

How do fiber-supplemented formulas affect antroduodenal motility during enteral nutrition? A comparative study between mixed and insoluble fibers^{1,2}

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ABSTRACT

Background: Fiber supplementation during enteral nutrition has been recommended, but the effect of soluble compared with insoluble fiber supplements on antroduodenal motility is unknown.

Objective: The objective of this study was to compare antroduodenal motor patterns in 8 healthy volunteers during and after gastric infusion of 3 different diets: a fiber-free diet, an insoluble-fiber diet, and a mixed-fiber diet (50% soluble fiber and 50% insoluble fiber).

Design: Manometric studies with the 3 different diets (2100 kJ) were performed in random order. Antroduodenal motility was monitored continuously for 6 h by using a pneumohydraulic system to calculate the number, amplitude, and duration of the pressure waves; the area under the curve (AUC); and the percentage of time occupied by motor activity before, during, and after each type of infusion. Variations in antral areas were measured by ultrasonography.

Results: The gastric motor response was significantly higher, whatever the diet, in the distal antral recording site than in the 2 more proximal sites. In the proximal but not the distal antrum, the number of waves, the AUC, and the percentage of time occupied by motor activity were higher ($P < 0.04$) with the mixed-fiber than with the insoluble-fiber diet. No significant differences in variations of antral area were observed among the 3 diets. In the duodenum, motor variables were not significantly different among the 3 diets.

Conclusions: A gastric infusion induced a greater motor response in the distal than in the proximal antrum. A mixed-fiber diet was associated with significantly greater proximal antral motility than was an insoluble-fiber diet. There was no significant difference among the 3 formulas in duodenal motor variables or in variations in antral area as measured by ultrasound. *Am J Clin Nutr* 2000;72:1040–6.

KEY WORDS Enteral nutrition, antroduodenal motility, ultrasound gastric emptying, dietary fiber, healthy volunteers

INTRODUCTION

Fiber supplementation during enteral nutrition with liquid formula diets has been recommended to normalize bowel function and improve feeding tolerance (1–3). Short-chain fatty acids, which are products of carbohydrate fermentation in the colon, play an important role in salt and water absorption in the colon (4) and

could help in the management of diarrhea related to enteral feeding (5, 6). Short-chain fatty acids, such as butyrate, are also the main fuel for colonocytes (7, 8). Experimental studies showed that enteral feeding with fiber results in better colon mucosal trophicity and in a lower rate of bacterial translocation than does enteral feeding without fiber (9–11). For enteral formulas, water-soluble fiber seems to be the fiber of choice as a substrate; it has better potential trophic effects than does insoluble fiber (12). However, until recently, water-soluble fiber supplements were used rarely in enteral formulas because of high viscosity, which results in a slower gastric emptying, delayed absorption in the small intestine, and a reduced luminal flow by causing resistance to the propulsive action of intestinal contractions (13). Moreover, this high viscosity enhances the risk of the feeding tubes becoming clogged. As a result, soluble fibers such as pectin and guar gum, which tend to form a gel, are not well suited supplements for tube-feeding formulas; soy polysaccharide, which contains 94% insoluble fiber, is the most common source of fiber in enteral formulas (14).

Recently, new fiber processing techniques have been used to produce highly water-soluble and low-viscosity dietary fibers for use as alternative fiber supplements in enteral formulas. The use of these new water-soluble fibers might be recommended if they have no deleterious effects on gastric emptying and antroduodenal motility. Thus, the purpose of this study was to compare gastric emptying and antroduodenal motility in healthy volunteers during the gastric infusion of a formula with new water-soluble fibers from pea and inuline extracts and of a traditional formula enriched with insoluble fiber from soy polysaccharide extracts.

SUBJECTS AND METHODS

Subjects

Eight healthy male volunteers were included in the study; their mean age was 36 y (range: 22–48 y) and their mean body

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weight was 77.2 kg (range: 58–89 kg). None of the subjects had known gastrointestinal disease or a history of abdominal disease, had undergone intraabdominal surgery other than appendectomy, or were taking any medication. The study was approved by the Ethics Committee of the Medical School of University Hospital of Rouen. All the subjects gave written, informed consent.

Manometric technique

Antroduodenal tube

A 2.2-m-long radiopaque multilumen polyvinyl tube with 6 separate catheters (0.8 mm inner diameter) bonded together was used (Marquat, Boissy-Saint-Léger, France). The side holes were placed so that 3 were located in the antrum (3 cm apart) and 3 in the duodenum (3 cm apart). The distal antral and most proximal duodenal holes were 10 cm apart. A weight containing 1 mL mercury was attached to the distal tip to facilitate progression of the tube through the pylorus.

Recording system

Antroduodenal motility was monitored with a manometric system based on the pneumohydraulic capillary infusion system described by Arndorfer et al (15) for esophageal manometry. All manometric channels were perfused continuously with distilled gas-free water from a pressurized reservoir with a low-compliance pump. The rate of perfusion was 0.5 mL/min (16). Resistance to infusion in the system was detected by a series of external transducers (Statham P23 XL; Gould, Oxnard, CA). Pressure values from the transducers were assigned at a frequency of 5 Hz/channel and stored on the hard disk of an IBM PC (Pentium 133; IBM, Armonk, NY).

Analysis of the tracings

Analysis was both visual and computerized. Visual analysis was performed by 2 observers (PD and MB) who had been trained to analyze manometric recordings of the upper gastrointestinal tract. The purpose of this analysis was to detect the occurrence of phase III activity in the antrum and duodenum and to identify coordinated antroduodenal contractions propagated from the antrum to the duodenum.

Phase III activity in the antrum was defined as regular contractions of >1 min occurring at a frequency of 2.5–3.5/min and with a temporal overlap with duodenal phase III. Phase III activity in the duodenum was defined as regular contractions of ≥1 min at a frequency of 10–12/min occurring in all duodenal recording sites followed by ≥5 min of relative quiescence (phase I), consisting of sporadic low-amplitude contractions (17).

Antroduodenal coordinated waves were defined on the basis of Houghton's description as the association of pressure waves in ≥1 antral recording sites with pressure waves in adjacent channels in ≥1 duodenal site (17). A pressure wave was considered to be aborally propagated when the leading edge of the contraction complex occurred >1 s but <5 s after a similar contraction in the adjacent oral recording site (18).

Computerized analysis was performed by using previously validated 2ERL software (Lomatech, Rennes, France) (18) that analyzed the digital recording in successive steps. First, pressure waves due to breathing were eliminated by filtering out all waves with an amplitude of <10 mm Hg. Second, when peak pressures were detected during contractions, wave criteria were applied to confirm that the peak had originated from a genuine contraction.

Third, the computerized analysis included 5 items: the number of pressure waves, the area under the curve (AUC), the percentage of time occupied by motor activity, the amplitude of the waves, and the duration of the waves. These variables were calculated for the entire recording and for every half hour of recording.

Diets

A separate polyvinyl nasogastric tube (ref 1147 221; Ansell Medical, Cergy Pontoise, France) was used to infuse the 500 mL of liquid meal. Three diets were studied: a fiber-free diet with 0 g fiber supplement (Sondalis Iso; Clintec Laboratory, Sèvres, France); a diet with 15 g insoluble fiber/L, including 94% polysaccharide soy fiber (Fresubin; Fresenius Pharma, Sèvres, France); and a diet with 15 g mixed fiber/L, including 50% soluble fiber and 50% insoluble fiber (Sondalis fibers; Clintec Laboratory). Each formula provided 2100 kJ and the same ingredients except for the fiber (carbohydrates, 55%; proteins, 15%; lipids, 30%; **Table 1**).

Ultrasound evaluation of antral area

The antral area was measured by using ultrasonography. Ultrasound examination was performed with a high-resolution real-time scan (CGR, Radius CF; General Electric, Issy les Moulineaux, France) with a 5-MHz linear array transducer. All examinations were performed by the same ultrasound specialist (MB) to avoid differences due to interobserver variations. The subjects were studied in a half-seated position. The gastric antral area was measured as described previously in 2 sagittal planes, at the level of the aorta and the inferior vena cava (19). The antral area was calculated (in mm²) by measuring the longitudinal (L) and the anteroposterior (AP) diameters from the outside profile of the wall. The cross-sectional area was then calculated by using the formula $AP \times L\pi/4$. Measurements were taken immediately before the liquid meal infusion was started (T0) and then at 20-min intervals during the 2-h infusion and every 30 min for 3 h after the infusion.

Study design

Each subject was studied 3 times with an interval of ≥1 wk between each study. The order of the 3 studies was determined randomly. Each study was performed as follows: the subjects fasted overnight for ≥2 h before the study. The nasogastric tube and the catheter were inserted through an anesthetized nostril and positioned under fluoroscopic control. The most distal of the 3 proximal side holes of the antroduodenal probe was located in the terminal antrum. The 3 distal side holes were located in the second and third duodenum. The nasogastric tube ended 5 cm from the nearest proximal antral opening. Once the tube was placed correctly, both the manometric probe and the feeding tube were attached firmly to the subject's nose with adhesive tape. The antroduodenal catheter was connected to transducers and the nasogastric tube was connected to the enteral pump. The subjects were studied in a half-seated position and were not allowed to drink for the 6 h of the study. Antroduodenal motility was recorded continuously from 0900 to 1500. After 30 min of basal recording of fasting motility, the formula was instilled from 0930 to 1130 at a flow rate of 250 mL/h by using a peristaltic infusion pump.

Antroduodenal motility was monitored continuously for 6 h, including the 2 h of feeding and the 4 h after the end of feeding. At the end of each recording session, fluoroscopy was used to check for correct probe placement.

TABLE 1
Composition of the 3 diets per 100 mL

	Fiber free ¹	Mixed fiber ²	Insoluble fiber ³
Proteins (g)	3.8	3.8	3.8
Lipids (g)	3.9	3.9	3.4
Carbohydrates (g)	12.5	12.5	13.8
Fiber (g)	0	1.5	1.5
Osmolarity (mosmol/L)	250	270	250
Energy (kJ)	420	420	420
Viscosity (Pa/s)	11	16	23

¹Sondalis Iso, Clintec Laboratory, Sèvres, France.

²Sondalis fibers, Clintec Laboratory.

³Fresubin, Fresenius Pharma, Sèvres, France.

Statistical analysis

Statistical analysis was performed by using BMDP software (version 2; BMDP Statistical Software Inc, Berkeley, CA). Analysis of variance with repeated measures for one or several factors and the Wilcoxon test for paired data were used.

RESULTS

All the subjects completed the study as planned. None of the subjects were excluded because of clinical intolerance. Enteral nutrition with the 3 different diets was well tolerated by all the volunteers and none described any adverse effects, especially digestive effects (ie, nausea, diarrhea, bloating, or abdominal pain), before, during, or after the infusion. There were no clogged feeding tubes or abnormal migration of the manometric probe during recording.

Antral areas

Variations in antral areas with the 3 diets are shown in **Figure 1**. During the 2 h of intragastric infusion of the 3 diets, antral area increased progressively in all subjects to reach a peak after a median of 50 min (range: 20–80 min) with the fiber-free formula, 60 min (range: 40–80 min) with the mixed-fiber formula, and 70 min (range: 40–100 min) with the insoluble-fiber formula; the difference was not significant. During the 4 h after the end of the gastric infusion, the antral area decreased progressively and returned to initial values after 4 h. The mean (\pm SEM) half time to return to baseline values was not significantly different among the 3 diets: 211 \pm 49 min with the fiber-free diet, 222 \pm 75 min with the mixed-fiber diet, and 257 \pm 73 min with the insoluble-fiber diet. When the changes in antral area for all 6 h were analyzed, there was no significant difference in mean antral area values among the 3 types of infusion at any time.

Antral motor results

All motor variables were low during infusion of all 3 enteral formulas and then increased progressively after infusion before returning to baseline values (**Figure 2**). Whatever the formula, a significantly higher number of waves, AUC, amplitude of waves, duration of waves, and percentage of time occupied by motor activity ($P < 0.05$) were recorded in the distal antral recording site than in the 2 more proximal sites.

Interstudy comparisons showed that the number of waves ($P < 0.04$), AUC ($P < 0.03$), and percentage of time occupied by motor activity ($P < 0.04$) were significantly higher with the mixed-fiber diet than with the insoluble-fiber diet in the proxi-

mal antrum but not in the distal antrum. The results for the fiber-free diet were between those for the mixed- and insoluble-fiber diets; there was no significant difference with the other formulas. In contrast, no significant difference was observed for the amplitude and the duration of the pressure waves in any of the recordings for the 3 different formulas.

Antroduodenal coordinated waves were observed in all subjects for all formulas. The median number of waves for the 6 h was 12.5 (range: 7–25) with the fiber-free diet, 15.5 (8–18) with mixed-fiber diet, and 8 (1–21) with the insoluble-fiber diet. Coordinated contractions occurred both during and after infusion. The number of coordinated contractile events and the time of onset did not differ significantly among the 3 diets.

The mean (\pm SEM) delay for reoccurrence of phase III was not significantly different among the 3 diets: 188 \pm 17.7 min for the fiber-free diet, 229 \pm 16.5 min for the mixed-fiber diet, and 222 \pm 4.2 min for the insoluble-fiber diet (Wilcoxon test). The median number of occurrences of phase III recorded during the postinfusion period was 1 (range: 0–2), 1 (0–3), and 0 (0–1) after the fiber-free, mixed-fiber, and insoluble-fiber diets, respectively; the difference was not significant. The onset of phase III was associated with an increased number of waves, AUC, and percentage of activity during the postinfusion period (**Figure 2**). Among the 8 occurrences of phase III recorded with the mixed-fiber diet, 6 occurred during the last 30 min of recording. By contrast, only 3 of 6 occurrences of phase III recorded with the fiber-free diet and 2 of 2 recorded with the insoluble-fiber diet occurred during the last 30 min of recording. This finding explained why the gastric motor results did not return to baseline values at the end of recording after the mixed-fiber infusion.

Duodenal motor activity

Duodenal motor variables are shown in **Figure 3**. There were no significant differences among the 3 duodenal recording sites. The results show the means in the 3 duodenal sites. In all subjects, whatever the diet, motor values were low during infusion and then increased slightly after infusion; there were no significant changes over time during the postinfusion period. None of the duodenal motor variables was significantly different among the 3 types of enteral feeding.

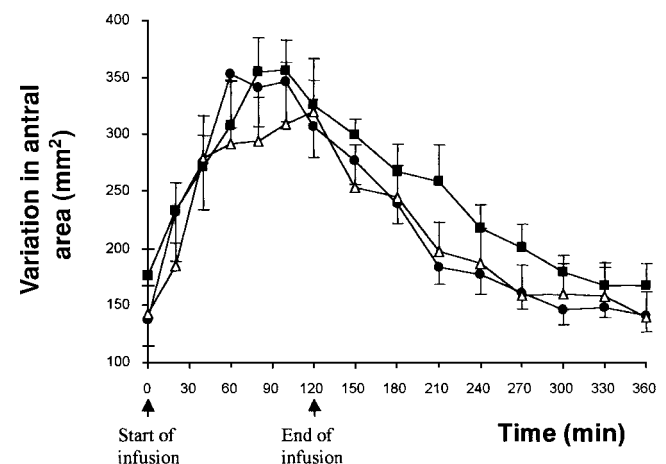


FIGURE 1. Evolution of the mean (\pm SEM) antral area (in mm²) with the fiber-free diet (●), the mixed-fiber diet (Δ), and the insoluble-fiber diet (■).

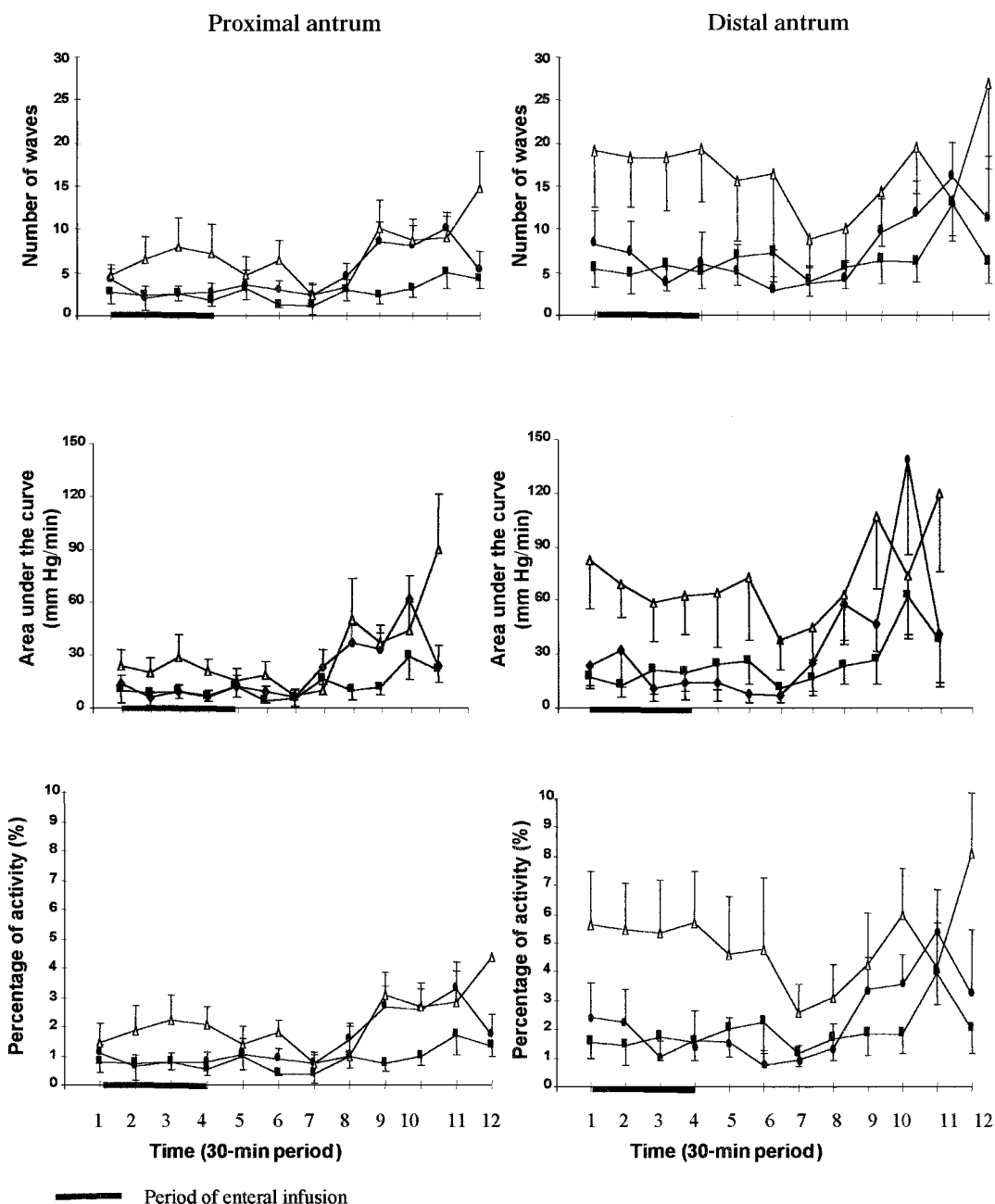


FIGURE 2. Evolution of the mean (\pm SEM) number of pressure waves, area under the curve, and percentage of time occupied by motor activity in the 2 most proximal sensors (proximal antrum) and in the distal antral sensor (distal antrum) from the beginning of the manometric study at each level of recording with the fiber-free diet (●), the mixed-fiber diet (△), and the insoluble-fiber diet (■).

DISCUSSION

We compared the motor response to intragastric enteral nutrition with a mixed-fiber formula with the response to insoluble-fiber or fiber-free formulas. To provide useful clinical information, this study was designed to reproduce normal conditions of enteral nutrition with a gastric rather than a duodenal site of infusion and with isoosmolar polymeric solutions (2). The 3 diets had the same osmolarity and energy contents, except for fiber, to allow interstudy comparisons, because osmolarity and energy content both influence gastrointestinal motility (20, 21).

Variations in antral area, which reflects gastric emptying, were not significantly different among the 3 diets despite a trend toward smaller antral areas during the second hour of infusion and an earlier plateau in antral area variations during infusion with mixed than with insoluble fiber. Gastric infusion induced a different gastroduodenal motor response than that reported after a standard meal (22). The only motor difference among the formulas was a significantly greater gastric motor activity during the mixed-fiber infusion than during the insoluble-fiber infusion (AUC, number of waves, and percentage of activity, $P < 0.04$) as a result of more

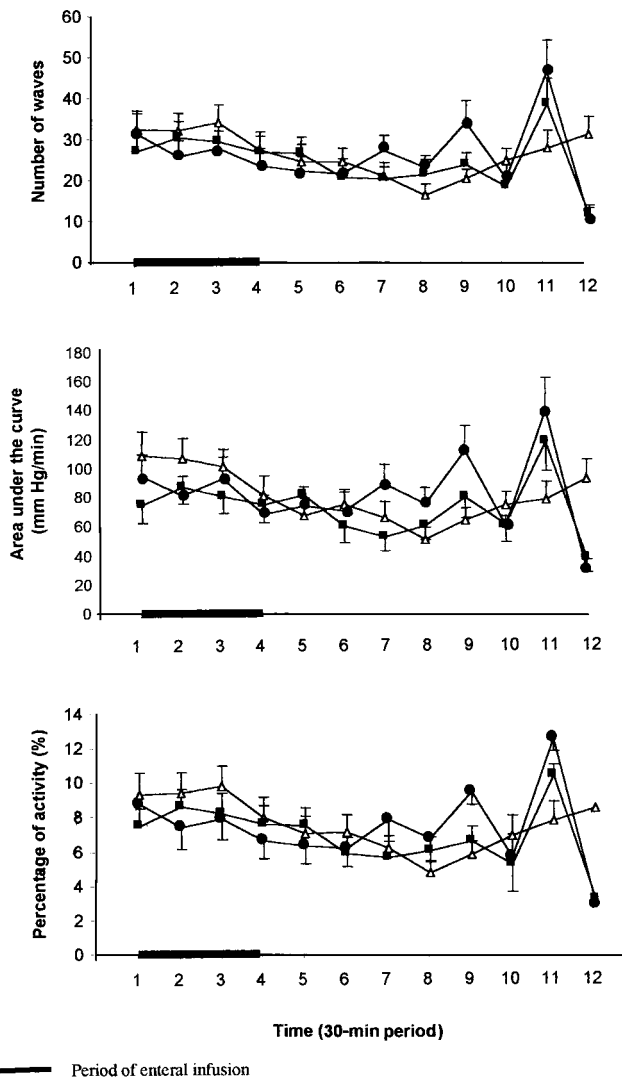


FIGURE 3. Evolution of the mean (\pm SEM) number of pressure waves, area under the curve, and percentage of time occupied by motor activity in the duodenum from the beginning of the manometric study at each level of recording with the fiber-free diet (●), the mixed-fiber diet (Δ), and the insoluble-fiber diet (■).

numerous contractions when amplitude and duration were similar. On the other hand, duodenal motor activity was not significantly different for any variable among the 3 types of enteral feeding.

Although scintigraphy is the method of choice for assessing gastric emptying (23–25), comparative studies have shown that ultrasonography is effective for evaluating the gastric emptying of liquids (19, 23, 25, 26). Ultrasonography has the advantage of being the only validated, noninvasive procedure that can be used to study gastric emptying during antroduodenal manometry performed under stationary conditions. Identical experimental conditions and repeated assessment of antral areas over time by only one observer minimize intrastudy variations. In this study, the profile in the antral area was not different from those reported previously with ultrasonography (26, 27). We cannot be certain that variations in antral area were not influenced by back flow into the more proximal stomach. If back flow took place, however, it may not have been different among the 3 groups. Because

the nutritional formula was infused directly into the antrum while the subjects were half seated, the possibility of back flow of the infused formula from the distal to the proximal stomach seems limited. Thus, ultrasound measurements of the antral area were probably a good indication of gastric volume, with no underestimation due to proximal redistribution of the meal in the stomach.


Strictly speaking, antral volume is not the intragastrically infused volume but the sum of this volume and gastric secretion in response to infusion. No published study has shown that fiber content alone alters gastric secretion. The 3 diets in this study each provided 2100 kJ and contained the same ingredients except for fiber. Under these conditions, gastric secretion can be considered to have been the same for all 3 formulas. The variations in gastric areas in the present study were not different from those reported with the same infusion rate of 16.7 kJ/min by Vidon et al (28) with a perfusion method.

Previous animal studies (29) and human studies (30, 31) showed that soluble fiber, such as guar, slows emptying of the liquid part of a meal. The results of our study did not support these findings. We provided only 7.5 g mixed fiber during the 2 h of infusion, whereas delayed gastric emptying has been reported with ≥ 15 g of soluble fiber (30–32), and we tested a commercially available mixed formula composed of 50% soluble and 50% insoluble fibers rather than a pure soluble-fiber formula. The viscosity of the gastric content is critical for gastric emptying. The results of our study support this, because the highest gastric areas were measured with the most viscous formula (Table 1). Soluble fibers are usually considered to be the most viscous (29). We tested less viscous soluble fibers extracted from inuline and peas (Sondalis fibers, Clintec Laboratory), whereas previous studies of soluble fiber tested guar or pectin (31, 32). The findings of our study confirmed results in animals, which suggested that findings with one type of fiber cannot be extrapolated to other types of fiber (33). Finally, we tested an energy formula with fiber; however, in other studies that showed a delayed effect of fiber on gastric emptying, solutions containing fiber alone were tested. All these reasons could explain the lack of a significant difference among the 3 types of infusion in our study.

Antroduodenal motility was monitored by a continuously perfused catheter system, as recommended (16, 18), but, to avoid disturbing gastric emptying, a sleeve probe was not used to record pyloric pressures. During infusion of all 3 diets, only low motor activity was recorded in the antrum, confirming previous results (34). The gastric motor response was significantly higher at the distal antral recording site than in the 2 more proximal sites with all 3 diets. This result is probably a reflection of pyloric motor activity, as suggested by previous studies (17, 35). However, because we decided not to record pyloric motor activity with a sleeve to avoid disturbing gastric emptying, we could not confirm this hypothesis. We showed that liquid is emptied from the stomach despite few antral phasic pressure waves (34) or coordinated antroduodenal propagated motor events (17). This suggests that liquid emptying is not influenced greatly by antral motor behavior and results mainly from fundus motor activity, even with only a slight antroduodenal pressure gradient. An enriched diet with mixed fiber significantly affected antral motility. The results of our study do not explain why the antral motor response was different for the 3 different enteral formulas.

The duodenal motor response observed in the present study after gastric infusion, whatever the fiber content of the formula (ie, reduced motor activity without any maximum immediately

after the meal) was markedly different from that observed after a meal of solids and liquids (36). This confirms data obtained by Rees et al (34) and Schönfeld et al (37), who studied a liquid meal given as a bolus compared with a standard mixed meal. A relation has been suggested between gastric emptying and the postprandial small-bowel motor response (20). The lack of decrease in motility over time in our study could have been related to the duration of the infusion and the progressive infusion of the meal into the duodenum as well as to the gastric emptying curve. In our study, the 3 different diets did not induce different duodenal motor patterns. In animals, Bueno and al (33) showed that the fed pattern in the duodenum and the jejunum were influenced by the type of dietary fiber and suggested that these different motor patterns were related to different bulking activity. These differences were not confirmed in all animal studies (38) and could be species-related. In humans, the addition of 5 g viscous fiber (guar) to an energy meal had no effect on the incidence or the amplitude of jejunal contractions (37).

In this crossover study, healthy subjects received commercially available formulas during enteral feeding with either 50% soluble or 100% insoluble fibers and constant amounts of all other macronutrients. The addition of both types of fiber to the formula had limited effects on gastric emptying and antroduodenal motor responses to enteral feeding. Therefore, the addition of fiber to an enteral formula does not seem to have any serious deleterious effects on the gastroduodenal motor response to infusion. 

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