Gut, 1980, **21**, 500–506

Normal patterns of human upper small bowel motor activity recorded by prolonged radiotelemetry*

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SUMMARY In order to characterise human interdigestive cyclical motor activity, and its interruption by food, jejunal pressure changes in healthy volunteers were recorded continuously for 24 hours, using an ingested pressure-sensitive radiotelemetry capsule tethered at the duodenojejunal flexure. In 20 studies, the subjects fasted throughout; in another 20 studies they received a single standard meal. Using this technique, fasting motor complexes were easily detected. There was considerable variation in interdigestive cycle duration and in the interruption caused by food. The data were not normally distributed. The study indicates that any descriptions of 'atypical' jejunal motility patterns must take into account the wide variations seen in health, before they can be regarded as representing dysfunction or disease.

Cyclical fasting motor activity has been recognised as 'hunger contractions' in man for many years.[1] In the last decade, since Szurszewski clearly defined cyclic fasting activity as migratory in dogs,[2] and Code and Marlett[3] demonstrated the abolition of the migrating motor complex by feeding, interest in this field has been renewed. In animals, study is facilitated by chronically implanted electrodes or force transducers; in man, this is not ethically permissible, and hitherto study by perfused orointestinal intubation systems has been the method of choice. Using this method, Stanciu and Bennett[4] showed that human fasting migratory motor activity, previously reported in man by Beck *et al.*,[5] is a cyclical phenomenon with an apparent periodicity of about 90 minutes. The cycle consists of a period of quiescence (phase I) followed by a period of irregular activity (phase II) which terminates in a burst of regular contractions (phase III) as shown in Fig. 1. Vantrappen *et al.*[6] have reported atypical fasting motor activity associated with bacterial overgrowth.

Intubation is cumbersome and uncomfortable for the subject; mobility is restricted and feeding is difficult. Because of this, periods of observation tend to be limited to a few hours.[6 7] For this reason, we have used the 'radio-pill', a pressure sensitive transducer emitting a low power frequency-modulated radio signal, to study human jejunal motor activity. Two decades ago, the radio-pill was used extensively in an effort to discriminate patterns of motor activity, but little useful information emerged. In these early studies, the pill was allowed to move freely through the bowel; not only was its location often uncertain, but the signal was often lost.

We have modified the technique by attaching the radio-pill to a thread. After ingestion, it is allowed to pass to the duodenojejunal flexure, but its onward passage is then arrested by the thread. Used thus, the pill behaves as a relatively stationary transducer; moreover, the thread causes little discomfort or interference with feeding or speech, and, as the pill's anatomical position is reasonably constant, the aerial system can be arranged for optimal reception. This technique allows continuous observation for the length of life of the pill's power source.

Methods

Pressure was detected using a pressure-sensitive radio-pill (Rigel Research Ltd, 99 Gander Green Lane, Sutton, Surrey). A 200 cm thread was attached to the pill, and over this was threaded 60 cm of fine radio-opaque PVC tubing. The pill transmitted a signal at approximately 460 kHz frequency,

*This work was supported by grants from the Wellcome Trust, the Medical Research Council, and the Mason Medical Research Foundation.

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Received for publication 20 November 1980

modulated by changes in pressure; it was calibrated at 37°C so that a 100 cm column of water produced a full-scale deflection on the recording apparatus. The signal was detected by an array of three coil aerials arranged around the waist of the subject. Two coil aerials were arranged at right angles in the vertical plane; the third aerial coil consisted of multiple turns of cable around the subject's waist. The aerials were connected by leads 2000 mm in length to an automatic aerial scanner and FM receiver (Rigel Research Ltd). The aerial scanner automatically selected the strongest signal and passed it to the FM receiver. The output of the receiver was a DC voltage proportional to the ambient pressure surrounding the pill; after attenuation, the DC signal was passed to the input of a carrier amplifier fitted into one channel of a miniature cassette tape recorder (Medilog 4–24, Oxford Medical Systems Ltd, Asheville Trading Estate, Abingdon, Oxon) and recorded on $\frac{1}{8}$ inch magnetic tape in a C 120 cassette. A second tape channel was used to record a time pulse and to mark events.

The subjects were healthy males and females (age 20–31 years) who gave informed consent to the procedure. The study protocol was approved by the local ethical committee. On the evening before the start of the study, the subjects swallowed the radio-pills and were instructed to allow it to advance until 100 cm of the thread had been ingested. On the following morning the pill was located by *x*-ray screening, and, if required, withdrawn until it lay just distal to the duodenojejunal flexure. The distal 60 cm of radio-opaque tubing allowed the stomach and duodenal loop to be identified to ensure that the pill was in the correct position, but only the thread passed up the oesophagus and oropharynx, the free end being looped around a tooth, or taped to the subject's cheek to secure it. The aerials were then connected to the signal detection and recording system. During study, subjects were seated or recumbent according to choice; excessive movement was discouraged to minimise sudden changes in intra-abdominal pressure. Each subject was provided with a push-button unit; when the button was depressed, it recorded a signal on the magnetic tape; at the same time, the subject kept a written record of the timing and nature of the recorded event.

Two study protocols were used. The fasting protocol (20 studies in 18 subjects) consisted of a minimum of 24 hours of continuous recording without food, but with sips of water *ad libitum*. The feeding protocol (20 studies in 20 subjects) consisted of a preliminary fasting period of up to nine hours, followed by a mixed meal (Table); postprandial recording was then continued for a period of 15 hours.

Table *Details of diet*

Composition of mixed meal	*Analysis of meal*	
56 g roast chicken	Volume	540 ml
112 g mashed potato	Calorie content	492 Kcal
84 g peas	Carbohydrate	39 g
35 ice cream	Protein	28 g
28 g cheese	Lipid	28 g
10 g butter		
14 g crackers		
200 ml water		

At the conclusion of the study, the aerial array was removed from the subject, the pill was recovered by traction on the thread and recalibrated. There were no untoward after-effects or side-effects of the study, apart from boredom. The continuous pressure record was obtained by high-speed tape replay on the Medilog PB 2 replay unit (Oxford Medical Systems Ltd) with the demodulated signal passed directly to the y axis of the y/t chart recorder. The recorded tape incorporated a time signal which allowed location of any desired portion of the type to the nearest minute; adjustment of the recorder time-base allowed the time axis to be expanded or compressed.

The 'activity fronts' (phase III) of motor complexes were identified as periods of regular 10–12/min contractions lasting at least two minutes, usually followed by quiescence. Feeding was followed by irregular pressure activity without prolonged periods of absent, or sustained regular, contraction. The duration of cycles, as shown by the interval between successive motor complexes, was measured from the graphic record. Results are expressed as median values; median and range data were tested for significant statistical difference using non-parametric tests[8] and illustrated using 'box and whisker' plots[9]; the latter are described in the legend of Fig. 3.

Results

SIGNAL LOSS

Signal loss as here defined includes not only failure of the receiver to detect the signal but also disconnection of the subject from the apparatus for any reason. Signal loss is easily identified on replay by loss of the baseline. Nine of 20 fasting studies showed only transient (less than two minutes) signal loss. In 11/20 fasting studies, there were more prolonged periods of signal loss (loss/24 h $1{\cdot}8 \pm 0{\cdot}9$ h, mean $\pm$SD) but, over 24 hours, this represents less than 10% loss of signal. The frequency of motor complexes in the latter group was not significantly different from the frequency of complexes in the former group, suggesting that signal loss did not impair detection of motor complexes. In the feeding studies, the extent of signal loss was similar, but in

no case was the signal lost during the transition from fed to fasted pattern.

FASTING STUDIES

Figure 1 shows pressure activity representative of fasting activity. Three motor complexes are seen, each preceded by irregular pressure activity and followed by a period of quiescence. Figure 2 shows the incidence of motor complexes in the 20 studies; signal loss is indicated by absence of the baseline for the appropriate period. The incidence of motor complexes is shown in Fig. 3, the median value for complexes per 24 hours being 13 (range 7–17).

FEEDING STUDIES

An example of the motor response to a meal is shown in Fig. 4. The distribution of motor complexes, timing of meals, and sleep periods for this group are shown in Fig. 5. The median interval between a meal and the next motor complex was 319 minutes; this suggests that our test meal should, on average, abolish 3 motor complexes. This was confirmed by the finding, in this group, of a median value of 10 complexes per 24 hours (Fig. 3).

INTERVALS BETWEEN MOTOR COMPLEXES

Figure 2 and Fig. 5 show the considerable inter-subject and intra-subject variation in the intervals between motor complexes during waking and sleeping, and when interrupted by a meal. Figure 6 shows the intervals between the meal and the succeeding motor complex, and also intervals between motor-complexes combined for both study groups according to periods of waking and sleeping. It is apparent that the data are non-normally distributed. Thirteen motor complexes during a 24-hour fast suggest a mean interval of 110 minutes, but the data being non-normal, mean values do not apply. The median interval during sleep (85 minutes) was lower than the median waking interval (95 minutes), but, using the median test,[8] the difference was not significant. Nevertheless, Kolmogorov-Smirnov's test[8] showed a significant difference ($P<0.01$) between waking and sleeping, showing that the groups do differ. Inspection of Fig. 6 suggests that the difference lies in the occurrence of a greater number of prolonged intervals during the day, increasing the skew of the data. The notable feature in Fig. 6 is the variability of motor complex intervals in normal subjects, with overlap of all three ranges of data, suggesting

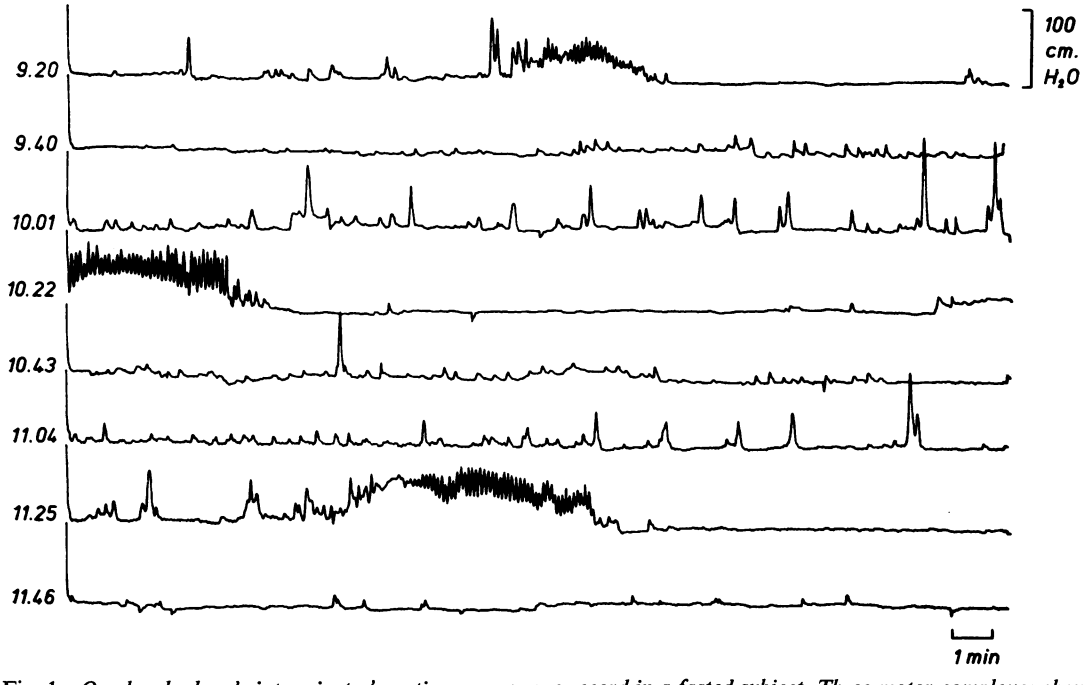

Fig. 1 *One hundred and sixty minutes' continuous pressure record in a fasted subject. Three motor complexes showing rapid phasic oscillation with tonic elevation of the baseline are shown; each is preceded by irregular pressure activity and followed by quiescence.*

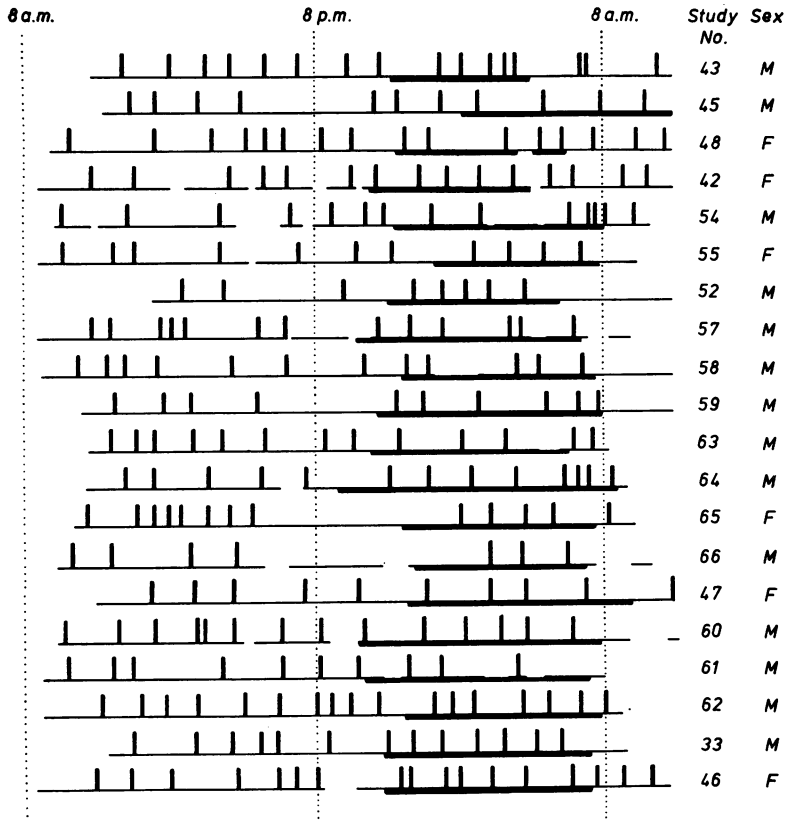

Fig. 2 *Incidence of motor complexes in 20 studies on 18 fasted subjects. Notation in the right-hand margin indicates the number of the study and sex of the subject. Two subjects were studied twice (43+45) and (42+48). Motor complexes are indicated by vertical bars below each baseline. Breaks in the baseline indicated periods of signal loss of five minutes or more. Thick portions of the baseline indicate sleep periods.*

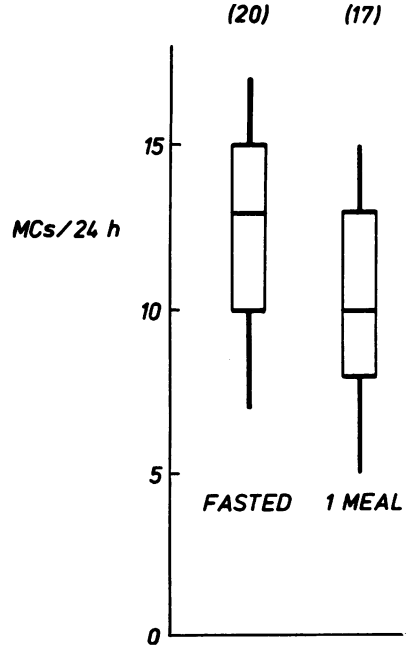

Fig. 3 *'Box and whisker' plots of the total number of motor complexes in 24 hours in (left) fasted subjects and (right) subjects given one meal. The range of data is indicated by the upper and lower vertical lines, while the box extends between the two interquartile limits and is divided by a horizontal line indicating the median value. Numbers in parentheses denote number of observations.*

that significant deviations from the normal pattern will be established only by prolonged periods of study.

Discussion

This study demonstrates that prolonged observation of intestinal motor activity can be achieved with little discomfort for the patient, using available inexpensive technology in reasonably physiological conditions. In the fasted subjects, the median number of motor complexes per 24 hours was 13, giving a mean cycle length of 110 minutes; this mean value agrees well with other published estimates.[6 7 10] However, our prolonged observations have also

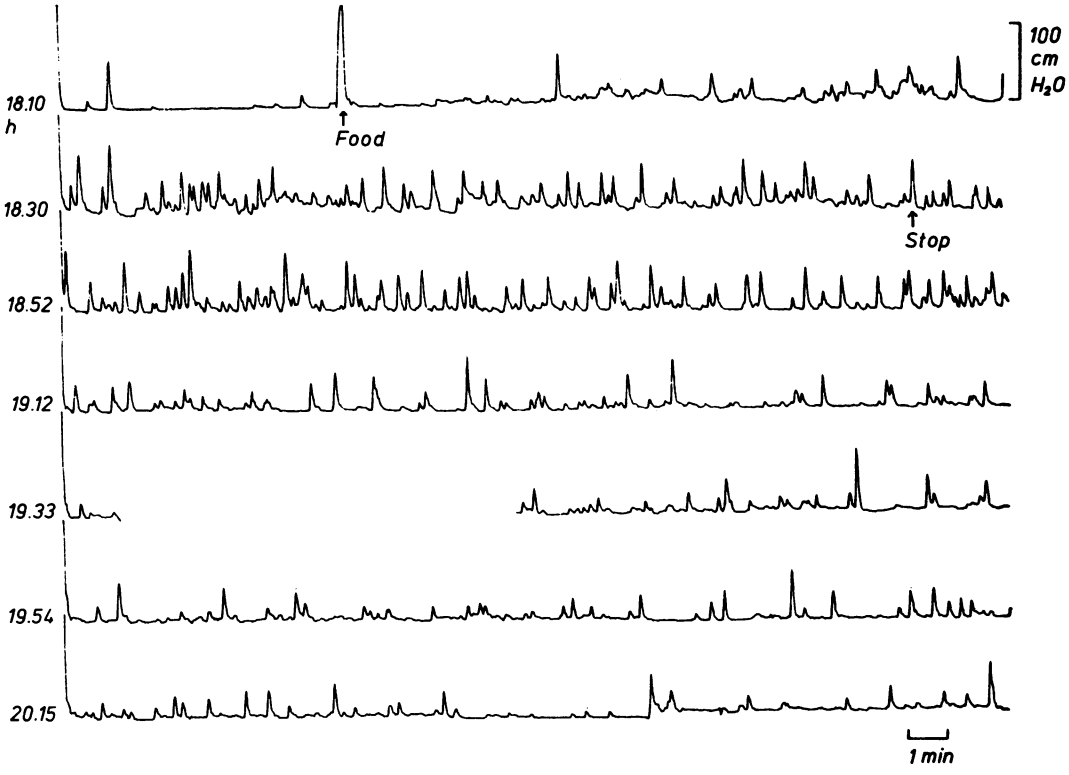

Fig. 4 *The response to feeding in the same subject as shown in Fig. 1. The time of administration of food is shown, as is the termination of eating. The break in the recording indicates a period of absence of signal when the apparatus was temporarily disconnected to allow the subject to leave the room.*

shown greater variation in the intervals between motor complexes and in their interruption by food than has hitherto been documented in animals or man, although short intervals between motor complexes have been documented in postoperative patients.[11 12] The data are non-normally distributed, as can be seen from the 'box and whisker' plots (Figs. 3 and 6). Mean and median values for intervals between motor complexes do not coincide; the median values are lower. It is possible that the variability in cyclic activity in man compared with experimental animals[3] may be a true species difference, but results should be compared with caution. Experimental animals are trained to submit to repeated study; our subjects were not familiar with the experimental conditions. In testing the response to food, animals are usually fed their standard daily meal, whereas this is not possible with humans who vary their diet greatly. Whatever the cause of the variation, it has to be taken into account in the design and interpretation of studies on man. Our data point towards three conclusions. First, median values should replace mean values; the use of the latter may be misleading. Secondly, prolonged rather than brief studies of cyclical activity are required to ensure the inclusion of long intervals between complexes; in short studies, such long intervals may be mistaken for the complete absence of cyclical activity. Finally, a technique which is sufficiently comfortable to allow normal sleep is important. Continuous monitoring by radiotelemetry seems, in this contest, superior to study by relatively bulky intubation systems.

The disadvantage of the present system, with a single sensor, is that propagated, or migratory, pressure changes cannot be demonstrated. We are satisfied that our complexes are migrating motor complexes, as phase III of the motor complex has a characteristic appearance, and we know of no instance in human and canine studies of pressure or myoelectric activity where phase III has not been migratory. Where greater technical sophistication, with two or more sensors, will be required is to determine whether irregular pressure activity is propagated or non-propagated.

The existing radio-pill was developed a quarter of

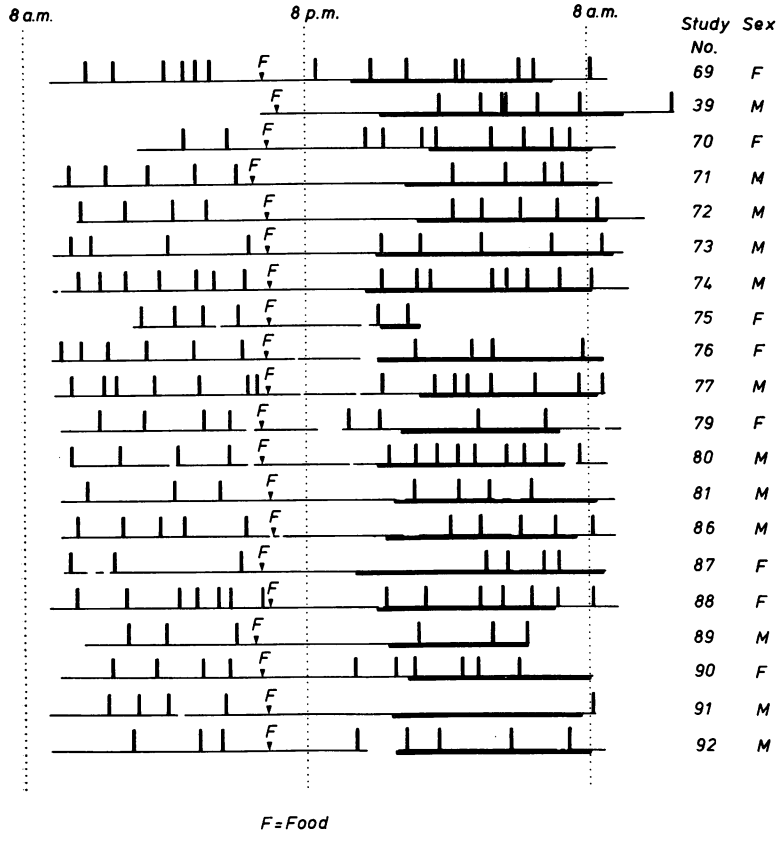

Fig. 5 *The interruption of motor complexes due to feeding, in 20 subjects who were fed at F after an overnight fast. Symbols as in Fig. 2.*

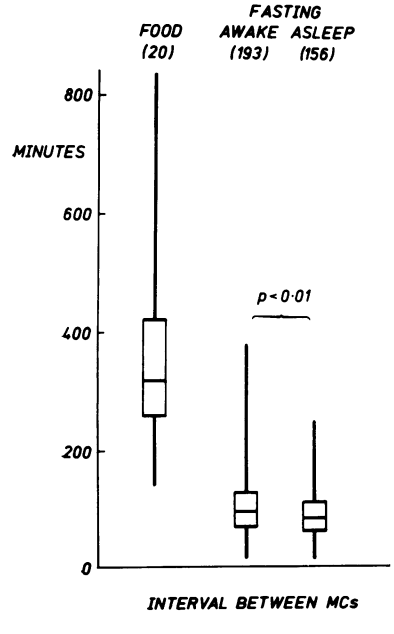

Fig. 6 *'Box and whisker' plots of (left) the intervals between food and the next motor complex, and the intervals between complexes during fasting while awake (centre) and during sleep (right). For explanation of plots, see Fig. 3.*

a century ago, before the era of the 'silicon chip'. An improved system, incorporating two or more sensors, can, and probably will, be built. The present study provides essential data on normal function, and also helps to define the design parameters of a better system.

We wish to thank C Browning, W Dobinson, T G Barnett, and Sister Greta Keenan SRN for technical assistance, and our volunteer subjects whose support made this study possible. LA, MJB, WJG, and RJH, undertook this project as part of an intercalated BSc course at the London Hospital Medical College.

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