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Caloric Content of a Meal Affects Duration but not Contractile Pattern of Duodenal Motility in Man

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The variability of the fasted duodenal contractile pattern and the patterns of contraction during the fed phase was examined in normal volunteers. Prolonged recordings from the duodenum and proximal jejunum were achieved using a series of transducers mounted on a 2.3-mm catheter. A total of 58 interMMC intervals and the response to 18 meals was examined. There was marked inter- and intrasubject variability in the fasted state, even within one study. The phase II pattern was examined in detail and propagated single peaks, propagated clusters, and repeated propagated clusters are described. Single peaks could be propagated as rapidly as 16 cm/sec. Single peaks were propagated more rapidly than propagated multiple peaks. During phase III, duodenal contractions occurred at 11.3 ± 0.09/min and jejunal contractions at 10.73 ± 0.15/min. The rate of progression of the onset of phase III was 0.145 ± 0.015 cm/sec. The effect of the caloric content of the meal was examined by determining the effect of 150-kcal, 300-kcal, and 600-kcal meals on the fed pattern. Increasing caloric content increased the duration of the fed pattern but had no effect on the total or normalized motility index or on the change in motility index over time during the fed pattern. The types of contractions seen during the fed pattern are described. Propagated clusters over at least 16 cm are common during the fed phase in normals, with 10% of all contractions seen during the fed phase being propagated over 28 cm. No difference in the patterns of contractions or their propagation was seen with the different caloric contents of the meals. These studies demonstrate the variability of the normal fasted pattern and demonstrate the motor equivalents of a variety of myoelectric patterns that have been described. A method of analyzing the fed pattern is described.

KEY WORDS: migrating myoelectric complex; duodenum; jejunum; motility; motility index.

The patterns of contraction in the small intestine during the fasted and fed state are complex. A distinct recurrent cycle of contractility, the interdigestive migrating motor complex (IMMC) is seen in man during fasting (1–7), but the specific details of contractile patterns during each phase of the IMMC are less well defined. It is apparent, from several studies, that there is considerable variability within and between subjects (1, 3, 4–8) and even a diurnal variation has been described (3). Food interrupts the IMMC, which is replaced by a pattern of contraction that, superficially, appears more chaotic (7). In dogs, caloric content, food constituent content, and consistency of the meal all affect the duration of the fed pattern, the amount of contraction, and the types of contractile patterns seen (9–11). Such information is not available in man. In

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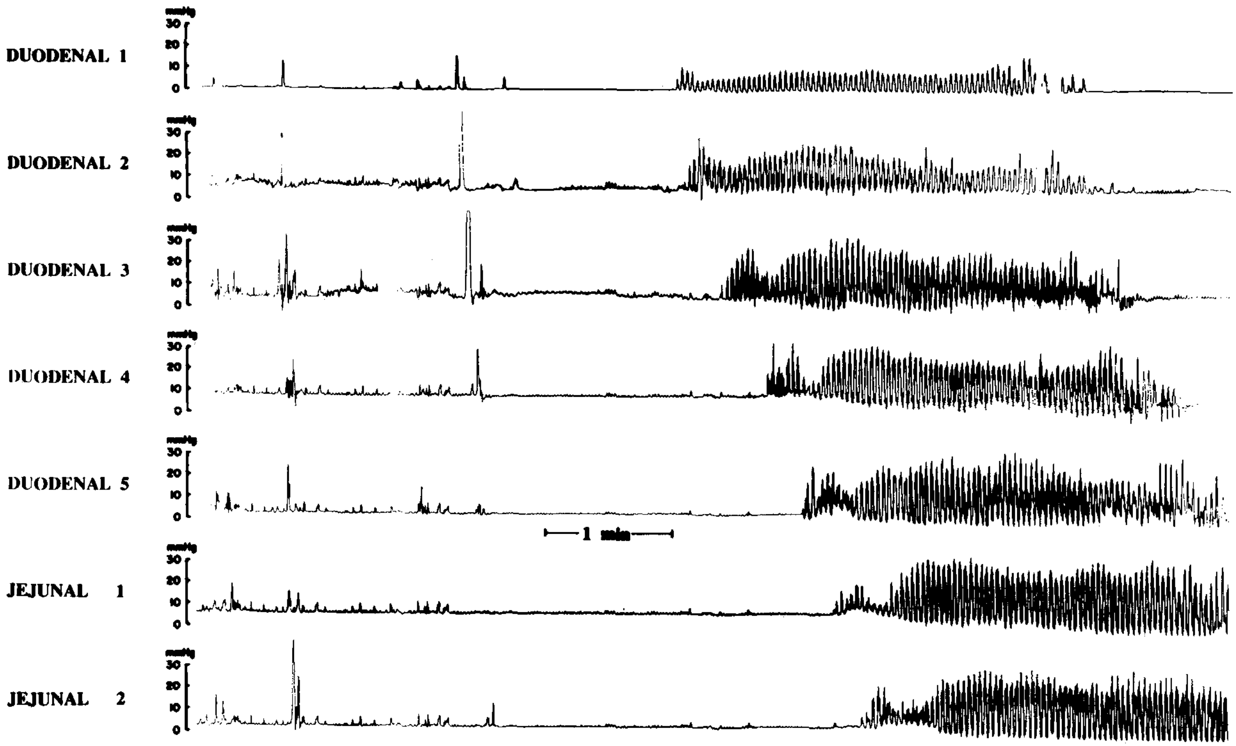


Fig 1. Tracing of fasted pattern in a normal subject: five duodenal and two jejunal tracings are shown. Shown in this tracing is the end of phase II leading into the propagated phase III, followed by the quiescent phase I (seen in the most proximal lead).

order to determine what is abnormal, the "normal" small intestinal motility needs to be better defined.

The aims of this study were to examine the patterns of contraction seen in the duodenum when fasting and to examine the effects of calories on the fed pattern. The presence of propagated contractions was examined using a probe with closely spaced pressure transducers.

MATERIALS AND METHODS

Six healthy male volunteers ages 21–28 were studied. Each was fasted overnight for each study and underwent between one and three studies in a random order with at least a week between each study. Two subjects underwent three studies each, two subjects underwent two studies each, and two subjects underwent only one study each. At 7:00 AM, on the day of the study, a 8F catheter on which were mounted eight pressure transducers 4 cm apart (Mikro-Tip catheter pressure transducer, Millar Instruments, Inc., Houston, Texas) was passed via the nose. The catheter tip was advanced into the duodenum under fluoroscopic guidance so that at least two pressure transducers were beyond the ligament of Treitz whenever possible. The transducers were connected via control units (model TC-500, Millar Instruments) to a rectinlinear recorder (Beckman R711, Beckman Instruments, Inc., Fullerton, California). The output was simultaneously recorded on FM tape using a Hewlett-Packard FM tape recorder (3968A) for later analysis using a Hewlett Packard computer (HP 9826). Recordings were initiated and continued with the subject supine until six phase III patterns were recorded. A meal was ingested by the subject and recordings were continued until a phase III pattern was again recorded.

Each of three meals were ingested in random order by four subjects in three separate studies. The meals were 150, 300, and 600 kcal. Each test meal consisted of poached egg white, white bread, butter, and water with the composition of the meals being constant: 40% carbohydrate, 20% fat, and 40% protein. The ratio of the meal components was maintained constant between studies, as was the total volume. This proportion has been previously used by other investigators (1).

The fasted and fed motor activities were analyzed separately. Three phases were recognized visually in the fasted tracings (Figure 1). Phase I was defined as the period in which no contractions were seen. Phase II was defined as containing contractile activity and occurred between phase I and phase III. Phase III, was characterized by a burst of rhythmic activity lasting at least 2 min and migrating down the intestine over all leads distal to the lead in which it originated. The interMMC duration was defined as the duration between the end of phase III of one cycle and the end of phase III of the adjacent cycle. The termination of phase III was chosen rather than the beginning as the quiescent phase I was more easily defined than the transition from the intermittent activity of phase II to the rhythmic activity of phase III. The duration of each phase was determined for each subject within the five cycles that were recorded in each study and between each of the two or three studies each subject performed. The maximum frequency of contractions in the duodenum and jejunum was determined by the frequency of contraction at each site during phase III. The motor pattern in phase II was examined for the patterns of contractile peaks that could be seen and the rate and distance of propagation of single and clustered peaks.

The motor activity in the fed state was examined both visually and by computer analysis for motility index. The duration of the fed pattern was defined as the interval between the loss of the fasted pattern, which coincided with the onset of the irregular contractile activity seen in all leads characteristic of the fed pattern, and the return of the phase III of the interdigestive pattern in the most proximal lead in which it was seen. The output of the FM tape recording of the fed pattern was digitized and analyzed using a computer program that determined the area under the motility tracing curve in mm Hg × sec. This is equivalent to the sum of the amplitude of all the contractile peaks multiplied by the duration occupied by these contractions. The motility index was determined per 5 min and expressed as a total motility index and as a ratio of total index divided by time (in minutes) to allow comparison between studies. The change in motility index over time, during the duration of the fed pattern, was also examined. For this analysis, the duration of the fed pattern was divided into 10 equal parts and the motility index during each 10% segment was expressed as a percentage of the total motility index to allow comparison between subjects.

The patterns of contractile activity seen in the fed phase were examined visually. The tracings were examined by three observers in the following manner: One duodenal lead was examined. Each contraction was defined as consisting of less than 3 peaks, 3–5 peaks, 6–10 peaks, and more than 10 peaks. A cluster was defined as being one unit with repetitive peaks if the interval between peaks was equal to or less than the interval between peaks seen in phase III of the fasted pattern. It is assumed that the peaks in phase III represent the slow wave rate, as phase III consists of spiking and contraction on each slow wave. The distance of propagation of each cluster was determined. The cluster was said to have propagated if a contraction was seen in the subsequent lead within one interpeak interval as calculated from phase III.

The duration of the phases of the fasted pattern were compared using an analysis of variance. The duration, the motility indices of the fed patterns, and the proportion of different types of contractions and the distances propagated by different clusters of contractions following the three meals were compared using an analysis of variance. Statistics were conducted using the CLINFO system. The study was approved by the Committee on Studies Using Human Beings at the University of Pennsylvania on February 20, 1986. Radiation exposure is less than 2% of the dose limit acceptable to the general population by the National Commission on Radiation Protection.

RESULTS

Fasting Motility Patterns

A total of 58 interMMC intervals were analyzed using the recording from the most proximal duodenal lead. Marked intra- and intersubject variability was noted (Table 1). Even within one study, variations in interMMC intervals of 40 min to 215 min could be seen (subject 2). Phase III demonstrated the least variability, while marked variability was seen in phases I and II (ranges of 6–79 and 2–203 min, respectively) (Table 1). Similar variability was seen when the phases were examined as a percentage of the cycle duration (Figure 2). The variability of the duration of the components of the MMC did not allow for the demonstration of any differences between subjects.

The rate of contraction during the phase III for each subject was calculated for the duodenum and jejunum. Duodenal contractions occur at 11.3 ± 0.09/min (mean ± SEM) and jejunal contractions 32 cm distally at 10.73 ± 0.15/min (P = 0.002). The rate of progression of the junction of phase II and phase III was 0.14 ± 0.015 cm/sec. The duration of

TABLE 1. DURATION OF PHASES OF FASTED PATTERN IN 6 SUBJECTS

	Duration (min)						
	Subject 1	*Subject 2*	*Subject 3*	*Subject 4*	*Subject 5*	*Subject 6*	*Overall*
Phase 1							
Mean ± SEM	37.9 ± 6.6	27.0 ± 2.9	38.6 ± 5.9	38.4 ± 6.2	56.4 ± 11.4	59.1 ± 13.7	37.7 ± 2.9
Range	6.0 – 65	13.3 – 46.3	14.0 – 63.7	13.5 – 65.3	28.6 – 72.5	39.6 – 78.6	6.0 – 78.6
Phase II							
Mean ± SEM	45.0 ± 5.7	48.1 ± 13.7	59.4 ± 8.1	56.2 ± 17.9	13.4 ± 0.6	39.2 ± 12.2	50.2 ± 5.9
Range	9.9 – 71.3	4.9 – 173	34.2 – 108	2.0 – 203.8	8.9 – 21.2	21.9 – 56.5	2.0 – 203
Phase III							
Mean ± SEM	4.5 ± 0.4	5.4 ± 0.3	7.9 ± 0.8	4.2 ± 0.3	4.3 ± 0.8	6.5 ± 1.1	5.3 ± 0.3
Range	2.6 – 8.3	4.4 – 7.7	3.3 – 11.9	2.3 – 6.2	2.7 – 6.2	5.0 – 8.0	2.4 – 11.9

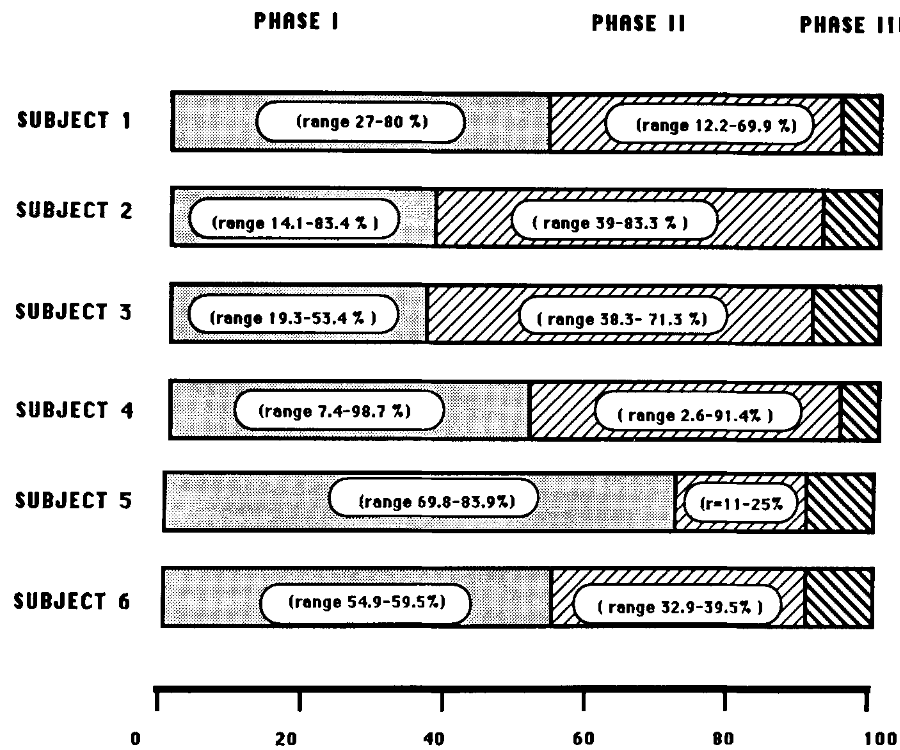


Fig 2. Phases I, II, and III as percentages of the total interMMC interval for each of six subjects. The mean of the duration of each phase as a percentage of the total interMMC interval is shown as a horizontal bar with range for each phase written over the bar representing that phase.

phase III is longer in the jejunum than the duodenum. No differences in rates of contraction or rate of progression of the phase III contraction was seen between subjects. Within one study, the rate of progression of the onset of phase III could be quite variable for each individual with ranges between 0.05 and 0.17 cm/sec. The rate of progression of the end of phase III was similarly variable.

Phase II of the interMMC interval was quite variable, both in types of contractions and duration, as shown in Table 1 and Figure 2. The characteristics of phase II were variable within a study and between patients. In general, activity in phase II was initially greater in the duodenum than the jejunum. This was characterized as single contractile peaks which were often propagated over three to eight leads. Later, clusters of contractile peaks were seen, more often in the jejunum than in the duodenum, although propagated repeated peaks often originated in the duodenum. Most multiple peaks were propagated over shorter distances than the duodenal single peaked contractions. As phase III approached, in several subjects, prolonged clusters lasting 2 min or more and occurring at the same rates as seen in phase III were seen in the jejunum. These contractions were sometimes seen in one jejunal lead, followed by the more proximal lead and then recurred in the original site. Phase III usually started within 10 min of such bursts being seen and usually originated in the duodenum.

Propagated contractions in the duodenum could be divided into propagated single peaks and propagated multiple peaks. The single peaks were propagated either at 2–4 cm/sec or, less commonly, very rapidly, at rates up to 16 cm/sec (Figure 3A). Clusters or propagated multiple peaks were propagated at a slower rate, between 0.3 and 2.3 cm/sec. These clustered contractions could be divided into those lasting less than 1 min (Figure 3B) and those lasting greater than 1 min (Figure 3C). Clustered peaks were often repeated with about a 2-min interval between, the so-called minute rhythm (Figure 3C). The prolonged repetitive contractions seen in the jejunum prior to phase III was propagated at about 0.04 cm/sec, similar to the true phase III, which was defined as a prolonged repetitive contraction propagated over all distal leads. Thus single propagated peaks were propagated more rapidly than multiple propagated contractions, which in turn were propagated more rapidly than the

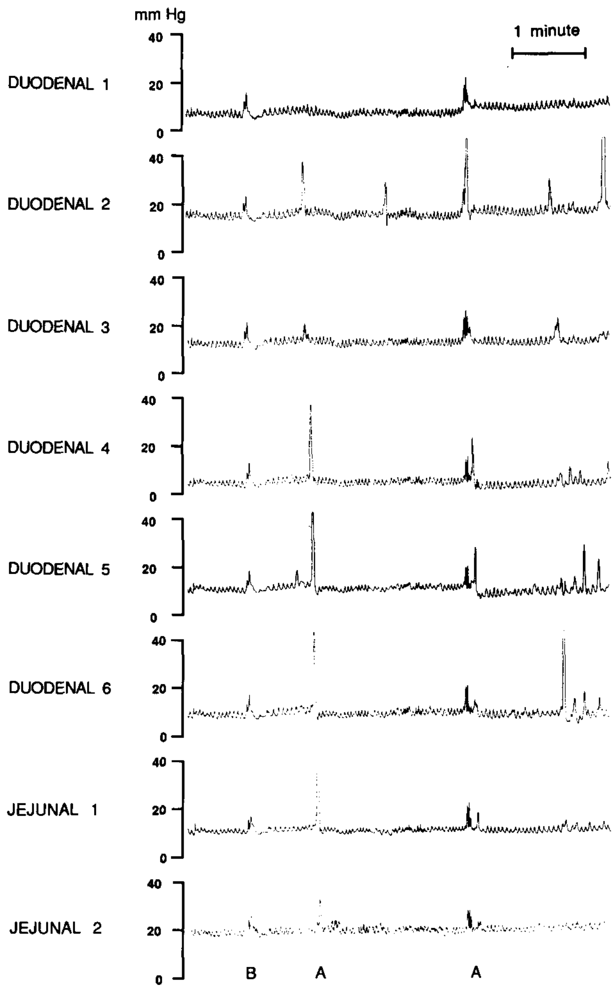


Fig 3. (A) Examples of propagated single contractions during phase II of the fasted pattern. Propagated single contractions were propagated at a velocity of 2–4 cm/sec (A) or as ultrarapid rushes, at up to 16 cm/sec (B). (B) Example of a propagated multiple contraction (C) lasting less than 1 min. (C) Example of propagated multiple contractions (D) lasting greater than 1 min. These propagated contractions were recurrent and separated by intervals of quiescence lasting 1–2 min, the minute rhythm (E).

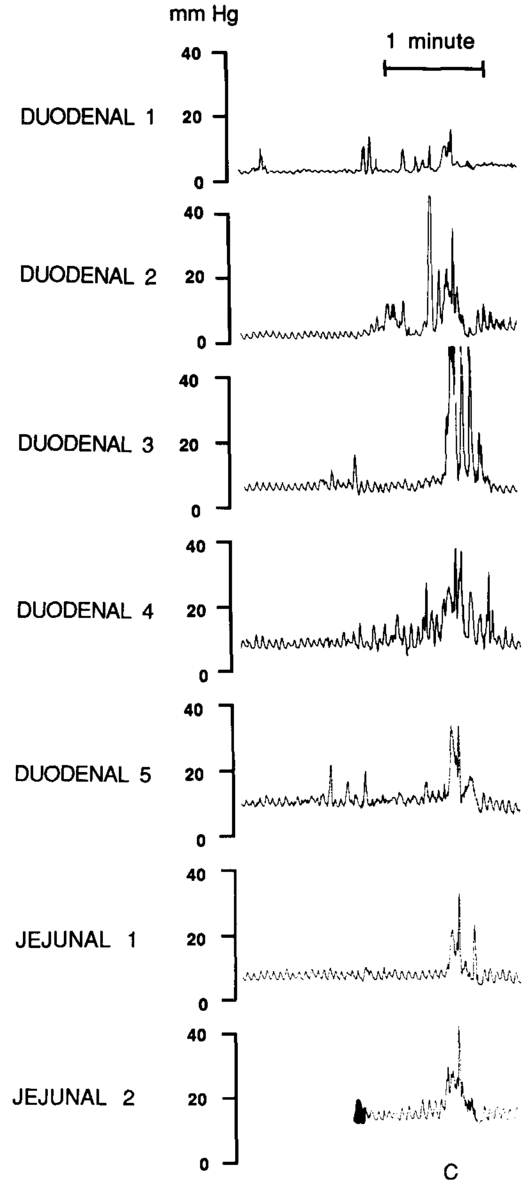


Fig 3. Continued.

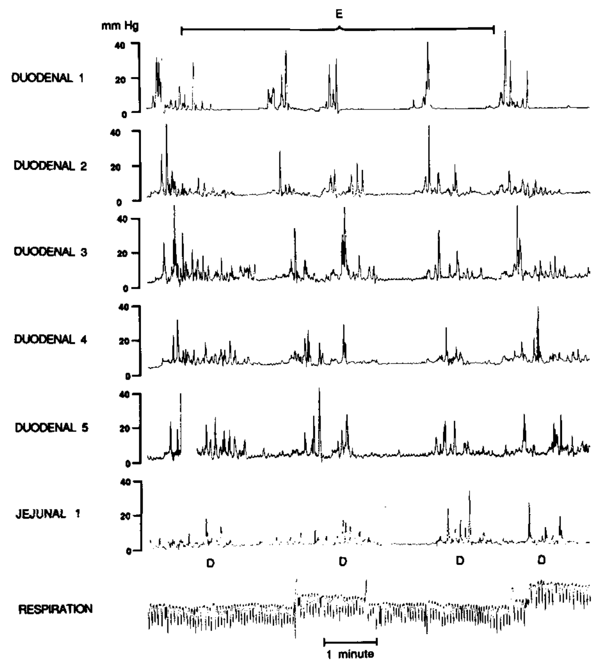
prolonged propagated peaks, characterizing phase III.

Fed Pattern

Several characteristics of the fed pattern were examined: (1) the duration of the fed pattern, (2) the motility index, and (3) the types of contractile patterns seen during the fed pattern. The correlation of each of these features with the caloric content of the meal was examined.

Duration of Fed Pattern. The duration of the fed pattern was associated with the caloric content of the meal. The duration of the fed pattern following the 150-kcal, 300-kcal, and 600-kcal meals were 177 ± 28 min, 359 ± 65 min, and 411 ± 29 min, respectively. The duration of the fed pattern after the 300- and 600-kcal meals were not significantly different, but both resulted in a significantly longer fed pattern than following a 150-kcal meal ($P < 0.05$)

Motility Index. The motility index (MI) was calculated for the enitre fed period. Since there was variability in the duration of the fed period, the motility index was normalized by dividing the total motility index by the duration of the fed pattern. No correlation was seen between the caloric content of



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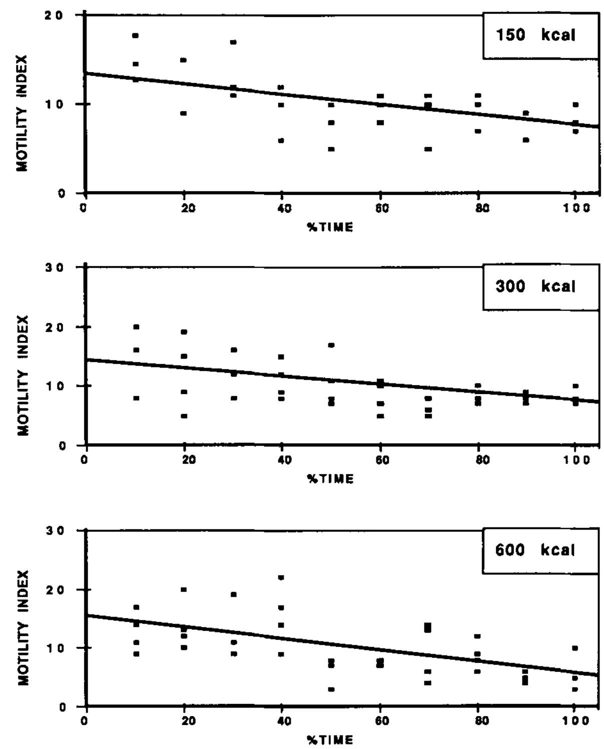

Fig 4. Change in motility index (mm Hg × sec) over the duration of meals of three different caloric contents (150, 300, and 600 kcal). The duration is normalized by dividing the total duration of the fed period in 10 equal portions. The motility index is negatively correlated with the duration of the fed period. There is no difference in the correlation coefficient for each of the three meals.

the meal and either the total motility index or the normalized motility index (total MI/time). The normalized motility indices for the 150-kcal meal, the 300-kcal meal, and the 600-kcal meal were 253 ± 113 mm Hg × sec/min, 116 ± 45 mm Hg × sec/min, and 142 ± 42 mm Hg × sec/min, respectively ($P > 0.05$). Following each meal, however, the motility index demonstrated a significant inverse relationship with time (Figure 4). The correlation coefficients between the motility index and time for the 150-kcal, 300-kcal, and 600-kcal meal were 0.565 ($P < 0.001$), 0.547 ($P < 0.0001$), and 0.575 ($P < 0.0001$), respectively. No differences in this relationship were seen between meals of different caloric value.

Contractile Patterns. The types of contraction seen during the fed pattern were analyzed (Figure 5). The fed pattern and the pattern seen during phase II were similar. Most of the contractile peaks seen appeared propagated at least over a short distance, with 10% of contractile peaks propagated over the entire length of the intestine that was examined and 47% propagated over at least 16 cm. The contractions were arbitrarily evaluated in groups depending on number of peaks occurring in any cluster. No statistical difference was seen between the distribution of the clusters of contractions following the different meals (Figure 6). In addition, if one looked at the likelihood of propagation of the different clusters, no difference was seen. Clustered peaks (greater than 3 peaks per cluster) comprised 28% of contractions seen, and of these, 63% propagated over more than 16 cm.

DISCUSSION

A method to examine the fed pattern is described in this paper. We examined this pattern to determine any correlation between the amount of contractile activity, as measured as a motility index, and the caloric intake. The duration of the fed pattern is related to caloric content of a meal. This has significance for the absorption of enteric-coated capsules, which may depend on the MMC to empty them from the stomach (12, 13). Interestingly, the characteristics of the fed pattern are not related to the caloric intake. Propagated contractions are common; 46% of the contractions seen after meals were propagated, indicating that this pattern is not a marker of disease as previously suggested (7). In studies in dogs and monkeys, there is evidence that

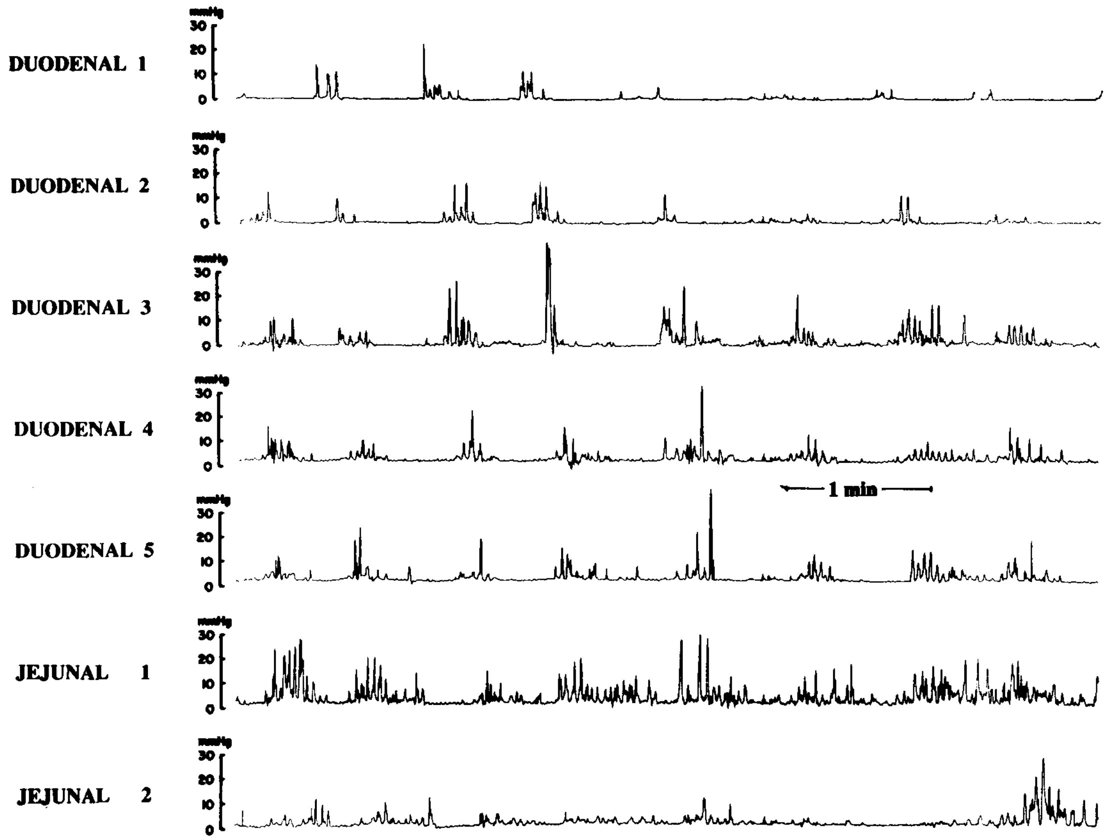

Fig 5. Tracing showing the fed pattern in one subject

the food constituent and the fiber content can alter patterns of contraction (10, 11, 14). The relationship to the food constituents is complex. Although fat, carbohydrate, and protein affect the duration of the fed state in a particular order, the effect on the motility index, which reflects the amount of contractile activity, is not correlated in the same order (10). In man, it not possible to keep constant all potential variables in a meal except one. In this study we chose to maintain the relationship between the fat, carbohydrate, and protein content of the meal, maintaining the relative contribution of the constituents and the volume ingested. Gastric emptying may affect the duration of the fed pattern and giving the meal by duodenal intubation would eliminate this factor. This study, however, was designed to examine the normal pattern of motility that might be seen in healthy volunteers and normal ingestion of a meal was felt to be the most physiologic.

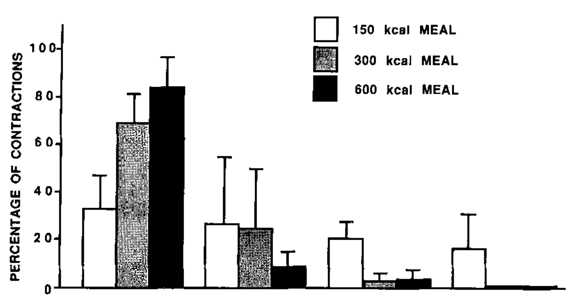

Fig 6. Distribution of the different clusters of contractions seen in the fed pattern following 150-kcal, 300-kcal, and 600-kcal meals. No difference in distribution is seen between the three meals.

The change in the motility index over time during the fed phase has not been previously examined. In our studies, the motility index is correlated with the fed pattern in that it decreases throughout the duration of the fed pattern. In absolute terms, however, it is not possible to determine a threshold level of activity at which the phase III reappears. No difference is seen in the motility index response following the meals of different caloric contents. The 150-kcal meal may therefore be the most most useful to examine the response of the small intestine in disease states as it induces the shortest duration of fed pattern without altering the character of the fed pattern.

TABLE 2. COMPARISON OF MOTOR AND MYOELECTRIC PATTERNS DURING PHASE 2

Myoelectric description	*Rate of propagation (cm/sec)*	*Manometric description*	*Rate of propagation (cm/sec)*
		Single propagated peaks	
Single propagated spikes (SPSB)	2.6 ± 0.1	Slow single propagated peak	2–4
Ultrarapid single spike bursts (URSSB)	16.3 ± 0.8	Rapid single propagated peak	16
		Multiple propagated peaks	
Migrating action potential complex (MAPC)	similar to RBAP		
Repetitive bursts of action potentials (RBAP)	1.9 ± 0.3	Duration of less than 1 min	0.3–2.3
Migrating clusters of repetitive spike bursts (MRCSB)	0.9 ± 0.05	Duration of greater than 1 min	0.3–2.3

Abnormalities in fasting small bowel motor patterns have been described in bacterial overgrowth, the short bowel syndrome, advanced scleroderma, intestinal pseudoobstruction, and the irritable bowel syndrome (5, 6, 15–23). The marked intra- and intersubject variability in man described here and by others suggests that true abnormalities in the fasting pattern will only be recognizable if they are extreme (1, 3, 4, 7). This variability is in contrast to the regularity of these patterns in the dog (24).

We have examined the patterns of contraction during the phase II of the fasted pattern. Coremans has described a number of myoelectric patterns in the phase II when recorded in subjects using a suction electrode catheter (4). We describe contractile patterns that appear to be equivalents of these myoelectric patterns (Table 2). Propagated contractile activity (propagated over at least 20 cm) can be divided into propagated single peaks and propagated multiple peaks. The propagated single peaks fall into two groups, those propagating at between 2 and 4 cm/sec and those propagating at rates close to 16 cm/sec (Figure 3A). Propagated multiple peaks can be divided into those with a duration of less than 1 min, but having more than one peak (Figure 3B), and those lasting more than 1 min (Figure 3C). In addition, the minute rhythm was noted (Figure 3C). As the migrating action potential complex is rare in healthy subjects, the propagated multiple peaks seen are probably equivalents of the myoelectric pattern of repetitive bursts of action potentials described by Coremans (4). Propagated single contractions are propagated more rapidly than the multiple contractions, which in turn are propagated more rapidly than the phase III of the interMMC. Different mechanisms may exist to control the progression of these different patterns. Such patterns may not be distinguishable if recording points are distant from each other, as it becomes difficult to prove that contractions seen at adjacent leads are truly propagated. In animal models, altered patterns of contraction with propagated spike bursts have been described in response to cholera enterotoxin and toxigenic *Escherichia coli* (25–27). The clinical significance of the phase II patterns in man will only become clear if detailed analysis is performed in both healthy and diseased states but may prove to be a more sensitive marker of diseases than the duration of the major phases.

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