CURRENT SURVEY

Colonic motility in man

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Summary

Studies of the motor activity of the large intestine have led to a better understanding of the normal physiology of this organ. The disturbed patterns which occur in functional and pathological states are easily recorded by modern technology. While of limited use as a diagnostic aid, investigation of the motor activity has contributed significantly to elucidate the aetiology of various disorders of colonic function.

SINCE the beginning of the century many workers, using various techniques, have sought to clarify the rôle of colonic motor activity in health and in pathological states. Although useful contributions emerged from earlier physiological studies using balloon-kymographic techniques, it is true to say that the most significant advances have followed the introduction of more sensitive and accurate methods of detection and analysis of pressure recordings.

Important physiological factors

Optical manometers and electromanometers

Earlier water manometers of the 'U' tube or spirometer type gave a poor frequency response and their inadequacies are now well recognized. Optical manometers such as described by Rowlands *et al.* (1953) have a high frequency response and have proved more useful and accurate. Modern multi-channel physiological electromanometers with direct pen-writing systems yield a highly sensitive and most convenient method of recording.

Miniature balloons and open-ended tube techniques

The limitations and inaccuracies of a bulky balloon were pointed out by Quigley & Brody (1950). Miniature balloons measuring 7×10 mm as used by Rowlands *et al.* (1953) have proved satisfactory in assessing unstimulated pressure activity in the lumen of the bowel. The miniature balloon detects rather more activity than an open-ended tube recording simultaneously in the same segment. While large balloons have been largely discarded as a means of measuring intraluminal pressure changes, they still have a place in the

measurement of muscle tone or resistance of the bowel wall to distension (Davidson *et al.*, 1956; Parks & Connell, 1969a).

Open-ended polythene catheters which may be either air-filled or fluid-filled are frequently used as pressure-transmitting channels. The main disadvantage of the open-ended tube is that blocking of the lumen by faeces or mucus may occur. Infusion of a slow stream of air or fluid helps to keep the catheter clear though it cannot always prevent plugging. Partial blocking of a catheter can cause a damping effect on the recorded waves which may not be recognized and thus lead to error.

It is usual to make use of three or four tubes which are so arranged that their recording tips (open-ended or miniature balloon) are 5 or 7.5 cm apart (Fig. 1). For convenience, the tubes may be closely bound together using tetrahydrofuran. Multiple channels allow the independent assessment of the nature and degree of activity occurring simultaneously in different segments.

Telemetry capsules

The only convenient method for studying the pressure activity of the intact proximal colon incorporates the use of a sensitive, ingestible telemetering capsule (Farrar, Zworykin & Baum, 1957). Figure 2 shows the device which measures 8 mm in diameter and 25 mm in length. It is powered by a small replaceable battery with a working life of 30-40 hr. The 'pill' which is swallowed emits signals as it passes along the intestinal tract. Subsequently it may be recovered from the faeces. A self-propelling motorized capsule, the endomotorsonde, has also been used in a limited number of studies.

When a pressure change occurs in the lumen of the bowel the frequency of oscillation of the circuit in the miniature radio-transmitter is altered and this is picked up by a receiving aerial outside the abdomen. The main disadvantage of the telemetering capsule is that it is frequently changing position so that recording for a prolonged period from a particular segment is not always possible.

Records obtained using the radio pill are essen-

FIG. 1. Diagrammatic representation of pressure-transmitting channels with tips in the upper rectum, rectosigmoid and sigmoid regions.

tially the same as those obtained by the open-ended tube or miniature balloon techniques. This has been confirmed by using all three methods simultaneously in a readily accessible segment of bowel.

Radiological advances

The development of radiological techniques including time-lapse cine-fluorography has allowed a more detailed study of colonic movements than

had previously been possible by conventional radiology. Combined studies of intraluminal pressure recordings and simultaneous cine-radiography have increased our understanding of motor activity in the sigmoid colon (Ritchie, Ardran & Truelove, 1962; Painter & Truelove, 1964).

Normal colonic activity

Motility of the distal bowel

The majority of studies of the motor action of the large intestine have been concerned with the distal 25 cm, as this is the most readily accessible segment.

The large bowel is a relatively active organ with periods of activity alternating with periods of quiescence. Under resting conditions the colon may be active for 10–50% of the time of recording. There is a wide range of variation not only from one subject to another, but also a considerable day to day variation occurs in the same patient. Figure 3 is a record from a normal subject under resting conditions.

Waves are usually segmental in type and activity in one region is often independent of contraction in a neighbouring segment. Simultaneous recordings obtained from points along the bowel only 1–2 cm apart are often dissimilar. The principal waves, which are not primarily concerned with transit, represent slow pressure changes which wax and wane, usually over a period of 10–30 sec. Occasionally rises in pressure may persist for more than a minute.

Peristalsis is uncommon in the colon and particularly rare in the sigmoid and rectum. The function

FIG. 2. Ingestible pressure-telemetering capsule. Scale in cm.

FIG. 3. Normal resting motility at 15, 20 and 25 cm from anus.

of the majority of colonic contractions is to slow rather than accelerate the onward passage of faecal residue. The frequency of segmental waves appears to be higher in the recto-sigmoid region than elsewhere in the colon and it would seem that there is a physiological braking mechanism, which tends to prevent the constant forward movement of faeces into the sensitive rectum.

Motility of the right side of the colon

There have been a limited number of motility studies on the right side of the colon due to its relative inaccessibility. Radio-telemetry capsules have proved to be the most satisfactory means of assessing this segment in intact man. These capsules record changes in intraluminal pressure as well as movement of the sensor itself. In the right colon, as in other parts of the large intestine, it has been confirmed that the principal waves are not primarily concerned with transit of intestinal contents as evidenced by progression of the radio pill. High pressures should not be regarded as an index of propulsion and considerable pressure changes can and do occur without progressive movement of the radio pill or faecal residue.

The motility patterns recorded in the right colon

are similar to those in the left. Waves are usually simple in form. Activity in the proximal colon occurs independently of the distal colon and the converse is also true. The duration of activity tends to be less on the right side than on the left side, although the amplitude of the principal waves is much the same.

During simultaneous recording of activity in the right and left sides of the colon in normal subjects, propulsion is rarely demonstrated under resting conditions or in response to food or prostigmine (Fink & Friedmann, 1960; Misiewicz, Connell & Pontes, 1966).

Analysis of motility records

Following earlier balloon-kymographic studies in animals, Templeton & Lawson (1931) described various wave forms and classified them into Type I, II and III contractions. A similar classification, including a Type IV wave has been used in man (Spriggs *et al.*, 1951; Code, Hightower & Morlock, 1952). Davidson *et al.* (1956) found this classification unsatisfactory and they divided waves into 'phasic waves' of short duration and 'tonus waves' of longer duration.

It is now generally agreed that an adequate

classification of colonic pressure waves does not exist and attempts at qualitative analysis have been largely abandoned in favour of one or other form of quantitative assessment of motility records (Fig. 4).

Chaudhary & Truelove (1961) grouped waves according to their amplitude and their duration. They expressed the total motor activity by calculating the 'Colonic Motility Index'. This parameter was calculated by multiplying the amplitude by the duration of each wave occurring during a 1 hr recording period and adding all the values together.

Connell (1961) measured the duration of activity and the mean amplitude of the contractions and used the product of these two parameters as an expression of the overall or total activity.

Arfvidsson (1965) made recordings on paper of uniform standard weight and subsequently obtained the area between the tracings and baseline by cutting out and weighing the area under the curve—the values obtained were then converted to cm^2 which he used as the unit to express the 'Total Intrasigmoid Pressure'. The area under the curve is now more often assessed by the use of a planimeter or by electronic integration. At a motility symposium (Connell, Texter & Vantrappen, 1965) it was agreed that although any system for quantitating colonic motility has its deficiencies, the measurement of the area under the curve is probably the most accurate. An approximation of this area is given by the product of one-half of the height of the waves and the

FIG. 4. Diagram demonstrating methods of quantitative analysis of the overall colonic motor activity. Total activity may be expressed as:

(a) Sum of the products of amplitude and duration of each wave, i.e. $ae + bf + cg + dh + \dots$

(b) Product of mean amplitude of the waves and duration of activity expressed as a percentage of the time of analysis, i.e.

$$\left(\frac{a+b+c+d}{4} \right) \times (e+f+g+h).$$

(c) Area under curve in mm^2/min of time of analysis.

duration (assuming that the tracing of each wave is an isosceles triangle).

Factors influencing colonic motility

Spontaneous alterations in motor activity frequently occur in the human colon and rectum under resting conditions and this must be borne in mind when the possible effects on the bowel of the various stimuli are being tested. It is also important to ascertain that a recorded change in motility following administration of a pharmacological agent is due to drug and not to emotional stress or discomfort associated with the injection.

Physiological factors

It has been shown that during sleep the motor activity of the colon is diminished and it is considered that this is due to the reduction in the number of physiological stimuli affecting this organ (Adler, Atkinson & Ivy, 1941).

The ingestion of food is one of the main physiological stimuli that affects colonic motor activity, and usually results in an increase in segmental activity of the order of 30–50% in normal subjects. Although the response may be elicited by the sight and smell of food, the main effect is evident during the meal and is maintained for a considerable post-prandial period in most subjects.

Emotional factors

Almy, Kern & Tulin (1949) studied the effect of experimentally produced emotional stress in normal subjects and found that the colonic motility was increased in some, decreased in some and unchanged in others. Patients with irritable colon syndrome also had a variable response to emotional conflict. Chaudhary & Truelove (1961) reported that a high percentage of normal subjects and patients with large bowel disease demonstrated colonic hyperactivity in response to stress.

Humoral factors

Connell & Logan (1967) have shown that gastrin or its active terminal tetrapeptide administered in physiological doses results in increased motor activity of the colon in the dog and in man. They have shown that the gastro-colic feeding response is humorally mediated and they consider that gastrin is an important activator. However, the more recent experience of Misiewicz, Waller & Holdstock (1969) does not support the suggestion that gastrin has a direct role in the colonic response to meals.

Serotonin (5-hydroxytryptamine) has been shown to inhibit both the proximal and distal colon (Misiewicz, Waller & Eisner, 1966) although Fink & Friedmann (1960) considered that serotonin stimulated the proximal colon and inhibited the distal

colon. Using isolated strips of human colonic circular muscle, Fishlock & Parks (1963) showed that serotonin causes inhibition of spontaneous activity and tone of circular muscle from all regions of the colon. They also showed that muscle from the human ileum reacted differently. Circular muscle taken from the ileum at a point 2.5 cm proximal to the ileo-caecal valve contracted in response to serotonin while circular muscle taken from a point 2.5 cm distal to the ileo-caecal valve relaxed. It may be that a reduction in segmental activity in the colon, resulting in diminished peripheral resistance, is one of the factors responsible for the diarrhoeal state associated with the carcinoid syndrome.

Various prostaglandins have been shown to increase the electrical and motor activity of isolated colonic muscle strips in the dog and in man (Schuster & Vanasin, 1971). Prostaglandin E₁ has been shown to increase the transit rate through both small and large intestine. Administration of this preparation may result in the passage of fluid faeces and gas per rectum, associated with bouts of abdominal cramp (Misiewicz, Waller & Kiley, 1969).

Effects of drugs

Cholinergic drugs stimulate motor activity and anti-cholinergic drugs tend to diminish it. When prostigmine is administered intramuscularly in a dose of 0.5 mg to normal subjects there is three- to four-fold increase in segmental activity in the sigmoid and a less marked increase in rectal activity (Fig. 5).

Anticholinergic drugs such as atropine relax smooth muscle and diminish colonic motor activity by blocking cholinergic nerve fibres (Painter & Truelove, 1964). Their action is less consistent than that of cholinergic drugs. In therapeutic doses these drugs tend to produce side-effects elsewhere in the body.

Another group of drugs, typified by mebeverine (Colofac) has a spasmolytic effect and a direct musculotropic rather than neurotropic action. The obvious advantage is that there are virtually no atropine-like side-effects. When given intravenously, mebeverine causes marked diminution of colonic activity, even in the colon stimulated by prior injection of prostigmine. Figure 6 shows the effect of mebeverine on colonic motility of a patient with irritable colon syndrome who had had a prior injection of prostigmine. The usual effect is to diminish, rather than abolish, contractions and the action often begins to wear off within 20–30 min of the injection.

A therapeutic dose of morphine stimulates the segmental activity and increases the colonic muscle tone, thereby increasing the peripheral resistance to the passage of intestinal contents. The constipating effect of morphine and its derivatives can be

FIG. 5. Motility recording from a normal subject following prostigmine 0.5 mg i.m. Miniature balloons at 15, 20 and 25 cm from anus.

FIG. 6. Motility recording from a patient with irritable bowel syndrome showing marked fast wave pattern in response to 0.5 mg prostigmine i.m. (left) and the effects of 50 mg mebeverine i.v. (right).

explained on this basis. By contrast, pethidine does not cause the sigmoid to generate high pressure (Painter & Truelove, 1964).

Effect of local agents

It is well known that motor activity of the colon can be stimulated by an enema and progressive waves of contraction may develop which empty long segments of bowel. These induced peristaltic waves or so-called 'stripping' waves are often seen during barium enema examination (Williams, 1967).

The effect of introduction of pharmacological agents directly into the colon has been assessed by Hardcastle & Mann (1968). Responses in the right and left sides of the colon were investigated following the insertion of the recording tubing and the pharmacological agents via well-established transverse and left iliac colostomies. Bisacodyl and

oxphenisatin regularly stimulated peristalsis, whereas spontaneous peristalsis was observed on only four occasions during recordings in forty-eight patients. The direction of all peristaltic waves was towards the rectum and antiperistalsis was not demonstrated. Induced peristalsis on the right side of the colon was usually held up at the transverse colostomy and seldom traversed to the distal limb. The response to Bisacodyl can be effectively blocked by the prior application of Lignocaine to the mucosa.

Effects of mechanical distension

The effects of distending the wall of the colon using a large balloon vary considerably from one subject to another (Parks & Connell, 1969a). Generally, there is a marked increase in activity, with more vigorous and more frequent contractions, as detected by open-ended tubes lying in the lumen

of the bowel immediately above and below the distending balloon. This exaggerated segmental activity may be recorded over segments of the large bowel 15 cm or more proximal and distal to the distending balloon. The volume of fluid in the distending balloon required to effect stimulation may be as little as 10 ml but in some instances 80 ml or more may be introduced before appreciable change in the wave pattern occurs. The strength and frequency of the contractions do not necessarily continue to increase with increasing degrees of distension. When larger volumes are used there may be inhibition of the contractions.

The waves initiated by distension of the colonic wall are simple in form and are usually segmental rather than peristaltic in type. Waves are broader-based than normal indicating sustained contractions which may last for more than one minute. They are always positive and relaxation ahead of the distending 'bolus' is not usually demonstrable.

Motility in the disordered colon

Diarrhoea and constipation

Before modern techniques for the assessment of

colonic motor activity became available, it was generally assumed that diarrhoea was a hypermotile state, whereas it was considered that constipation was associated with hypomotility of the colon. There is now a considerable amount of evidence that the converse is true. A reduction in motor activity in diarrhoeal states has been demonstrated by Kern *et al.* (1951), Spriggs *et al.* (1951), Chaudhary & Truelove (1961) and Connell (1962). In constipated subjects, particularly in younger persons, the degree of activity is greater than normal (Connell, 1962; Bloom, Lo Presti & Farrar, 1968). This is well demonstrated by Fig. 7 in which typical sections were taken from tracings obtained from the same subject on consecutive days—the first while constipated, the second during a period of diarrhoea.

The rapid transit which occurs in diarrhoeal states is associated with a reduction in the amount of segmenting activity in the distal colon. The resultant lowered intraluminal pressure and the diminished peripheral resistance facilitate the more rapid passage of intestinal content. Conversely, where segmental activity is a prominent feature and peripheral resistance is increased, there is a tendency to constipation.

FIG. 7. Typical sections from two records from the same patient on consecutive days, using miniature balloons placed at 20, 15 and 10 cm from the anus, (a) during a period of constipation, (b) during a period of marked diarrhoea (from Connell, 1962).

Ulcerative colitis

There is general agreement that the motor activity during the active phase of ulcerative colitis is decreased (Kern *et al.*, 1951; Spriggs *et al.*, 1951; Chaudhary & Truelove, 1961; Bloom, Lo Presti & Farrar, 1968). The latter workers found that in ulcerative colitis all wave forms had lower amplitude and shorter duration than those from normal controls.

Chaudhary & Truelove (1961) recorded motility patterns in different stages of disease. Normal recordings were obtained when the disease was clinically inactive. During mild activity there was a tendency for the motor activity to be decreased. This was also true in some of the severely affected cases, but other patients in this group exhibited an exaggerated motility.

The well known 'drain pipe' appearance of the colon in longstanding ulcerative colitis is associated with diminution of the segmenting contractions. It is not surprising that the peripheral resistance to the onward passage of intestinal content is low in such cases and diarrhoea can occur without an exaggerated propulsive force.

Diverticular disease

Painter & Truelove (1964) could find no evidence of any major difference in the intraluminal pressure in patients with diverticular disease and in healthy controls studied under basal conditions. In response to a therapeutic dose of morphine they found that diverticula-bearing segments showed an exaggerated pressure activity, while normal segments in the same patients gave a normal response. The increase in frequency and amplitude of pressure waves following prostigmine was also greater in the affected than in the normal segments. Thus, the area of the colon affected by diverticular disease acts differently from the rest of the colon.

Arfwidsson (1964) found that the overall pressure activity and the number of large waves (> 30 cm H_2O) were significantly higher in diverticular disease than in normal subjects under resting conditions. He claimed that the activity after food in patients with diverticular disease was more than five times that of normal subjects and the response to prostigmine intravenously was three-fold that of the controls.

Using open-ended tube techniques Parks & Connell (1969b) detected a higher basal and postprandial activity in diverticular disease than normal. Using miniature balloon techniques as an alternative method the strength of the contractions recorded was greater than normal in diseased subjects. However, the overall activity detected by miniature balloons in these patients was no greater under resting conditions,

or after the physiological stimulus of eating, than that of controls.

In a recent study by Parks & Connell (1972) a distinct fast wave pattern (five or more waves/min) in response to prostigmine injected intramuscularly was recorded, but the overall activity following the injection was similar to that of control subjects.

Following resection of the segments of colon affected by diverticular disease, it has been shown by Parks (1970) that the apparently normal segments that remain may have an abnormal response to stimuli, similar to regions of established disease. In segments free from diverticula, the response of the muscle to a stretching force resembles that of diverticula-bearing segments, suggesting that there is a primary muscular abnormality which exists before the appearance of diverticula.

Attisha & Smith (1969) measured the intraluminal pressure in the distal colon pre-operatively and found that basal pressure was not raised, but they demonstrated an exaggerated response to food and prostigmine. Following the operation of colomyotomy there was a significant reduction of the excessive stimulation by food and prostigmine. However, when pressure studies were repeated more than 2 years after operation the results were little different from the pre-operative values (Smith, personal communication).

Irritable bowel syndrome

During studies in patients with irritable colon syndrome, Chaudhary & Truelove (1961) found that under resting conditions there was increased pressure activity in those patients who had pain as a prominent symptom at the time of study, but not in those who were in a symptomless phase. Patients with pure diarrhoea showed reduced motor activity while symptoms were present, but normal motility when symptom-free. All the clinical categories had a greater response to prostigmine than normal subjects, whether they were in a stage of symptoms or not. Wangel & Deller (1965) demonstrated that patients suffering from spastic colon had more pressure activity and patients with functional diarrhoea had less pressure activity than control subjects after an injection of prostigmine.

Parks & Connell (1972) have shown that in the irritable colon syndrome the most prominent feature of motility recordings is the frequent occurrence of fast wave patterns, particularly after stimulation by prostigmine. Figure 6 demonstrates the type of response to prostigmine which is recorded not infrequently in patients with irritable bowel syndrome. This is in contrast to the principal wave pattern which is the more typical response to prostigmine in normal subjects (Fig. 5).

Connell, Avery Jones & Rowlands (1965) have

demonstrated an exaggerated response to eating in a group of patients with irritable bowel syndrome, who suffered from postprandial discomfort at the time of recording. These workers suggested that segmental hyperactivity in the sigmoid colon produces resistance to propulsion of faeces and gas which causes distension of the colon with resulting abdominal pain. An increased response to prostigmine has also been demonstrated in the post-dysenteric irritable colon (Connell *et al.*, 1964).

The effects of emotional stress on colonic motor activity in the irritable bowel syndrome have been studied by Almy *et al.* (1949), Almy, Abbott & Hinkle (1950) and Chaudhary & Truelove (1961). Although some patients showed a considerable rise in intracolonic pressure during periods of emotional stress, there was no clear difference from the controls.

Idiopathic megacolon

During balloon-kymographic studies on patients with Hirschsprung's disease, it has been shown that activity in the contracted distal segment was diminished or absent (Swenson, Rheinlander & Diamond, 1949). When activity was present, it did not appear to be co-ordinated with activity in the proximal dilated segment. In the early stages of Hirschsprung's disease there may be hyperactivity in the proximal ganglionic segment, but as this region of the colon becomes distended and thinned out, the motor activity is usually less than normal. Also the response to pharmacological stimulation by prostigmine tends to diminish.

Paraplegia

Studies by Connell, Frankel & Guttmann (1963) in patients with spinal cord injuries, revealed alteration in colonic motility. Destruction of the lumbosacral cord resulted in an exaggerated and irregular type of spontaneous colonic activity which was unaltered by mechanical distension. The integrity of this part of the spinal cord is essential for regulating normal colonic motor action and inhibiting excessive activity.

Transection of the spinal cord in the thoracic region may have relatively little effect on the spontaneous segmenting activity of the colon. In patients with this injury whose reflex arcs are intact below the level of the lesion, it is possible to demonstrate inhibition of segmenting activity of the colon when an adjacent segment is distended.

The response to food is independent of longitudinal conduction in the spinal cord and occurs in patients with complete transection and in patients who have sustained injury to the lumbosacral segment.

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