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Original Article

Variation in small bowel length: Factor in achieving total enteroscopy?

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Background and Aim: Estimation of small bowel length is of interest following the recent development of device-assisted enteroscopy. This new technology allows access to the deep small bowel, but rates of examination of the entire small bowel (total enteroscopy) differ between study populations. Variation in small bowel length could factor into this observed irregularity in total enteroscopy rates. Medical literature contains limited information regarding small bowel length in living patients and conflicting data regarding small bowel length and its relationship to height and weight. We carried out small bowel measurements on surgical patients to further define the total length of the small bowel and its relationship to height, weight and body mass index (BMI).

Methods: Measurement of ileojejunal length on 91 surgical patients undergoing laparotomy for routine indications. Demographic data were collected for each subject, including height, weight and BMI.

Results: Small bowel length was found to vary widely between individuals (average 998.52 cm, range 630–1510 cm). Linear regression analysis demonstrated a statistically significant relationship between small bowel length and height (regression coefficient = 0.0561, *P*-value = 0.0238). A linear relationship between small bowel length and weight or BMI was not observed.

Conclusions: Length of the small bowel in humans is pertinent to advances in deep enteroscopy and existing surgical applications such as intestinal bypass and prevention of short gut syndrome. If average small bowel length varies with height, total enteroscopy may be easier to achieve in patients who are short in stature.

Key words: device-assisted enteroscopy, ileojejunal length, small bowel length, small intestinal length, total enteroscopy

INTRODUCTION

ESTIMATION OF SMALL bowel length has been relevant for many years in the planning of small bowel resections, as the development of malabsorption is closely related to the total length of small intestine that remains after surgery.[1] In recent years, the development of endoscopic techniques such as double-balloon, single-balloon and rotational enteroscopy have enabled access to the jejunum and ileum by pleating the small bowel onto a plastic overtube. These technologies have generated a renewed interest in small bowel length estimates, as length (in cm) is the primary indicator for location within the bowel. In addition, total small bowel length likely impacts success in attempts to visualize the entire small intestine (total enteroscopy) by device-assisted enteroscopy (DAE).

Distal to the ligament of Treitz, the small intestine is divided into two segments with the proximal 40% as jejunum and the distal 60% as ileum.[2] Anatomical study of the small bowel reveals subtle changes in small bowel caliber and number of valvulae between these segments, but these are not highly accurate for endoscopic orientation. As a result of this lack of reliable visual landmarks, endoscopists currently estimate location in the small intestine by number of centimeters distal to the ligament of Treitz (peroral/anterograde approach) or proximal to the ileocecal valve (peranal/retrograde approach) combined with an estimate of average ileojejunal length derived from antiquated cadaver studies. Examination of the entire length of small bowel is frequently attempted using both approaches but is often unsuccessful.[3,4] In situations where total enteroscopy is required, total ileojejunal length is of major importance as only a finite amount of small intestine can be examined by DAE.

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Table 1 Demographics of study population†

Sex (M/F)	51/40
Height (cm)	166.66 ± 10.16
Weight (kg)	81.72 ± 23.42
BMI	29.45 ± 8.38

†*n* = 91 subjects for all measurements.
BMI, body mass index.

METHODS

FOLLOWING INSTITUTIONAL REVIEW board (IRB) approval, measurements of small bowel length were carried out on adult subjects undergoing laparotomy for routine indications between July 2010 and August 2011 at St. Vincent's Medical Center (Bridgeport, CT, USA). All measurements were done by the same surgeon observer to ensure no variability related to observer or technique using a standardized method as described by Backman and Hallberg.[5] The small bowel was measured from the ligament of Treitz to the ileocecal valve using a sterile, flexible 10-centimeter ruler along the antimesenteric side of the splayed bowel. Minimal bowel manipulation was carried out and measurements were done immediately upon entry into the abdomen to reduce the effect of temperature and anesthesia. The antimesenteric border was used because it is the most easily reproducible and variable in terms of length, as it is not anchored by the mesentery. Patients with excessive abdominal adhesions, infectious peritonitis, or a history of previous small bowel surgery were excluded from the study. In addition to documentation of small bowel measurements, demographic data were collected for each subject including height, weight and body mass index (BMI) (Table 1). Data were entered into Microsoft Excel data files, summarized and analyzed using programs and procedures in the Statistical Analysis System (SAS; SAS Institute, Cary, NC, USA). Simple linear regression was done using least squares and analysis of regression techniques.[6]

RESULTS

A TOTAL OF 91 subjects were included in the present study with all measurements completed by the same observer per protocol. No adverse events related to study participation were observed. Average small bowel length in our population was found to be 998.52 cm with a standard deviation of 168.95 cm. As observed in previous studies, small bowel length was found to vary widely between individuals with the shortest measurement observed to be 630 cm and the longest measurement observed to be 1510 cm. (Table 2)

Table 2 Results of small bowel measurements†

Mean (cm)	998
SD (cm)	± 169
Range (cm)	630–1510

†Ileojejunal length.

Linear regression analysis was carried out to evaluate the relationship of small bowel length with height, weight and BMI. A statistically significant linear relationship was found between small bowel length and height ($R^2 = 0.056$, $P = 0.0238$). The linear regression model in Figure 1 depicts this relationship. The relationship between BMI and small bowel length was also characterized as a linear relationship but was not statistically significant ($R^2 = 0.0089$, $P = 0.3736$) (Fig. 2). An analysis of the relationship between small bowel length and gender was carried out with demonstration of a positive correlation. However, as in previous studies that demonstrated a positive relationship between small bowel length and gender, this correlation was considered to be a function of height.

When subjects were divided into two study groups by measured height above or below the US average height of 176.3 cm,[7] average small bowel length was 992.51 cm in the shorter than average group (SD 158.43 cm) and 1024.65 cm in the taller than average group (SD 212.47). The linear relationship between small bowel length and height was strongest in the shorter than average group ($R^2 = 0.1286$, $P = 0.0017$) compared to the taller group ($R^2 = 0.0087$, $P = 0.7221$). The data also indicate that there is a threefold improvement in the relationship between small bowel length and height in shorter subjects (<165 cm), and also shows that for height <165.1 cm there is a 13.72 unit increase in small bowel length for every unit increase in height. This suggests that height is a more reliable predictor of small bowel length in individuals below the population height mean.

DISCUSSION

PUBLISHED RESEARCH INVOLVING small bowel length consists of multiple protocols and study populations as summarized in Table 3. The most commonly quoted small bowel length estimate is derived from antiquated autopsy studies that calculated small bowel length to average approximately 600 cm, although wide variability between individuals was observed even in these early studies.[8,9] Some researchers have found a positive correlation between small bowel length and height, whereas others have not. Autopsy studies in infants and children clearly demonstrate that small bowel length increases progressively with height as children grow. However, there is some disagreement regarding

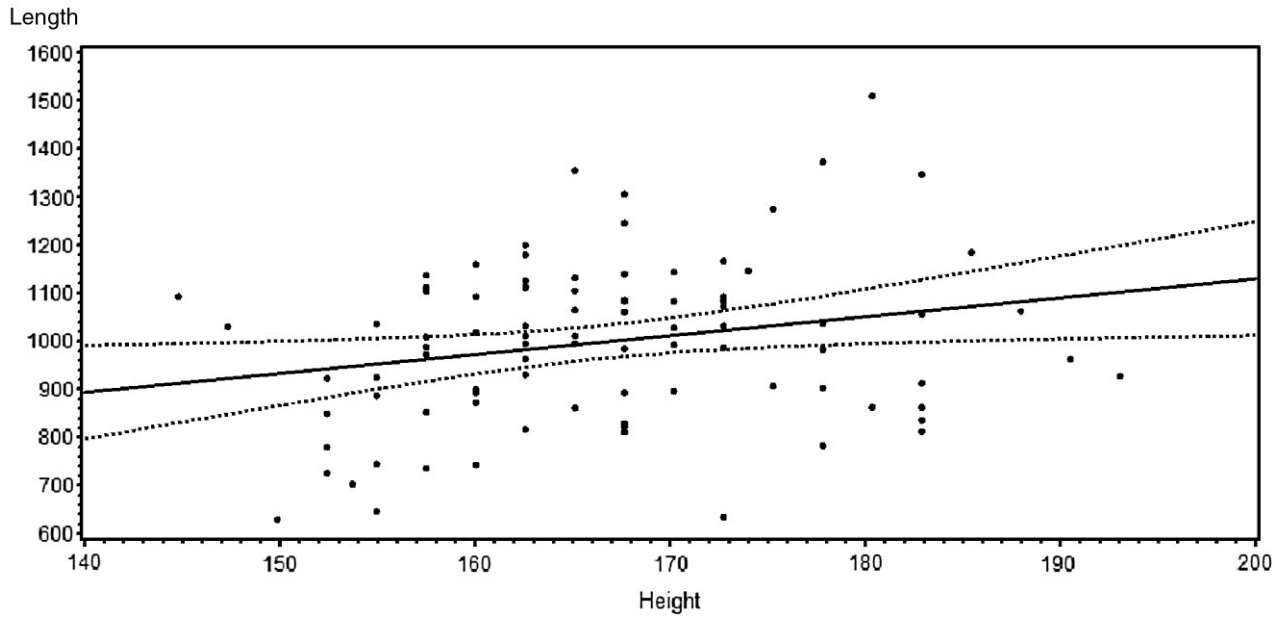

Figure 1 Linear regression model of small bowel length *vs* height. Values are confidence limits for the mean.

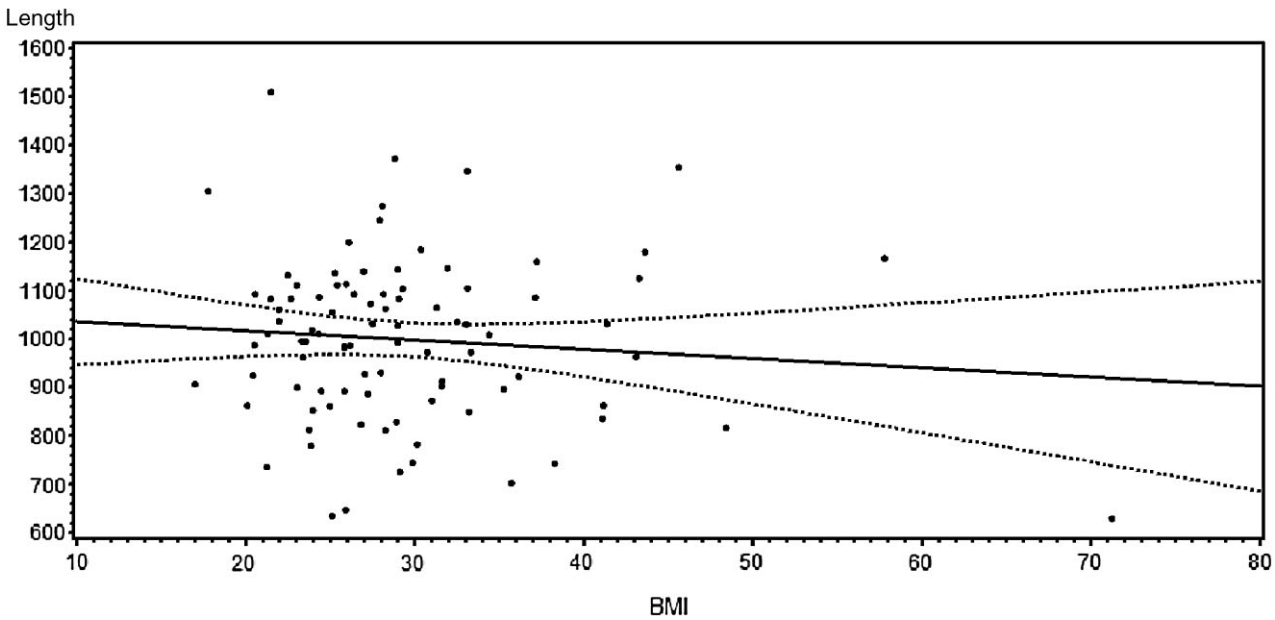

Figure 2 Linear regression model of small bowel length *vs* body mass index (BMI). Values are confidence limits for the mean.

whether this progression continues in adolescence and early adulthood to correlate with adult height.[10,11]

Subsequent radiographical studies of small bowel length were carried out in living adults as a result of concerns about the accuracy of small bowel measurements with loss of muscle tone in cadavers. In 1956, Hirsch *et al*. carried out small bowel measurements using a balloon-tipped catheter passed through the nose and entire digestive canal in 10 patients with an average estimated jejunoileal length of 261 cm (range 206–329 cm).[12] Two studies of small bowel length by barium examination then found average ileojejunal length to be 280–291 cm and one of these demonstrated a

Table 3 Studies of small bowel length in adults

Study	Subject	Measurement	No. subjects	Small bowel length	Linear relationship with height	Linear relationship with weight or BMI
Bryant (1924)[8]	Cadavers	Autopsy	160	611 cm SD ± 100 cm	Negative	NA
Underhill (1955)[9]	Cadavers	Autopsy	100	599 cm (range 335–762 cm)	Positive	NA
Hirsch *et al*. (1956)[12]	Living adults	Enteral catheter	10	261 cm (range 206–329 cm)	NA	NA
Fanucci *et al*. (1984)[13]	Living adults	Barium radiography	10	280 cm (range 230–370 cm)	Positive	Positive
Fanucci *et al*. (1988)[14]	Living adults	Barium radiography	158	291 cm (range 160–430 cm)	NA	NA
Backman & Hallberg (1974)[5]	Living adults	Operative	56 (obese)	755 cm (range 575–1022 cm)	Positive	Positive
			32 (control)	657 cm (range 400–846 cm)		
Guzman *et al*. (1977)[16]	Living adults	Operative	272 (obese)	512 cm SD ± 95 cm	NA	Negative
			121 (control)	525 cm SD ± 91 cm		
Nordgren *et al*. (1997)[17]	Living adults with IBD	Operative	279 (CD)	460 cm SD ± 93 cm (range 280–740 cm)	Positive	Positive
			315 (UC)	528 cm SD ± 95 cm (range 310–830 cm)		
			77 (control)	564 cm SD ± 111 cm (range 360–1090 cm)		
Hosseinpour & Behdad (2008)[18]	Living adults	Operative	100	459.6 cm SD ± 78.5 cm (range 285–620 cm)	Negative	Negative
	Cadavers	Autopsy	30	632.5 cm SD ± 89 cm		

CD, Crohn's disease; IBD, irritable bowel disease; NA, not available; UC, ulcerative colitis.

statistically significant correlation between ileojejunal length and bodyweight.[13,14] The accuracy of measurement of small bowel segments by barium examination was confirmed by surgery in one study but the sample size was small and measurements were found to be accurate only when the bowel segment was less than 250 cm in length.[15]

Operative measurements have been done in four previous studies. Backman and Hallberg measured ileojejunal length in 56 obese patients during small intestinal shunt procedures and in 32 controls with measurements averaging 755 cm (range 575–1022 cm) and 657 cm (range 400–846 cm) in the two groups, respectively. A significant correlation was found between small bowel length and BMI as well as patient height.[5] Guzman *et al*. carried out measurements during jejunoileal bypass in 272 obese patients and 121 non-obese patients with hyperlipidemia. Total small bowel length averaged 512 cm (SD 95 cm) in the obese group and 525 cm (SD 91 cm) in the non-obese, hyperlipidemic group. No significant correlation was found between small bowel length and age, sex, or BMI but height was not recorded.[16] A study on inflammatory bowel disease found that patients with Crohn's disease had significantly shorter small bowel measurements compared to controls, and also found a statistically significant correlation between ileojejunal length and height as well as weight.[17] Recently, a study of ileojejunal length in 100 patients undergoing laparotomy compared to 30 cadavers found average small bowel length was 459.6 cm (SD 78.47 cm) in living patients versus 632.5 cm (SD 88.9 cm) in cadavers, but there was no correlation found regarding patient age, sex, height, or weight.[18]

Compilation of published research regarding small bowel length in humans clearly demonstrates that small bowel length varies considerably between individuals, although the factors influencing these variations are unclear. The results from our study and summary of data from previous studies are compelling for a linear correlation between small bowel length and height, likely as a function of small bowel lengthening that accompanies growth during childhood and adolescence. Variation between average small bowel lengths among previous studies could be attributed to a number of factors, including subject type (cadaver *vs* living adult), method of measurement and subject characteristics such as

height, weight, BMI and environmental factors dictated by geographical location and lifestyle. The difference between the average small bowel length defined in this study and the average length reported in studies of populations in Europe and Iran suggests that environmental factors may have a major impact on average small bowel length. It is also possible that the studies that failed to observe a linear relationship between small bowel length and height or weight did not include enough variability in the study population to detect these relationships.

Research involving small bowel length is significant in a number of different settings. In patients undergoing intestinal resection, the length of bowel remaining after resection is the best predictor of short gut syndrome; therefore, individual bowel length should be measured in all patients undergoing resection.[19] Intraoperative measurement of total small bowel length might also affect the length of intestine that should be bypassed in patients undergoing surgery for weight loss.

As the use of DAE to access the deep small bowel becomes more common, our understanding of small bowel length is of renewed importance. The length of the small intestine is likely a major factor not only in our ability to achieve total enteroscopy, but also in estimating the amount of bowel that remains to be examined after incomplete procedures. In a recent meta-analysis of double-balloon enteroscopy (DBE) studies, the pooled success of total enteroscopy was found to be only 44%.[20] Reported rates of total enteroscopy vary greatly between populations with quotes of 86% success in Japan,[3] yet these rates were not reproduced in European populations.[21–23] Interestingly, average height in Japan (171 cm in men and 157 cm in women) is significantly less than average height in Germany (178 cm and 165 cm respectively).[24]

Study of factors affecting success in total enteroscopy thus far involve DAE technique and operator experience. The DBE technique has been found to be superior to single-balloon enteroscopy (SBE) with total enteroscopy rates of 66% versus 22% in a prospective multicenter trial[25] and 57% versus 0% in another trial.[26] Procedural experience in enteroscopy is also a likely factor influencing total enteroscopy rates. In one study by Gross and Stark, the total enteroscopy rate using DBE was 8% in the first 50 studies and 63% after 150 studies.[27] Finally, obesity has been theorized to be a factor in successful manipulation of the small bowel by DAE as retroperitoneal fat may fix the small bowel in place preventing adequate pleating (K. Bhattacharya, pers. comm., 2010).

It is evident that there is great variability in small bowel length between individuals. As endoscopic examination of the small bowel becomes increasingly common, our ability to predict small bowel length becomes ever more important. Specifically, with regards to DAE, the success rate of total enteroscopy may be impacted not only by procedural technique and experience, but also by the length of the small bowel. The present study shows a statistically significant positive correlation between small bowel length and height, and this relationship strengthens for shorter individuals. These data imply that patient height may be a predictor in achieving total enteroscopy in individual patients and may affect total enteroscopy success rates reported from the study of different populations.

CONFLICT OF INTERESTS

AUTHORS DECLARE NO conflict of interests for this article.

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