Introduction

Conventional methods for clinical investigations of the human small bowel provide only scattered data about the various characteristics of the human gut. Different procedures are applied to explore the intestine, such as manometry, radiology, ultrasound, endoscopy, scintigraphy, fluoroscopy or electromyography. These techniques are either invasive or imprecise, most of them using catheter probes which are swallowed or introduced through natural orifices. The small intestine is too far from both the mouth and the anus to be efficiently reached using conventional methods. For instance, samples of intestinal bacterial flora, intraluminal enzyme content or mucosal biopsies from the middle or the distal end of the small bowel cannot be reliably obtained.

The development of a noninvasive procedure to simultaneously explore various parameters of intestinal function is of great importance for medical practice. Telemetry, which is the transmission of data at a distance without any material link, was previously used to solve this problem. Some devices, designed to be swallowed, have previously been reported to be capable of measuring the pH (Noller, 1962), the pressure (Browning et al., 1981) or the picking up (Uchiyama et al., 1980) or releasing (Hemat, 1969) of fluid substances. All of them used telemetry, but none was able to permanently transmit its precise location inside the small bowel. The main originality of this device is the location detector (international patent) which has not previously been reported.

Technical characteristics of the capsule

The device, shown in Fig. 1, consists of a plastic cylinder (39 mm in length, 11 mm in diameter and with a weight of 3.5 g) which can be separated into two parts: the main element and the interchangeable tip. The main element contains a lithium battery, a radiotransmitter, a location detector and a magnetic switch, which is able to give its precise location along the small bowel, its velocity and its direction of progression, and is capable of picking up or releasing fluid substances. The main originality of this device is the location detector (international patent) which has not previously been reported.

Fig. 1 The telemetric capsule: Rotations of the cogwheel induced by the progression of the capsule in the small bowel are transmitted by the radiotransmitter. The interchangeable tip, made for aspiration or release of liquid, is remotely controlled by the magnetic switch. A lithium battery supplies the device for 24 h.

Abstract—An intestinal telemetric capsule has been developed to study the small bowel in man. It consists of a cylinder (11 mm in diameter and 39 mm in length) containing a location detector, a radiotransmitter, a lithium battery and an interchangeable tip. After having been swallowed by the patient, the capsule passes through the whole gut and is recovered in the stools. During the transit through the small bowel, the information provided by the radiotransmitter allows continuous monitoring of the distance covered from the pylorus, the direction and the velocity of progression. Moreover, according to the type of interchangeable tip, it is possible, by remote control, to sample 0.5 ml of intraluminal fluid for subsequent analysis or to release 1 ml of any liquid substance in a precisely determined place for pharmacological studies. The main originality of the capsule is its ability to transmit its precise location inside the small bowel.

Keywords—Capsule, Clinical investigation, Intestinal motility, Telemetry, Transducer

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2.1 Location detector

The location detector (Fig. 2) allows permanent data collection during the passage through the gut. The system consists of a plastic cogwheel with a diameter of 10 mm and a width of 1 mm. It is retractable into a small cavity inside the capsule like a landing wheel. The cogwheel retracts completely into its cavity with a force of 0.15 N. The rotation axis of the wheel is stainless steel and is mounted on a plastic support. It remains in contact with a flexible lamella on which a strain gauge transducer (Kulite UHP 5000 060) is bonded. Because of the triangular section of the axis, each ¼ rotation of the wheel bends the lamella which then returns to its resting position. It moves left or right according to the rotation direction, leading to an increase or decrease of the gauge resistance. These variations in resistance are transmitted by means of the radiotransmitter to an appropriate receiver. Thus, a positive pulse is emitted for each ¼ rotation clockwise (i.e., for a forward movement) and a negative pulse for movement in the opposite direction (i.e., for a backward movement).

Positive and negative pulses are measured on a graphic recorder (Beckman R611) as positive or negative spikes, respectively, and counted in real time. The testing procedure shows that one spike represents a 1 cm movement of the capsule. Thus, the arithmetic sum of the spikes gives the distance covered by the capsule.

2.2 Power supply

The power supply is a lithium battery (Sanyo CR772) providing 3 V, with an autonomy of about 24 h for the system.

2.3 Electric settings

Data concerning the movement of the ingested capsule are transmitted through a radiofrequency link to an external receiver. The variations in resistance induced on the strain gauge are converted to voltage drops, which in turn modulate the frequency of the radiotransmitter. The transmitter (Fig. 3) consists of a Colpits oscillator tuned to a frequency of 108 MHz; the frequency swing is ±100 kHz. The construction uses surface mount components, which are grouped on a small substrate (8 × 12 mm²). The radiating element (antenna) is the oscillator tuning coil itself, which is wound at the perimeter of the substrate. The total current drain of the transmitter is 1.2 mA with the 3 V supply of the lithium battery.

The receiver uses basic components developed for FM broadcast devices. The frequency range has been shifted to 100–125 MHz. The global sensitivity of the receiver has been adjusted to 0.3 µV (26 dB signal-to-noise ratio with ±75 KHz swing), by using a +18 dB high-frequency amplifier placed directly onto the dipole antenna. A wide range automatic frequency control (±1 MHz) has been designed to track the frequency drifts of the transmitter. Indeed, during the transit of the capsule through the digestive tract, the load of the high-frequency oscillator varies according to the distance between the device and the skin, thus inducing frequency shifts. The telemetry range can reach 15 m, but as the radiation is highly directive, the reliable range has been estimated to be about 2 m.

2.4 Magnetic switch

The magnetic switch (Hermetic switch HSR 005) allows the remote control of the desired function of the interchangeable tips. It is activated by bringing a permanent magnet close to the capsule (less than 15 cm away). This procedure induces the electric alimentation of a micro furnace (0.5 mm in diameter and 1.8 mm in length) which is in contact with a strip of plastic. After 2 s of heating, the plastic strip breaks, causing a clip to open which frees a piston pushed by a previously compressed spring, thus starting the desired action. This strip of plastic is destroyed by each investigation and must be replaced before each experiment. Owing to the high current drain (50 mA), remote control is only possible during the first 8 h of investigation. The future use of silver oxide cells will extend this control to up to 20 h.

2.5 Interchangeable tips

Until now, two different remote-controlled types of tips may be fixed to the front of the device, according to the chosen experiment. They either aspirate a sample of intestinal juice or release a liquid substance in the intestinal lumen of the small bowel.

An aspiration tip (Fig. 4) can be fixed to the front of the capsule to sample intestinal juice. The capacity of the reservoir is 0.5 ml. Before the investigation, a vacuum is...