New Methods for Diagnosis and Research

WIRELESS TELEMETERING FROM THE DIGESTIVE TRACT

BY

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This paper describes the construction and use of "radio pills" which transmit changes in intraluminal pressure.

Most patients dislike intragastric tubes, whether for tests or treatment, more than any other diagnostic or surgical procedure: this was the general opinion of patients recovering from a gastrectomy at Central Middlesex Hospital. There is no doubt, too, that the nausea and distress caused by the presence of a tube has vitiated a great deal of clinical investigation, since the patient's emotional state is known to exert a profound influence on all aspects of gastrointestinal function. For this reason there is an urgent need for tubeless methods of investigation and also because most of the small and large intestine is inaccessible to tubes for all practical purposes (Rowlands, 1960).

The preliminary publications about the construction of wireless transmitters sufficiently small to be swallowed by a patient (Mackay and Jacobson, 1957; Farrar, Zworykin, and Baum, 1957; von Ardenne and Sprung, 1958) seemed to us to represent a distinct advance in gastrointestinal investigation. We therefore decided to follow this up and were fortunate in obtaining the collaboration of Mr. H. S. Wolff and the Bioengineering Laboratories of the National Institute of Medical Research. Theoretically, a wide variety of physiological parameters can be transmitted by such wireless pills. We decided to start by incorporating transducers for recording pressure and temperature into the pills, because these are the easiest to construct. This project having proved successful, a pH-sensitive pill is now being developed, using a glass electrode (Wolff and Russ, 1960).

We have studied the performance of these pills in the gastrointestinal tract during the course of their development. This paper presents our experiences and indicates some of the problems we have encountered in the clinical use of the pills, with special reference to those incorporating a pressure transducer.

CONSTRUCTION OF PILL

In designing the pill, it was felt that the clinical value of this promising technique could only be assessed if pills were freely available and of constant quality and performance. It was therefore decided that only commercially available components should be used so that the pills could be produced by a commercial organization as soon as possible.

The construction of the pills and receivers has been described elsewhere (Rowlands and Wolff, 1960; Wolff and Russ, 1960; McCall, 1960). A typical pill is illustrated in Fig. 1 and a diagrammatic cross section in Fig. 2. One end of the pill housing is formed by a "perspex" diaphragm to which a ferrite disc is attached. When the diaphragm bends, the disc is moved and this changes the inductance and hence the frequency of oscillation. This frequency change is transmitted and picked up by a suitable receiver. The power supply is a cylindrical shaped battery, 7.7 mm. in diameter and 3.4 mm. high, and this determines the overall diameter of the pills at 8.8 mm. The battery life is between 30 and 40 hours. In the earlier pills an inertia-operated mercury switch was used. By shaking the complete pill sharply along its axis in the appropriate direction, the mercury could be moved to the ON or OFF position (Fig. 2). This device proved unsatisfactory because the pill sometimes switched itself off in the act of swallowing, indicating that the diameter of the capillary containing the mercury was critical and very difficult to standardize.

A new switch has been devised, consisting of a peg which is pulled out of the pill before use so that two spring wires make contact and switch the pill ON. This has proved very satisfactory. It was found that pills which were perfectly stable in air developed a serious drift

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during recordings from the gut. This proved to be due to the effect of fluid acting on the outer surface of the diaphragm, thus causing a small dimensional change. This can be largely prevented by placing a layer of silicone grease in the cup over the diaphragm. The pills are calibrated in water at 37°C before use and the calibration has been checked in those pills recovered before expiry of the battery.

**Transit Times**

Thirty-two pills have been swallowed, so far, mostly by normal subjects but a few by patients suffering from gastrointestinal disease. None of our subjects or patients has had any difficulty in swallowing the pills. The transit time through the gastrointestinal tract has varied from 18 hours to four days. The major points of hold-up in normal people are in the pyloric antrum and in the caecum. The factors causing delay in the caecum are not known but the delay at the pylorus appears to be related to the presence of food in the stomach. Although these pills may become sufficiently cheap to be expendable it is a simple matter to recover them if required: the receiving aerial is brought close to the stool and the position of the maximum signal noted. The pill is then directly extracted from this point.

In one patient the pill failed to pass through the gastrointestinal tract. This was a patient in whom a tentative diagnosis of idiopathic steatorrhoea was made on the basis of increased faecal fat excretion, abnormal small bowel enema, delayed xylose excretion, and
abnormal small intestinal biopsy. In this patient the pill passed out of his stomach but failed to progress beyond the left iliac fossa where it remained for three weeks. A repeat small bowel enema was performed which revealed areas of dilatation and multiple strictures of the upper small intestine. At laparotomy, multiple strictures were found in six feet of jejunum and upper ileum resulting from Crohn's disease. The pill was recovered from the resected specimen. While it is not recommended that pills should be given routinely to patients suspected of having intestinal obstruction, in this particular patient the delay in the transit of the pill did speed up further investigation which led to an early laparotomy and resection. Farrar and Bernstein (1958) have reported a similar experience.

**Localization of Pill**

One of our main problems has been in localizing the pill after it has passed beyond the ligament of Treitz, despite frequent screening using an image intensifier. For example, in the above patient, the pill appeared to be in the descending colon but the small bowel enema showed that it was actually held up in the jejunum. However, it is sometimes possible to locate the pill approximately from its movement and position on screening. Moreover, we are familiar with the characteristic pressure patterns at different levels throughout the gastrointestinal tract from our previous motility records, using tubes. By correlating these pressure patterns with those transmitted by the pill during its passage through the gut, it has been possible to localize the pill in most cases with a fair degree of accuracy, and with more experience it may be possible to dispense with fluoroscopic control altogether.

**The Pressure Records**

Two types of recorder have been used, a direct writing pen recorder (Fig. 3) and a mirror galvanometer. Figures 4 to 8 are illustrative tracings of records obtained at different levels of the gastrointestinal tract.

**Loss of Contact.**—In some of the records the trace drops transiently below the base line. This results from loss of contact with the pill when a directional aerial is used. We have observed pills radiologically during a period when contact was being repeatedly lost and noted that this seems to coincide with certain movements of the pill, particularly when it spins on its axis. It does not necessarily imply forward propulsion. This loss of contact has occurred repeatedly in several of our records, especially in the small intestine, but an omnidirectional aerial has recently been devised to overcome this difficulty. However, it may be that some information can be obtained from observation of these periods of loss of contact as they seem to indicate some movement of the pill which may or may not be associated with a rise in intraluminal pressure. For example, it is known that contractions occur in the pyloric antrum at a rate of 3 per minute. When these contractions are powerful, resulting in a rise in intraluminal pressure, the pill is unlikely to spin and a trace as illustrated in Fig. 4 (lower tracing) is obtained. If, however, the contraction rings passing along the antrum are feeble and do not result in a rise in intraluminal pressure, the pill probably rotates and a trace showing loss of contact at a rate of 3 per minute is obtained (Fig. 9). If this interpretation is valid it is possible that more information can be obtained using a combination of a directional and omnidirectional aerial than by an omnidirectional aerial alone.
Fig. 4.—Gastric pressure waves. Upper trace showing gastric tonus activity. Lower trace showing typical 3 per minute antral waves.

Fig. 5.—Small intestinal pressure waves (recorded through an ileostomy).
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**Fig. 6.—**Pressure waves in the area of ileo-caecal valve. On the extreme left is small intestinal activity; on the right caecal activity.

**Fig. 7.—**Colonic pressure waves from the region of the splenic flexure.

**Fig. 8.—**Pressure waves from the pelvic colon.

**Fig. 9.—**Record from the pyloric antrum showing loss of contact with pill at 3 per minute.
Figs. 10 and 11.—Simultaneous records from a pill and open-ended tube in the same segment of colon. Upper trace, pill record using a mirror galvanometer. Middle trace, open-ended tube record from the same segment. Lower trace, record from miniature balloon 10 cm. distant.

Fig. 12.—Simultaneous records from pill and miniature balloon in the same segment of colon. Upper trace, pill record using a mirror galvanometer. Middle trace, miniature balloon recording from the same segment. Lower trace, miniature balloon recording from 10 cm. distant.
Correlation with Tube Methods.—The records are essentially the same as those we have obtained in the past using open-ended tube and miniature balloon methods from all readily accessible areas of the gut. To confirm this impression it was necessary to obtain simultaneous records with pills and tubes. This could only be done accurately and conveniently by tying the pill to the recording tube and inserting it through an ileostomy or per rectum. It is essential that the diaphragm of the pill is in precisely the same position as the other recording device to ensure that the comparison is made in the same segment of intestine at all times (Connell, 1959). Thirteen studies have been made in this way. There is an exact quantitative and qualitative correlation between the open-ended tube and pill records (Figs. 10 and 11), but there are some minor quantitative differences between balloon and pill records (Fig. 12). However, these occur only when the miniature balloon is subjected to a high squeeze pressure and can be explained by the different dynamics of balloon and diaphragm recordings under these circumstances (Edwards and Rowlands, 1960). Of 100 waves selected at random from the pill tracings, only 19 differed from the corresponding balloon record by more than 33%.

Discussion

The battery life is usually adequate for recordings from normal subjects but in some patients it has not been long enough for studies of the distal gut. It is possible to prolong the battery life for as much as three weeks (Jacobson, 1960). It is also possible to construct pills which are externally energized, but this introduces other problems and is unlikely to be a satisfactory solution (Farrar, Zworykin, and Berkley, 1960).

Another problem arises from the fact that the reference pressure is that of the air trapped inside the pill body. To allow for changes in atmospheric pressure after manufacture, a small hole is left in the outer case of the pill which is blocked immediately before use. After this has been done, any subsequent changes in barometric pressure will result in errors in the reference pressure, but it is possible to correct these by noting changes in barometric pressure (Jacobson, 1960). In clinical practice this error is unlikely to be important.

A further problem which has not yet been solved is to devise a method for using the pills to record propulsive activity. This can easily be done when tubes are used because three or more recording tips can be used simultaneously. In contrast, it would be difficult to swallow three pills strung like beads on to a short piece of semi-rigid tubing. For this and other reasons we feel that fine tubes will remain the method of choice for studying oesophageal function.

Despite these limitations, there is no doubt that the further development of this tubeless method will result in considerable advances in our knowledge of gastrointestinal function in health and disease. Already, certain new features of gastrointestinal motility have been noted, especially in the previously unexplored areas of the intestine. The method is applicable not only to the study of motility but can be adapted to obtain data about the secretory and absorptive functions of the gastrointestinal tract. These developments present exciting prospects of much new physiological information from an area of the body about which we urgently need new knowledge.

We wish to thank Dr. F. Avery Jones and Dr. T. D. Kellock for permission to study their patients.

References

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*Gut* 1960 1: 266-272
doi: 10.1136/gut.1.3.266

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