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Digital Ambulatory Manometry of the Small Intestine in Healthy Adults

Estimates of Variation Within and Between Individuals and Statistical Management of Incomplete MMC Periods

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A new technique for ambulatory manometry of the small intestine with digital storage of signals is presented. Postprandial motility after a 1700-kJ meal and nighttime fasting motility were recorded in 19 healthy young adults. A comprehensive statistical approach was worked out to illuminate the statistical properties of fasting motility data from long-term studies. Separate quantifications of the variation within and between individuals are presented for the migrating motor complex (MMC). The overall mean for the MMC period was 107 min, with incomplete periods included as censored data. Standard deviation within individuals was 49 min, and standard deviation between individuals 16 min. Presented in the same manner, phase III in the proximal jejunum lasted 5.3 min, with standard deviations of 1.5 and 1.1 min, respectively. The propagation velocity of phase III in the distal duodenum was 10.8 cm/min, with standard deviations of 3.7 and 4.1 cm/min, respectively. Fed-state lasted 324 ± 110 min (mean ± SD), and adjusted fed-state, an alternative definition proposed in this study, 290 ± 80 min. This variance component model, extended to handle censored data, provides a useful statistical approach for the analyses of the MMC. The MMC period proved to be less suitable for quantitative comparisons because of dominating intraindividual variance. Comparisons presented indicate that discrepancies in reference values depend, to a great extent, on the statistical methods applied.

KEY WORDS: ambulatory recording; computer program; manometry; small intestine motility; statistical analysis.

The cyclic pattern of muscular contractions in the small intestine during the fasting state, the migrating motor complex (MMC), has been considered the "housekeeper" because of the propulsive properties of phase III (1, 2). This phenomenon has been thoroughly reviewed by others (3–6). Meal induce a pattern of irregular contractions for a period depending on caloric and osmotic load (7, 8). Most manometric studies of the small intestine have entailed the application of open-tip perfused catheters with low-compliance systems (9). Because of patient compliance and the technical and personal requirements involved, fasting examinations have commonly been confined to a few hours, often one complete MMC period.

Ambulatory techniques have been developed lately for long-term studies. Portable tape recorders have been used to sample analog signals from

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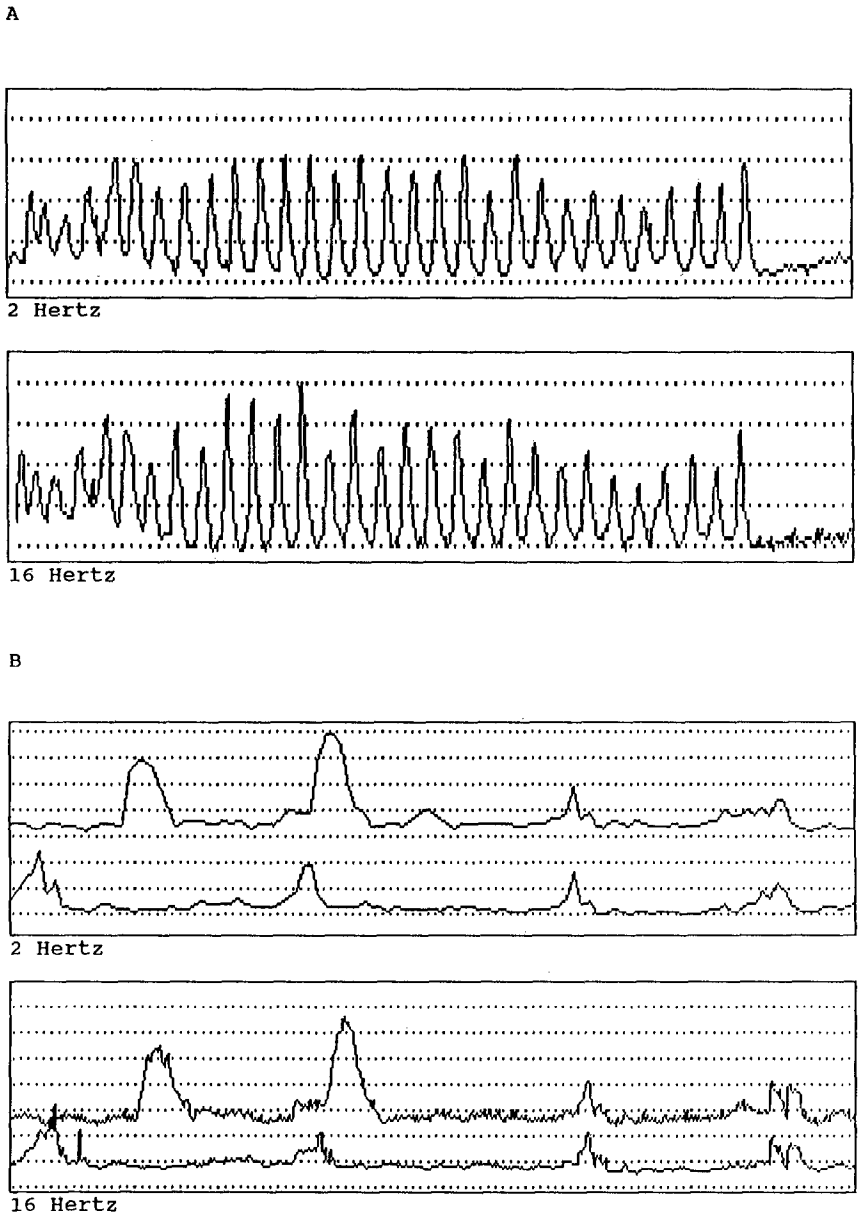

Fig 1. Intraluminal pressures recorded by pairs of oppositely located transducers placed in the antrum and distal duodenum of a healthy individual. The transducers in each pair were sampled at 2 and 16 Hz, respectively. Sampling frequency is given below each box. Small deflections of baseline between peaks within the range of 5 mm Hg represent noise. (A) The upper two boxes: phase III of the MMC recorded in the distal duodenum, lasting 2.6 min. Vertical scale: distance between dotted lines in 20 mm Hg. Horizontal scale: distance between dots is 2 sec. (B) The lower boxes: fed pattern. In each box the lower curve represents gastric antrum and the upper curve distal duodenum. The two peaks to the left represent phasic contractions, while the two to the right show artifacts. Vertical scale: distance between dotted lines is 10 mm Hg. Horizontal scale: distance between dots is 1 sec.

radio pills (10) and catheters with microtip transducers (11). A similar ability to detect phasic events has been proved for microtip-transducers compared with open-tip perfused catheters (12). Portable units for storage of digital signals are now available. We have set up a new ambulatory technique for small intestine manometry, with microtip transducers and a portable digital memory (13).

Incomplete MMC periods will ordinarily occur in fasting motility records. If the incomplete peri-

ods are ignored, a biased estimate for the MMC period may result. To solve this problem we have used a statistical method for censored data.

Great variation, within and between individuals, has been observed for MMC in humans (11, 14–18), but quantitative estimates of these components of variance have not been given. The fasting motility parameters often have been calculated by a mean value for each individual (19) or by the pooling of data (14). We present a more appropriate statistical approach for the cyclic events encountered in long-term fasting motility records, including separate determination of the variance within and between individuals.

The aims of the study were to test this new digital ambulatory technique in healthy adults and to obtain more informative estimates for the MMC in humans.

MATERIALS AND METHODS

Digital Recording System

Two strain-gauge sensors (16CT/S/L2-2), with a stated maximum linearity error of ±0.2% and a maximum hysteresis error of 0.5%, were placed 15 cm apart on a flexible silicone-covered 3-mm-diameter catheter (Gaeltec Ltd., Isle of Skye, Scotland). This was a practical compromise for recognition of pressure patterns. The sensors were spaced too far apart to permit propagation analysis of single contractions (20). An air-channel through the catheter allowed inflation of a rubber balloon at the tip to facilitate the movement through the small intestine. The catheter was connected to a small portable lightweight unit serving as a power supply, preamplifier, analog-to-digital converter, and memory for two channels, with a total storage capacity of 198 kilobytes (Synectics AB, Stockholm, Sweden). The sampling frequency can be preset at fixed values between 1/32 and 1024 Hz. At 2 Hz, pressures can be recorded continuously from both sensors for 13.6 hr. An event marker allowed localization of events on the record by the test subject. Data were transferred to a PC AT computer without any reduction. The pressure curves were displayed and printed by Motilitygram 1.97 (Synectics AB).

Equipment Tests

Drift and Noise. The catheter was submerged in 13.6 cm of water with a temperature of 37° C, after 2 hr calibration in water at 20° C. The sampling frequency was preset at 2 Hz, and six full time registrations were performed.

Sampling Frequency. A 37-year-old healthy male was examined in the morning, after an overnight fast. Two identical catheters were anchored together by sutures, with the proximal and distal sensors opposite each other, and with separate portable memory units. The sampling frequencies were preset at 2 and 16 Hz, respectively. The sensors were placed in the antrum and the distal duodenum, controlled by fluoroscopy. Phases I, II, and III of fasting activity and fed pattern after a light meal were recorded.

Phase III was analyzed both manually and by computer (Motilitygram version 1.97, Synectics AB). In the computer analysis the fixed baseline was placed at the lower limit of deflections during phase III (Figure 1A). Amplitude threshold was set at 5 mm Hg, according to the noise level detected in the water bath. Minimum duration threshold for a phasic event was set at 2.5 sec. In the manual analysis, the amplitude was measured from the minimum pressure immediately before rise in pressure to peak.

Investigation of Healthy Adults

Subjects. Nineteen healthy individuals (15 males and 4 females) with median age 26 years (range 22–50) were examined. Weights for females were median 65.5 kg (range 65–67) and for males median 77.5 kg (range 64–90). Seventeen were nonsmokers. All gave their informed consent. The study was approved by the local ethics committee.

Protocol. On the examination day, the test subjects fasted after a light breakfast before 8 AM. They were allowed to drink water *ad libitum*. At 1 PM the catheter, after calibration in water at room temperature for 2 hr, was introduced transnasally after 4% lidocaine aerosol to the nose and throat. Sampling position with the distal sensor in the proximal jejunum at the ligament of Treitz was confirmed by fluoroscopy. The proximal sensor was then always located in duodenum, usually in the middle or distal part. Time spent from intubation of the nose to final position was noted. The sampling frequency was set at 2 Hz, which reliably identified phasic events during the equipment test. They left the hospital between 2 and 4 PM. At 5:45 PM the portable unit was switched on, and at 6 PM they had the standardized mixed meal consisting of two slices of coarse-grained bread with soya margarine, jam, cheese, and 200 ml orange juice. This mixed solid–liquid meal provided 1700 kJ in the proportions: fat 20%, carbohydrate 68%, and protein 12%.

All were requested to press the event marker at the start of the standardized meal, when going to bed and waking up, and immediately before performing three sit-ups. Each subject kept a diary of the type and time of events located. They went to bed at 10–11 PM and set their alarm clocks for 6:30 AM the next morning. At 7:25 AM, after 13.6 hr of continuous registration, the memory was completed. They returned to the hospital, and the catheter was removed after fluoroscopically checking the location. Data were missing from the proximal sensor in three subjects and from the distal sensor in two subjects, because of weakness in a connecting cable. Altogether, 260 hr of continuous pressure registration from the proximal small intestine was obtained.

Each subject estimated the time elapsed from going to bed to falling asleep, according to three alternatives: 0–30, 30–90, or more than 90 min. The quality of sleep was evaluated by a visual analog scale from 0 to 100%. One hundred percent corresponded to a "normal" night for the individual. Duration as well as the subjective

experience of the quality of sleep were included in this score.

Definitions and Data Analyses. The motility patterns were recognized visually. A phasic event was defined as an increase of pressure exceeding baseline pressure for each peak by more than 5 mm Hg (noise level), lasting more than 2.5 and less than 10 sec. Baseline pressure for each peak was defined as the minimum pressure immediately before rise in pressure. Sit-ups always involved simultaneous increase of pressure at both sensors with similar amplitude and identical duration. Such pressure events were regarded as artifacts.

Phase III was defined as contractions at a regular frequency of 10–12/min (slow-wave frequency) at the proximal sensor propagated to the distal sensor or at the distal sensor only, followed by quiescence. A minimum duration of 2 min was required at the distal sensor.

The interval between consecutive phase IIIs at the distal sensor was divided into 10-min periods. Complete quiescence or less than three single contractions within such periods was considered as phase I activity (19). Phase II activity was defined as three phasic contractions or more.

The MMC period was taken as the time interval between termination of phase III of consecutive periods at the distal sensor (16). An incomplete MMC period was defined as the time interval between termination of the last observed phase III and the end of the recording at the distal sensor.

Propagation velocity was defined as the distance between the two sensors divided by the time interval between the onset of phase III at the two sensors. Calculated length was defined as the duration of each phase III at the distal sensor multiplied by the propagation velocity.

Fed state was calculated as the time from commencement of the meal to the return of phase III in the small intestine (15). Adjusted fed state was calculated from the commencement of the meal to the return of phase III, or phase I if such activity preceded the first-appearing phase III. The stated definition for phase I activity was applied.

Phase III-like activity during fed-state was defined as regular contractions at the slow-wave frequency lasting more than 1 min, occurring more than 5 min after intake of the meal.

Statistical Analyses

Summary values are given as means ± 1 SD, unless otherwise stated. Comparisons of means are carried out either by a two-sample or a matched-pair Student's t test. The influence of phase I and phase III-like activity on the duration of fed state is tested by multiple regression. Correlation techniques are used.

The MMC parameters are analyzed by a variance component model (21). This means that each parameter value Y_{ij}, i denoting the individual and j numbering the observations for a given individual, is modeled on the following equation: $Y_{ij} = \mu + X_i + e_{ij}$. Here μ is the overall mean, X_i and e_{ij} are normally distributed with mean zero and standard deviations σ_b and σ_w, respectively. The quantity X_i models the variation between individuals, while e_{ij} models the variation within individuals.

TABLE 1. COMPUTER ANALYSIS OF PHASE III RECORDED SIMULTANEOUSLY AT 2 AND 16 Hz*

	16 Hz	*2 Hz*	*2/16 Hz (%)*
Phasic events (number)	24	24	100
Mean duration of phasic events (sec)	4.8	4.9	102
Mean amplitude (mm Hg)	49	44	90
Maximum amplitude	80	58	73
Phasic events ≥ 50 mm Hg (number)	16	13	81
Phasic events ≥ 60 mm Hg (number)	10	0	0
Area under the curve (sec mm Hg)	3078	2862	93

*The phase III recorded in the equipment test, shown in Figure 1.

Estimation is performed by maximum likelihood (22). The estimate of μ is denoted m, while those of σ_b and σ_w are denoted s_b and s_w, respectively. The quantities s_b^2 and s_w^2 are called variance components between and within individuals, respectively. Summing up these quantities and taking the square root produces the standard deviation, s, of a single observation.

In the analysis of the MMC periods, the variance component model was extended to take care of censored periods at the end of the observation interval. This was done by appropriate modification of the likelihood function (23).

RESULTS

Equipment Tests

Drift and Noise. A continuous signal was obtained from both sensors during all registrations in the water bath. Drift was 3.1 ± 2.6 mm Hg during 13.6 hr. Maximal observed drift within 30 min was 1 mm Hg. Noise was a constant phenomenon in both channels with an amplitude of maximum 5 mm Hg. Single spikes exceeding 5 mm Hg were occasionally seen, at a maximum four times during one registration. The duration of these spikes was always exactly 1 sec.

Sampling Frequency. The occurrence of phasic events was almost identical at 2 Hz and 16 Hz (Figure 1). As a rare exception, a phasic event was detected by only one of two oppositely located sensors, without preference for any of the sampling frequencies.

In the analysis of phase III, at both sampling frequencies the computer analysis identified 24 of the 30 phasic events shown in Figure 1A. The computer analysis of phasic events at 2 and 16 Hz is shown in Table 1. By manual analysis, mean amplitude was 44 mm Hg (range 18–62 mm Hg) at 2 Hz, and 49 mm Hg (range 23–80 mm Hg) at 16 Hz. The difference was statistically significant ($P < 0.005$).

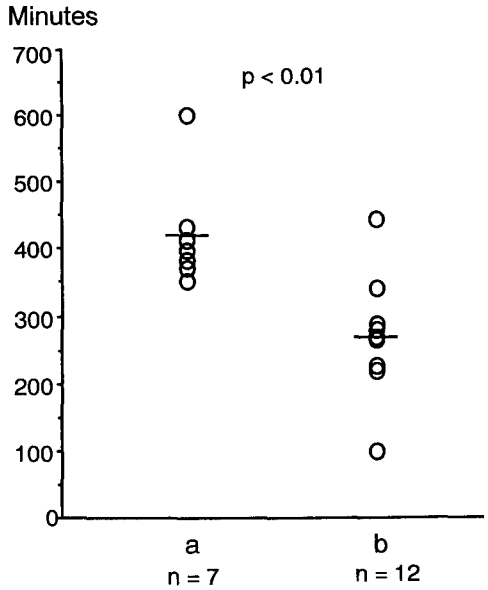

Fig 2. Duration of fed state is presented for two subgroups: (a) represents the seven individuals with phase I activity during fed state, and (b) the 12 individuals without phase I activity during fed state. Mean values are indicated by bars. *P* value for two-sample *t* test is given.

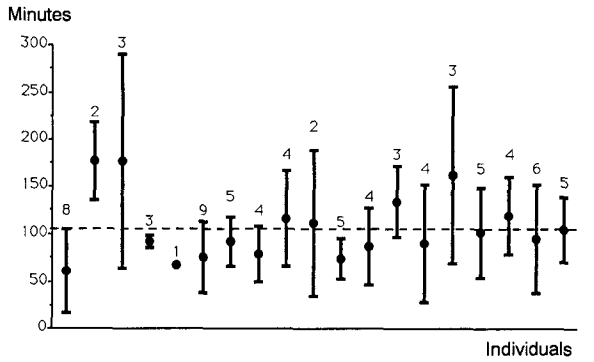

Fig 3. Duration of complete MMC periods is shown as mean ± 1 SD for each individual. Figures above the bars denote number of complete MMC periods recorded per individual. The dashed line represents the estimate for the overall mean (*m*), with incomplete periods included.

Small Intestine Motility in Healthy Adults

Compliance. Apart from short-lasting unpleasantness during intubation, the catheter was well tolerated. There were no complications or dropouts. The intubation time was 92 min (range 25–180 min), and positively correlated to the mean MMC period (only complete periods) for each individual ($r = 0.85$, $P < 0.001$). Sixteen of 19 individuals stated subjectively that they fell asleep within less than 30 min, the remaining three within 1.5 hr. Sleep quality was mean 88% (range 62–100%).

Fed State. The duration of fed state was 324 ± 110 min. The adjusted fed state lasted 290 ± 80 min. Phase I activity was observed within fed state in seven subjects, and their fed state lasted 422 ± 83 min, compared with 266 ± 80 min for the 12 without (Figure 2). This difference was statistically significant (*t* test, $P < 0.01$). Phase III-like activity was observed during fed-state in five individuals. Fifty-nine percent of the variation in the fed state could be explained by phase I and phase III-like activity during fed state (*F* test, $P < 0.001$).

Fasting State. The main results, based on the variance component model, are shown in Table 2.

The MMC period (Figure 3) lasted 107 min (*m*) with the incomplete periods included. The incomplete periods lasted a mean of 59 min (range 4–131 min). The shortest MMC period lasted 20 min, and the longest 288 min. The first MMC period after fed state lasted 126 ± 53 min and the second 99 ± 59 min. The difference was not statistically significant ($P = 0.09$). The MMC period lasted 100 ± 8 min (*m* ± SE), when the first period after fed state was left out.

Phase I amounted to 67% of the first, and 67% of the second MMC period after the fed state. A similar percentage of phase I activity was found also for later periods.

TABLE 2. MMC OF HEALTHY ADULTS IN PROXIMAL SMALL BOWEL*

	m (SE)	s (SE)	s_w (SE)	s_b (SE)	*Test* s_b	V_b (%)
MMC period (min)†	107 (7)	52 (4)	49 (4)	16 (9)	P = 0.24	10
Phase III duodenum (min)	4.6 (0.4)	2.5 (0.2)	2.1 (0.2)	1.3 (0.4)	P < 0.01	29
Phase III jejunum (min)	5.3 (0.3)	1.8 (0.2)	1.5 (0.1)	1.0 (0.3)	P < 0.01	32
Propagation velocity (cm/min)	10.8 (1.2)	5.6 (0.7)	3.74 (0.4)	4.1 (0.9)	P < 0.01	55
Calculated length (cm)†	53.9 (5.8)	28.3 (3.4)	20.7 (2.2)	19.2 (5.0)	P < 0.01	46

*m: Estimate of the overall mean; SE: standard error; s: standard deviation = $\sqrt{(s_w^2 + s_b^2)}$; s_w: standard deviation within individuals. s_b: standard variation between individuals; V_b (%): variance between individuals as percentage of the total variance = $s_b^2/(s_w^2 + s_b^2) \times 100$ %.
†Proximal jejunum.

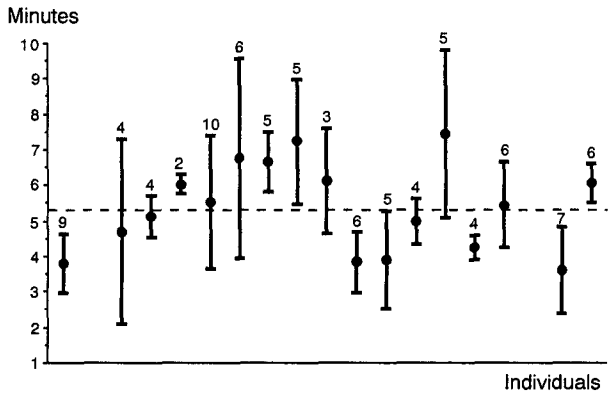

Fig 4. Duration of phase IIIs in the proximal jejunum is shown as mean ± 1 SD for each individual. Figures above the bars denote number of phase IIIs observed per individual. The dashed line represents the estimate for the overall mean (*m*).

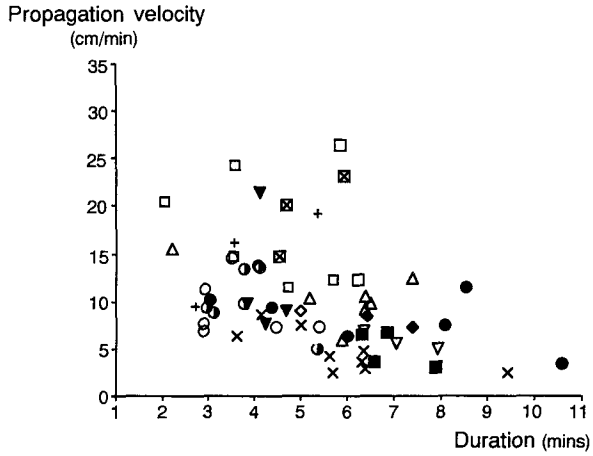

Fig 5. A scatter plot of propagation velocity versus duration of all phase IIIs recorded in the proximal jejunum is shown. Each symbol (△, etc) denotes observations in the same individual.

Ninety-nine phase IIIs were recorded, mean 5.2 (range 2–10) in each individual (Figure 4). Eleven phase IIIs (11%), in eight subjects, were recorded in the proximal jejunum only. Phase III lasted 4.6 min (*m*) in the distal duodenum and 5.3 min (*m*) in the proximal jejunum. The difference was significant ($P < 0.001$). The maximum duration of phase III was 13.2 min. Of the phase IIIs recorded in the proximal jejunum, 23% lasted less than 4 min and 11% less than 3 min.

Phase III migrated at 10.8 cm/min (*m*) (propagation velocity). The slowest phase III migrated at 2.5 cm/min, and the most rapid at 26.5 cm/min. Phase III appeared almost simultaneously at the proximal and distal sensor on two occasions in one individual, and at the distal sensor before the proximal sensor once in another individual. The calculated length was 53.9 cm (*m*).

The association between the propagation velocity and the duration of phase III is shown in Figure 5. As an unequal number of phase III was obtained for each individual, a variance component model for propagation velocity was applied, with duration of phase III in the proximal jejunum as covariate. A negative covariate coefficient, −0.50, was found for the duration of phase III, ($P < 0.01$), confirming the association shown in Figure 5.

DISCUSSION

How should the fasting parameters be estimated when an unequal number of MMCs was recorded for each individual? Our answer is a variance component model to avoid the statistical pitfalls and limitations associated with pooling data or using a mean value based on means for each individual. The variance component model is a standard statistical tool, and our purpose was to show its usefulness in the analysis of the fasting motility pattern. The inclusion of incomplete MMC periods as censored data is a methodological innovation, which extends the use of the variance component model.

In general, the variation within individuals was considerable for all parameters; however, a distinction was encountered. The variance within individuals for the MMC period came to 90% of the total variance (Table 2). Hence, the variance between individuals was not significant for the MMC period, as opposed to the other parameters. Therefore, only huge differences in the MMC period can be verified by statistical tests, even in long-term studies, if a realistic number of individuals are examined. The informative value of recording one single complete MMC period should therefore be questioned. Qualitative confirmation of MMC activity is obtained by one phase III only. Registration for at least 5 hr in the fasting state at night seems necessary to state absence of such activity, as the longest MMC period observed was 288 min. This concurs with Vantrappen, who states that 6 hr of fasting registration is sufficient (24).

We also calculated the MMC period by two statistical analyses commonly used in motility studies, and compared the outcome with the variance component model (Table 3). The estimate for the MMC period was too short when the pooling of data was applied, while a mean value based on means for each individual diverged only slightly from the variance component model. However, the standard

TABLE 3. MMC PERIOD CALCULATED BY THREE DIFFERENT STATISTICAL METHODS*

	Variance component		*Mean based on means‡*		*Median of pooled data‡*		
						Percentile	
MMC period (min)	m	s	*Mean*	SD	*Median*	*10th*	*90th*
Without incomplete periods	102	53	106	35	90	41	166
With incomplete periods	107	52	not possible			not possible	

*m: estimate for the overall mean; *s*: standard deviation for a random observation; SD: standard deviation for an individual mean value.
†Incomplete MMC periods are included as censored data.
‡Pitfalls are illuminated in the discussion section.

deviation obtained by the method based on means did not express the real dispersion of random observations.

The MMC period has been reported to last 108, 112, and 109 min in stationary manometry (15, 18, 19), and 66 and 85 min in long-term, ambulatory manometric studies (11, 14). Shorter MMC periods at night have been reported by Ritchie et al (25). The composition and timing of an evening meal also will influence nighttime motility, and reference to these conditions is necessary for comparisons. Our protocol corresponds to the study of Thompson et al (14). When we pooled all the complete MMC periods and used the median, as they did, the estimate for the MMC period was 90 min compared with 85 min in their study. The basic observations therefore seem to agree, and the discrepancy in results presented is due mainly to the statistical analyses applied. Individuals with short MMC periods will have more periods recorded during a certain interval. Therefore, pooling data will increase the influence of short periods. Remington et al (19) estimated the MMC period by a mean value (109 min) based on individual mean values. In the present study, this method of computation did not result in a great bias for the mean estimate (Table 3), but it requires complicated statistical analysis to derive standard deviation and standard error of the mean, as the individual means are based on a different number of MMC periods per individual.

The incomplete periods prolonged the overall estimate for the MMC period by approximately 5%, when included as censored data. If incomplete MMC periods are ignored, a reduced estimate will ensue as long periods are more prone to be cut off than short ones. In short-term recordings or if the MMC periods are prolonged, the influence of incomplete MMC periods will obviously be more dominant.

The first MMC period after the meal, which should be regarded as a nighttime period because of the dominant influence of phase I activity, tended to last longer than the second period, as earlier presented (26). Unabsorbed materials in the lumen, still present during the first MMC period after the meal (27), may have exerted some inhibitory effect on the fasting motility. The estimate for the MMC period without this first period was 100 min. The relationship to the last meal should therefore be considered when MMC periods are evaluated.

For the other parameters of the MMC, the variance between individuals turned out statistically significant, because of a less dominant variation within individuals (Table 2). The same line of argument, already presented, favors the variance component model for these calculations, too. The duration of phase III in duodenum (4.6 min) agrees with Vantrappen et al (18) and Gill et al (11), while Kellow et al (15) reported mean 8.7 min. Phase III was more variable in the duodenum than in the proximal jejunum. Standard deviation was 53% and 40%, respectively, of the overall mean. This emphasizes the proximal jejunum as a suitable sensor position. The higher frequency and longer duration of phase III in the proximal jejunum compared with the horizontal part of duodenum has previously been shown (15, 18).

The propagation velocity of phase III (10.8 cm/min) in the present study was considerably higher than reported by Kumar et al (2.9 cm/min, median of pooled data) at the ligament of Treitz at night (28). The more proximal location of the sensors in our study may explain this difference, as the propagation velocity of contractions during phase III has been shown to increase in the distal duodenum and gradually decrease from the proximal jejunum in aboral direction (15, 29). Possibly, the pooling of data may have biased the estimate in their study (28). During daytime, propagation velocity in the duodenum has been reported to be 6.4, 7.7, and 21.9 cm/min (18, 28, 30). Fleckenstein found the propagation velocity in the duodenum twice as fast as in

the proximal jejunum by myoelectric registration in humans (31). We found that short-lasting phase IIIs propagated somewhat faster than long-lasting ones, a negative correlation also shown by Larsen and Osnes (32). The defined minimum duration of phase III will therefore influence the estimate for the propagation velocity. Single retrograde and apparently simultaneous phase III complexes, known as features of disease (33), may occur in healthy adults, too, at this location. With only two sensors, however, we cannot exclude initiation of independent phase IIIs at two levels.

Calculated length (53.9 cm) was longer than that found by Fleckenstein (31) (35 cm) and Vantrappen et al (18) (34.2 cm). These differences may be explained by the greater propagation velocity in our study, and possibly, to some extent, by the statistical methods applied.

The duration of fed state accords with previous studies using meals with similar caloric content (8, 14). The first phase III after fed state, which determines the duration of fed state, almost invariably starts in the small intestine, often distal to the ligament of Treitz (15, 27). With the most distal sensor in the proximal jejunum, the first phase III after the fed state may have been missed in some individuals. Our estimate may therefore be too high. We found that phase I activity was a major contributor to a long-lasting fed state (Figure 2). When the return of either phase III or phase I was used to define the termination of the fed state, a somewhat shorter estimate with less variation between individuals was obtained. It is tempting to assume that fasting motility can return as any of its three phases, depending on the biorhythm of the enteric nervous system. As phase I activity is a fasting motility pattern, we propose the adjusted fed state as a more specific estimate for duration of motor activity induced by a meal.

The presence of phase III more than a few and less than 90 min after the start of the meal is regarded as an abnormality (33). Phase III-like activity occurred during the fed state in some healthy adults in this study. These temporary elements of fasting activity during the fed state were associated with postponed return of the first phase III.

Intubation and accomplishment were more convenient than expected. The discomfort of ambulatory examinations of this kind is limited, as demonstrated by the preserved quality of sleep.

The technical quality of the equipment was good, and drift and noise were stable and within acceptable limits. A fixed baseline, adjustable for present intervals, was applied in this software. Therefore, the computer analysis ignored the phasic events superimposed on the tonic component of the phase III shown in Figure 1A. Tonic contractions, baseline shift, and artifacts make automatic baseline correction and recognition of artifacts a prerequisite for computer analysis in small intestine manometry.

The equipment test confirmed 2 Hz as sufficient sampling frequency for reliable recognition of phasic events and, hence, identification of motility patterns. However, the mean amplitude of phasic events during phase III was reduced by 10% at 2 Hz compared with 16 Hz, a dampening effect especially on the high amplitude pressure peaks. Underestimation of the mean amplitude and the area under the curve and reduction of high-amplitude peaks, in particular, are possible biases when intraluminal pressure is recorded at a sampling frequency of 2 Hz.

Even if computerization is not a prerequisite for analysis of the motility patterns in the small intestine, this technology provides advances in recording, processing, and storage of data. In anticipation of computerized systems able to perform detailed and accurate analyses of single phasic events, it is a good idea to store data from consecutive manometric studies in the digital form without reductions.

The statistical analyses and comparisons performed indicate that discrepancies in estimates for the MMC between studies, apart from random variation and diverging protocols, depend on the statistical methods applied. As presented here, the variance component model extended to handle incomplete MMC periods provides a useful statistical approach for the analysis of the MMC. The considerable intraindividual variation renders the MMC period less useful as a quantitative parameter and requires long-term recording to obtain informative estimates for the MMC.

The digital ambulatory technique presented is suitable for ambulatory long-term manometry of the small intestine.

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