopsy mechanism with intraluminal ultrasound devices [33].

3.2. Instrumentation on Intraluminal Ultrasonic Technology

Depending on the direction of the image formed, intraluminal ultrasonic devices can be divided into two types: radial and curvilinear [21]. Intraluminal ultrasonic devices can be inserted alone or within a standard endoscope. Radial imaging devices, they utilize a 360º rotating ultrasound transducer. All ultrasonic waves travel within a plane that is perpendicular to the direction of the endoscope insertion. As a result, the image formed is parallel to those axial CT images, but it is more intuitive to interpret ultrasonic images compared to their computed tomography (CT) counterparts [29]. As for the curvilinear imaging devices, the transducer is positioned at the tip of the endoscope and is producing sector images which are parallel to the direction of the endoscope insertion [29]. Although such images are difficult to interpret, they present a significant advantage over radial imaging when used for guiding FNA that is inserted at an oblique angle from the endoscope [29]. Moreover, Doppler imaging can be implemented in the curvilinear devices to detect blood flow in blood vessels. It is useful to prevent bleeding when performing FNA [34].

3.3. Ultrasonic Applications for GI Disorders

Mittal *et al* [21] performed preliminary studies of utilizing ultrasonic techniques in evaluating various esophageal diseases. The cross-sectional structure of the esophageal lumen during liquid swallows and liquid gastroesophageal reflux (GER) can be measured by a ultrasound probe. Meanwhile, analysis of the esophageal contents and dimensions during transient lower esophageal sphincter (LES) relaxations can be performed as well [21-24]. Extremely small ultrasonic crystal arrays are often mounted circumferentially on a single site of an intraluminal catheter to inspect visually the cross-sectional image of the esophagus at a specific level [28]. Studies have shown that imaging can measure esophageal cross-sectional area (CSA) distensions during liquid GER episodes [25].

Comparison of esophageal CSAs between GER patients and controls showed that the peak esophageal luminal CSAs was significantly dilated in GER patients than that in controls [26,27]. However, there are still limitations for the ultrasonic technique in GER diagnosis. For example, the current intraluminal ultrasound device can only measure esophageal luminal distension at one level of the esophagus, because there is only one ultrasonic sensor integrated on the catheter. Therefore, it was suggested to mount multiple ultrasonic sensors at various levels of a catheter for more comprehensive GER testing [35]. This has not been implemented, most likely due to the limited room left in the catheter, the high manufacturing cost of the ultrasonic sensors, as well as the tedious image analysis process [28].

Ultrasound has been greatly applied for diagnosing malignant gastric disorders [29], ultrasound has added greatly to the staging of gastric cancers, especially when the cancers are limited to the mucosa level [29]. Ultrasound is also more favorably used than CT because it can be combined with endoscopic mucosa resection for histologic confirmation. As for staging cancers evolving into the muscularis mucosa, high-frequency miniprobes can be used, which can delineate the fine details of the gastric wall as a 9- or 1l-layer structure as opposed to the 5 layers shown in lower frequency ultrasound [29, 30].

Ultrasound is also outperforming traditional endoscopy in characterizing submucosal tumors in the GI tract because it is able to distinguish whether a tumor is cystic, solid or hypervascular from its echo pattern [29]. However, ultrasound alone is difficult to differentiate malignant and benign tumors. Biopsy exam from ultrasound-guided FNA can improve the diagnosis, especially when the tumors are in the first few layers shown on the ultrasonic images [33].

In the past two decades, studies have shown that intraluminal ultrasound is consistently accurate in staging rectal cancers, especially those in early stages [31], which CT or magnetic resonance imaging (MRI) are unable to resolve. Ultrasound is also an alternative modality for assessing inflammatory bowel disease through observing features such as increased bowel wall thickness and enlarged vessels [32].

4. Discussion and Conclusions

The idea of diagnosing GI diseases using sound and ultrasound devices is very attractive because of their relatively low manufacturing costs and non-invasiveness to the human body. This paper reviewed the relevant research on them in the past 20 years. With the advances in device miniaturization and computing capacity, new diagnosing devices and associated methods evolve and are being clinically tested. Intraluminal ultrasound has been gradually accepted in the diagnosis of many GI diseases. Sonic technologies, which are capable of revealing many interesting features of the GI organs though, are still under investigation. More understanding on the origins of the abdominal sounds is needed. In the future, more precise sonic detection and analysis devices and methods are expected for accurate diagnosis of GI diseases.

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