THE MOTILITY OF THE SMALL INTESTINE

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'Every point of the intestine is in a state of activity, which can be played upon and modified by impulses arriving at it from all positions of the gut, above and below'—Bayliss and Starling, 1899.

ALTHOUGH the dynamic state of the intestinal musculature was well appreciated by Bayliss and Starling at the end of the last century, subsequent progress in our understanding of the mechanisms controlling intestinal motility has been disappointingly slow. Progress has been delayed by a confused nomenclature. The terms 'motility', 'peristalsis' and 'tone' are often used indiscriminately and without precise definition. For example, the term 'motility' is used to describe a variety of different features of the intestinal movements, including the rate of passage of food and other materials along the alimentary tract, the appearances of the gut on direct observation or at fluoroscopy, the 'tone' or rigidity of the bowel wall and the pressures developed in the lumen of the bowel. The result is that references to bowel movements in clinical writings are frequently so vague and imprecise as to be, at times, meaningless. Progress in this field of study has also been hindered by difficulties in methodology. Patients and subjects always dislike swallowing tubes and as it has until recently been necessary to pass a tube into the small intestine to obtain information about bowel movements, there has been a natural reluctance on the part of clinical physiologists to subject their patients to this discomfort. Furthermore, the nausea and distress caused by the presence of a tube in the alimentary tract may vitiate studies using these methods.

The advent of the ingestible telemetering capsule, however, has for the first time made it possible to obtain quantitative data from the alimentary tract without the use of tubes and it seems likely that the prototypes undergoing development at present herald a new era in the study of gastrointestinal function. It is therefore an appropriate time to examine existing knowledge about the motility of the small intestine in man.

Methods of Study

In animals a great deal of information has been

obtained about intestinal movements by direct observations of loops of bowel of which the Thiry-Vella (Thiry, 1864; Vella, 1888) is the best known. Alternatively, recordings have been made from balloons or other devices introduced into fistulous openings in the alimentary tract.

In man, direct observation can be made, but only at surgery where the situation is complicated by the effects of trauma and anaesthesia, or of the limited area of bowel exteriorized to form a colostomy or ileostomy. However, a number of indirect methods are available. These include the use of X-rays, the detection of intestinal sounds by a microphone on the abdominal wall, recording of intestinal electropotentials, the recording of wall tension by large balloons and the recording of intra-luminal pressures by open-ended tubes or miniature transducers. There is no ideal method, and each method can only give information about a limited aspect of motility so that in any given study the method used must be selected with consideration to the particular aspect of motility about which information is desired. For example, radiology remains the best method of timing intestinal transit but even cineradiography is of limited value in investigating other aspects of motility and while the large balloon remains the best method of assessing the 'tone' or rigidity of the bowel wall it does not accurately record intra-luminal pressure. A review of the methods of measurement of gastrointestinal motility in man has recently been published by Farrar and Davidson (1960).

Large Balloons

For many years the large balloon has had an honoured place in the study of intestinal motility and much of the information we now have has been obtained by this method. Balloon-manometer systems have certain well-known disadvantages which have been discussed by Quigley and Brody (1952), Lorber and Shay (1954), and more recently by Chaudhary and Truelove (1961). Unhappily, the impression has been created that the considerable amount of data accumulated by this method is invalid. However, in spite of the availability of newer and more refined methods,

FIG. 1.—Diagrammatic representation of the structure of the radio pill. (By courtesy of the Editor of the *British Communications and Electronics*.)

the large balloon remains a useful method in the study of intestinal motility. By virtue of its stimulant effect on the bowel it provides a base-line of activity against which the effects of drugs can be assessed and it is still the only method of determining the rigidity or 'tone' of the bowel wall.

Small Balloons

Many of the disadvantages of the large balloon system result from the insensitive water manometers usually employed. Many of the disadvantages can be overcome if a smaller balloon with an optical recording system is used. Code, Hightower and Morlock (1952) described a small balloon (3 cm. in diameter) recording on an optical manometer and Hightower (1952) showed good correlation between this device and a pressure transducer in all areas of the gastrointestinal tract with the exception of the pyloric antrum.

Miniature Balloons

Atkinson, Edwards, Honour and Rowlands (1957) introduced a miniature balloon (7 mm. by 10 mm.) recording on a metal capsule optical manometer (Rowlands, Honour, Edwards and Corbett, 1953). An almost exact comparison exists between tracings obtained with a miniature balloon and an open-ended tube (Edwards and Rowlands, 1960; Connell, 1961a) and a miniature balloon and

a radio pill recording from the same segment of gut (Connell and Rowlands, 1960) provided that the balloon is not squeezed by the bowel wall. These miniature balloons record true intraluminal pressures, do not act as a stimulus to motility and cannot be blocked by the bowel content.

Open-ended Tubes

Open-ended tubes, which may be either air-filled (Rowlands, Honour, Edwards and Corbett, 1953) or fluid-filled (Smith, Texter, Stickley and Barborka, 1957), measure true intraluminal pressures, but plugging of the catheter with mucus can be troublesome and result in damping or distortion of the record. To overcome this, most investigators keep the tubes patent by introducing air or fluid continuously into the recording system at a very slow rate (Quigley and Brody, 1952).

Electromagnetic Pressure Transducers

A miniature pressure transducer in the bowel records true intraluminal pressures and, provided the response characteristics of the recording system are satisfactory, is free of the difficulties due to damping or distortion which occur using open-ended tubes. A pressure transducer was introduced by Abbott, Hartline, Hervey, Inglefinger, Rawson and Zetzel (1943), but failed to be accepted into general use, probably on account of technical difficulties. A miniature manometer, however,

devised by Gauer and Gienappe (1950) for cardiovascular research has been used with good results in the study of alimentary motility, including the small intestine (Quigley and Brody, 1952; Code, Wilkinson and Sauer, 1954).

Radio Pill

The discomforts and obvious disadvantages of oro-nasal intubation have stimulated the development of radio telemetering capsules for studying the gastrointestinal tract (Mackay and Jacobson, 1957; Farrer, Zworykin and Baum, 1957; Connell and Rowlands, 1960). The pressure-sensitive capsule devised by the Medical Research Council is illustrated in Fig. 1 (Rowlands and Wolff, 1960). 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 of the transmitter. The frequency change is transmitted and picked up by a suitable aerial. The power supply is a battery with a life of up to 80 hours. In later models the switching device illustrated in this pill has been replaced by a peg which on removal permits contact between two wires. For accurate recording it is necessary to screen the patient and receiving system against unwanted electronic interference.

This technique permits quantitative recording of small intestinal intraluminal pressures without any discomfort to the patient. Moreover, when the pill changes its position with reference to the aerial the strength of the signal received also changes. By recording variations in signal strength information is provided about movements of the capsule not necessarily associated with changes in intraluminal pressure (Connell and Rowlands, 1961). At the same time, information about gastrointestinal transit can be obtained by following the movements of the pill fluoroscopically using an image intensifier. This may become the method of choice in small intestinal studies in spite of the disadvantages of expense and the fact that records can be obtained from only one position in the intestine at a time. The problem of localizing the pill can largely be overcome by the judicious use of contrast media and fluoroscopy (Ridgeway and Smith, 1961; Connell, 1961b).

X-rays

Although radiology permits simultaneous visualization of the activity of several areas of the intestinal tract, the method suffers from some serious limitations. Outstanding among these are the lack of any continuous record from which to make quantitative measurements, the fact that one segment of gut may obscure another and the short time available for study due to the radiation hazard

even when an image intensifier is used. X-ray studies, however, can supplement and illustrate other techniques and they also provide the only means of estimating intermediate transit times.

Abdominal Sounds

Cannon (1905) first used intestinal sounds as a measure of total intestinal activity. Although this method has been used to estimate the gross effect of drugs on motility (Farrer and Inglefinger, 1955; Du Pleissis, 1954), it is not an accurate index, as the intensity and quality of the sound depend not only on the contraction of the intestinal muscle, but also on the relative proportions of gas and fluid in the bowel and the distance of the active loop from the surface. Intestinal movements frequently occur without the production of any sound (Louckes, Quigley and Romans, 1953).

Electropotential Recording

Electropotential changes have been recorded from the small intestine of dogs (Armstrong, Milton and Smith, 1956) and from the intestinal muscle of the exteriorized ileum in conscious men (Daniel and Bogoch, 1959). Action potentials have been described in association with forceful segmental contractions, but changes in electrical activity occur in the absence of pressure changes. However, it is clear that much further work is necessary to establish the significance of these potentials.

Pressure Patterns from the Small Intestine *Duodenum and Jejunum*

A typical record of the pressure changes of the upper small intestine obtained using miniature balloons is illustrated in Fig. 2. The waves illustrated here are of short duration (2 to 6 seconds), of varying amplitudes (up to 75 cm. of water pressure) and occur in rhythmic sequence at a rate of 11 to 12 per minute. Larger, slower waves lasting from 10 seconds to 8 minutes may also occur, but with less regularity. They may have superimposed faster components. The proportion of slow waves is greatest in the duodenum and they become less prominent both in number and size in the jejunum (Inglefinger and Abbott, 1940).

While there is general agreement about the description of the waves of the small intestine, there is confusion about their nomenclature. Inglefinger and Abbott (1940) described the small fast waves as 'S' waves in distinction to large slower waves, which they called 'L' waves. Smith and others (1957) divided the waves into 'A' waves of less than 30 seconds duration and 'B' waves of more than 30 seconds duration. Foulk, Code, Morlock and Barger (1954), on the other hand, adopted the classification devised by Templeton and

FIG. 2.—Rhythmic fast waves from the duodenum recorded by a miniature balloon. These correspond to S Waves (Inglefinger and Abbott, 1943), A waves (Smith and others, 1957) and Type I (Foulk and others, 1954). Verticals equal 1-minute intervals.

Lawson (1931) to describe the motility of the colon in dogs. In this scheme fast waves are called Type I and the slower waves Types II or III. Type III is a base-line rise with superimposed waves. This classification was also used by Fink (1959) and Oddone, de la Pierre, Bertero and Jona (1959). Andrew (1954) gave the slow waves a functional significance and called them 'tetany' waves. Farrar and Bernstein (1958), however, noting that none of the published classifications had proved satisfactory, did not attempt any classification of waves into distinct types. This is, undoubtedly, a realistic view, but it is essential for further progress that an agreed nomenclature of motility should be established.

In a normal record there are periods of activity alternating with periods of inactivity, but the recorded duration of activity of the upper small intestine differs considerably in various publications (Table 1). Some of the differences may be due to different methods of recording, but other, and possibly more important, reasons are the interval since the previous meal (Foulk, Code, Morlock and Barga, 1954) and the exact method of analysis. In this latter respect Fink (1959) showed that the percentage of the total time of observation occupied by active and inactive periods was approximately the same. On the other hand, where the duration of each wave was measured and the sum of these durations used to compute percentage activity the mean was only 12%. There is, therefore, a variation between observers depending on the criterion of 'activity' selected.

The duration of activity is the same in normal subjects, patients with duodenal ulcer in remission, patients with ulcerative colitis (Foulk, Code, Morlock and Barga, 1954), patients with duodenal

TABLE 1

Author	Method of Recording	Percentage Duration of Activity
Foulk, Code, Morlock and Barga (1954)	Balloons, 3 cm. diameter	34 (fasting 24 hours) 62 (fasting 5-12 hours)
Smith, Texter, Stickley and Barborka (1957)	Open-ended tubes	14 (fasting)
Oddone, de la Pierre, Bertero and Jona (1959)	Small balloons (2 cm. diameter)	25
Fink (1959)	Open-ended tubes	<30-65
Barbero, Chin Kim and Davis (1958) (children)	Open-ended tubes	23

diverticula and patients with cholelithiasis (Fink, 1959). Smith and others (1957) report an increased duration of activity in patients with duodenal ulcer who are experiencing symptoms. The duration of activity was found to be diminished in patients with idiopathic steatorrhea (Fink, 1959; Inglefinger and Moss, 1943), but not in children with celiac disease (Barbero, Chin Kim and Davis, 1958).

There is complete agreement that the rate of rhythmic contractions of the duodenum is between 8 and 12 cycles per minute and that the predominant frequency is 11 per minute. The frequency of contraction of the jejunum is not altered in asymptomatic duodenal ulcer or in ulcerative colitis (Foulk, Code, Morlock and Barga, 1954).

FIG. 3.—Large waves with superimposed fast components from the terminal ileum recorded by miniature balloon. These correspond to L waves (Inglefinger and Abbott, 1943), B waves (Smith and others, 1957), Type III (Foulk and others, 1954) and tetany waves (Andrew, 1954). Verticals represent 1-minute intervals.

Ileum

Less information is available about the motility of the terminal ileum and some of the data have been obtained by recording through ileostomy stomas where it is doubtful if conditions are the same as in the intact bowel. Recording by an open-ended tube passed through the mouth, Fink (1959) showed that the activity of the terminal ileum was characterized by low-amplitude rhythmic waves, present for 50 to 90% of the time of study. Large simple waves were less frequently seen than in the duodenum, but so-called Type III waves were frequently seen (Fig. 3). Inglefinger and Abbott (1940) found essentially similar patterns of activity and we have seen in recent studies, using the radio pill, rhythmic fast waves at a rate of six per minute occurring continuously for $2\frac{1}{2}$ hours in a normal subject. During this time no forward movement of the pill occurred. Farrer and Bernstein (1958), recording from a radio capsule in the terminal ileum, also found, in contrast to Fink (1959), that the rate of rhythmic contractions of the ileum was slower than in the duodenum. A similar observation was made by Code, Rogers, Schlegel, Hightower and Bargaen (1957), who studied the motility of the terminal ileum through ileostomies in two subjects.

The balance of evidence is that in man the rate of rhythmic contraction decreases progressively on moving from the duodenum to the ileum. The same gradient was noted in rabbits by Alvarez (1915), who claimed that the rate of rhythmic contraction of any segment of the small intestine varied inversely with its distance from the pylorus. Douglas and Mann (1939a) made similar observa-

tions on dogs. The rate of rhythmic contraction is very constant at any one site and is not affected by eating, sleep, vagotomy and splanchnicectomy (Douglas and Mann, 1939a) or psychic influences (Castleton, 1934).

Douglas (1949), in an attempt to explain the different rates of contraction of different parts of the small intestine, showed that the rate of rhythmic contraction of a length of jejunum could be reduced by any procedure which divided the intrinsic nerve supply of the segment from that of more proximal segments. He concluded that the rate of contraction of the jejunum was influenced by the duodenum. Armstrong, Milton and Smith (1956) noted that the rate of the slow components of electropotential records from the small intestine of dogs also decreased from duodenum to ileum. At any one site, however, the rate of the slow components was very similar to the rate of rhythmic contraction. Subsequently, on the basis of this work, Milton and Smith (1956) suggested that the slow component of the electrical record was the factor which controlled the frequency of rhythmic contraction of the bowel. They also showed that the slow component of the duodenum and upper jejunum was influenced by discharge from an area in the region of the bile duct, but ectopic foci of slow electropotential waves may be artificially produced. On this basis, they postulated a pace-making area in the duodenum analogous to those of the cardiac muscle.

While there is evidence that the rate of contraction of the upper small intestine is controlled from the duodenum, Daniel, Carlow, Wachter, Sutherland and Bogoch (1959) showed that the

distal small intestine is independent of duodenal control and it seems likely that local pacemaker areas exist throughout the length of the gut which impart a distinct rhythm to segments of gut immediately distal to them.

Basal Pressure in the Small Intestine

The basal pressure in the jejunum was recorded by Abbott and others (1943) at between 8 and 10 cm. of water. Kewenter and Kock (1960) recorded basal pressures in the duodenum of between 6 and 10 cm. of water. These authors considered that the hydrostatic pressure of the body tissues and the 'tone' of the abdominal muscles provided the greater part of this pressure. Fink (1959), although noting individual variations, showed a correlation between body weight and basal pressure. Confirmation that the 'tone' of the bowel wall contributed very little to the basal pressure was provided by Edwards and Rowlands (1961) who demonstrated that the basal pressures in the cadaver were in the same range as in the living subject, and that the pressure recorded was directly related to the distance of the recording point from the body surfaces. All these authors used either open-ended tubes, miniature balloons, or electromagnetic transducers. Using large balloons, however, the 'tone' of the bowel wall contributes a much greater proportion to the basal pressure.

Correlation of Pressure Records with X-ray Appearances

At present there is no clear picture of what the various types of waves on the pressure records represent in terms of the observed contractions of the intestinal wall. Ingelfinger and Abbott (1940) outlined their balloons with barium and showed that both large and small waves were associated with contractions passing caudally over the balloon. The small waves were associated with narrow indentations on the balloon surface while the large waves lasting up to one minute might compress the balloon in its length. In a similar study Chapman, Pelazzo, Taylor and Proudfoot (1949) reported that low amplitude rhythmic waves corresponded to ring-like contractions lasting 5 to 10 seconds running caudally over the balloons. These contractions may have moved the balloons and barium slightly but barium was never propelled forwards. They were, therefore, not propulsive waves. Movements of the barium were associated with slow sustained contractions which might last up to two minutes. In ileostomies, Posey and Bergen (1951) noted expulsion of fluid faeces in the presence of both small and large waves (Types I, II and III). However, in the presence of small waves the faeces welled passively from the stoma,

whereas with large waves (Types II and III) they were expelled with force. Solid stool was expelled only in association with large waves. Fink (1959) showed a relationship between the rate of transit of a balloon and the proportion of large (Type III) waves in the record. The evidence is that the low amplitude rhythmic waves may either represent stationary annular contractions or propagated waves with no propulsive force. Peristalsis, therefore, in the sense of a propagated contraction should not necessarily be correlated with transport of chyme. On the other hand, transport does occur frequently, but not universally (Daniel, Sutherland and Bogoch, 1959) in association with more prolonged powerful rises in intraluminal pressure. Propulsion depends not only on the nature of the wave form but also on the size and nature of the bolus, the resistance to flow and the strength of the contraction. The radio pill has several times been seen to undergo rapid forward movements during the decline in pressure of a powerful wave, as it is thrust away from the grip of the constricting contraction ring. Radiologically, forward movement of chyme usually occurs in 'squirts' and such a rapid movement could be produced either by a sudden strong contraction of a segment of bowel with low resistance to escape of the content distally, or by a rapid peristaltic wave.

Transit Times in the Small Intestine

The classical methods of estimating transit such as the ingestion of carmine markers and the use of glass beads are not only crude but applicable only to the study of mouth-to-anus times. Small intestinal transit in man necessitates the use of contrast radiology in one form or another, the use of tubes, or the study of patients with ileostomies. Most markers, especially barium, can give information only about the rate of passage of the first and last traces of the material but a more useful measurement is that of the time of passage of the main concentration. As barium sulphate probably stimulates bowel activity (Childrey, Alvares and Mann, 1930) its rate of passage is not an index of the transit time of ordinary meals, but for most purposes this is adequate. The rate of passage through the upper small intestine is more rapid than through the lower. Using balloons outlined by barium Ingelfinger and Abbott (1940) showed that the rate of passage of the balloon through the duodenum is five minutes, through the jejunum two hours, and through the ileum, three to six hours. Van Liere, Stickney and Northup (1945) obtained similar results in dogs. The rate of passage through the duodenum is extremely rapid. We have found that a radio pill passes from the pylorus to the fourth part of the duodenum in

FIG. 4.—Duodenal motility recorded by radio pill. In the time occupied by a wave (arrowed) the pill had an uninterrupted movement from the position of the pylorus to the fourth part of the duodenum. The dots represent 1-minute intervals.

few seconds (Fig. 4) confirming the view of Douglas (1948) that the function of the duodenum is transport and not trituration. At the other end of the small intestine the rate of transit is particularly slow. A radio pill may remain for several hours in the terminal ileum although rhythmic waves may be recorded almost continuously throughout this period. Hertz (1913) and Oppenheimer (1940), in studies with barium, also commented on the delay in the terminal ileum although contractions occurred almost continuously. Many of these passed along the ileum towards the colon. Hertz (1913) believed that 'ileal stasis is a normal physiological condition of the utmost importance for adequate digestion'.

Both Hertz (1913) and Oppenheimer (1940) also described powerful peristaltic waves which occurred at irregular intervals and propelled the contents of the terminal ileum into the cæcum. These waves were associated with relaxation of the ileocæcal sphincter. They were much more frequently seen immediately after meals (Hertz, 1913) and it is known that evacuation of an established ileostomy occurs at infrequent intervals, usually after meals.

Factors Affecting Intestinal Motility

Nervous Control of Intestinal Movement

The gut has both an extrinsic supply via autonomic nervous pathways and an intrinsic supply in the plexuses in the gut wall, which permit complicated movements even when the extrinsic supply is completely removed. The intricate nervous network in the wall of the intestine is often described as being concentrated into two relatively distinct

plexuses, but the anatomical picture is, in fact, less simple and Garven (1957) describes at least five distinct plexuses. There is evidence that there is a functioning protoplasmic syncytium including both the nervous networks and the smooth muscle cells (Boeke, 1940).

Bayliss and Starling (1899) originally postulated a neurogenic basis for the peristaltic reflex and, although this was disputed by Alvarez (1950), recent anatomical and physiological studies have strengthened the original concept. Bulbring, Lin and Schofield (1958) have shown that, although the peristaltic reflex is not abolished by extrinsic denervation of the small intestine, it can be prevented by local anaesthesia, asphyxiation or removal of the mucous membrane. These experiments provide evidence that there are within the bowel wall intrinsic reflex arcs consisting of at least two neurones: a sensory neurone with a nerve ending on the mucosa and a motor neurone innervating the muscle cell.

On the basis of their work on the peristaltic reflex, Bayliss and Starling (1899) formulated a law of the intestine which stated that a contraction of the bowel was associated with a distal relaxation. It is not always realized that the law is only valid within the conditions of the experimental situation in which it was first established; that is, on distension of the denervated intestine of a dog with a balloon. The 'law' does not hold universally and Posey and Barger (1951), using balloons, were unable to confirm it in man.

Extrinsic Nervous Control

Afferent Pathways from the Small Intestine. Afferent impulses arising in the gut result in reflex alteration in the function of various organs (Whitteridge, 1956). Extensive sensory pathways from the intestine have been described, and Paintal (1954) and Iggo (1957) have described sensory receptors in the small intestine. Agostoni, Chinnock, Daly and Murray (1957) have shown that 90% of the fibres of the vagus are afferent. Afferent pathways also occur in the sympathetic system.

Efferent Pathways to the Small Intestine. Much of our information about the autonomic control of intestinal motility has been obtained from animal experiments. From the earlier studies emerged the general concept that the parasympathetic outflow was motor and the sympathetic outflow inhibitory to the intestine. However, experimental physiologists, even using the most elegant techniques, recognize the necessarily artificial nature of the experimental situation and the inherent capriciousness of the results of nerve section or nerve stimulation. The response to nerve section will depend almost entirely on the state of the bowel at the time of section. For example, section of a motor

nerve produces negligible effects unless the nerve is 'tonically' active (Youmans, 1952). Stimulation of nerves can be even more confusing. Garry and Gillespie (1955) indicated some of the reasons for the confusion when they showed that the response of the gut varies with the frequency and strength of stimulation to the extent of reversing the original response. Animal studies, therefore, must be interpreted with caution.

Effect of the Vagus. In common with the general view that the vagus is motor to the small intestine, Harper, Kidd and Scratcherd (1959) showed that stimulation of either the central or peripheral end of the vagus resulted in an increase in the tone of the small intestine and in the amplitude of the contraction. Division of the nerve did not influence the rate of rhythmic contraction of the small intestine of the dog (Douglas and Mann, 1939a), although Alvarez, Hosoi, Kiyoshi, Overgard and Ascanio (1929) found that vagotomy always reduced the rate in rabbits. In man, vagotomy results in little disturbance of small intestinal function, although diarrhoea and occasionally steatorrhoea may result (Kay, 1960). There is, however, no experimental evidence that this is a result of a direct effect on the small intestine.

Effect of the Sympathetic Outflow. Section of the sympathetic nerves also results in very little alteration in small intestinal function. Douglas and Mann (1939a) found no alteration in the rate of rhythmic contraction of the small intestine of the dog following splanchnicectomy, although one dog did develop diarrhoea. Ivy, Grossman and Bachrach (1950) observed no ill effects following preganglionic sympathectomy in dogs, but bloody diarrhoea and ulceration of the stomach and small intestine with a high mortality occurred following removal of the coeliac ganglia. In man, Bingham, Inglefinger and Smithwick (1950) studied the motility of the small intestine both radiologically and manometrically following bilateral-thoracolumbar sympathectomy for hypertension and found no significant effect on motility. There was an increase in the frequency of bowel action in one-fifth of the patients studied and three of 100 patients complained of persisting severe diarrhoea. Some looseness of the bowels following sympathectomy was also noted by Ross and Broolsma (1951), but no patients had serious gastrointestinal sequelae.

The minimal effects of sympathectomy and vagotomy on small intestinal function in man support the modern concept that the sympathetic and parasympathetic outflows, rather than mediating opposing and antagonistic impulses, exert a continuous and complementary regulatory action, which integrates the function of the small intestine and permits a smooth response to the diversity of

stimuli to which it is exposed. This regulatory function is largely carried out by utilizing a series of reflex pathways, some of which include the central nervous system, while others are largely in the intrinsic nerve networks.

Intestino-intestinal Reflexes

The intestino-gastric reflexes, which effect inhibition of gastric motility following upper intestinal distension, are probably mediated through the vagus (Thomas and Mogan, 1931). On the other hand, intestino-intestinal inhibitory reflexes which have been extensively studied in Thiry and Thiry-Vella loops in dogs, are independent of the vagus (Youmans, 1944). As a result of these reflexes, distension of one segment results in generalized inhibition of motility of the whole small intestine. There is agreement that both the afferent and efferent pathways are in the thoracolumbar system and that the central connections are in the spinal cord from the seventh thoracic to the second lumbar segments (Youmans, 1944; Chang and Hsu, 1942; Morin and Vial, 1934). These studies do not discount the possibility that subsidiary pathways may exist in the intrinsic plexuses. These observations underline the self-perpetuating nature of the distension of intestinal ileus and offer an explanation of the beneficial effects of decompression by suction.

Reflex Responses to Feeding

The increase in small intestine activity after eating was first described by MacEwan (1904) who watched the writhing movements of the terminal ileum through a caecal fistula. He noted that the response was too quick to be explained by peristalsis spreading along the intestine and attributed it to a reflex. Since then other workers have demonstrated increased ileal activity following meals (Daniel and others, 1959; Kewenter and Kock, 1960) associated with occasional relaxation of the ileocaecal valve and discharge of the ileal contents into the caecum (Hertz, 1913).

Gregory (1950) showed that this reflex could be elicited in dogs by placing small quantities of food in the stomach, by distending it with a balloon or even by sham feeding. Douglas and Mann (1940) elicited the reflex by placing food in the duodenum. Gregory's experiments led him to the view that the reflex was dependent on the integrity of the thoracolumbar outflow but Douglas and Mann (1939b, 1940) held that the response depended on the continuity of the intestine and that the increased activity was transmitted mechanically along the bowel wall. This latter explanation, however, would not account for the cephalic phase of the reflex. The response is independent of the vagus nerves (Douglas and Mann, 1939b) but can be

FIG. 5.—The motility of the ileum recorded by radio pill. At the first arrow this normal subject was told that his lunch was being prepared and at the second arrow he began to eat his lunch. The dots represent 1-minute intervals.

abolished by atropine (Daniel and others, 1959). Fig. 5 shows the effects of food on the small intestine and demonstrates the cephalic phase of the reflex in a normal man. Post-prandial symptoms are prominent in many gastro-intestinal disorders and some of these symptoms may have a basis in a disorganization or incoordination of the gastro-ileo-colic reflexes.

Effect of Drugs

The effect of a drug on the pressure patterns can only give an approximate index of the likely clinical effect as the relationships between intestinal pressures and clinical symptomatology are not established, but if a drug fails to produce any effect on a pressure record it is unlikely that it will be useful in clinical practice. Certain proprietary preparations tested by Rowlands, Chapman, Taylor and Jones (1950a) did not affect small intestinal motility, and no subsequent clinical evidence has been advanced to indicate that these drugs have any therapeutic value. The difficulties of assessing the effect of drugs in the alimentary tract are made even more formidable in that placebo tablets may result in a decrease in small intestinal activity (Chapman, Rowlands, Taylor and Jones, 1950). Unwarranted claims about the effectiveness of drugs may be made either because of failure of adequate experimental control or because of unwarranted interpolation from the experimental result into clinical practice. The problems associated with the measurement of the effects of drugs on the gastrointestinal tract have recently been reviewed by Rowlands (1959).

Drugs Inhibiting Motility. Chapman, Rowlands and Jones (1950) showed that atropine and belladonna alkaloids result in a much greater decrease in upper small-intestinal motility than placebo preparations. The most striking fall is in

propulsive motility. All forms of motility in the terminal ileum are reduced by atropine (Code and others, 1957). Banthine also produces a decrease in propulsive and total contractions and causes a decrease in tone. It has a more rapid effect and reduces motility to a greater degree than tincture of belladonna (Chapman, French, Hoffman and Jones, 1952) and delays the transit time through the small intestine (Lepore, Golden and Flood, 1951). Other drugs which cause reduction in small intestinal motility are tetraethylammonium (Chapman, Stanbury, Jones and Dennison, 1948), amphetamine (Elsom, Glenn and Drossner, 1939), ephedrine (Posey, Barger, Dearing and Code, 1948), and adrenaline (Barger, Wesson and Jackman, 1940). The effect of the sympathetic amines, however, is biphasic as following a short period of relaxation there is frequently a rebound phase of increased activity (Dreyer, 1954). This effect was initially demonstrated in the cat intestine but also occurs in the human intestine (Daniel, Sutherland and Bogoch, 1959).

Drugs Stimulating Motility. The injection of prostigmine results in a moderate increase in the frequency and amplitude of the propagated waves in the small intestine (McMahon, Code, Sauer and Barger, 1949; Kewenter and Kock, 1960). That these waves are propulsive has been demonstrated by barium studies (Liljedahl, Mattsson and Pernow, 1958a) and by direct observation of ileostomies (Schwartz, Reingold and Necheles, 1942). Mecholyl also causes an increase in propulsive motility in adults (Ginsberg and Miller, 1953) and in children (Barbero, Chin Kim and Davis, 1958).

Morphine. The effect of morphine on the small intestine has been reviewed by Vaughan Williams (1954). Manometrically, in the jejunum, morphine produces a rise in base-line sustained over several minutes on which fast waves may be superimposed

(Rowlands, Chapman, Taylor and Jones, 1950b; Kewenter and Kock, 1960). Similarly, in the terminal ileum it does not reduce the total activity, but increases the percentage of rhythmic small waves and almost eliminates the large waves (Code, Rogers, Schlegel, Hightower and Barga, 1957). Daniel, Sutherland and Bogoch (1959) showed that the morphine-induced spasm is abolished by atropine, but not by vagotomy or by large doses of hexamethonium. Morphine does not, however, stimulate either the human or dog ileum *in vitro*. These authors conclude that the spasm could be produced both through a direct effect on smooth muscle and by a central effect mediated by the autonomic nerves. It is also known that morphine increases the transit time of the small intestine (Rowlands, Chapman, Taylor and Jones, 1950b; Grebell, 1958), but this is not due to a generalized depression of small intestinal motility, but to the reduction in propulsive activity (Vaughan Williams and Streeten, 1950), together with spasm preventing the onward passage of chyme. Vaughan Williams and Streeten (1950) showed that in conscious dogs morphine is a more powerful inhibitor of intestinal propulsion than amidone and that pethidine has the least effect.

Unfortunately, no drug is available whose sole effect is to increase the normal segmenting activity of the small intestine. On theoretical grounds it is likely that such a drug would be of great value clinically in controlling intestinal hurry. At present the nearest approach to the ideal is morphine and its derivative, codeine, which is widely used for this purpose.

5-hydroxytryptamine (5 H.T., Serotonin). Following the discovery that argentaffin tumours contained large quantities of serotonin it was postulated that the diarrhoea associated with the condition was the result of the excess circulating hormone. This finding stimulated investigation into the effects of 5 H.T. on the intestinal musculature. *In vitro*, Bulbring and Lin (1958) demonstrated that 5 H.T. derived from the intestinal mucosa is released from the ileum of the guinea pig in response to a rise in intraluminal pressure. Application of 5 H.T. to the mucosal surface of the bowel resulted in an increase in peristalsis, whereas application to the serosal surface diminished peristalsis. They postulated that serotonin sensitized pressure receptors in the intestinal mucosa. Experiments in the intact animal (Bulbring and Crema, 1959) gave less definite results. Intraluminal application failed to give a response and intravenous administration increased segmenting movements, but not propulsion. They attributed the failure to obtain a response in the intact animal partly to excessive desensitization of the sensory nerve ending and

partly to the destruction of 5 H.T. by amine oxidase. In man, when given orally even in large doses, 5 H.T. has no effect (Hendrix, Atkinson, Clifton and Inglefinger, 1957; Connell, Rowlands and Wilcox, 1960) on intestinal motility, but when administered intravenously a temporary rise in base-line with superimposed fast waves has been noted (Hendrix, Atkinson, Clifton and Inglefinger, 1957). Haverback and Davidson (1958) obtained a similar response with the serotonin precursor 5-hydroxytryptophan, and showed that the effect could not be inhibited by atropine, but was antagonized by 2-bromolysergic acid diethylamide (BOL). Daniel, Honour and Bogoch (1960), recording both mechanical and electrical responses to intravenous serotonin, confirmed these findings and concluded that the effect of serotonin on the small intestine was a direct one and not mediated by any other known intestinal stimulant. In spite of these studies, the exact role of 5 H.T. in gastrointestinal physiology remains in doubt.

Substance P. Substance P is a pharmacologically active material distinct from histamine, serotonin or acetylcholine, which can be extracted from the intestinal wall with a motor effect on isolated intestinal muscle (Pernow, 1951). Liljedahl, Mattsson and Pernow (1958b) have shown that injection of substance P results in an increase in small intestinal movements, producing more propulsive activity than prostigmine. It is claimed that greater quantities of substance P than normal can be extracted from the small intestine of patients with the dumping syndrome (Wallenstein, Garsten, Johnson and Salzman, 1959). It is difficult to see, however, how significant progress in our understanding of the role of this material can be made until it is prepared in purer form, if, indeed, the pharmacological actions described are, in fact, the effect of a single substance.

Motility and Absorption

It is frequently assumed that altered states of intestinal motility affect absorption from the gut, but there is little experimental evidence for this. In an attempt to determine the relationship Cummins and Almy (1953) estimated the uptake of glucose and methionine from the bowel by a direct method during periods of normal motility and periods of hypermotility induced by urecholine and physostigmine. They rather hesitantly concluded that absorption of these substances was increased during periods of increased activity. Grossier and Farrar (1960), using both the radio pill and tube methods, attempted to correlate the uptake of ^{24}Na and small intestinal motility, but were able to show no more than a possible relationship between segmental activity and ^{24}Na uptake. Conversely, Higgins, Code and Orvis

(1956) in a careful study reported a decrease in the rate of absorption of deuterium-labelled water and ^{24}Na following reduction of small intestinal motility by banthine. Rapid transit is frequently incriminated as a cause of malabsorption, although evidence on the point is almost non-existent.

There is a generalized reduction in the pressure changes of the small intestine in idiopathic steatorrhœa in relapse (Inglefinger and Moss, 1943; Fink, 1959) although Barbero, Chin Kim and Davis (1958) were unable to show any difference in the pressure patterns of cœliac children as compared with normal. There is also a delay in the transit of barium through the small intestine in sprue (Golden, 1950). Although in our own laboratory we have confirmed the marked decrease in intra-luminal pressure changes in idiopathic

steatorrhœa we have at the same time noted phasic alterations on signal strength of the radio pill occurring continuously over long periods indicating gentle rocking movements of the pill. These can be confirmed fluoroscopically. The intestine in idiopathic steatorrhœa is not totally inactive but perhaps it is not generating sufficient power to produce normal segmenting movements (Connell, Misiewicz and Rowlands, 1961). It is not possible to say whether this is a primary or secondary effect, but the interesting observation of Schneider, Bishop and Shaw (1960) that gluten inhibits peristalsis in smooth muscle *in vitro* tends to support the secondary nature of the muscular defect in steatorrhœa. This aspect of intestinal motility is particularly poorly studied and one which will almost certainly repay further work.

REFERENCES

- ABBOTT, W. O., HARTLINE, H. K., HERVEY, J. P., INGLEFINGER, F. J., RAWSON, A. J., and ZETZEL, L. (1943): Intubation Studies of the Human Small Intestine: XXI. A Method for Measuring Intraluminal Pressures and its Application to the Digestive Tract, *J. clin. Invest.*, **22**, 225.
- AGOSTONI, E., CHINNOCK, J. E., DALY, M. DE BURGH, and MURRAY, J. G. (1957): Functional and Histological Studies of the Vagus Nerve and its Branches to the Heart, Lungs and Abdominal Viscera of the Cat, *J. Physiol.*, **135**, 182.
- ALVAREZ, W. C. (1915): The Rate of Rhythmic Contraction in the Small Intestine of the Rabbit, *Amer. J. Physiol.*, **37**, 267.
- , HOSOI, KIYOSHI, OVERGARD, A., and ASCANIO, H. (1929): The Effects of Degenerative Section of the Vagi and the Splanchnics on the Digestive Tract, *Ibid.*, **90**, 631.
- (1950): The Muscular Versus the Nervous Origin of the Rhythmic Contractions of the Gut, chapter X, in 'An Introduction to Gastroenterology', 4th edition. London: Heinemann.
- ANDREW, R. (1954): Gastric, Duodenal and Jejunal Motility in Man: Physiological Studies by Balloon Kymography, *Aust. J. exp. Biol.*, **32**, 479.
- ARMSTRONG, H. T., MILTON, G. W., and SMITH, A. W. (1956): Electropotential Changes in the Small Intestine, *J. Physiol.*, **131**, 147.
- ATKINSON, M., EDWARDS, D. A. W., HONOUR, A. J., and ROWLANDS, E. N. (1957): Comparison of Cardiac and Pyloric Sphincter, *Lancet*, **273**, 918.
- BARBERO, G. J., CHIN KIM, I., and DAVIS, J. (1958): Duodenal Motility Patterns in Infants and Children, *Pædiatrics*, **22**, 1054.
- BARGEN, J. A., WESSON, H. R., and JACKMAN, R. J. (1940): Studies in the Ileocæcal Junction, *Surg. Gynec. Obstet.*, **71**, 33.
- BAYLISS, W. M., and STARLING, E. H. (1899): The Movements and Innervation of the Small Intestine, *J. Physiol.*, **24**, 99.
- BINGHAM, J. R., INGLEFINGER, F. J., and SMITHWICK, R. H. (1950): The Effects of Sympathectomy on the Motility of the Human Gastrointestinal and Biliary Tract, *Gastroenterology*, **15**, 6.
- BOEKE, J. (1940): 'Problems of Nervous Anatomy'. London: Oxford University Press.
- BULBRING, E., LIN, R. C. Y., and SCHOFIELD, G. (1958): An Investigation of the Peristaltic Reflex, in Relation to Anatomical Observations, *Quart. J. exp. Physiol.*, **43**, 26.
- , — (1958): The Effect of Intraluminal Application of 5-Hydroxytryptamine and 5-Hydroxytryptophan on Peristalsis: The Local Production of 5-HT and its Release in Relation to Intraluminal Pressure and Propulsive Activity, *J. Physiol.*, **140**, 381.
- , and CREMA, A. (1959): The Action of 5-Hydroxytryptamine, 5-Hydroxytryptophan and Reserpine on Intestinal Peristalsis in Anæsthetized Guinea Pigs, *Ibid.*, **146**, 29.
- CANNON, W. B. (1905): Auscultation of the Rhythmic Sounds Produced by the Stomach and Intestines, *Amer. J. Physiol.*, **14**, 339.
- CASTLETON, K. B. (1934): An Experimental Study of the Movements of the Small Intestine, *Ibid.*, **107**, 641.
- CHANG, P. Y., and HSU, F. Y. (1942): Localization of the Intestino-intestinal Reflex Arc, *Quart. J. exp. Physiol.*, **31**, 311.
- CHAPMAN, W. P., STANBURY, J. B., JONES, C. M., and DENNISON, A. Y. (1948): The Effect of Tetraethyl Ammonium on the Small Bowel in Man, *J. clin. Invest.*, **27**, 346.
- , PELAZZO, W. L., TAYLOR, A., and PROUDFOOT, W. (1949): Multiple Balloon Kymograph Recording of Intestinal Motility in Man with Observations on the Correlation of the Tracing Patterns with Barium Movements, *Ibid.*, **28**, 1517.
- , ROWLANDS, E. N., TAYLOR, A., and JONES, C. M. (1950): Multiple Balloon Kymograph Recording of Variations in Motility of the Upper Small Intestine in Man During Long Observation Periods Before and After Placebo Administration, *Gastroenterology*, **15**, 341.
- , —, and JONES, C. M. (1950): Multiple Balloon Kymographic Recording of the Comparative Action of Oral Administration of Atropine, Tincture of Belladonna and Placebos on the Motility of the Upper Small Intestine in Man, *New Engl. J. Med.*, **243**, 1.

- , FRENCH, A. B., HOFFMAN, P. S., and JONES, C. M. (1952): Multiple Balloon Kymograph Recording of the Effect of Banthine, Belladonna and Placebos on Upper Intestinal Motility, *Ibid.*, **246**, 435.
- CHAUDHARY, N. A., and TRUELOVE, S. C. (1961): Colonic Motility: A Critical Review of Methods and Results, *Amer. J. Med.*, **31**, 86.
- CHILDREY, J. H., ALVAREZ, W. C., and MANN, F. C. (1930): Digestion: Efficiency with Various Foods and under Various Conditions, *Arch. intern. Med.*, **46**, 361.
- CODE, C. F., HIGHTOWER, N. C., and MORLOCK, C. G. (1952): The Motility of the Alimentary Tract in Man, *Amer. J. Med.*, **13**, 328.
- , WILKINSON, G. R., and SAUER, W. G. (1954): Normal and Some Abnormal Colonic Motor Patterns in Man, *Ann. N.Y. Acad. Sci.*, **58**, 317.
- , ROGERS, A. G., SCHLEGEL, J., HIGHTOWER, N. C., and BARGEN, J. A. (1957): Motility Patterns in the Terminal Ileum: Studies in Two Patients with Ulcerative Colitis and Ileal Stoma, *Gastroenterology*, **32**, 651.
- CONNELL, A. M., ROWLANDS, E. N., and WILCOX, P. B. (1960): Serotonin, Bananas and Diarrhoea, *Gut*, **1**, 44.
- , — (1960): Wireless Telemetering from the Digestive Tract, *Ibid.*, **1**, 266.
- (1961a): The Motility of the Pelvic Colon: Motility in Normals and in Patients with Asymptomatic Duodenal Ulcer, *Ibid.*, **2**, 175.
- (1961b): Localization of Ingested Telemetering Capsules, *Lancet*, **i**, 557.
- , and ROWLANDS, E. N. (1961): Clinical Application of Radio Pill for Measuring Gastro-intestinal Pressure, in 'Proceedings of the Third International Conference on Medical Electronics', p. 126. London:
- , MISIEWICZ, J. J., and ROWLANDS, E. N. (1961): In preparation.
- CUMMINS, A. J., and ALMY, T. P. (1953): Studies on the Relationship between Motility and Absorption in the Human Small Intestine, *Gastroenterology*, **23**, 179.
- DANIEL, E. E., SUTHERLAND, W. H., and BOGOCH, A. (1959): Effects of Morphine and other Drugs on the Motility of the Terminal Ileum, *Ibid.*, **36**, 510.
- , and BOGOCH, A. (1959): The Mechanism of the Spasmogenic Action of Morphine on the Small Intestine of Man and Dog, in 'Proceedings of the World Congress of Gastroenterology, Washington, 1958', p. 138. Baltimore: Williams and Wilkins.
- , CARLOW, D. R., WACHTER, B. T., SUTHERLAND, W. A., and BOGOCH, A. (1959): Electrical Activity of the Small Intestine, *Gastroenterology*, **37**, 268.
- , HONOUR, A. J., and BOGOCH, A. (1960): Antagonism of Serotonin Induced Contraction and Electrical Activity in the Ileum, *Ibid.*, **39**, 62.
- DOUGLAS, O. M., and MANN, F. C. (1939a): An Experimental Study of the Rhythmic Contractions in the Small Intestine of the Dog, *Amer. J. dig. Dis.*, **6**, 318.
- , — (1939b): The Activity of the Lower Part of the Ileum of the Dog in Relation to the Ingestion of Food, *Ibid.*, **6**, 434.
- , — (1940): The Gastro-ileac Reflex: Further Experimental Observations, *Ibid.*, **7**, 53.
- (1948): The Activity of the Duodenum, *J. Physiol.*, **107**, 472.
- (1949): The Decrease in Frequency of Contraction of the Jejunum after Transplantation to the Ileum, *Ibid.*, **110**, 66.
- DREYER, N. B. (1954): Rebound Effects on the Cat's Intestine, *Arch. int. Pharmacodyn.*, **97**, 54.
- DU PLEISSIS, D. J. (1954): Clinical Observations on Intestinal Motility, *S. Afr. med. J.*, **28**, 27.
- EDWARDS, D. A. W., and ROWLANDS, E. N. (1960): An Air Filled Metal Capsule Optical Manometer System, in 'Proceedings of the Second International Conference on Medical Electronics, Paris, 1959', p. 307.
- , — (1961): Unpublished studies.
- ELSON, K. A., GLENN, P. M., and DROSSNER, J. L. (1939): Intubation Studies of the Small Intestine: The Effect of Pitressin and Amphetamine (Benzedrine) Sulphate on Motor Activity of Small Intestine and Colon, *Amer. J. dig. Dis.*, **6**, 593.
- FARRAR, J. T., and INGLESFINGER, F. J. (1955): Gastrointestinal Motility as Revealed by Study of Abdominal Sounds, *Gastroenterology*, **29**, 789.
- , ZWORYKIN, V. K., and BAUM, J. (1957): Pressure Sensitive Telemetering Capsule for the Study of Gastrointestinal Motility, *Science*, **126**, 975.
- , and BERNSTEIN, J. S. (1958): Recording of Intraluminal Gastrointestinal Pressures by a Radio Telemetering Capsule, *Gastroenterology*, **35**, 603.
- , and DAVIDSON, M. (1960): The Measurement of Gastrointestinal Motility in Man, in 'Methods on Medical Research', **8**, 200.
- FINK, S. (1959): The Intraluminal Pressures in the Intact Human Intestine, *Gastroenterology*, **36**, 661.
- FOULK, W. T., CODE, C. F., MORLOCK, C. G., and BARGEN, J. A. (1954): A Study of the Motility Patterns and the Basic Rhythm of the Duodenum and Jejunum in Human Beings, *Ibid.*, **26**, 601.
- GARRY, R. C., and GILLESPIE, J. S. (1955): The Responses of the Musculature of the Colon of the Rabbit to Stimulation *in vitro* of Parasympathetic and of the Sympathetic Outflows, *J. Physiol.*, **128**, 557.
- GARVEN, H. S. D. (1957): 'A Student's Histology'. Edinburgh: E. and S. Livingstone.
- GAUER, O. H., and GIENAPPE, E. A. (1950): A Miniature Pressure Recording Device Devised for Cardio Vascular System Research, *Science*, **112**, 404.
- GINSBERG, M., and MILLER, J. M. (1953): Physiologic Observations on a Segment of Normal Human Jejunum, *Gastroenterology*, **24**, 307.
- GOLDEN, R. (1950): Some Clinical Problems in Small Intestinal Physiology: Mackenzie-Davidson Memorial Lecture, *Brit. J. Radiol.*, **23**, 390.
- GREBELL, F. S. (1958): Some Radiological Observations on the Effect of Morphine Sulphate on the Gastrointestinal Tract in Man, *Ibid.*, **31**, 534.
- GREGORY, R. A. (1950): Some Factors Influencing the Passage of Fluid Through Intestinal Loops in Dogs, *J. Physiol.*, **111**, 119.

- GROSSIER, V. W., and FARRAR, J. T. (1960): Absorption of Radioactive Sodium from the Intestinal Tract of Man: I. Effect of Intestinal Motility; II. Effect of an Organomercurial, *J. clin. Invest.*, **39**, 1607.
- HARPER, A. A., KIDD, C., and SCRATCHERD, T. (1959): Vago-vagal Reflux Effects on Gastric and Pancreatic Secretion and Gastrointestinal Motility, *J. Physiol.*, **148**, 417.
- HAVERBACK, B. J., and DAVIDSON, J. D. (1958): Serotonin and the Gastrointestinal Tract, *Gastroenterology*, **35**, 570.
- HENDRIX, J. R., ATKINSON, M., CLIFTON, J. A., and INGLESFINGER, F. J. (1957): The Effect of 5-Hydroxytryptamine in Intestinal Motor Function in Man, *Amer. J. med.*, **23**, 886.
- HERTZ, A. F. (1913): The Ileo-Cæcal Sphincter, *J. Physiol.*, **47**, 54.
- HIGGINS, J. A., CODE, C. F., and ORVIS, A. L. (1956): The Influence of Motility on the Rate of Absorption of Sodium and Water from the Small Intestine of Healthy Persons, *Gastroenterology*, **31**, 708.
- HIGHTOWER, N. C., JR. (1952): Comparison of Intraluminal Pressures and Motility Patterns in the Gastrointestinal Tract of Human Beings when Recorded by Balloons and Direct (Electrical Transducer) Pressure System, *Fed. Proc.*, **11**, 69.
- IGGO, A. (1957): Gastrointestinal Tension Receptors with Unmyelinated Afferent Fibres in the Cat, *Quart. J. exp. Physiol.*, **42**, 130.
- INGLESFINGER, F. J., and ABBOTT, W. O. (1940): Intubation Studies of the Human Small Intestine: The Diagnostic Significance of Motor Disturbance, *Amer. J. dig. Dis.*, **7**, 468.
- , and MOSS, R. E. (1943): The Motility of the Small Intestine in Sprue, *J. clin. Invest.*, **22**, 345.
- IVY, A. C., GROSSMAN, M. I., and BACHRACH, W. H. (1950): Peptic Ulcer, Chapter XII, in 'Role of the Nervous System', p. 412. Philadelphia: The Blakiston Co.
- KAY, A. W. (1960): Some Surgical Aspects of the Malabsorption Syndrome, *Brit. med. J.*, **1**, 1291.
- KEWENTER, J., and KOCK, N. G. (1960): Motility of the Human Small Intestine: A Method for the Continuous Recording of Intraluminal Pressure Variations, *Acta chir. scand.*, **119**, 430.
- LEPORE, M. J., GOLDEN, R., and FLOOD, C. A. (1951): Oral Banthine, an Effective Depressor of Gastrointestinal Motility, *Gastroenterology*, **17**, 551.
- LILJEDAHN, S. O., MATTSOON, O., and PERNOW, B. (1958a): Cineroentgenography of the Intestine with Special Reference to the Effect of Stimulating Agents upon Motility, *Acta Radiologica*, **49**, 348.
- , —, — (1958b): The Effect of Substance P. on Intestinal Motility in Man, *Scand. J. clin. Lab. Invest.*, **10**, 16.
- LORBER, S. H., and SHAY, H. (1954): Technical and Physiological Considerations in Measuring Gastrointestinal Pressures in Man, *Gastroenterology*, **27**, 478.
- LOUCKES, H., QUIGLEY, J. P., and ROMANS, W. E. (1953): Sounds at the Pyloric Sphincter, *Fed. Proc.*, **12**, 91.
- MACEWAN, W. (1904): The Function of the Cæcum and Appendix, *Lancet*, **ii**, 995.
- MACKAY, R. S., and JACOBSON, B. (1957): Endoradiosonde, *Nature*, **179**, 1239.
- McMAHON, J. M., CODE, C. F., SAUER, W. G., and BARGEN, J. A. (1949): A Study of the Action of Prostigmine on the Bowel of Human Beings, *Gastroenterology*, **12**, 970.
- MILTON, G. W., and SMITH, A. W. M. (1956): The Pacemaking Area of the Duodenum, *J. Physiol.*, **132**, 100.
- MORIN, G., and VIAL, J. (1934): Réactions Respiratoires et Circulatoires provoquées par la Distension brusque de l'intestine chez le Chien, *Arch. int. Physiol.*, **38**, 428.
- ODDONE, I., DE LA PIERRE, M., BERTERO, R., and JONA, E. (1959): Prime Osservazioni sulla Duodenografia, 'Estratto da Minerva medica', p. 1.
- OPPENHEIMER, A. (1940): The Ileo-cæcal Region, *Radiology*, **34**, 545.
- PAINTAL, A. S. (1954): The Response of Gastric Stretch Receptors and Certain Other Abdominal and Thoracic Vagal Receptors to some Drugs, *J. Physiol.*, **126**, 271.
- PERNOW, B. (1951): Substance P Distribution on the Digestive Tract, *Acta physiol. scand.*, **24**, 97.
- POSEY, E. L., BARGEN, J. A., DEARING, W. H., and CODE, C. F. (1948): The Effects of So-called Antispasmodics on Intestinal Motility, *Gastroenterology*, **11**, 344.
- , — (1951): Observations of Normal and Abnormal Human Intestinal Motor Function, *Amer. J. med. Sci.*, **221**, 10.
- QUIGLEY, J. P., and BRODY, D. A. (1952): Physiologic and Clinical Considerations of Pressures developed in the Digestive Tract, *Amer. J. Med.*, **13**, 73.
- RIDGEWAY, M., and SMITH, A. N. (1961): The Management of Recording Pressure Changes in the Gastrointestinal Tract using Telemetering Capsule, *J. roy. Coll. Surg. Edin.*, **6**, 192.
- ROSS, J. R., and BROLSMA, M. P. (1951): Splanchnicectomy: Its Clinical Effects on the Gastrointestinal Tract, *Gastroenterology*, **17**, 389.
- ROWLANDS, E. N. (1959): Measurement of the Effect of Drugs on the Gastrointestinal Tract, in 'Quantitative Methods in Human Pharmacology and Therapeutics', p. 31. Oxford, London, New York and Paris: Pergamon Press.
- , CHAPMAN, W. P., TAYLOR, A., and JONES, C. M. (1950a): Multiple Balloon Kymograph Recording of the Action of Syntropan and of Trasentin on the Motility of the Upper Small Intestine in Man, *Surg. Gynec. Obstet.*, **91**, 513.
- , —, — (1950b): Multiple Balloon Kymograph Recording of the Comparative Action of Morphine and Placebos on the Motility of the Upper Small Intestine in Man, *Ibid.*, **91**, 129.
- , HONOUR, A. J., EDWARDS, D. A. W., and CORBETT, B. D. (1953): Metal Capsule Optical Manometer for measuring Pressures in the Human Gut with an open-ended Tube, *Clin. Sci.*, **12**, 299.
- , and WOLFF, H. S. (1960): The Radio Pill, *British Communications and Electronics*, **7**, 598.
- SCHNEIDER, R., BISHOP, H., and SHAW, B. (1960): The Inhibition of the Peristaltic Reflex by Substances from Protein Sources, *Brit. J. Pharmacol.*, **15**, 219.
- SCHWARTZ, A. H., REINGOLD, I., and NECHELES, H. (1942): Study of the Mechanism of Action of Prostigmin on Intestinal Motility in Human Beings and in the Dog, *Surgery*, **11**, 746.
- SMITH, H. W., TEXTER, E. C., STICKLEY, J. H., and BARBORKA, C. J. (1957): Intraluminal Pressures from the Upper Gastrointestinal Tract: II. Correlations with Gastro Duodenal Motor Activity in Normal Subjects and Patients with Ulcer Distress, *Gastroenterology*, **32**, 1025.
- TEMPLETON, R. D., and LAWSON, H. (1931): Studies in the Motor Activity of the Large Intestine: 1. Normal Motility in the Dog, recorded by the Tandem Balloon Method, *Amer. J. Physiol.*, **96**, 667.

- THIRY, L. (1864): Über eine Neue Methode den Dumdarn zu Isolieren, *S.-B. Akad. Wiss. Wien., math.-nat. Kl.* **50**, 77.
- THOMAS, J. E., and MOGAN, C. H. (1931): The Enterogastric Reflex, *Proc. Soc. exp. Biol. Med.*, **28**, 968.
- VAN LIERE, E. J., STICKNEY, J. C., and NORTHUP, D. W. (1945): The Rate of Progress of Inert Material Through the Small Intestine, *Gastroenterology*, **5**, 37.
- VAUGHAN WILLIAMS, E. M. (1954): The Mode of Action of Drugs Upon Intestinal Motility, *Pharmacol. Rev.*, **6**, 159.
- , and STREETEN, D. H. P. (1950): The Action of Morphine, Pethidine and Amidone upon the Intestinal Motility of Conscious Dogs, *Brit. J. Pharmacol.*, **5**, 584.
- VELLA, L. (1888): Neues Verfahren zur Gewinnung reinen Darmsaftes und Feststellung seine Physiologischen Eigenschaften, 'Moleschott's Untersuchungen zur Naturlehre der Menschen und der Thiere', **13**, 40.
- WALLENSTEN, S., GARSTEN, P., JOHNSON, M., and SALZMAN, G. F. (1959): The Dumping Syndrome: I. Roentgencinematographic Study of the Motility of the Small Intestine in the Dumping Syndrome following Partial Gastrectomy, *Acta chir. scand.*, **118**, 117.
- WHITTERIDGE, D. (1956): The Effects of Distension of Viscera, 'Lectures on the Scientific Basis of Medicine', Vol. IV, 1954-55, p. 305. London: Athlone Press.
- YOUNG, W. B. (1944): The Intestino-intestinal Inhibitory Reflex, *Gastroenterology*, **3**, 114.
- (1952): Neural Regulation of Gastric and Intestinal Motility, *Amer. J. med.*, **13**, 209.
-