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Original article

Bowel length: measurement, predictors, and impact on bariatric and metabolic surgery

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Abstract

Background: Small bowel length (SBL) determines the caloric absorptive capacity. The aim of this study was to evaluate SBL to identify patient-specific predictors and the interrelationships of SBL with anthropometric variables.

Methods: Sex, age, and weight were recorded at the time of surgery when SBL and the estimated jejunal length (JLe) were measured by 3 different methods.

Results: The mean SBL of 443 patients undergoing laparotomy (78% female) was 690 ± 93.7 cm (range 350–1049 cm). Sex was correlated with SBL, as men had a longer small bowel than women (729 ± 85 versus 678 ± 92, $P < .0001$) and were significantly taller (173 ± 8.2 versus 161 ± 6.9, $P < .001$). Age did not correlate with SBL. The differences in length between fully stretched small bowel and nonstretched small bowel and between fully stretched small bowel and laparoscopic bowel were 137 ± 19 cm and 32.4 ± 11.4 cm, respectively. In a multivariate linear regression analysis model that included sex, age, height, and weight, only height was significantly correlated with SBL ($P < .00001$) and explained 12% of the variance in SBL. Sex, age, height, and JLe, but not SBL, were statistically highly significant in predicting 75% of the variance of body weight.

Conclusions: A positive association between height and SBL was found. Sex, age, height, and JLe may be strong predictors of weight. Individual JLe may be of importance in determining the weight loss and resolution of metabolic co-morbidities. Measuring the SBL can prevent the risk of nutritional consequences in malabsorptive, revisional, and metabolic procedures. (Surg Obes Relat Dis 2015;11:328–334.) © 2015 American Society for Metabolic and Bariatric Surgery. All rights reserved.

Keywords: Intestinal length; Jejunal length; Bariatric surgery; Metabolic surgery; Revision; Obesity

The variation in intestinal length in humans is a controversial subject. Differences in measurement techniques, small study groups and large interindividual variation have contributed to the uncertainty associated with defining a normal range for intestinal length.

Early in the history of obesity surgery, when jejunoileal bypass was the most common procedure, there was a lot of discussion about the best jejunal and ileal lengths to be left in alimentary continuity [1–3]. For surgeons performing biliopancreatic diversion the accurate measurement of the alimentary and common limb was necessary both in primary and revisional surgery [4–6]. The recent popularity of gastric bypass procedures has revitalized interest in the measurement of alimentary and biliary limb length [7]. Nevertheless, there are no real standard measurement method or standard bowel limb lengths. The lengths reported by different surgeons are very difficult to compare. Some surgeons measure the bowel limbs from the ligament of Treitz, and some measure the bowel limbs from the ileocecal valve (ICV). Almost no surgeons measure the entire bowel, and some surgeons do not measure any portion of the bowel [8].

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Anatomy, gastroenterology, and surgery textbooks provide normal values for small bowel length (SBL, Table 1) [9–18]. SBL is not only of academic interest; for bariatric surgeons, bowel length determines the bowel's caloric absorptive capacity and its ability to absorb micronutrients. The relationship between different bowel limb lengths and SBL is of utmost importance for the success of bariatric surgery. An erroneous evaluation can lead to catastrophic consequences.

Here, we present a series of intraoperative measurements taken in normal weight and obese subjects undergoing laparotomy and laparoscopy. We compared different methods of measurement and attempted to develop a key to standardize and interpret SBL measurement. We searched for patient specific predictors of SBL and the interrelationships between anthropometric variables. Important implications for bariatric surgery are discussed.

Methods

The small bowel was measured by a single surgeon at a single institution in patients undergoing laparotomy for general surgery and obesity treatment. Height and weight were measured with a mechanical scale with a stadiometer (SECA, Hamburg, Germany). Patients who had undergone previous intestinal surgery or had adhesions were excluded. The bowel length was repeatedly measured midway between the mesenteric and antimesenteric borders of the intestine with a 100-cm heavy silk suture with marks at 50 and 10 cm. This was done without applying any tension to the bowel. The repeated measurement was taken a second time with the bowel fully stretched to its maximum elasticity. Laparoscopic measurement was performed by stretching the bowel with small bowel clamps marked at 5 and 10 cm and was compared with another measurement after conversion to laparotomy. The SBL was measured from the ligament of Treitz to the ICV.

The length of the jejunum (JLe) was estimated by identifying the morphological change of the bowel at the transition between the jejunum and ileum. The jejunum and ileum have macroscopic and microscopic differences. The jejunum is usually a tract of bowel that is normally empty of content. Peristalsis is very active. The bowel wall is significantly thicker than the ileum with patchy nodularity and a doughy feeling. The blood supply in both the mesentery and bowel wall is more developed. Occasional fatty streaks can be observed on the wall and mesenteric lymphatics. The ileum is thin walled, almost transparent to its fluid content. Peristalsis is not very active. There is no line of demarcation between the jejunum and the ileum and the transition is gradual. Sometimes a short portion of the jejunal appearance can be found after the initial ileal appearance. Moving distally, the last visible bowel with jejunal characteristics was defined as the end of the jejunum. It should be noted that prolonged fasting can alter and blunt the jejunal landmarks (Fig. 1).

As anesthesia and cold exposure can alter the apparent bowel length, the measurements were performed as early in the course of the operation as possible, immediately after laparotomy or laparoscopy. Epidural anesthesia was not used [19].

Table 1
Small bowel length and its correlations in historical series

Author	Number of cases	C/L	Sex	SBL			Correlation with		
				Minimum	Average	Maximum	Age	Height	Weight
Treves (1885) (4)	100	C	M	472	686	970	NO	NO	NO
			F	574	711	894	NO	NO	NO
Dreike (1894) (5)	27	C	M	421	633	1013			
	23		F	340	526	856			
Bryant (1924) (6)	160	C	Both	305	625	864	Negative correlation		
	27		M	457	663	813			
	17		F	406	587	762			
Underhill (1955) (7)	65	C	M	488	638	785	NO	YES	
	35		F	335	592	716			
Backman (1974) (8)		C	Obese M	455	824	1193			
			Obese F	497	734	971			
			Non-obese M	365	698	1031			
			Non-obese F	361	616	871			
Guzman (1977) (9)	56	L	Obese	253	562	871			
	22		Non-obese	201	530	813			
Nordgreen (1997)(10)	40	L	M	380	591	1090	NO	YES	YES
	37		F	360	534	740	NO	YES	YES
Hounnou (2002) (11)	100	C	M	365	644	1000	Negative correlation	NO	YES
	100		F	280	573	840	Negative correlation	NO	YES
Hosseinpour (2008) (12)	54	L	M	285	459	619	NO	NO	N
	46		F	308	468	620			
Teitelbaum (2013) (13)	240	L	(113 M + 127 F)	285	506	845	NO	YES	NO

SBL = small bowel length (cm); C = cadaver data; M = males; F = females; L = live patient data

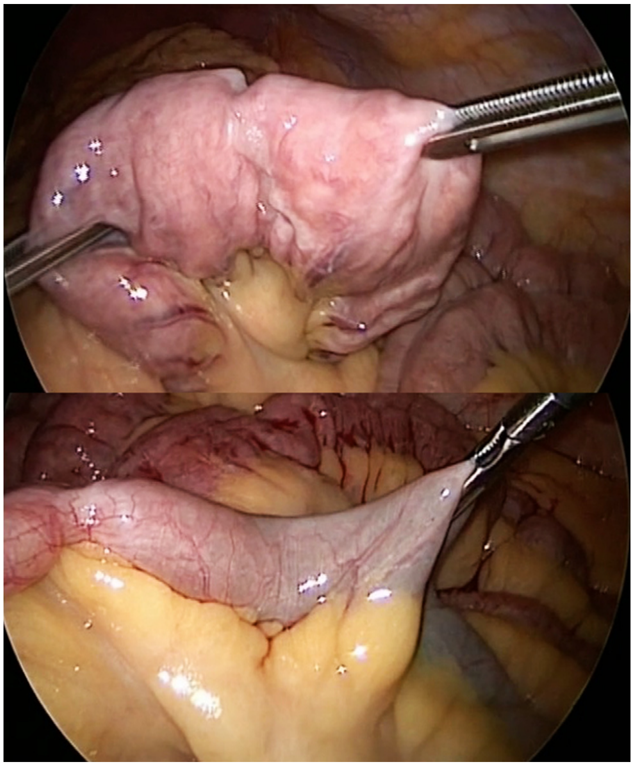

Fig. 1. Jejunum and ileum: morphological differences.

The number of valid cases and the number of missing values are reported. Repeatability was evaluated with a test-retest reliability coefficient.

Linear relationships between the variables were explored by Pearson's correlation test. To explore the causal relationships, univariate and multivariate linear regression analysis models were applied. Linear regression fitting to the model was used as a direct measure of sensitivity.

Statistical analysis was performed using Statistica (version 7.0, StatSoft, Tulsa, TX, USA).

Results

SBL was measured intraoperatively in 443 laparotomies. Of the included patients, 342 were females (78%). The study was terminated when the laparotomy approach was completely abandoned in favor of laparoscopy. The transition between the jejunum and ileum was clearly identifiable in all cases. The results were tested for normality of distribution to confirm the applicability of the parametric multiple linear regression (Table 2). The fully stretched SBL, the nonstretched SBL (SBLns), and the laparoscopic bowel length (SBLlap) showed a reliability coefficient of .94, .73, and .87, respectively. Fully stretched SBL versus SBLns showed a mean difference of 137 ± 19 cm (range 72–212 cm). The predictability of the stretched measure from the SBLns value was highly significant (SBL = 91.2 + 1.09 × SBLns, R^2 = .86, $P < .0001$). In 34 patients, laparotomy versus SBLlap showed a mean difference of 32.4 ± 11.4 cm (range 10–58 cm) (SBL = 21.3 + 1.02 × SBLlap, R^2 = .93, $P < .0001$). For the remaining analyses, we report data obtained with the full stretch measurement method.

Table 2
Description and distribution of anthropometric and demographic measurements

Variable	Mean	Minimum	Maximum	Standard deviation	Skewness	Kurtosis
Age	37.7	15.4	68.1	10.4	.23	-.64
Height (cm)	163.5	143.0	187.0	8.8	.30	-.25
Weight (kg)	128.1	75.0	230.0	27.4	.88	.85
SBL (cm)	690.1	350.0	1050.0	93.7	-.02	1.25
JLe (cm)	170.4	110	265	27.6	.46	.28

SBL = short bowel length; JLe = estimated jejunal length

Fig. 2 is a histogram of the SBL values with the normal distributions for the entire patient population and the male and female patient populations. Sex and height were correlated with SBL, as men had a longer SBL than women (729 ± 85 versus 678 ± 92, $P < .0001$) and were significantly taller (173 ± 8.2 versus 161 ± 6.9, $P < .001$). Age did not correlate with SBL. SBL positively correlated with weight ($r = .24$, $P < .0001$) as well as with JLe ($r = .27$, $P < .0001$). By univariate regression analysis, height was positively correlated with SBL ($r = .32$, $P < .0001$). This correlation did not differ significantly between the 2 sex subgroups.

A multivariate linear regression analysis model to predict SBL that included sex, age, height, and weight showed a significant correlation ($P < .00001$) and explained 12% of the variance in SBL: SBL=136.86 + 8.09 × Sex + .87 × Age + 2.93 × Height + .29 × Weight R^2 = .12 F(4,255) = 8.49 SEE = 86.26 Increased height was the only independent predictor of increased SBL ($P < .0005$).

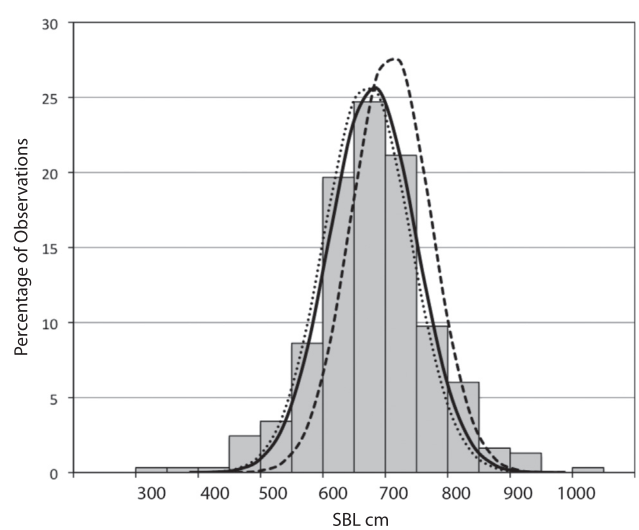

Fig. 2. Frequency distribution of small bowel length observations in 443 laparotomies. Dashed line, males. Dotted line, females.

For this reason, the causative relationships of weight with various anthropometric variables were evaluated in a multivariate model. Sex, age, height, and JLe were statistically highly significant in predicting 75% of the variance in body weight. SBL showed no significant correlation to body weight: Weight = -59.62 + 6 × Sex + 0.202 × Age -.653 × Height + .004 × SBL + .961 × JLe R^2 =.75 F(5,253) = 152.34 SEE = 13.77.

Discussion

For this cohort of 443 operative patients, we found a mean SBL of 690 cm. Conflicting data have been reported in the literature concerning SBL. The differences in SBL that we obtained with the nonstretched relative to fully stretched method may explain some of the variability of previous studies. Visceral smooth muscle is characterized by a state of continuous partial contraction referred to as tone. Tonicity can cause the SBL to be shorter in live patients than in cadavers. The SBLs obtained with the bowel fully stretched, 678 cm for females and 729 cm for males, were similar to those of the cadaver studies. In both cases, the tonicity of the bowel does not affect the SBL measurement. Therefore, we suggest using the fully stretched approach in order to obtain repeatable SBL values. When measurements were taken without stretching, we can still compare the values, if we know the relationship between the 2 measurement methods. Regarding the accuracy of laparoscopic measurements, even though the number of data comparisons in this study was few, we found that it is possible to obtain a reproducible measurement of bowel length during laparoscopy.

Predictors of SBL

Using univariate analyses to study the anthropometric determinants of SBL, we found that height and male sex, but not age or weight, were associated with a longer SBL. Height was the only anthropometric determinant that was a statistically significant predictor of SBL in the multivariate analysis. Thus, we can conclude that sex is not a predictor of SBL. Rather, height is correlated with sex; men have a longer bowel because they are taller than women. Taller subjects will also weigh more, explaining why weight does not have a causative correlation with SBL. The SBL of the obese group did not differ from that of the normal weight group, and no correlation was found between SBL and degree of obesity.

Predictors of weight

Height is an anthropometric determinant and predictor of SBL and weight. Taller subjects can have longer bowels and greater weights within normal BMI limits. Weight, however, is not a determinant of bowel length. A greater weight is only related to greater height and to weight gain above normal values, as in cases of obesity. Weight gain cannot determine an increased bowel length in individual subjects. Rather the opposite may be true: subjects with longer bowels could be predisposed to weight gain.

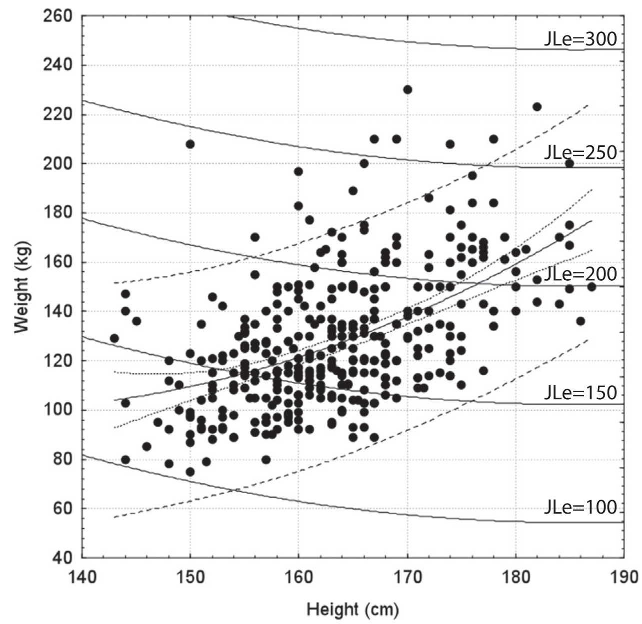

Fig. 3. Relationship between height, JLe, and weight. The best regression is plotted with its 95% confidence intervals, dotted lines. 95% prediction limits are represented by the dashed lines. Lines of constant JLe are also plotted. Height cm. Weight kg, JLe cm.
Weight = 387- 4.6 × Height +.0125 × $Height^2$ + .95 × JLe
R = .85 R^2 = .72 Adjusted R^2 = .71 F(3,295) = 246.87 $P < .0000$ Std. Error of estimate: 13.965

When we consider the determinants of weight, we see that sex, age, height and JLe are significant determinants of body weight. The sex effect is independent of height in accordance with anatomic and physiological data that attribute a larger body mass to the male sex. Additionally, the relationship of weight with age can be understood in terms of the progressive weight gain with age. SBL, however, did not predict weight, but JLe showed a very strong predictive power for weight. Overall 75% of the variance in body weight can be explained by these parameters. This is particularly interesting to observe in the obese patients (Fig. 3). The dashed lines represent the regression analysis relationship between height and weight. The continuous lines indicate different JLe. We can observe that obese subjects tend to have greater weight in relation to their height. For any given height, subjects with a longer JLe will be more obese, and for any given JLe, taller patients will have a lower weight.

Relevance for bariatric surgeons

There is debate in the literature on the importance of limb length in Roux-en-Y gastric bypass (RYGB) in relation to weight loss results, occurrence of malnutrition and resolution of comorbidities, diabetes in particular [3,7,20–23].

Short bowel syndrome can be the consequence of an intestinal resection large enough to induce nutritional disorders [24]. Malabsorption and diarrhea will be dependent on the extent of resection, whether the terminal ileum is preserved, and the function of the remaining small bowel and the ability of the shortened intestine to undergo functional adaptation. Bariatric surgeons do not normally resect portions of the bowel, but, rather, exclude them from the intestinal continuity, bypassing significant portions of the intestine and, thus, mimicking a proximal bowel resection. The resulting physiology and the consequences of the procedure can be similar to that which occurs in patients after short bowel syndrome.

The distribution of SBLs in the male and female subjects shows that a significant number of subjects (3% of females and 2% of males) have SBLs shorter than 400 cm. In 15% of males and 5% of females the SBL was longer than 800 cm. This significant number of patients poses a potential problem for bariatric surgeons. Techniques such as RYGB with biliary and alimentary limbs of 2 meters, distal RYGB, long biliary limb RYGB, minigastric bypass, duodenal switch, biliopancreatic diversion, duodenojejunal bypass, and other novel procedures could result in a short absorptive bowel [21,25–34].

RYGB is still the most commonly performed procedure worldwide. Even in the case of very short limbs it is associated with a well-documented limitation of absorption. Mason et al. [35] first demonstrated a reduction of biliopancreatic secretions and Ponsky et al. [36] recently confirmed this mechanism as a contributing factor to weight loss. Only mono- and disaccharides can be absorbed in the alimentary limb, as in the absence of biliopancreatic secretions no complex carbohydrate can be absorbed. Malabsorption of fat and related fat-soluble nutrient are a clinical consequence of the procedure, which intestinal adaptation can only partially compensate [37]. Although there is insufficient literature evidence to favor better weight loss with a longer alimentary Roux limb, the increase in nutritional complications is more strongly documented [3,7,20–23]. Thus, while 2 meters of bowel could be sufficient in normal gastrointestinal continuity, it might not be after a RYGB with excessively long limbs. Another growing category at risk is represented by the revisional surgery for failed RYGB or sleeve gastrectomy. Revision usually implies elongating the existing bowel limbs or adding a gastro ileal anastomosis. Also in this case, attention should be paid to the total SBL. A significant number of nutritional deficiencies are reported after the revisions [38–44].

Finally, there are the so-called "metabolic procedures". Many authors are changing the limb lengths to improve the metabolic results of diabetes [3,45–50]. Numerous animal and human studies report a significantly better control of diabetes with long biliary limbs. There are also a growing variety of operations proposed for metabolic purposes that manipulate and rearrange the bowel anatomy. This is a small number of patients but at even higher risk of nutritional consequences.

The strong correlation of JLe with weight, and thus possibly with nutrient absorption, is first reported by our study and should be investigated further. The individual JLe and the bypassed length could play a role in the resolution of metabolic diseases. The cases of surgical importance are obviously those in the group with an abnormally short small gut. In such patients, the exclusion of what would in the average person be a perfectly "safe" length may leave them with a grossly inadequate absorptive surface.

The limitations of the report can be the definition and reproducibility of the jejunal measurement. The size of the sample representative of a wide range of patient anthropometric characteristics can compensate for individual measurement errors.

The period of overlap between the laparotomic and laparoscopic technique was short. For this reason the sample size used for comparison is small, but we believe it is sufficient to confirm that a reproducible measurement can be obtained also in laparoscopy. Although SBL measurement was continued also when switching to the laparoscopic technique we reported only the laparotomic data because a single surgeon did all patients thus eliminating a possible confounding factor.

Conclusion

To summarize, our results suggest that accurate and reproducible measurements of bowel length can be obtained in laparotomy and laparoscopy. Bariatric surgeons can choose between different measurement methods, the fully stretched method being the most repeatable.

There appears to be a positive association between height and SBL, and obese subjects do not have a longer SBL. Sex, age, height, and JLe may be strong predictors of weight.

Caution should be applied when performing malabsorptive and revisional procedures, as significant number of patients will have a small bowel short enough to risk nutritional consequences. In these bariatric and metabolic surgeries, it is wise, therefore, to measure the length of the bowel that remains distal to the excluded segment, rather than to infer its length after measuring the excluded portion. Given the interrelationship between different limb lengths elongating alimentary or biliary limb will shorten the common limb. The measurement of SBL can help to interpret the results of different procedures. Finally further investigation on the importance of JLe on weight loss and metabolic effect is necessary.

Disclosures

The authors have no commercial associations that might be a conflict of interest in relation to this article.

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