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Nutritional Absorption in Short Bowel Syndrome

Evaluation of Fluid, Calorie, and Divalent Cation Requirements

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Eight patients with a short bowel resulting from intestinal resection and clinically stable for at least one year were studied for 10 days. The diet chosen was lactose-free with a low fiber content and contained 22% of total calories as protein, 32% as carbohydrate, and 46% as fat. Total fluid volume was kept constant, and all patients were in positive nitrogen balance. During the 10-day period, blood chemical concentrations, stool, and/or ostomy volume, urine volume, electrolyte excretion, and calorie and divalent cation absorption were measured. In addition it was determined that fluid restriction during meals did not affect these parameters. In these patients the absorptions of fat, carbohydrate, protein, and total calories were 54%, 61%, 81%, and 62%, respectively. Similarly the absorption of the divalent cations, calcium, magnesium, and zinc, were 32%, 34%, and 15%, respectively. We suggest that patients with short bowel syndrome, who have been stable for at least one year and who can tolerate oral diets, do not need to restrict fat or to separate fluids from solids during their meals. Furthermore, they should increase their oral intake to 35–40 kcal/kg ideal body weight in order to counteract their increased losses. The diet should contain 80–100 g protein/day in order to maintain a positive nitrogen balance and a large margin of safety. In addition, these patients may take oral supplementation of calcium, magnesium, and zinc to maintain divalent cation balance.

Extensive loss of small bowel leaves insufficient mucosal surface for the absorption of nutrients and fluids. Transit time decreases, and therefore contact time between luminal nutrients and pancreatic and biliary secretions is reduced. Malabsorption of protein, carbohydrate, fat, and divalent cations ultimately follow.

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However, the loss of bowel is followed by a process of adaptation and compensatory hypertrophy (1–6). Thus there is a continuous improvement in the ability of the bowel to absorb nutrients and a corresponding decrease in diarrhea with time. Therefore, different regimens during this initial period may give erroneous results and may not be applicable to patients in a stabilized state.

With the advent of total parenteral nutrition (TPN) and the increasing sophistication of surgical techniques, more practitioners will be encountering patients with the short bowel syndrome. Many studies have stressed a variety of regimens in the treatment of the patient with a short bowel. However, few have been done with stable patients many

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TABLE 1. CLINICAL DATA

Patient no.	Group no.*	Associated disease	Remaining bowel: Duodenum	Jejunum	Ileum	Colon and rectum	Years since last resection
1	2	Bowel infarction	All	42 in.	None	TDR†	7
2	1	Crohn's	All	All	None	None	5
3	1	Crohn's	All	All	None	TDR	23
4	2	Diverticulitis	All	All	None	None	7
5	1	Crohn's	All	48 in.	None	None	5
6	2	Crohn's	All	All	None	None	8
7	1	Bowel infarction	All	72 in.	None	TDR	1
8	2	Ulcerative colitis + bowel infarction	All	42 in.	None	None	4

*Group 1: PF diet first, Group 2: RF diet first.
†TDR: transverse descending colon plus rectum.
‡Sodium and intravenous fluids only.

years after resection, and no study has investigated in a controlled manner the effect of different dietary and fluid intakes on calorie and divalent cation absorption. In addition, previous studies have not reported total calorie balances, which are important in determining whether there is any difference in the absorption of different calorie sources, and also have not accounted for any colonic absorption of calories as short-chain fatty acids.

We have undertaken a 10-day randomized, controlled, cross-over study to determine the effect of fluid intake on absorption as well as to evaluate general nutrient absorption in patients with the short bowel syndrome.

MATERIALS AND METHODS

Patients. The clinical features of the eight patients are given in Table 1. These patients had no evidence of active inflammatory bowel disease, either clinically or by x-ray examination and had been clinically stable for at least one year. The details of the study were approved by the review committee on the use of human subjects at the University of Toronto. All patients gave written informed consent for participation in the study. The nutritional status of each patient is also given in Table 1 and indicates that while weight-for-height and creatinine–height indices were reduced in some patients, the serum albumin levels were normal in all. Two patients were on supplemental parenteral nutrition. All patients were ambulatory and were active housewives or working.

Protocol of Study. The patients were admitted to the Clinical Investigation Unit (CIU) of the Toronto General Hospital. A complete medical history and physical examination was performed. Blood was drawn for baseline values, and the diet history was reviewed by the CIU dietitian. All patients were on an *ad libitum* diet for the first two days. The *ad libitum* diet was assessed for total calorie intake, and the experimental diet was designed to closely match the values observed for the patient's food and fluid intake. Continuous 24-hr urine and stool collections were started on admission.

During the next 10 days the patients were kept on diets that were isocaloric, isonitrogenous, lactose-free, and provided a constant intake of protein, fat, and carbohydrate calories, fiber, and fluid. All medication was also kept constant. Divalent cation intake was kept constant as well.

In addition we studied what effect fluid would have on nutrient absorption if it was limited during meals to 1 hr before and 1 hr after meals, but not with meals. We felt that if fluid was restricted during meals, transit time would be prolonged, increased absorption would occur, and the patients would gain weight.

Patients randomized to group 1 received fluid with their meals (PF) for the first five days and those randomized to group 2 had their fluids restricted during their meals (RF) for five days. On day 6 patients in group 1 were changed to RF and vice versa. Daily fluid intake was kept constant for the 10 days. Days 1 and 6 were allowed to be equilibrium periods, and stool and urine were not collected. Blood was taken twice during each five-day period. Because of the crossover nature of the study, the effect of fluid manipulation was judged by comparing each patient with himself or herself, avoiding the variables induced by the degree of resection and adaptation.

Methods. Administration of marker ensured completeness of collection. In our previous study (7), we showed that in patients with a short bowel, over 95% of the ^{51}Cr marker was recovered in the stool or ostomy output within 3 hr of administration. Hence intestinal transit time was very rapid, and therefore a single day of equilibrium was adequate for these patients before beginning the collections.

Routine blood chemical determinations were done by the Department of Biochemistry at Toronto General Hospital. Urine electrolytes were measured by flame photometry (8). Fecal fat measurement was by the Van de Kamer method (9). Fecal sodium and potassium were measured by wet ashing of stool using perchloric acid as

TABLE 1. CONTINUED.

Patient no.	Sex	Age	Weight (kg)	Height (cm)	TPN (yes/no)	Serum albumin (g/dl)	Weight/height (% of normal)	24-hr urinary creatinine/height index (% of normal)
1	M	50	71.6	177	No	4.0	101	84
2	F	45	83.0	160	No‡	4.1	149	110
3	F	63	42.1	155	No	4.3	80	82
4	M	61	65.3	170	No	4.1	99	87
5	M	65	77.6	183	Yes	4.3	103	89
6	F	63	61.8	154	No	4.0	118	74
7	F	71	46.8	153	No	4.7	91	106
8	F	56	65.8	159	Yes	3.9	119	115

described (10) and then estimating the electrolyte content of the ashed aliquot by flame photometry.

Total dietary and fecal calorie contents were measured by bomb calorimetry as previously described (7). Total calories absorbed were calculated by subtracting the calories excreted from the calories ingested. By subtracting fat calories from total calories, the excretion of calories derived from malabsorbed carbohydrate plus protein was calculated. This was partitioned into protein calories from measured nitrogen excretion and into carbohydrate calories by subtracting the protein calories from the total nonfat calories.

Fecal calcium, magnesium, and zinc measurements were made by wet ashing the stools as described (10) and estimating these elements by atomic absorption spectrometry. Nitrogen in the urine and stool was determined by a microKjeldhal technique (11). As concerns basal metabolic rate, it has been shown previously that the measured metabolic rate is comparable to that calculated by the Harris-Benedict equation (12, 13). This equation is accurate only in normal or underweight persons because metabolic rate depends upon the lean body mass. Therefore we have used ideal body weight to calculate the metabolic rate.

Statistical Analysis. The data gathered while receiving the two fluid diets were tested for statistical significance using the Student's t test for paired variables.

RESULTS

Dietary Intake of Nutrients. Based on diet history and observation in hospital, the 10-day diet approximated the usual diet of the patient. This approach ensured nutritional equilibrium during the study and good patient compliance. Although the diets differed from patient to patient, protein, fat, carbohydrate, fiber, and fluid volume were kept constant for each patient for the duration of the study.

Dietary Constituents. The total calorie, fluid, protein, fat, carbohydrate, and fiber intakes are shown in Table 2. The diet was lactose-free and contained 22% of total calories as protein, 32% as carbohydrate, and 46% as fat. The sources of these dietary constituents were kept constant in each patient by providing a diet from a common source which was made up in bulk and divided into daily rations.

Major protein-containing foods were ham, tenderloin, chicken, cheese, eggs, and fish. Fat sources were derived from butter, margarine, oil, peanut butter, Coffeerich®, and mayonnaise. Animal sources made up 71% of the fat intake and vegetable sources made up the remaining 29%. Carbohydrates were derived from bread, rice, crackers, vegetables, tea, coffee, and sugar-free ginger ale. Simple sugars made up 24% of the carbohydrate while complex sugars made up the remaining 76%. Fiber content was kept constant by food manipulation and the addition of bran. Total food volume averaged 1679 ± 102 ml daily.

TABLE 2. DIETARY CONSTITUENTS*

	Fluid (ml)	Fat (kcal)	Carbohydrate (kcal)	Protein (kcal)	Fiber (g)	Total calories (kcal)
Mean ± SEM	2196 ± 243	871 ± 97	607 ± 37	397 ± 37	13 ± 1	1869 ± 174
Range	1200–3640	437–1308	424–868	260–572	9–21	1165–2708

*Dietary constituents were kept constant during the 10-day study period.

Clinical Effects of Diets. There was no change in weight or in blood pressure during the 10-day study period. Change from PF to RF and vice versa did not alter these parameters.

Routine Blood Chemical Levels. There were no significant differences between PF and RF groups in serum electrolytes, urea, creatinine, blood sugar, calcium, magnesium, zinc, phosphorus, albumin, globulins, bilirubin, alkaline phosphatase, transaminase, cholesterol, triglycerides, hemoglobin, white blood cell count, and platelets. There were also no changes observed during the 10-day study period.

Differences Between the Two Five-Day Study Periods. There were no significant differences between the first and second periods of study with respect to any of the parameters of fecal and urinary excretion, nor in the balance of fat, calories, electrolytes, and the divalent cations. Hence the patients were clearly in equilibrium and stable. Furthermore the timing of fluid intake was not critical with respect to the absorption of calories and was not related to the degree of diarrhea. Hence the data for the 10 days were amalgamated.

Urine Volume, Electrolytes, Creatinine, and Urea. The results are set out in Table 3. The reproducibility of the observations over the 10-day study period reveal no significant effect of fluid restriction during meals and emphasizes the stability of the patients.

Fecal Weight, Osmolality, and Electrolytes. These results are also given in Table 3. In any one patient there were no significant differences during the 10-day study in the parameters measured even when patients with a short jejunum (Nos. 1, 5, and 8) were considered separately. However, in those patients without a colon (Nos. 1, 3, and 7) the fecal sodium losses were greater (110 ± 8 mmol/day) than in the patients with a partial colectomy (46 ± 11 mmol/day) ($P < 0.005$). A trend to greater fecal weight was seen as well in patients without a colon (1490 g/day) as compared with those with a partial colectomy (994 g/day). However, this was not statistically significant. Furthermore, fecal sodium was significantly correlated with fecal weight ($r = 0.62$). In contrast, the excretion of potassium was not correlated with fecal weight ($r = 0.07$). One patient with chronic hypokalemia (No. 3) had very high fecal losses of potassium.

In addition, patients without a colon did not excrete significantly more fecal water than those with a colon (1349 cc/day vs 866 cc/day, respectively). Total dry fecal weight averaged 136 g/day during the 10-day study and represented 12% of total stool weight. The remaining 88% was water.

There was a significant osmolar gap in all patients between the measured and the calculated [(Na + K)/2] osmolality. When the total fecal nonelectrolyte osmolar loss (osmolar gap multiplied by fecal volume) was correlated with the excretion of fat, carbohydrate, and carbohydrate plus protein calories, it became clear that the fecal nonelectrolyte osmolar loss correlated best with carbohydrate excretion ($r = 0.74$). In contrast, excretion of carbohydrate plus protein ($r = 0.64$) and of fat ($r = 0.38$) correlated to a lesser degree with the fecal nonelectrolyte osmolar excretion.

Nitrogen Balance. The results are shown in Table 4. All patients were in a positive nitrogen balance of 4.1 g N/day.

Estimated Metabolic Rate Requirements. The results are set out in Table 5. Patients 1–4, 7, and 8 were in metabolic balance since their calorie intake/day (A) was sufficient to maintain their basal

TABLE 3. 24-HOUR URINARY AND FECAL EXCRETION

	Volume (cc)	*Creatinine (mmol/day)*	*Urea Nitrogen (mmol/day)*	*Sodium (mmol/day)*	*Potassium (mmol/day)*	*Chloride (mmol/day)*
Urinary excretion						
Mean ± SEM	1529 ± 171	10755 ± 1801	336 ± 41	87 ± 18	61 ± 17	118 ± 18
Range	879–2372	5619–20336	193–524	5–145	20–139	47–194
	Weight (mg)	Osmolality (mmol/day)				
Fecal excretion						
Mean ± SEM	1304 ± 200	549 ± 50		113 ± 17	32 ± 9	101 ± 21
Range	560–1938	412–878		33–167	12–93	25–175

*There were no differences seen in urinary and fecal parameters over the 10-day study period in any one patient.

TABLE 4. NITROGEN BALANCE (G N/DAY)*

	Diet	Urine	Stool	Nitrogen balance
Mean ± SEM	15.9 ± 1.5	9.1 ± 1.1	2.7 ± 0.6	4.1 ± 0.6
Range	10.4–23.0	4.9–14.3	1.0–6.7	2.0–7.4

*There were no significant changes in nitrogen excretion during the 10-day study.

metabolic rate (B). However patients 5 and 6 were only consuming 15.5 and 27.5 kcal/kg ideal body weight, respectively, but actually required 33.0 and 41.3 kcal/kg ideal body weight, respectively.

Total Calorie Absorption. The results are given in Table 6. Fat absorption was not significantly different from carbohydrate absorption. In contrast, protein absorption was significantly better than that of fat ($P < 0.005$) and carbohydrate ($P < 0.01$).

Divalent Cation Absorption. The results are shown in Table 7.

DISCUSSION

After massive small bowel resection it is well known that the remaining bowel undergoes compensatory hypertrophy and adaptation (1–6) in order to improve nutrient absorption and that many months are required to complete this process (14). We have undertaken a randomized, crossover, controlled study to determine the nutrient requirements in patients with the short bowel syndrome.

Stability of Patients. In order to determine the patient's needs accurately, we felt that stability would be an important factor and this was measured in several ways. We purposely chose those patients who had not had a bowel resection, and who had been in remission with no active disease, for at least one year (mean 7.5 ± 2.3 years). All were active housewives or working. When fluid was added during the meal, there was no change in feeling of well-being, weight, or blood pressure. Blood chemistry, and urine and fecal excretions remained constant during the fluid challenge which confirmed previous reports (15, 16). Nutritional parameters such as serum albumin, weight–height ratio, and 24-hr urinary creatinine/height index were all within normal limits. All patients were in positive nitrogen balance which averaged 4.1 g N/day. Absorption of protein, fat, carbohydrate, and divalent cations also remained constant for the 10-day period.

Thus in all respects the patients were free of active disease and were nutritionally and metabolically stable.

Effect of Intestinal Resection on Absorption of Fluid and Electrolytes. The effect of intestinal resection on fluid and electrolyte absorption will depend upon both the extent of resection and the site. As long as the colon is intact, diarrhea is minimal. Fluid and electrolyte losses will not be excessive, unless (1) the fluid load delivered to the colon following small bowel resection exceeds its reserve

TABLE 5. ESTIMATED BASAL METABOLIC RATE (BMR) REQUIREMENTS

Patient	Ideal body weight (kg)	Calorie intake per day		Observed calories absorbed/day		Expected calories absorbed needed*		Intake needed to maintain BMR	
		kcal	kcal/kg (A)	kcal	kcal/kg	kcal	kcal/kg	kcal	kcal/kg (B)
1	71.1	2708	38.1	1462	20.6	1585	22.3	2936	41.3
2	55.7	1633	29.3	1241	22.3	1261	22.6	1656	29.7
3	52.6	1885	35.8	1376	26.2	1138	21.6	1556	29.6
4	66.0	2381	36.1	1404	21.3	1406	21.3	2383	36.1
5	75.4	1165	15.5	733	9.7	1572	20.8	2489	33.0
6	53.0	1457	27.5	752	14.2	1139	21.5	2191	41.3
7	52.6	1826	34.6	1223	23.3	1096	20.8	1633	31.0
8	55.2	1900	34.4	1026	18.6	1202	21.8	2228	40.4
Mean ± SEM	60.2 ± 3.3	1869 ± 174	31.4 ± 2.6	1152 ± 101	19.5 ± 1.9	1300 ± 70	21.6 ± 0.2	2134 ± 172	35.3 ± 1.8
Range	52.6–75.4	1165–2708	15.5–38.1	733–1462	9.7–26.2	1096–1585	20.8–22.6	1556–2936	29.6–41.3

*Values obtained from the Harris-Benedict equation (12). See text for further explanation.
(A) Estimated calorie intake
(B) Estimated metabolic rate

TABLE 6. TOTAL CALORIE ABSORPTION (KCAL/DAY)*

	Fat	*Carbohydrate*	*Protein*	*Total absorption*
Diet	871 ± 97	608 ± 56	396 ± 36	1875 ± 174
Stool	405 ± 73	239 ± 42	76 ± 15	719 ± 108
Absorption (%)	54 ± 4	61 ± 7	81 ± 5	62 ± 3

*There was no change in absorption in any of the parameters measured over the 10-day study period.

capacity or (2) the contents of the small intestinal dejecta entering the colon inhibit colonic absorption. Normally the reserve capacity of the colon is about 5 liters per day (17), but bile salts and free fatty acids both alter the ability of the colon to absorb water and sodium. Furthermore, certain forms of vegetable residue and carbohydrate can be degraded by colonic bacteria into titratable acids which also increase the osmotic load and therefore the water output.

Thus proximal resection results in little diarrhea because the ileum can resorb the increased fluid and electrolyte load and any remaining excess is taken up by the colon. The resorption of bile salts by intact ileum results in the colon not receiving any substances capable of preventing water and electrolyte absorption. In contrast, when the ileum is resected, the colon receives a larger fluid load because the contents are isotonic. Furthermore, because bile salt loss occurs, there are additional substances (bile salts, fatty acids, unabsorbed carbohydrates) which reach the colon and reduce the resorption of water and electrolytes. These effects result in diarrhea (18).

Basal Metabolic Requirements. The Harris-Benedict equation has limitations when the patient's actual weight does not correspond with the ideal body weight. However, studies have shown that techniques of continued expired air analysis correlate with the estimated metabolic expenditures (19–21).

Six of the eight patients were within normal limits with respect to their basal metabolic needs. Of the two patients who were not in balance, one (No. 5) was receiving additional nutrients from TPN which placed him above his requirements. The other patient (No. 6) had been stable for eight years and her ideal body weight was 10 kg less than her actual weight. We suspect that even though she did not lose weight while on the study her intake at home was greater than in hospital. In all patients it will be observed that eating 35–40 kcal/kg/day (equivalent to 2450–2800 kcal/day in a 70-kg man) would allow sufficient calories to be absorbed to meet metabolic demands assuming that they absorbed 60% of this intake.

TABLE 7. DIVALENT CATION ABSORPTION (MG/DAY)*

	Calcium	*Magnesium*	*Zinc*
Diet	703 ± 111	254 ± 23	13 ± 1
Stool	448 ± 62	166 ± 19	11 ± 1
Absorption (%)	32 ± 7	34 ± 6	15 ± 8

*There were no changes in divalent cation absorption during the 10-day study period.

Total Calorie Absorption. In healthy subjects with full-length small and large intestines, over 95% of ingested calories is retained while only 5% is lost in the feces (22, 23).

Over the course of the 10-day study, the eight patients absorbed 62% of the total calorie intake (range 52–76%). There were no significant differences when patients with a short jejunum were compared to those with a full-length jejunum or between those patients with or without a colon. The likely explanation for the similarities in absorption is again that our patients did not have active disease and had adapted to their fullest extent (1, 7).

Fat Absorption. During the 10-day study only 54% (range 35–71%) of dietary fat was absorbed. The average fecal excretion of fat was 45 g/day (range 21–93 g). Weser (24) states that the extent and site of resected small bowel is one of the most important factors in fat malabsorption. In particular, resection of the ileum will lower the concentration of bile salts available for micellar formation. All our patients had their ileum and ileocecal valve resected, but the remaining bowel had hypertrophied and compensated for the short length.

Fat is an important source of energy and makes the diet more palatable. Several studies have shown that when the intake of dietary fat is increased, the same percentage of fat calories is absorbed (7, 25–27). In the stable patient with short bowel, we feel it is unnecessary for dietary fat intake to be restricted. However, these patients do lose large quantities of fat in their stools and deficiencies of fat-soluble vitamins may occur.

Carbohydrate Absorption. During the study, 61% of dietary carbohydrate was absorbed (range 24–81%). The most likely reason for short bowel patients to absorb carbohydrate as well as they do is that oligosaccharide digestion is nearly complete by mid-jejunum, and this area was relatively spared in our patients (28).

In patients with lactase deficiency, catabolism of nonabsorbed disaccharides by small and large bowel bacteria increase stool osmolality (29). The patients in our study malabsorbed 40% of the carbohydrate ingested, and thus the large osmolar gap is most likely due to malabsorbed disaccharides and short-chain fatty acids.

Protein Absorption. Our patients absorbed a surprising 81% (range 71–90%) of dietary protein, and all patients were in a mean positive nitrogen balance of 4.1 g N/day. There may be several reasons for this absorption rate.

Protein digestion and absorption in normal individuals is very efficient, where as little as 2% of intake is excreted (30). Small intestinal bacterial overgrowth or stasis syndrome can cause significant protein wasting and may be severe enough to resemble protein–energy malnutrition (31, 32). Residual mucosal disease is one of the most important causes of protein malabsorption and can contribute to a continued state of negative nitrogen balance. Our patients had no evidence of active disease or excessive bacterial overgrowth, and this may be reflected in the high protein absorption.

Divalent Cation Absorption. During the study patients absorbed 32%, 34%, and 15% of the dietary calcium, magnesium, and zinc, respectively. The intake of divalent cations was within the recommended daily nutrient intake for their sex and age (33); however, these values assume normal cation absorption from the bowel. It has been shown in normal patients that approximately 35%, 40%, and 15% of ingested calcium, magnesium, and zinc is absorbed by the intact gut (34, 35). These percentages are rather close to the values obtained in our patients.

Several studies have evaluated divalent cation absorption with varying intakes of fat. Andersson (36) showed improved divalent cation absorption with a 40-g fat diet compared with a 100-g fat diet, whereas Woolf (7) in a more controlled study showed no significant difference. Therefore, we felt that the high fat intake during the present study did not contribute significantly to the malabsorption of the cations.

Some feel that zinc deficiency occurs most frequently and that this trace element needs to be replaced in patients who have small bowel resection with diarrhea that is severe (10, 34, 36).

CONCLUSION

We have studied eight patients with short bowel and a normal oral intake in terms of fat, carbohydrate, and protein calories and divalent cations. It was determined that these patients absorbed 54% of dietary fat, 61% of carbohydrate, 81% of protein with an overall absorption of 62% of total dietary calories. Restricting fluid intake during meals did not improve absorption of calories or of divalent cations. The patients were in positive mean nitrogen balance of 4.1 g N/day. Calcium, magnesium, and zinc absorptions were 32%, 34%, and 15% of dietary intake, respectively, and were quite similar to those found with normal intact bowel.

We suggest that patients with the short bowel syndrome who have been stable for at least one year and who can tolerate an oral diet do not need to restrict fat in their diet or to separate fluids from solids during their meals. Furthermore, they should increase their oral intake to 35–40 kcal/kg/day of ideal body weight to counteract their increased losses. The diet should contain 80–100 g protein/day in order to maintain a positive nitrogen balance and a large margin of safety. In addition, these patients may take oral supplementation of calcium, magnesium, and zinc to maintain their divalent cation balance if these levels are found to be low in the blood or negative upon balance study.

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