✶IFSO®

ORIGINAL CONTRIBUTIONS

Check for updates

Limb Length in Gastric Bypass in Super-Obese Patients—Importance of Length of Total Alimentary Small Bowel Tract

Kamran Shah[1] 🄳 · Bent Johnny Nergård[1] · Morten Wang Fagerland[2] · Hjörtur Gislason[1]

Abstract

Background In super-obese patients, rates of weight loss failure and weight regain are high after RYGB. In order to improve weight loss, lengthening of the biliopancreatic limb is vital. In this study, efficacy and safety of two types of RYGB with 2-m BP-limb were assessed in improving weight loss and in the resolution of comorbidities compared with standard RYGB in a long-term follow-up.

Methods This is a retrospective cohort analysis on 671 super-obese patients operated in a 10-year period. Patients were classified into three groups: (1) 155 patients; roux limb 150 cm, BP-limb 60 cm; (2) 230 patients; roux limb 60 cm, BP-limb 200 cm; and (3) 286 patients; roux limb 150 cm, BP-limb 200 cm. EWL, TWL, BMI, failure, weight regain, comorbidity resolution, nutritional status, and complications were assessed.

Results Total alimentary limb length was shortened with 60 cm in group 1 and with 200 cm in groups 2 and 3. EWL, BMI change, and TWL were higher in the 2-m BP-limb groups vs group 1. No differences in complication rates were found, except higher frequency of marginal ulcers in patients with a shorter roux limb. EWL failure was higher in group 1 (10.3%) vs the other groups (4.3%; 5.2%). Group 3 had significantly less weight regain (26.6%). Remission of comorbidities was higher in the 2-m BP-limb groups at expense of nutritional and vitamin deficiencies (3.9%; 5.9%). No difference in hypoalbuminemia was noted.

Conclusion Lengthening of the BP-limb gives significantly higher weight loss, lower rate of EWL failure, and lesser weight regain along with better resolution of obesity-associated comorbidities.

Keywords Gastric bypass · RYGB · Limb length · Super-obese · Biliopancreatic · Total alimentary small bowel tract

Background

The rising prevalence of obesity has been described as a global pandemic [1] and worldwide prevalence of overweight and obesity combined has risen by 27.5% for adults between 1980 and 2013 [2]. Super-obesity, defined as ≥ 225% of the ideal body weight [3], thus having a BMI ≥ 50 kg/m², is increasing five times faster than other obesity categories with a sixfold increase in the last 15 years of the twentieth century [4].

✉ Kamran Shah
kamranshaah@gmail.com

[1] Aleris Obesity Clinic and Department of Surgery, Aleris Hospital, Fredrik-Stangsgate 11–13, 0264 Oslo, Norway

[2] Oslo Centre for Biostatistics and Epidemiology, Research Support Services, Oslo University Hospital, Oslo, Norway

The prevalence of obesity-related comorbidities such as type 2 diabetes (T2DM), metabolic syndrome (MetS), and cardiovascular diseases is more frequent in patients with BMI above 50 as compared with lesser degrees of obesity [5]. Solution-wise, laparoscopic Roux-en-Y gastric bypass (LRYGB) generally produces significant and sustained weight loss [6, 7]; however, in super-obese patients, high weight loss failure rates are a serious problem [7–10]. Some studies report up to 34.9% weight loss failure for super-obese patients compared with 20.4% for morbidly obese patients in a 10-year follow-up [11].

In order to account for this, novel procedures such as SADI-S (single anastomosis duodenoileal bypass with sleeve gastrectomy), SASI (single anastomosis sleeve ileal bypass), and OAGB (one anastomosis gastric bypass) are gaining ground along with more malabsorptive procedures like biliopancreatic diversion with duodenal switch. The latter has been performed on super-obese patients with greater weight loss than LRYGB [7]. Moreover, in a large cohort study, the risk of weight loss

failure is significantly reduced with duodenal switch with a rate of 6% 2 years postoperatively [12]. However, this is at the expense of an increased rate of protein and nutritional deficiencies and gastrointestinal side effects on short-/mid-term follow-up [13] and long-term follow-up [14] as well as increased rates of early complications and perioperative mortality [15].

Different variations of distal gastric bypass have also been performed on the super-obese patients with varying results with no real consensus on the length of bypassed intestines and the relationship between the different limb lengths [16]. Several studies with low number of included patients focus on the ratio between the Roux limb and the common channel without changing the length of the total alimentary limb length (TALL). This has been associated with a high risk of complications, high rates of malnutrition and vitamin deficiencies, and no notable difference in BMI reduction between the distal gastric bypass and the standard gastric bypass [17–21].

In this study, we aimed at investigating long-term results of RYGB with 2-m biliopancreatic limb with varying Roux limb length (60 vs 150 cm) while maintaining the same total alimentary limb length and compared these to the standard gastric bypass. TALL was shortened with 140 cm in the 2-m BPL groups. TALL is defined as the added value of the Roux limb and the common channel and is also denoted by the total alimentary small bowel tract. Primary outcome was defined as weight loss changes expressed in excess weight loss (EWL), BMI change, and total weight loss (TWL%). Secondary outcome was defined as resolution of comorbidities. Furthermore, we investigated whether a better weight loss change came at the expense of a higher rate of vitamin and nutritional deficiencies.

Methods

This study is a retrospective analysis of prospectively collected data on patients who underwent bariatric surgery from January 2006 to November 2015 at a private high-volume center, Aleris Hospital, Oslo, Norway. Guidelines from the Interdisciplinary European Guidelines on Surgery for Severe Obesity were used as indication for operation, including BMI > 40 kg/m^2 or BMI > 35 kg/m^2 with concurrent comorbidities such as metabolic disorders, cardio-respiratory disease, or severe joint disease. A total of 3896 bariatric operations were performed at our center in this period.

Our standard gastric bypass was done with a Roux limb (RL) of 150 cm and biliopancreatic limb (BPL) of 60 cm as described previously [22]. Propensity score matching was done to the surgical population with only a criterion of BMI ≥ 50 preoperatively and BMI ≥ 48 at operation, in order to create a standard gastric bypass reference group (group 1). Revisional operations and other types of gastric bypass operations were excluded. A number of patients were operated

with variations in the length of the BPL and the RL as our hypothesis stipulated that higher rates of excess weight loss percentages would be achieved. The variations included an elongation of the BPL to 200 cm with concomitant reduction of the RL to 60 cm (group 2), or an elongation of the BPL to 200 cm while keeping the RL at 150 cm (group 3). The variations in the limb lengths were done primarily on super-obese patients. Amongst the selection criteria for varying the limb lengths were age < 50 years and patients living locally (not farther than 100 km from the hospital) due to the Norwegian geography in order to reduce the number of patients lost to follow-up.

Multidisciplinary approach from gastroenterologists, surgeons, nurses, and dieticians was initiated from the patient's first visit. Written informed consent for the participation in research was obtained. Preoperative fasting blood analyses were taken prior to the initiation of intensive dietary and nutritional changes. Before the operation, the patients attended a whole day information and lifestyle modification course. Fast-track settings and enhanced recovery after surgery (ERAS) protocol were applied as described previously [23].

Clinical data were prospectively collected and registered in our database (FileMaker 11) as part of our routine patient record system, approved by The Norwegian Data Protection Authority. Data included registration of metabolic status preoperatively, 3 months and 1 year postoperatively, and hence every second year.

Statistical Methods

Statistical analyses were performed using SPSS for Windows, version 22.0, and StataSE version 15. Values were reported as mean + standard deviation if not mentioned otherwise. Comparison between groups was made with one-way ANOVA, t test, or chi-square test. A p value < 0.05 was considered statistically significant. The repeated measures of excess weight loss (range 2 to 23 measures per patient) were analyzed with a linear mixed model, with fixed effects for group, time, and group x time interaction, and a random intercept. Time was modeled as piecewise linear with two knots at 20 and 40 months after operation. Based on the fitted model, group means at 2, 5, and 10 years and between-group differences at 2, 5, and 10 years were estimated with 95% confidence intervals. Propensity score matching was initially done with several degrees of matching to the different covariates in order to obtain three perfectly aligned subpopulations. However, we found that the number of patients was heavily reduced and thus statistical power likewise. Also, possible selection bias was introduced and thus propensity matching was done with the only criteria of BMI ≥ 50 for the standard gastric bypass.

Results

A. (Patient Material, Short-Term Data, and Perioperative Results)

A total of 671 super-obese patients operated in a 10-year period from January 2006 were included in the study. Patients were classified into three groups according to the variation in limb length, see Table 1 and Fig. 1. The lengths of RL and BPL were fixed numbers, while the length of CL was an approximation based upon mean estimated values as the total small bowel limb length from previous studies was mean 620 cm (range 420–870). Baseline characteristics preoperatively are listed in Table 2. BMI at initial patient contact was noted and prior to surgery a mean reduction of two BMI points took place in all three groups. The difference in mean BMI at surgery between groups 1 and 2 was significant (51.4 vs 49.3, $p < 0.0001$) while it was non-significant between groups 1 and 3 (51.4 vs 51.0, $p = 0.312$).

Groups 1 and 3 were deemed comparable in terms of basic anthropometrics; thus, no statistically significant differences were found regarding gender, weight, waist circumference, or mean follow-up. Patients in group 2 had a lower weight than group 1 (144 kg vs 151 kg, $p = 0.006$), smaller waist circumference (135 cm vs 144 cm, $p > 0.0001$), and a higher representation of female patients (0.78 vs 0.63, $p = 0.001$). Follow-up was longer in group 2 (125 months) vs. group 1 (91 months) and group 3 (73 months). Patients in group 1 were slightly older (42.2 years) than in group 2 (39.5 years) and group 3 (37.1 years). Distribution of obesity-related comorbidities (hypertension, type 2 diabetes, and obstructive sleep apnea) is shown in Table 2.

Length of mean surgical time was almost the same in groups 1 and 3 (49 min vs 47 min, $p = 0.245$) while it was longer in group 2 (58 min, $p < 0.0001$), see Table 3. No difference in days of hospitalization was noted between groups 1 and 3 (1.9 days vs 1.8 days, $p = 0.375$). Patients in group 2 were hospitalized for a longer period (2.5 days, $p < 0.0001$).

No difference in short-term complication rates was noted (Table 4) between groups.

The number of readmissions for the patients included in this study was 104/671 (15.5%) and did not differ amongst

Table 1 Length of different intestinal limbs in cm

Groups	No. of patients	A-limb	BP-limb
1	155	150	60
2	230	60	200
3	286	150	200

All operations were done with a small gastric pouch, antegastric antecolic Roux-en-Y gastric bypass, closure of mesenteric effects from October 2010, floppy entero-entero anastomosis. Variations of limb lengths were done according to the above table

A, alimentary (fixed); *BP*, biliopancreatic (fixed)

the different groups. Seventy percent of these were due to actual dehydration or fear of dehydration in the immediate postoperative period and the relatively high number is due to internal policy guidelines that dictate if patients do not daily partake at least 1.5 l fluids orally in the first 2 weeks after surgery; they must be administered iv fluids in the hospital.

B. (Long-Term Data, Effect of Surgery)

Mean follow-up differed significantly between the groups: 91 months in group 1, 125 in group 2, and 73 in group 3.

As shown in Fig. 2 and Tables 5, 6, and 7, significant difference ($p < 0.001$) in excess weight loss (EWL, expressed in percentage) was noted when comparing both groups 2 and 3 with group 1 in the first 10 years after surgery. After 2 years, EWL was 76.8% in group 1 (95% CI, 74.0–79.5) compared with 90.8% in group 2 (95% CI, 88.6–93.0) and 88.8% in group 3 (95% CI, 86.8–90.9). After 5 years, the statistical difference holds ($p < 0.001$) and after 10-year follow-up ($p < 0.001$), the EWL is 56.7% in group 1 (95% CI, 52.6–60.8), 64.8% in group 2 (95% CI, 62.3–67.2), and 68.4% group 3 (95% CI, 64.7–72.1). The same tendency is seen regarding BMI change with significant better results in groups 2 and 3 vs group 1 and with no significant difference between groups 2 and 3. TWL% follows the same pattern except at 10-year follow-up comparison between groups 1 and 2, where the difference is not considered significant (2.45 (95% CI, − 0.12 to 5.03); $p = 0.062$).

Excess weight loss failure and weight regain are shown in Table 8. EWL failure is defined as not reaching the 50% threshold of EWL% or BMI ≥ 33 and weight regain is defined as gaining more than 15% of nadir weight achieved. No difference in EWL failure was found between groups 2 (4.3%) and 3 (5.2%) ($p = 0.637$). However, when compared with group 1 (10.3%), EWL failure is significantly less in groups 2 and 3 ($p = 0.022$ and 0.046, respectively). Weight regain occurred in all groups and was similar in group 1 (41.3%) and group 2 (46.1%); however, weight regain occurred much less in group 3 (26.6%, $p = 0.002$). Difference holds also when comparing weight regain between groups 2 and 3 ($p < 0.001$).

Remission rate of hypertension, type 2 diabetes, and dyslipidemia after 10 years was higher (Table 9) in groups 2 (58.8%, 79.2%, 94.2%) and 3 (74.6%, 87.5%, 88.1%) vs group 1 (47.4%, 60.8%, 70.2%). Resolution of obstructive sleep apnea was higher in group 3 (96.8%) vs groups 1 (73.9%) and 2 (70.0%).

No difference in long-term complication rates was noted (Table 4) between groups. The occurrence of internal hernia did not differ significantly. Classified under other complications, one patient had pulmonary embolism 7 weeks after surgery in group 2. In group 3, one patient had a deep vein thrombosis and another achalasia needing surgery.

Albumin, vitamin A, vitamin B_{12}, vitamin D, iron, and ferritin were assessed at regular follow-up with a median follow-up of 96 months. Malnutrition necessitating high-
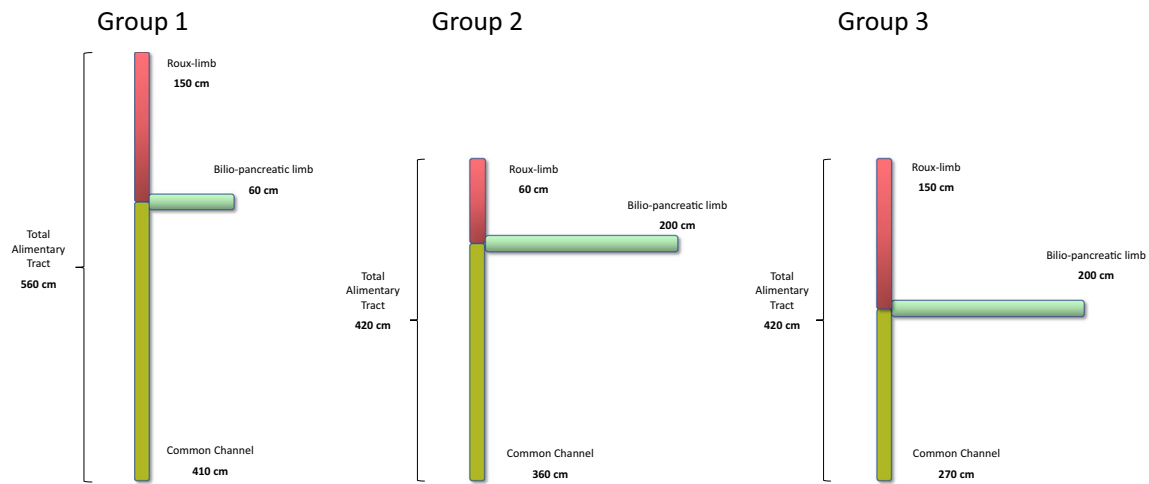
Group 1 Group 2 Group 3

Fig. 1 Schematic drawing of limb lengths in the included groups. In all groups, the length of the Roux limb and the biliopancreatic limb was fixed, while the length of the common channel and the total alimentary limb length are estimated mean values with some variation interpatient-wise based upon the measuring of a large number of patients.

dose enteral or parenteral treatment occurred more frequently in group 3 (5.9%, $p = 0.005$) compared with group 1 (0.6%) (Table 4). Even though higher rate of malnutrition was noted in group 2 (3.9%), it was not considered significant ($p = 0.055$) as compared with group 1. Comparing group 2 with 3, no statistically significant difference could be detected ($p = 0.319$). The most frequent nutritional deficiency was low iron values and six patients in both group 2 and 3 needed iron intravenously before plasma levels normalized. In groups 2 and 3, restoration of normal D-vitamin levels necessitated high doses of oral intake of vitamin D. In addition, two patients in group 3 also needed high oral intake of vitamin A.

No significant difference between the groups was noted in the occurrence of hypoalbuminemia ($p = 1.000$ and $p = 0.543$).

Seventeen deaths occurred in the follow-up period, none related to the bariatric surgery. One patient in group 2 underwent a ventral hernia operation at another hospital and died of postoperative complications not related to the obesity operation. Another patient in group 2 died due to a mortal knife wound attack. Majority of the other deaths were however due to cancer diseases. Overview of the number of patients available at each follow-up point is compared with the number of patients actually seen in Table 10.

Discussion

Are the Groups Comparable in the Present Study?

This study is a retrospective analysis of prospectively collected data on super-obese patients undergoing gastric bypass at

Table 2 Patient demographics at baseline for the different groups ($n = 671$)

	Group 1 ($n = 155$)	Group 2 ($n = 230$)	p value	Group 3 ($n = 286$)	p value
Mean follow-up, months[a]	91 (5–151)	125 (95–153)	< 0.0001	73 (22–147)	< 0.0001
Age, year[a]	42.2 (17–75)	39.5 (18–67)	0.026	37.1 (17–69)	< 0.0001
Female/male, ratio[b]	0.63 (98/57)	0.78 (180/50)	0.001	0.66 (189/97)	0.548
Weight, kg[a]	150.9 (108–263)	143.6 (109–205)	0.006	151.3 (107–218)	0.846
Waist circumference, cm[a]	144 (108–210)	135 (100–166)	< 0.0001	144 (109–174)	1.000
BMI, kg/m^2[a]	51.4 (48.0–81.1)	49.3 (42.3–60.2)	< 0.0001	51.0 (42.7–63.3)	0.312
HT[b]	84 (54.2%)	135 (58.7%)	0.382	109 (38.1%)	0.001
T2DM[b]	44 (28.4%)	50 (21.7%)	0.136	56 (19.6%)	0.035
DL[b]	44 (28.4%)	130 (56.5%)	< 0.0001	54 (18.9%)	0.024
OSA[b]	40 (25.8%)	41 (17.8%)	0.060	71 (24.8%)	0.821

p value calculated: Unpaired t test and chi-square test

BMI, body mass index; *HT*, hypertension; *T2DM*, type 2 diabetes mellitus; *DL*, dyslipidaemia; *OSA*, obstructive sleep apnea

[a] Mean (range)

[b] Number of patients (percentage)

Table 3 Length of hospital stay and operation expressed in number of patients and percentage

	Group 1, 60-cm BP/150-cm AL (n = 155)	Group 2, 200-cm BP/60-cm AL (n = 230)	p	Group 3, 200-cm BP/150-cm AL (n = 286)	p
Length of hospital stay (days)	1.9 (1–5)	2.5 (1–5)	< 0.0001	1.8 (1–11)	0.375
Surgical time (min)	49 (25–170)	58 (32–154)	< 0.0001	47 (27–209)	0.245

p value calculated: chi-square test

our institution in a 10-year period. The surgery and all treatment pathways are standardized except for the limb lengths in the three groups. As seen in Table 2, the control group (group 1) is comparable to group 3 in the basic demographic parameters that can influence weight loss over time. Group 2 was slightly different as BMI was marginally lower and representation of female gender higher while conversely, the follow-up was longer. In a previous randomized study [22] of obese patients (not only super-obese), we compared the RYGB with 60-cm AL and 2-m BPL (group 2) with the standard RYGB (group 1). Data in the present study are comparable with the results of that study but now in super-obese patients. Thus, although some differences in basic demographic data exist, the groups were deemed comparable.

Excess weight loss after 10 years for standard gastric bypass (group 1) in our study was 56.7% which is on par with the results from a recent systematic review and meta-analysis wherein weighted mean of 56.7% was calculated from 18 reports of gastric bypass [24]. Other systematic reviews have shown the same results [7]. In the present study, significantly higher EWL in group 2 (64.8%) and group 3 (68.4%) was

achieved when BPL was elongated to 2 m. The same overall tendency with better weight loss evaluated from BMI change and TWL% was seen in groups 2 and 3. We also found that group 3 had statistically significant less weight regain (26.6%) compared with the other groups. The results suggest a more durable effect compared with group 1, and this is of particular importance as the risk of EWL failure and weight regain is higher in the super-obese patient.

Does the BPL Play a Role in Achieving Higher Rates of EWL?

There is conflicting evidence concerning the importance of the BPL in the super-obese patient. Several studies indicate that the lengthening of the BPL is vital not only for weight loss but also for a better glucose metabolism; however, most of these studies are limited by small patient cohorts, short-term follow-up, animal-studies; are single-arm studies or alter the length of the BPL along with the Roux limb; or are revision operations [25–30]. However, other studies indicate that limb lengths do not affect weight loss significantly [31–33].

**Table 4** Early and late complications (> 30 days)

|	Group 1 (n = 155)	Group 2 (n = 230)	p value	Group 3 (n = 286)	p value
Early (< 30 days)					
Hemorrhage	0 (0%)	3 (1.3%)	0.277	3 (1.0%)	0.555
Leakage	1 (0.7%)	0 (0%)	0.403	4 (1.4%)	0.661
Wound infection	1 (0.6%)	2 (0.9%)	0.403	2 (0.7%)	1.000
Pneumonia	0 (0%)	2 (0.9%)	0.518	0 (0%)	1.000
Kinking at EEA	2 (1.3%)	2 (0.9%)	1.000	1 (0.3%)	0.283
Late (> 30 days)					
Hypoglycemic attacks	5 (3.2%)	6 (2.6%)	0.762	1 (0.3%)	0.022
Internal hernia	9 (5.8%)	19 (8.2%)	0.427	14 (4.9%)	0.661
Ulcers	5 (3.2%)	16 (7.0%)	0.169	7 (2.5%)	0.761
Hypoglycemic attacks	1 (0.6%)	6 (2.6%)	0.250	5 (1.7%)	0.670
Hypoalbuminemia	0 (0%)	1 (0.4%)	1.000	2 (0.7%)	0.543
Nutritional deficiency	1 (0.6%)	9 (3.9%)	0.055	17 (5.9%)	0.005
Deaths	1 (0.6%)	1 (0.4%)	1.000	0 (0%)	0.352
Other complications	0	1	1.000	2	0.543

No. of patients (percentage)

p value calculated: Fisher's exact test

Other complications: Group 2, 1 pulmonary embolism 7 weeks after surgery. Group 3, one with achalasia needing surgery, one with DVT, and one with small bowel obstruction due to bezoar

(a) Excess weight loss (%)
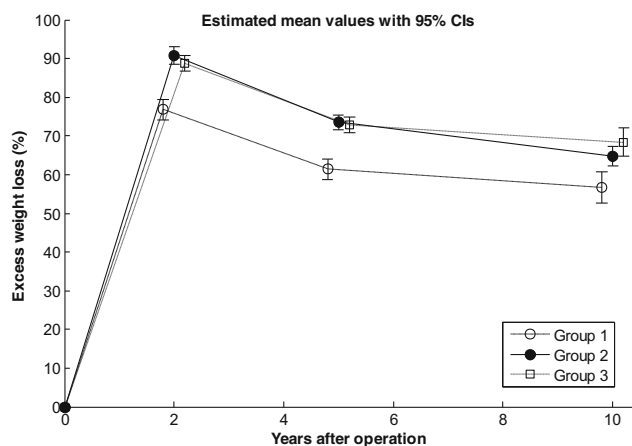
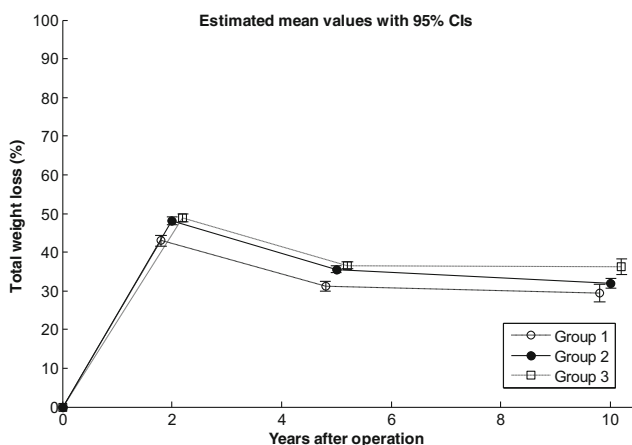**(b) BMI change**
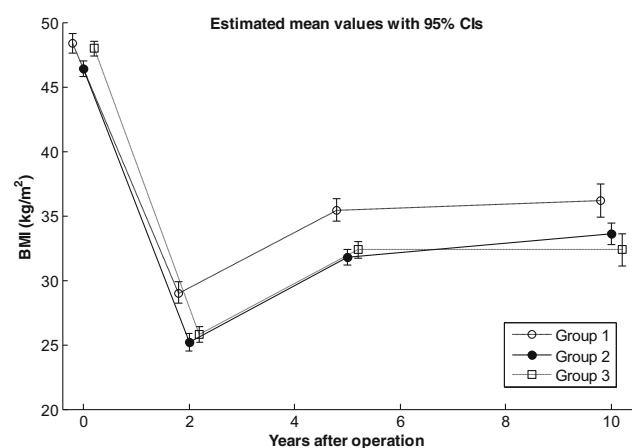
(c) Total weight loss (%)

Fig. 2 Postoperative weight loss expressed as percentage of excess weight loss (EWL%) (**a**), BMI change (**b**), and total weight loss (TWL%) (**c**) plotted against time with the lowest curves. Results from mixed model analysis

In our study, we found that lengthening of the BPL leads to higher rates of EWL in a long-term follow-up in a large cohort. And while it could be hypothesized that the length of the

BPL plays a role, we need to add to this hypothesis that a concomitant change in the Roux limb length does not play a significant role as it was shortened in group 2 to 60 cm while it was kept constant in group 3 at 150 cm. However, this would not explain the somewhat contradictory results in the abovementioned literature. In addition, studies have shown that even a common channel of 150 cm would not produce a greater BMI reduction compared with the standard bypass, as when Risstad et al. [21] in their randomized study had two groups with a common channel of 150 cm and BPL of 50 cm in one group, while RL was 150 cm and BPL 50 cm in the other group.

In our study, the values of the common channel were different in all groups and could be approximated to estimated mean values of 410 cm (group 1), 360 cm (group 2), and 270 cm (group 3), see Fig. 1. However, some uncertainty does exist in this estimation of the CL as variations in total small bowel limb length are present. Therefore, it would be more correct to say that the length of the CL varied across the three groups and was shorter in group 2 and shortest in group 3. The focus should not be on the common channel alone and neither on the roux limb alone, and we hypothesize that the total alimentary limb length is crucial and perhaps more explanatory when estimating the effect of weight loss in not just our study but in the previous studies as well. In groups 2 and 3, TALL was shortened with 200 cm, while it was shortened with only 60 cm in group 1. Therefore, we believe that greater weight loss results are achieved with shortening of the total alimentary limb length. Therefore, we believe that greater weight loss results are achieved with shortening of the total alimentary limb length.

Is the Lengthening of BPL Safe?

Looking at the early complications (within the first 30 days), we did not find any difference of statistical significance in the three groups. In late complications, we included type 1 and type 2 classification of internal hernia (strangulation or actual herniation through either Petersen's space or the space at the entero-entero-anastomosis). Even though we find a difference in the percentages of internal hernia in the three groups, these differences are not statistically significant. It should be noted that the percentages of internal hernia are relatively high in all groups and can be explained by the fact that the majority of patients were operated before January 2011 prior to the systematic closure of the mesenterial defects at our high-volume center [34].

The frequency of marginal ulcers was almost the same when comparing group 1 with groups 2 and 3. However, when comparing group 2 with group 3, we find a statistically significant difference ($p = 0.017$); thus, there is a higher occurrence of ulcers in group 2 vs. group 3. This difference could be explained due to the differences in the Roux limbs as a longer

Table 5 Postoperative weight loss expressed as percentage of excess weight loss (EWL%)

	Mean values (95% CI)		
	2 years	5 years	10 years
Group 1	76.8 (74.0 to 79.5)	61.4 (58.7 to 64.1)	56.7 (52.6 to 60.8)
Group 2	90.8 (88.6 to 93.0)	73.5 (71.5 to 75.5)	64.8 (62.3 to 67.2)
Group 3	88.8 (86.8 to 90.9)	72.9 (70.9 to 74.8)	68.4 (64.7 to 72.1)
	Mean between-group difference (95% CI); p value		
	2 years	5 years	10 years
Group 1 vs group 2	14.0 (10.5 to 17.6); $p < 0.001$	12.0 (8.68 to 15.4); $p < 0.001$	8.10 (3.32 to 12.9); $p = 0.001$
Group 1 vs group 3	12.1 (8.64 to 15.5); $p < 0.001$	11.4 (8.09 to 14.8); $p < 0.001$	11.8 (6.24 to 17.3); $p < 0.001$
Group 2 vs group 3	−1.95 (−4.97 to 1.07); $p = 0.21$	−0.61 (−3.39 to 2.18); $p = 0.67$	3.67 (−0.76 to 8.10); $p = 0.11$

RL might add an extra protection against possible reflux of bile and stomach acids.

In conclusion, elongation of the BPL is not associated with a higher frequency of short or late complications and is considered safe and overall, the complication rates were quite low when compared with other studies [21].

Hospital stay was significantly higher in group 2 (2.5 days), compared with group 1 (1.9 days) and group 3 (1.8 days) and surgical time was longer in group 2. This is due to the implementation of Fast-Track principles from 2008 to 2009 [25], where we gradually reduced hospital stay from 3 to 1–2 days.

Resolution of Comorbidities?

No controlled and stringent long-term follow-up for all patients was possible in our study due to geographical considerations amongst others; however, clinical consultations and questionnaires were completed for all patients with obesity-related comorbidities and thus we found that lengthening of the BPL to 2 m had higher rates of remission and resolution. Due to fewer numbers of patients in group 2 at follow-up, we could not determine a statistically significant change even though the remission rates are higher in group 2 versus group 1. However, in group 3, statistically significant remission rates

were noted with type 2 diabetes (87.5% vs 60.8%, $p = 0.019$), hypertension (74.6% vs 47.4%, $p = 0.001$), dyslipidaemia (88.1% vs 70.2%, $p = 0.002$), and obstructive sleep apnea (96.8% vs 73.9%).

Nutritional Status and Vitamin Deficiencies

The occurrence of serious nutritional deficiencies is usually due to poor patient compliance or inadequate follow-up. Hence, at regular follow-up, supplementation should be adjusted continuously according to the paraclinical values. In our environment, with a well-functioning follow-up system and committed primary care centers, severe malnutrition was very rare. No significant difference in hypoalbuminemia was noted between the groups. However, vitamin deficiencies occurred as well as higher rate of iron deficiency in groups 2 and 3 (Table 4) as compared with group 1. Theoretically, this can be explained due to iron absorption occurring predominantly in the duodenum and upper jejunum [35] as well as our clinical experience that lengthening the bypassed small intestine increases malabsorption, in particular that of iron.

A bias exists in the more stringent follow-up of groups 2 and 3 compared with group 1. This included more frequent outpatient controls and testing for lab values with subsequent

Table 6 Postoperative weight loss expressed as BMI change

	Mean values (95% CI)		
	2 years	5 years	10 years
Group 1	29.0 (28.2 to 29.9)	35.4 (34.6 to 36.3)	36.2 (34.9 to 37.5)
Group 2	25.2 (24.5 to 25.9)	31.8 (31.2 to 32.4)	33.6 (32.8 to 34.4)
Group 3	25.8 (25.2 to 26.4)	32.4 (31.7 to 33.0)	32.4 (31.1 to 33.6)
	Mean between-group difference (95% CI); p value		
	2 years	5 years	10 years
Group 1 vs group 2	−3.85 (−4.94 to −2.76); $p < 0.001$	−3.64 (−4.68 to −2.60); $p < 0.001$	−2.61 (−4.14 to −1.09); $p = 0.001$
Group 1 vs group 3	−3.24 (−4.29 to −2.19); $p < 0.001$	−3.08 (−4.11 to −2.04); $p < 0.001$	−3.85 (−5.65 to −2.04); $p < 0.001$
Group 2 vs group 3	0.61 (−0.31 to 1.53); $p = 0.19$	0.56 (−0.29 to 1.42); $p = 0.20$	−1.23 (−2.68 to 0.21); $p = 0.095$

Table 7 Postoperative weight loss expressed as percentage of total weight loss (TWL%)

	Mean values (95% CI)		
	2 years	5 years	10 years
Group 1	43.0 (41.6 to 44.3)	31.2 (29.8 to 32.5)	29.5 (27.2 to 31.7)
Group 2	48.1 (47.0 to 49.1)	35.5 (34.6 to 36.5)	31.9 (30.7 to 33.2)
Group 3	48.8 (47.8 to 49.8)	36.6 (35.7 to 37.6)	36.2 (34.1 to 38.3)
	Mean between-group difference (95% CI); P value		
	2 years	5 years	10 years
Group 1 vs group 2	5.10 (3.35 to 6.84); $p < 0.001$	4.34 (2.70 to 5.98); $p < 0.001$	2.45 (−0.12 to 5.03); $p = 0.062$
Group 1 vs group 3	5.81 (4.13 to 7.50); $p < 0.001$	5.44 (3.79 to 7.10); $p < 0.001$	6.72 (3.62 to 9.83); $p < 0.001$
Group 2 vs group 3	0.72 (−0.76 to 2.19); $p = 0.34$	1.10 (−0.24 to 2.45); $p = 0.11$	4.27 (1.81 to 6.74); $p = 0.001$

Table 8 Excess weight loss failure and weight regain expressed in number of patients and percentage

	Group 1, 60-cm BP/150-cm AL ($n = 155$)	Group 2, 200-cm BP/60-cm AL ($n = 230$)	p	Group 3, 200-cm BP/150-cm AL ($n = 286$)	p
EWL failure ($\leq$ 50% or BMI $\geq$ 33)	16 (10.3%)	10 (4.3%)	0.022	15 (5.2%)	0.046
Weight regain (gain of weight > 15% of lowest weight)	64 (41.3%)	106 (46.1%)	0.353	76 (26.6%)	0.002

p value calculated: chi-square test

adjustment of nutritional supplementation, especially in regard to iron and vitamin D. Therefore, we conclude that more adjustments of supplementation are needed in patients with long BP-limb and that adequate follow-up prevents serious malnutrition in these patients. The issues of malabsorption are well known in the duodenal switch and biliopancreatic diversion in the bariatric literature from systematic reviews [36, 37].

Our evidence also suggests that the attachment of the BPL to the total alimentary limb length does not play a role in terms of malnutrition and malabsorption when the Roux limb varies from 60 to 150 cm.

However, the effect of placement of the BPL further distal on TALL on malnutrition is currently unknown but it will be evaluated in an upcoming study, shedding light on the role of the total alimentary tract in the context of weight loss following obesity surgery as well.

There is no doubt that a BP diversion of 200 cm is efficient in achieving high and durable rates of weight loss; however, in cases of short total small intestinal limb lengths, one should be careful as patients in this group are prone to risks of malnutrition and malabsorption. Therefore, we recommend a BP diversion corresponding to 1/3 of the total small intestinal limb length.

Currently, the other ideal limb lengths in terms of efficacy and safety in the super-obese patient remain unknown. Our results indicate that a BPL of 200 cm is optimal to maintain a high rate of EWL and the Roux limb should be somewhere between 60 and 150 cm to balance the risk of complications and side effects. From this study, we propose an attachment of a 200-cm BPL to the small bowel tract with a 100-cm Roux limb as a very viable and durable operation in this patient population.

Table 9 Remission of obesity-associated comorbidities after surgery (percentage)

	Group 1		Group 2		p value	Group 3		p value
	Remission (%)	No remission (%)	Remission (%)	No remission (%)		Remission (%)	No remission (%)	
HT	47.4	52.6	58.8	41.2	0.169	74.6	24.4	0.001
T2DM	60.8	39.2	79.2	20.8	0.115	87.5	16.6	0.019
DL	70.2	29.8	94.2	5.8	< 0.001	88.1	11.9	0.002
OSA	73.9	26.1	70.0	30.0	0.775	96.8	3.2	0.013

p value calculated: chi-square test. H0-hypothesis: there are no differences in the remission of comorbidities in the different groups after surgery

HT, hypertension; *T2DM*, type 2 diabetes mellitus; *DL*, dyslipidaemia; *OSA*, obstructive sleep apnea

Table 10 Number and percentage of patients at different follow-up times

Year	Patients actually seen	Patients available	Fraction (%)
1	654	671	95
2	598	640	93
3	567	623	91
4	513	596	86
5	456	556	82
6	382	501	76
7	291	432	67
8	208	345	60
9	141	287	49
10	66	209	32

Conclusion

Durability of the gastric bypass in super-obese patients necessitates change of limb lengths and this study demonstrates that lengthening of the BPL leads to better weight loss results in super-obese patients with fever EWL failures and lesser weight regain up to 10 years following surgery as compared with the standard gastric bypass with higher resolution rates of obesity-associated comorbidities. Long BPL (2 m) was not associated with higher complication rates, but there was an increase in nutritional deficiencies that however were easily manageable by good follow-up settings. By creating a 200-cm BPL, the total alimentary limb length was reduced with 140 cm compared with the standard gastric bypass. As weight loss was similar in the 200-cm BPL groups, we conclude that TALL is of utmost importance for the long-term weight loss rather than focusing primarily on shortening of the common channel. A shorter Roux limb (60 cm) increased the frequency of ulcers, while a longer Roux limb (150 cm) was associated with more vitamin deficiencies. In conclusion, we propose shortening the TALL with a BPL of 200 cm and a Roux limb of 100. In our patients, this would estimate a reduction of TALL with 2 m corresponding to roughly one-third of the small intestine when assuming that the total small bowel limb length estimates 620 cm (unpublished results). Reducing the TALL with one-third—instead of a fixed number—is particularly important in cases of very short small bowel limb length in order to avoid malnutrition and malabsorption.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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

References

1. Swinburn BA, Sacks G, Hall KD, et al. The global obesity pandemic: shaped by global drivers and local environments. Lancet. 2011;378:804–14.
2. Ng M, Flemings T, Robinson M, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet. 2014;384:766–81.
3. Mason EE, Doherty C, Maher JW, et al. Super obesity and gastric reduction procedures. Gastroenterol Clin N Am. 1987;16(3):495–502.
4. Sturm R. Increases in clinically severe obesity in the United States, 1986–2000. Arch Intern Med. 2003;163(18):2146–8.
5. Vinciguerra F, Baratta R, Farina MG, et al. Very severely obese patients have a high prevalence of type 2 diabetes mellitus and cardiovascular disease. Acta Diabetol. 2013;50(3):443–9.
6. Buchwald H, Avidor Y, Braunwald E, et al. Bariatric surgery: a systematic review and meta-analysis. JAMA. 2004;292:1724–37.
7. Colquitt JL, Pickett K, Loveman E, et al. Surgery for weight loss in adults. Cochrane Database Syst Rev. 2014;8:CD003641.
8. MacLean LD, Rhode BM, Nohr CW. Late outcome of isolated gastric bypass. Ann Surg. 2000;231:524–8.
9. Melton GB, Steele KE, Schweitzer MA, et al. Suboptimal weight loss after gastric bypass surgery: correlation of demographics, comorbidities, and insurance status with outcomes. J Gastrointest Surg. 2008;12(2):250–5.
10. Sarhan M, Choi JJ, Al Sawwaf M, et al. Is weight loss better sustained with long-limb gastric bypass in the super-obese? Obes Surg. 2011;21(9):1337–43.
11. Christou NV, Look D, MacLean LD. Weight gain after short- and long-limb gastric bypass in patients followed for longer than 10 years. Ann Surg. 2006;244:734–40.
12. Nelson DW, Blair KS, Martin MJ. Analysis of obesity-related outcomes and bariatric failure rates with the duodenal switch vs gastric bypass for morbid obesity. Arch Surg. 2012;147(9):847–54.
13. Biertho L, Simon-Hould F, Marceau S, et al. Current outcomes of laparoscopic duodenal switch. Ann Surg Innov Res. 2016;10:1.
14. Bolckmans R, Himpens J. Long-term (>10 years) outcomes of the laparoscopic biliopancreatic diversion with duodenal switch. Ann Surg. 2016;264(6):1029–37.
15. Hedberg J, Sundström J, Sundbom M. Duodenal switch versus Roux-en-Y gastric bypass for morbid obesity: systematic review and meta-analysis of weight results, diabetes resolution and early complications in single-centre comparisons. Obes Rev. 2014;15(7):555–63.
16. Mahawar KK, Kumar P, Parmar C, et al. Small bowel limb lengths and Roux-en-Y gastric bypass: a systematic review. Obes Surg. 2016;26(3):660–71.
17. Torres JC. Why I prefer gastric bypass distal Roux-en-Y gastroileostomy. Obes Surg. 1991;1:189–94.
18. Murr MM, Balsiger BM, Kennedy FP, et al. Malabsorptive procedures for severe obesity: comparison of pancreaticobiliary bypass and very very long limb Roux-en-Y gastric bypass. J Gastrointest Surg. 1999;3(6):607–12.

19. Brolin RE, LaMarca LB, Kenler HA, et al. Malabsorptive gastric bypass in patients with superobesity. J Gastrointest Surg. 2002;6(2): 195–205.

20. Müller MK, Räder S, Wildi S, et al. Long-term follow-up of proximal versus distal laparoscopic gastric bypass for morbid obesity. Br J Surg. 2008;95(11):1375–9.

21. Risstad H, Svanevik M, Kristinsson JA, et al. Standard vs distal Roux-en-Y gastric bypass in patients with body mass index 50 to 60: a double-blind, Randomized Clinical Trial. JAMA Surg. 2016;151(12):1146–55.

22. Nergaard BJ, Leifsson BG, Hedenbro J, et al. Gastric bypass with long alimentary limb or long pancreato-biliary limb–long-term results on weight loss, resolution of co-morbidities and metabolic parameters. Obes Surg. 2014;24(10):1595–602.

23. Gislason H, Jacobsen HJ, Bergland A, et al. Fast-track in bariatric surgery: safety, quality, teaching aspects, logistics and cost-efficacy in 8,000 consecutive cases. Minimally Invasive Bariatric and Metabolic Surgery. 2015;119–129.

24. O'Brien PE, Hindle A, Brennan L, et al. Long-term outcomes after bariatric surgery: a systematic review and meta-analysis of weight loss at 10 or more years for all bariatric procedures and a single-centre review of 20-year outcomes after adjustable gastric banding. Obes Surg. 2019;3–14.

25. Murad Jr AJ, Cohen RV, de Godoy EP, et al. A prospective single-arm trial of modified long biliopancreatic and short alimentary limbs Roux-En-Y gastric bypass in type 2 diabetes patients with mild obesity. Obes Surg. 2018;28(3):599–605.

26. Chaux F, Bolaños E, Varela JE. Lengthening of the biliopancreatic limb is a key step during revisional Roux-en-Y gastric bypass for weight regain and diabetes recurrence. Surg Obes Relat Dis. 2015 Nov-Dec;11(6):1411.

27. Miyachi T, Nagao M, Shibata C, et al. Biliopancreatic limb plays an important role in metabolic improvement after duodenal-jejunal bypass in a rat model of diabetes. Surgery. 2016;159(5):1360–71.

28. Nelson WK, Fatima J, Houghton SG, et al. The malabsorptive very, very long limb Roux-en-Y gastric bypass for super obesity: results in 257 patients. Surgery. 2006;140:517–22.

29. Choban PS, Flancbaum L. The effect of roux limb lengths on outcome after Roux-en-Y gastric bypass: a prospective, randomized clinical trial. Obes Surg. 2002;12:540–5.

30. Nora M, Morais T, Almeida R, et al. Should Roux-en-Y gastric bypass biliopancreatic limb length be tailored to achieve improved diabetes outcomes? Medicine. 2017;96(48):e8859.

31. Inabnet WB, Quinn T, Gagner M, et al. Laparoscopic Roux-en-Y gastric bypass in patients with BMI < 50: a prospective randomized trial comparing short and long limb lengths. Obes Surg. 2005;15: 51–7.

32. Kao YH, Lo CH, Huang CK. Relationship of bypassed limb length and remission of type 2 diabetes mellitus after Roux-en-Y gastric bypass. Surg Obes Relat Dis. 2012;8:e82–4.

33. Abellan I, Lujan J, Frutos MD, et al. The influence of the percentage of the common limb in weight loss and nutritional alterations after laparoscopic gastric bypass. Surg Obes Relat Dis. 2014;10:829–33.

34. Aghajani E, Nergaard BJ, Leifson BG, et al. The mesenteric defects in laparoscopic Roux-en-Y gastric bypass: 5 years follow-up of non-closure versus closure using the stapler technique. Surg Endosc. 2017;31(9):3743–8.

35. Muir A, Hopfer U. Regional specificity of iron uptake by small intestinal brush-border membranes from normal and iron-deficient mice. Am J Phys. 1985;248(3 Pt 1):G376–9.

36. Topart PA, Becouarn G. Revision and reversal after biliopancreatic diversion for excessive side effects or ineffective weight loss: a review of the current literature on indications and procedures. Surg Obes Relat Dis. 2015;11(4):965–72.

37. Stroh C, Benedix F, Meyer F, et al. Nutrient deficiencies after bariatric surgery - systematic literature review and suggestions for diagnostics and treatment. Zentralbl Chir. 2015;140(4):407–16.