The intraluminal pressure patterns in diverticulosis of the colon

Part I Resting patterns of pressure

NEIL STAMFORD PAINTER AND S. C. TRUELOVE

From the Nuffield Department of Clinical Medicine, The Radcliffe Infirmary, Oxford

EDITORIAL SYNOPSIS It might be anticipated that patients with diverticulosis might have increased intraluminal colonic pressures but this could not be demonstrated under basal conditions (Part I).

With morphine there is an increased intraluminal pressure, particularly in the affected part of the colon (Part II). This differential response is of special interest in relation to the development and progression of diverticulosis.

The use of morphia is clearly contraindicated in acute diverticulitis. Similarly prostigmine (neostigmine methylsulphate) increases the frequency and amplitude of pressure waves in the colon (Part III).

These increased pressures can be abolished by the intravenous injection of propanthine (propantheline bromide) and it is likely that this may have a part to play in the treatment of acute diverticulitis either alone or to counteract the unwanted effects of morphine (Part IV). In therapeutic doses pethidine (Demerol) does not cause the sigmoid colon to generate high pressures and is recommended as the analgesic of choice for acute diverticulitis.

Colonic diverticula consist of herniations of the mucous membrane of the colon through the muscle coat that normally contains it. As herniation implies the existence of a propelling or pulsion force, with or without an initial defect in the integument, it has been suggested that colonic diverticula are caused by abnormal pressures in the lumen of the colon. However, at the time the present study began no systematic observations had been made to test this hypothesis and the pressures in the colon in diverticulosis were unknown (Thompson, 1959).

The main object of this study was to measure the pressure waves produced in the lumen of the human sigmoid colon in diverticulosis under basal conditions, and to compare the results with those obtained from control subjects studied under identical conditions.

METHOD OF STUDY

The intracolonic pressures were measured and recorded by the method of Chaudhary and Truelove (1961). Three water-filled open-ended polythene tubes were inserted into the sigmoid colon through a sigmoidoscope, which was then withdrawn, leaving the tubes *in situ*. The tubes were bound together so that their tips were 7.5 cm. apart. Each tip was enclosed in a metal cuff to permit radio-

logical visualization of the point of recording. The position of the tubes was ascertained radiologically by filling the tube located farthest up the colon with Hypaque. When a patient with diverticulosis was being studied, this radiograph was compared with the barium enema in order to determine which of the recording tips were situated in segments of the bowel that bore diverticula.

The polythene tubes were coupled to Shillingford-Muller transducers whose signals were fed into a Cambridge three-channel pressure recorder with direct pen-writers. This apparatus was calibrated against a standard sphygmomanometer, so that a pressure change of 2 mm. Hg caused a 1mm. deflection of the recording pen. Thus each large square on the recording paper corresponded to a pressure of 10 mm. Hg.

The Cambridge three-channel pressure recorder has a stable base line which allows accurate pressure recording to continue for several hours and yields a permanent tracing that can be studied at leisure. The recording paper moved at a standard speed so that the duration of any pressure wave could be measured easily.

After the introduction of the polythene tubes, the position of the recording tips was ascertained radiologically. The patient was then made comfortable in bed and allowed to settle down for a time, after which the pressures in the sigmoid colon were recorded for one hour. During this time, the patient abstained from food and tobacco, and was only engaged in conversation when this was essential to the performance of the experiment.

The pressure tracings thus obtained were later analysed to determine the number of pressure waves of various dimensions that had been recorded by each tube. The tube farthest up the colon was called 'lead 1', the middle tube 'lead 2', and that tube which was nearest the anus was labelled 'lead 3'. Data obtained from leads whose tips were situated below the recto-sigmoid junction were excluded from this analysis. Leads whose tips were situated in segments of the colon that bore diverticula were said to be 'related to diverticula', while leads whose tips recorded from apparently normal segments of colon in subjects with diverticulosis were designated leads 'not related to diverticula'. The reason for this subdivision will emerge later.

The numbers of subjects studied, observations made, and leads from which pressure tracings were obtained are given in Table I. These totals differ as some patients were observed twice. On average, two leads reached the sigmoid in normal subjects, while the structure of the diseased bowel often prevented more than one lead passing beyond the recto-sigmoid junction.

TABLE I
NUMBER OF SUBJECTS STUDIED, OBSERVATIONS
MADE, AND LEADS FROM WHICH PRESSURE TRACINGS WERE
OBTAINED

	Number of Subjects	Number of Observations	Number of Leads Analysed
Normal subjects	32	33	66
Patients with diverticulosis	28	29	20 (related to diverticula) 31 (not related to diverticula)

SUBJECTS STUDIED

NORMAL SUBJECTS These were persons who satisfied the following criteria. 1 They had no history of disease or dysfunction of the gut. 2 Their colons had been shown to be normal radiologically; a few of the younger patients did not have barium enemas, but clinically and sigmoidoscopically their colons were normal.

PATIENTS WITH DIVERTICULOSIS These patients had been examined by barium enema in the previous two years and found to have diverticulosis. Some had remained symptom-free while others had suffered attacks of diverticulitis.

It was realized that the control subjects were not ideal because their average age was different from that of the diverticulosis patients, but this criticism may be answered by stating that no correlation was found between age and the number or dimensions of the pressure waves.

RESULTS

RESTING PRESSURE PATTERNS IN THE NORMAL SIGMOID COLON The pressure tracings showed that each lead recorded a base line pressure, which was found

to be within a few millimetres of mercury of atmospheric pressure. This basal pressure results from the interplay of various factors, including the state of the bowel wall, the condition of the abdominal musculature, the height of the recording tip in relation to the manometer, and the weight of the viscera overlying the loop of bowel being studied (Rowlands, 1962). This basal pressure remained almost constant throughout any one observation, apart from the small rhythmic variations due to respiration.

The usual resting pattern of pressure waves consisted of the irregular occurrence of waves, sometimes singly and sometimes in series (Fig. 1). A series of waves might consist of two or three waves or a succession of several waves. Pressure waves at one level of the gut were frequently seen to occur independently of the pressure at another level. The gut might be producing pressures on all three leads at once, or, alternatively, one or more of the leads might remain at the basal level for long periods of time. These waves of pressure usually occurred independently on each lead without any strict temporal relationship to waves on other leads. When waves were recorded on all three leads simultaneously, their form might be similar or different and it was extremely rare to find waves of exactly similar dimensions occurring simultaneously on all three leads. No evidence of the analward progression of a pocket of high pressure from the region of lead 1 down the sigmoid so as to affect the other leads in their turn was obtained except when flatus was passed (Fig. 2).

There was considerable variation in the pressure waves recorded in different subjects, and in the same subjects if different periods of the same hour were considered. Some subjects were studied on two separate days and the number of pressure waves recorded in one hour was different on the two days.

Sometimes the intraluminal pressure remained approximately at atmosphere for long periods of time, only changing as a few waves of pressure were produced during an hour. On the other hand, very occasionally one or more pens were seen to move rhythmically almost continually for several minutes with little interruption.

The majority of waves recorded from normal subjects at rest were simple waves representing positive changes of pressure. These simple waves were of two main types. The first type showed a gentle rise in pressure to a height that was less than 10 mm. Hg and an equally gentle decline to the original level; the duration of these waves was between 10 and 30 seconds. The second type differed in that the rise of pressure was more rapid and reached a greater amplitude (10 to 30 mm. Hg)

FIG. 1. *Resting pressure patterns in the normal sigmoid colon. Tracings obtained from normal sigmoid colons; only lead 3 in the top tracing was not located above the rectosigmoid junction. Each tracing represents six minutes of recording time; this scale has been adhered to throughout this study unless otherwise stated. The variation in the number and dimensions of the pressure waves occurring in the sigmoid can be seen. The highest wave in the top tracing represents 30 mm. Hg pressure, while in the lowest tracing the intraluminal pressure hardly altered except for the small changes caused by respiration.*

and its fall steeper, so that its duration was 10 to 40 seconds. Between these two forms, every gradation has been seen. Exceptionally a similar form of wave that represented negative pressure was recorded.

These small waves corresponded in form to the type I wave described in the literature. These simple waves were the main type of pressure wave encountered in this study, although they were not so in reports of earlier observations made with the aid of balloons.

It was unusual to record types of waves other than these simple waves; only occasionally were complex waves, or waves of higher amplitude, recorded in normal subjects at rest. The configuration of the

complex pressure waves was similar to the type II waves that have been described by those workers who used balloons to study colonic motility. It is important to emphasize that the use of the terms type I and type II is merely a convenient method of describing the form of such waves and is not intended to imply that balloon tracings correspond to the exact pressure measurements that are recorded by open-ended tubes.

The considerable variation in the number of pressure waves produced by normal subjects in a given hour was noted by Chaudhary and Truelove (1961), and confirmed in this study, and consequently any quantitative data relating to colonic pressures

must be derived from a large number of observations. In this study, intraluminal pressure tracings were obtained from a considerable number of control subjects to provide a yardstick against which the levels of pressure produced by patients with diverticulosis could be compared.

RESTING PRESSURE PATTERNS IN THE SIGMOID COLON IN DIVERTICULOSIS As diverticula have been thought to owe their origin to an abnormality of the intracolonic pressure, the resting pressure patterns obtained from subjects with diverticulosis were examined to discover whether they differed from the normal resting pattern, but no obvious difference was found.

The variability of the wave forms, their irregular or rhythmic occurrence and their temporal and spatial independence of the pressure existing in a neighbouring part of the bowel that were described in the section dealing with the normal resting pattern of pressures apply equally to the resting pressure pattern of diverticulosis coli. No obvious increase in the height of the pressure waves or in the steepness of their rise and fall from the basal pressure was noted, and it was apparent that, in diverticulosis as well as in health, the intrasigmoid pressure sometimes remained at about atmospheric pressure for long periods of time (Figs. 2 and 3). Detailed analysis of the pressure tracings revealed that these impressions were correct as no significant difference in the shape or number of the pressure waves of various heights could be detected.

This failure to detect any difference between the normal resting pressure pattern and that of diverticulosis led to a further analysis of the pressure tracings. When it was remembered that the segments of the sigmoid that actually bear diverticula are sometimes structurally different from the neighbouring colon, from which they may be sharply demarcated (Fig. 4), it was considered that this anatomical difference might be reflected in an equally abrupt change in function as regards the generation of intraluminal pressures. Consequently it was decided to consider those leads whose tips were situated in segments that bore diverticula separately from those located in apparently normal bowel in subjects with diverticulosis. Therefore the resting patterns in diverticulosis were divided into two groups, 'resting patterns not related to diverticula' and 'resting patterns related to diverticula'. It will be appreciated that leads in the same patient might be distributed between the two groups, while all the leads in another patient might fall into only one of these groups. Thus some subjects acted as their own controls in the subdivision of the resting patterns of diverticulosis.

Once again, no obvious difference was apparent in the resting patterns, and quantitative tests that will be described later confirmed that this impression was correct. It was found that the resting patterns of pressure waves produced by the normal sigmoid, by the sigmoid that was beset with diverticula, and by those segments of the sigmoid that did not bear diverticula in subjects afflicted with diverticulosis, were essentially similar. In addition, no difference in the levels of basal intraluminal pressure was demonstrated.

QUANTITATIVE ASPECTS OF THE PRESSURE WAVES IN THE SIGMOID COLON IN NORMAL SUBJECTS AND IN THOSE WITH DIVERTICULOSIS Chaudhary and Truelove (1961) were unable to classify pressure waves into the types I, II, III, and IV that previous workers had described on the basis of balloon studies. Confronted with this situation, they decided to confine their analysis of pressure patterns to making simple measurements of the waves, regardless of their configuration, thus avoiding some of the difficulties that are inherent in those methods of description that rely entirely on the subjective judgement of the observer. In this way they established some values by which the number and character of the pressure waves produced by any two series of sigmoid colons in a given time may be compared. Their methods were used in this study.

The number of waves occurring in the standard time of one hour was counted. The height and duration of these waves were measured without regard to their form; the height was taken as the vertical distance between the basal pressure and the highest point of the wave, whether its form was simple or complex. Thus we determined for each group of subjects the total number of waves of various specific dimensions occurring on each lead located in the sigmoid colon. Thus a value could be obtained for the mean number of waves of any specific dimensions per lead per 60 minutes of recording time. These results are shown in Tables II and III.

When these values were examined, it was apparent that there was little difference in the three groups when the amplitude of the waves was considered (Table II). Fewer waves were recorded from leads that were in relation to diverticula. This difference was due to the smaller number of waves of the lowest amplitude that occurred in the affected segments. In the normal colon, fewer waves of between 10 and 19 mm. Hg were recorded compared with the other two groups, but waves of between 20 and 29 mm. Hg were commoner in this group. When waves greater than 30 mm. Hg were considered, there was little to choose between the three

FIG. 2. The effect of passing flatus. All leads situated in sigmoid colon of patient with diverticulosis, leads 1 and 2 being related to diverticula. The tracing remained at the resting basal level of pressure except when flatus was passed. This 'progression' of pressure towards the anus was not seen at any other time.

FIG. 3. Resting pressure pattern in diverticulosis. All three leads were in the sigmoid colon but had not reached the level of diverticula. The sudden drop in the basal level on the left of the tracing was due to the deliberate re-setting of the recording pens. Waves of over 60 mm. Hg are shown on lead 1, but these high pressures were confined to the vicinity of this lead, as lead 2 recorded lower pressures, although it was only 7.5 cm. distant. Comparison of this tracing with Figure 2 shows the variation in pressure pattern that occurs in the sigmoid colon in diverticulosis.

FIG. 4. Diverticulosis coli. This longitudinal section of a human colon shows two diverticula. The bowel below them (left) is apparently normal, and the change in structure between this and the diseased bowel is abrupt.

TABLE II

NUMBER OF WAVES BY AMPLITUDE OF WAVE IN SIGMOID COLON¹

Amplitude of Waves (mm. Hg)	Normal	Resting Values	
		Diverticulosis	
		Leads not Related to Diverticula	Leads Related to Diverticula
1-9	34.7	35.2	25.2
10-19	2.3	3.8	4.4
20-29	0.9	0.6	0.6
30-39	0.3	0.2	0.5
40-49	0.3	0.2	0.3
50-59	0.3	0.1	0.3
60+	0.02	0.1	0.05
Total	38.6	40.2	31.3

¹Mean values per lead per 60 minutes' recording time.

groups of leads. Over 80% of the waves in each group were of an amplitude less than 10 mm. Hg and few waves exceeded 20 mm. Hg. No marked difference was seen in the three groups, and no preponderance of waves of high pressure was produced by those segments that were affected by diverticulosis.

When the duration of the waves was considered (Table III), it was found that over 80% of the waves produced by the three types of colonic segments

TABLE III

NUMBER OF WAVES BY DURATION OF WAVE IN SIGMOID COLON¹

Duration of Waves (sec.)	Normal	Resting Values	
		Diverticulosis	
		Leads not Related to Diverticula	Leads Related to Diverticula
1-9	10.7	13.1	8.3
10-19	17.7	16.9	11.9
20-29	7.3	7.3	6.6
30-39	1.73	1.48	2.4
40-49	0.5	0.94	1.2
50-59	0.4	0.39	0.8
60+	0.3	0.13	0.15
Total	38.6	40.2	31.3

¹Mean values per lead per 60 minutes' recording time.

lasted less than 30 seconds. Those leads that were related to diverticula recorded more waves of a duration greater than 30 seconds than those that were situated in normal segments; such waves were about half as common again in the affected segments.

THE COLONIC MOTILITY INDEX Chaudhary and Truelove (1961) proposed that this index be used as a measure that would enable the motor activity of two groups of sigmoid colons to be compared. As most pressure waves are roughly triangular in shape, they argued that the product of the height (in mm. Hg) and the duration (in seconds) of a given wave was approximately proportional to twice the area

bounded by the wave and the basal pressure line. This area is proportional to the work done (*i.e.*, pressure $\times$ time) by the colon in generating or withstanding this wave of pressure.

They calculated this product for every wave recorded by one lead in an hour and called the sum of these products the 'colonic motility index'. This index is not a measure of the motility of the colon as Chaudhary and Truelove first thought, but a measure of the 'total pressure' or total work produced by the colon in the vicinity of one recording lead in one hour. It has the advantage of being a simple number that can be plotted on a scale. The left half of Fig. 7 in Part II of this study shows the colonic motility indices belonging to the leads from which the mean values that have already been given were derived. They are expressed in thousands and divided into the same three groups, according to the type of colonic segment in which the recording lead was situated. The average value of the indices in each column is shown by the horizontal line in that column.

It is at once apparent that despite the variation of the values of the indices in each column, the average value in each group is almost the same. This finding supports our previous impression that the resting patterns of pressure in health and diverticulosis are essentially similar and suggests that under basal conditions the 'total pressure' produced by the colon in diverticulosis is no greater than that generated by the normal colon.

DISCUSSION

The resting patterns of intraluminal pressure in the human sigmoid colon show considerable variation both in health and diverticulosis, not only in different subjects but in the same subjects when they are studied at different times. Consequently it is necessary to study a considerable number of subjects in order to compare the activity of groups of colons under basal conditions.

The resting pressure patterns produced by normal colons that have been obtained in this study are essentially similar to those reported by Chaudhary and Truelove (1961). No previous systematic study of the intraluminal pressure patterns in diverticulosis coli has been reported so that the present results for this disease cannot be discussed in relation to the work of others.

No obvious difference has been found in the resting pressure patterns produced by the sigmoid colon in health and in diverticulosis. This was true both for segments of the sigmoid that actually bore diverticula as well as for apparently normal segments of the colon in subjects with diverticulosis. Simple

quantitative analysis of the pressure tracings failed to reveal any preponderance of waves of high intracolonic pressure in diverticulosis. The segments that actually bore diverticula did produce more waves of longer duration than other segments, but such waves represented only a small proportion of the pressure waves recorded and would not appear to be important in the genesis of diverticula.

Despite the approximations inherent in its definition, the colonic motility index is the only measure so far available that allows the motor activity of two groups of colons to be compared with regard to the production of pressures. These indices were calculated and showed a considerable general measure of agreement in each group of leads, while their average values in each group of leads were very similar. This suggests that the total pressures generated or withstood by the colon in health and in diverticulosis are essentially the same under resting conditions.

However, a variety of factors influences the motor behaviour of the human colon, such as eating, drinking, defaecation, and emotion (Chaudhary and Truelove, 1961; Connell, 1961). Therefore the effects of these stimuli on the pressures in the sigmoid colon deserve to be studied as it is possible that they

play an important part in the aetiology of the disease by altering the intracolonic pressure patterns.

SUMMARY

The herniation of the colonic mucosa in diverticulosis may be the result of abnormally high intracolonic pressures, of weakness of the muscularis propria, or of a combination of these two factors.

A systematic study has been made of the intraluminal sigmoid pressures in diverticulosis coli and in the healthy sigmoid colon employing open-ended water-filled polythene tubes coupled to a Cambridge multi-channel pressure-recorder.

Under basal conditions no evidence was obtained of any major difference in the intraluminal pressures in diverticulosis and in health when the recordings were analysed in various ways.

REFERENCES

- Chaudhary, N. A., and Truelove, S. C. (1961). Human colonic motility: A comparative study of normal subjects, patients with ulcerative colitis, and patients with the irritable colon syndrome. *Gastroenterology*, **40**, 1-36.
- Connell, A. M. (1961). Personal communication.
- Rowlands, E. N. (1962). In a *Symposium on Small Intestinal Motility* given at the Annual General Meeting of the British Society of Gastroenterology, 1961. *Gut*, **3**, 94.
- Thompson, H. R. (1959). Diverticulitis of the colon. *Postgrad. med. J.*, **35**, 86-91.

Part II The effect of morphine

Morphine is still the most important analgesic. Much conflicting evidence has accumulated over the past 70 years regarding its effect on the intestine. Vaughan Williams and Streeten (1950, 1951) have pointed out that the opposing views of previous investigators are largely the result of the limitations of the techniques they employed, and that many of the differing conclusions that have been expressed can be reconciled when this fact is appreciated. Nevertheless, even though its mode of action and, in particular, its effect on the human intestine, are so little understood, the drug is very widely used. As it seemed possible that morphine might alter the pattern of the intracolonic pressures, we measured its effect on the pressures in the human colon both in health and in diverticulosis coli.

METHOD

The method of recording the intracolonic pressure has been described in Part I of this study. A large number of the subjects whose resting patterns have been described were given 10 mg. of morphine sulphate, either intravenously or intramuscularly, after their resting patterns had been recorded for one hour. The intracolonic

pressures were recorded for a further hour following this injection and the tracing thus obtained was called the 'post-morphine' pattern. Hence it was possible to compare the resting patterns of intrasigmoid pressures with those observed after morphine in both health and diverticulosis.

RESULTS

EFFECT OF MORPHINE ON THE PRESSURE PATTERNS IN THE NORMAL SIGMOID COLON When given intravenously, the effect of morphine became apparent almost at once in almost every patient (Fig. 1). Initially the basal intraluminal pressure nearly always rose one or two millimetres of mercury and, superimposed on this rise, there occurred a succession of waves of high pressure, which continued for several minutes. These dramatic changes were usually followed by a period lasting a few minutes during which the pressure tracing was more or less flat before another series of waves was generated. The height of the waves in the initial complex varied from lead to lead. The height of these initial pressures was seldom exceeded by the waves seen