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Sánchez-Pernaute, et al.**

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# Single-Anastomosis Pylorus-Preserving Bariatric Procedures: Review of the Literature

Francesco Martini<sup>1</sup> · Luca Paolino<sup>1</sup> · Ettore Marzano<sup>2</sup> · Jacopo D'Agostino<sup>2</sup> · Andrea Lazzati<sup>3</sup> · Anne-Sophie Schneck<sup>4,5,6</sup> · Andrés Sánchez-Pernaute<sup>7</sup> · Antonio Torres<sup>7</sup> · Antonio Iannelli<sup>4,5,6</sup>

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**Abstract** Single-anastomosis pylorus-preserving procedures (SAPPP) were recently introduced into bariatric surgery in order to combine the physiologic advantages of a post-pyloric reconstruction with the technical advantages of an omega loop. Surgery consists of a sleeve gastrectomy that is performed first, followed by a duodeno-enterostomy. Two main variants exist: proximal and distal SAPPP, with duodeno-jejunoostomy and duodeno-ileostomy, respectively. This review describes the SAPPP reported in the literature and analyzes their outcomes in comparison with the most frequently performed bariatric techniques. Preliminary results appear as promising in terms of both safety and effectiveness on weight loss and comorbidities improvement.

**Keywords** Single anastomosis · Omega loop · Pylorus preserving · Duodeno-ileal bypass · Duodeno-jejunal bypass · SADI

## Introduction

Most bariatric operations consist in a restrictive part at the level of the stomach with or without a malabsorptive component that is achieved with an intestinal bypass of variable length. Adjustable gastric banding (AGB), sleeve gastrectomy (SG), and Roux-en-Y gastric bypass (RYGB) are currently the most popular bariatric procedures worldwide [1]. Biliopancreatic diversion with duodenal switch (BPD/DS) is

✉ Antonio Iannelli  
iannelli.a@chu-nice.fr

Francesco Martini  
framartini77@hotmail.com

Luca Paolino  
lpaolino@hotmail.com

Ettore Marzano  
ettoremarzano@me.com

Jacopo D'Agostino  
jacopodagostino@yahoo.it

Andrea Lazzati  
andrea.lazzati@chicreteil.fr

Anne-Sophie Schneck  
escargot2@yahoo.com

Andrés Sánchez-Pernaute  
pernaute@yahoo.com

Antonio Torres  
atorres.hcsc@salud.madrid.org

<sup>1</sup> Digestive and Bariatric Unit, Joseph Ducuing Hospital, Toulouse, France

<sup>2</sup> Pole Obésité Etang de Berre, Clinique de Martigues, Martigues, France

<sup>3</sup> Digestive Unit, Centre Hospitalier Intercommunal de Creteil, Créteil, France

<sup>4</sup> Digestive Unit, Archet 2 Hospital, University Hospital of Nice, F-06202 Nice, France

<sup>5</sup> Inserm, U1065, Team 8 “Hepatic Complications of Obesity”, F-06204 Nice, France

<sup>6</sup> University of Nice Sophia-Antipolis, F-06107 Nice, France

<sup>7</sup> Department of Surgery, Hospital Clínico San Carlos, Madrid, Spain

considered the most effective operation on weight loss (WL) and comorbidities, but in reason of its higher surgical complexity and risk of malnutrition in most countries, it is usually performed in tertiary centers and reserved to superobese patients [2].

The great success recently encountered by the SG among the bariatric community is due to the several advantages it carries over the more complex RYGB, including the endoscopic access to the remnant stomach and the preservation of the pylorus that is associated with a significant improvement in functional outcomes of all upper GI surgical procedures [3]. Indeed, Traverso and Longmire reported the advantages of pylorus preservation in a complex procedure such as the pancreaticoduodenectomy [4]. In the field of bariatric surgery, Hess et al. showed a reduction of marginal ulcers by 90 % and no dumping syndrome with a postpyloric reconstruction during a BPD/DS [5]. Other potential benefits of postpyloric vs prepyloric reconstruction include a better absorption of iron, calcium, vitamin B12, and proteins [5].

In malabsorptive procedures, reconstruction can be performed via Roux-en-Y (RY) or Billroth II (BII) gastroenterostomy. In bariatric surgery, the RY reconstruction is usually preferred since the BII leads to biliary reflux into the stomach. This is the main reproach to the single-anastomosis gastric bypass (SAGB) [6]. Nevertheless, the interest for single-loop techniques is increasing because of its theoretical advantages on operative time and postoperative complications. A novel technique combining the physiological advantages of pylorus preservation and the technical benefits of single-loop reconstruction was introduced into bariatric surgery by Sanchez-Pernaute, who described the single-anastomosis duodeno-ileal bypass with sleeve gastrectomy (SADI-S) as an evolution of BPD-DS [7]. Aiming to reduce the potential malnutrition problems related to BPD/DS and to maintain at the same time its metabolic efficacy, the two Taiwanese teams of Huang and Lee subsequently developed a procedure with a proximal duodeno-enterostomy, which they named respectively loop duodeno-jejunal bypass with sleeve gastrectomy (LDJB-SG) [8] and single-anastomosis duodeno-jejunal bypass with sleeve gastrectomy (SADJB-SG) [9]. Therefore, the single-anastomosis pylorus-preserving procedures (SAPPP) can be divided in two main groups according to the position of the duodeno-enterostomy: a first group with proximal anastomosis (P-SAPPP), similar to RYGB and SAGB, and a second group with distal anastomosis (D-SAPPP), similar to BPD/DS.

Beside their possible advantages in term of operative time and postoperative complications, the growing interest for SAPPP concerns the rising issue represented by SG failure. Indeed, the increasing numbers of SG now being performed will likely be followed by increasing numbers of patients experiencing WL failure or complications such as leaks, strictures, twists, or new-onset gastro-esophageal reflux disease

(GERD) [10]. As SG is a relatively new procedure, it is still not clear which procedure should be proposed to patients who present with a failure. SAPPP appear as a promising alternative to RYGB and BPD/DS in this context. In case of superobese patients, SAPPP can be also performed in a staged manner with the SG being the first step.

The aim of this review is to describe the SAPPP reported in the literature and analyze their outcomes in term of safety, WL, and effect on comorbidities, in comparison with the most frequently performed bariatric techniques.

## Methods

### Search Strategy

We conducted a systematic review on PubMed, Embase, and Cochrane Library databases, adhering to PRISMA statement. The search was conducted in March 2016 and was not limited to any date range. We used as search terms: «single anastomosis», «gastric bypass», «biliopancreatic diversion», «duodenoileal bypass», «duodenojejunal bypass», and «mini-duodenal switch».

### Inclusion Criteria

Data search was restricted to studies reporting on single-loop anastomosis with pylorus preservation in bariatric surgery. Experimental studies on animals were excluded. Abstracts of the references retrieved were reviewed and the full text of all potentially relevant studies was analyzed for eligibility. Information from each study was extracted using a standardized data extraction form. Authors were not contacted.

### Data Extraction

Only articles describing single-loop techniques with pylorus preservation were retained for the final analysis. After inclusion, we retrieved from each study the following variables (when available): year of publication; number of patients; type of bariatric procedure; patients' characteristics (gender, age, BMI); surgical complications; WL; evolution of comorbidities; and mortality. When searched data were not available in the text, they were calculated whenever possible.

### Bariatric Procedures

The following SAPPP were retained:

- Single-anastomosis duodeno-ileal bypass with sleeve gastrectomy (SADI-S) described by Sanchez-Pernaute et al. [7, 10–14], Morales et al. [15], and Vilallonga et al. [16]

- Loop duodeno-jejunal bypass with sleeve gastrectomy (LDJB-SG) reported by Huang et al. [8, 17, 18]
- Single-anastomosis duodeno-jejunal bypass with sleeve gastrectomy (SADJB-SG or DJB-SG) proposed by Lee et al. [9, 19]
- Single-anastomosis loop duodenal switch (LDS) described by Cottam et al. [20, 21]
- Pylorus-preserving loop duodeno-ileostomy with sleeve gastrectomy (DIOS-SG) and pylorus preserving loop duodeno-jejunostomy with sleeve gastrectomy (DJOS-SG) proposed by Grueneberger et al., with the variant replacing SG by a gastric plication (DIOS-GP and DJOS-GP) [22, 23]

In order to simplify the discussion, the procedures were divided into two main groups according to the position of the duodeno-enterostomy: a first group with proximal anastomosis (P-SAPPP) and a second group with distal anastomosis (D-SAPPP).

P-SAPPP included SADJB-SG, LDJB-SG, DJOS-SG, and DJOS-GP.

D-SAPPP included SADI-S, LDS, DIOS-SG, and DIOS-GP.

## Results

### Study Selection

The search led to 502 articles. Finally, 16 papers describing single-loop techniques with pylorus preservation were retained for the final analysis. Fifteen articles were in English [7–9, 11–14, 16–23] and one in Spanish [15]. Five articles concerned case reports or surgical technique: one paper reported a case report of internal hernia (IH) after LDS [21], one article described the technique of robotic assisted SADI after previous laparoscopic SG in three cases [16], two papers discussed the surgical technique of SADI-S by Sanchez-Pernaute et al. [7] and of DJOS/DIOS-SG by Karcz and Grueneberger [23], one article described the technique of laparoscopic conversion from RYGB to LDJB-SG for intractable dumping syndrome in two patients [18]. The other 11 articles reported about six single-center series, retrospectively determined, with a short-term or a mid-term follow-up (FU). In particular, four articles described the series by Sanchez-Pernaute et al. from Spain (a total of 168 patients with 36 to 60 months FU) [11–14], two articles each concerned the series from Taiwan by Huang et al. (30 patients with 12 months FU) [8, 17] and by Lee et al. (89 patients with 12 months maximum FU) [9, 19], one article each reported the results of the series by Grueneberger and Karcz from Germany (16 patients

with 6 months FU) [22], by Cottam et al. from the USA (54 patients with 18 months FU) [20] and by Morales et al. from Chile (100 patients without FU) [15]. The total number of patients was 462.

Studies were quite homogenous with respect to gender (percentage of male patients 19–40 %) and mean age (36–52 years). In the four Western series, mean BMI ranged between 37 and 48 kg/m<sup>2</sup>, these values being higher than those reported in the two Asian papers from Taiwan: a mean of 28 kg/m<sup>2</sup> for Huang et al. and a median of 35 kg/m<sup>2</sup> for Lee et al. On the other hand, the percentage of diabetic patients was higher in the two Taiwanese studies, 87–100 vs 18–58 % in the four Western series. The characteristics of the studies, together with demographic and preoperative data are shown in Table 1. Table 2 reports operative data and postoperative complications. Finally, results concerning WL, evolution of comorbidities and long-term complications are listed in Table 3.

## Surgical Technique

### *The Sleeve Gastrectomy*

The surgeon is positioned between the legs of the patient with the operating table under forced anti-Trendelenburg position (“French position”). The sleeve gastrectomy is performed in a standard fashion and calibrated over a boogie of variable diameter (34–54 Fr). For patients after gastric banding, Karcz and Grueneberger performed a gastric plication over a 36 Fr boogie in order to reduce the risk of a staple line leak or bleeding [22, 23].

### *One- or Two-Step Operation*

While P-SAPPP was always performed as a single-step procedure, D-SAPPP were sometimes performed in two steps as revisional surgery in case of SG failure or in the context of a staged strategy. Sanchez-Pernaute et al. performed 21 two-step SADI-S with a mean interval of 24 months (range 16–38) between the two operations [12, 13]. Vilallonga et al. described three cases of two-step SADI-S with a 13–16-month interval between SG and the second step [16]. Grueneberger et al. performed nine two-step DIOS with a mean 18 months (range 4–42) interval between the two operations [22].

### *The Duodenal Division*

The dissection of the greater curvature is prolonged through the lower part and posterior wall of the first portion of the duodenum above the gastroduodenal artery. At this point, the duodenum is divided with a linear stapler at the level of the gastroduodenal artery, warranting a 2- to 4-cm proximal duodenal stump and preserving all the vascular supply of the

**Table 1** Main series of single anastomosis pylorus preserving procedures: characteristics of the studies, demographic, and preoperative data

	Authors, year (country)	Procedure	Study design	N of pts	Sex	Age (year)	Initial BMI	T2DM rate (%)	HT rate (%)	Dyslip rate (%)	SAS rate (%)
P-SAPPP	Grueneberger et al., 2014 (Germany) [22]	Primary DJOS-SG or revisional DJOS-GP after AGB (2 patients)	Retrospective	7	1 M	52	43 (36–48)	0	0	NR	NR
	Lee et al., 2015 (Taiwan) [19]	Primary SADJB-SG	Retrospective, matched cohort analysis vs SG	89	32 M	43 ± 10	35 ± 6	87	56	44	NR
	Huang et al., 2016 (Taiwan) [17]	Primary LDJB-SG	Retrospective, matched cohort analysis vs RYGB	30	12 M	50	28 (21–34)	100	40	60	NR
D-SAPPP	Morales et al., 2012 (Chile) [15]	Primary SADI-S	Retrospective	100	19 M	36	37	18	28	60	2
	Grueneberger et al., 2014 (Germany) [22]	Revisional DIOS-SG and DIOS-GP (after AGB 2 patients, after RYGB 2 patients)	Retrospective	9	3 M	44	41 (33–56)	89	67	NR	NR
	Coffam et al., 2015 (USA) [20]	Primary LDS	Retrospective, matched cohort analysis vs RYGB	54	16 M	52 ± 13	48 ± 9	57	63	NR	57
Sanchez-Pernaute et al., 2013 and 2015 (Spain) [12, 14]	Sanchez-Pernaute et al., 2013 and 2015 (Spain) [13, 14]#	Primary or revisional SADI-S (after SG 21 patients, after RYGB 1 patient, after VBG 3 patients)	Retrospective	168	37 % M*	47 (22–71)*	45 (33–67)*	58	57*	57*	27*
		Revisional SADI-S after SG	Retrospective	16	4 M	42 (18–62)	56 (41–72)	56	62	62	NR

Values are expressed as mean (eventually with range) or median ± SD

NR not reported, T2DM type 2 diabetes mellitus, HT hypertension, SAS sleep apnea syndrome, AGB adjustable gastric banding, SG sleeve gastrectomy, RYGB Roux-en-Y gastric bypass, VBG vertical banded gastroplasty, P-SAPPP proximal single anastomosis pylorus preserving procedures, D-SAPPP distal single anastomosis pylorus preserving procedures, DIOS-SG pylorus-preserving loop duodeno-jejunosotomy with sleeve gastrectomy, DIOS-GP pylorus-preserving loop duodeno-jejunostomy with gastric plication, DIOS-SG pylorus-preserving loop duodeno-ileostomy with sleeve gastrectomy, DIOS-GP pylorus-preserving loop duodeno-ileostomy with gastric plication, SADI-S single-anastomosis duodeno-jejunal bypass with sleeve gastrectomy, LDJB-SG loop duodeno-jejunal bypass with sleeve gastrectomy, LDS single-anastomosis loop duodenal switch, SADI-S single-anastomosis duodeno-ileal bypass with sleeve gastrectomy

\*Data calculated on 100 patients

#The cohort described in this study is a subgroup of the previous study

**Table 2** Main series of single anastomosis pylorus preserving procedures: operative data and postoperative complications

	Authors, year (country)	Procedure	Sleeve calibration (Fr)	Common channel length (cm)	BP limb Length (cm)	Mortality (%)	Postoperative complications
P-SAPPP	Grueneberger et al., 2014 (Germany) [22]	Primary DIOS-SG or revisional DJO-GP after AGB (2 patients)	35	2/3 of entire small bowel length (mean 466)	1/3 of entire small bowel length (mean 236)	0	1 small bowel perforation upon insertion of first trocar
	Lee et al., 2015 (Taiwan) [19]	Primary SADJB-SG	36	NM	150–250 (according to BMI value)	0	1 vomiting 1 dehydration 1 atelectasis 2 wound infections 3 bleeding requiring transfusions 1 bleeding requiring reoperation 1 ARDS requiring ICU management 1 sleeve stricture requiring reoperation 2 hemoperitoneum requiring transfusion 1 sleeve stricture requiring reoperation 3 leaks from sleeve
D-SAPPP	Huang et al., 2016 (Taiwan) [17]	Primary LDJB-SG	36	NM	200	0	1 sleeve stricture requiring reoperation in 2 cases requiring reoperation 3 leaks from duodenal stump in 1 case requiring reoperation
	Morales et al., 2012 (Chile) [15]	Primary SADI-S	34	300	NM	0	1 sleeve stricture requiring reoperation 2 small bowel lesions 1 bleeding requiring reoperation 1 trocart site hernia requiring reoperation 1 portal thrombosis 0
	Grueneberger et al., 2014 (Germany) [22]	Revisional DIOS-SG and DIOS-GP (after AGB 2 patients, after RYGB 2 patients)	35	1/3 of entire small bowel length (mean 246)	2/3 of entire small bowel length (mean 538)	0	1 nausea 1 abdominal wall spasms 1 anastomotic leak 2 leaks from sleeve
	Cottam et al., 2015 (USA) [20]	Primary LDS	40	300	NM	0	1 hemoperitoneum requiring reoperation 1 gastric bleeding requiring endoscopy 1 incarcerated umbilical hernia requiring reoperation
	Sanchez-Pernaute et al., 2013 and 2015 (Spain) [12, 14]	Primary or revisional SADI-S (after SG 21 patients, after RYGB 1 patient, after VBG 3 patients)	54	200 (50 patients) 250 (50 patients)*	NM	NM	1 trocart site hernia requiring reoperation 0
	Sanchez-Pernaute et al., 2013 and 2015 (Spain) [13, 14]#	Revisional SADI-S after SG	42–54	250	NM	0	

Values are expressed as mean (eventually with range) or median ± SD

NR not reported, MM not measured, BP biliopancreatic, T2DM type 2 diabetes mellitus, HT hypertension, SAS sleep apnea syndrome, AGB adjustable gastric banding, SG sleeve gastrectomy, RYGB Roux-en-Y gastric bypass, VBG vertical banded gastroplasty, P-SAPPP proximal single-anastomosis pylorus-preserving procedures, D-SAPPP distal single-anastomosis pylorus-preserving procedures, DJOS-SG pylorus-preserving loop duodeno-jejunostomy with sleeve gastrectomy, DIOS-GP pylorus-preserving loop duodeno-jejunostomy with gastric plication, DIOS-SG pylorus-preserving loop duodeno-jejunostomy with sleeve gastrectomy, DIOS-GP pylorus-preserving loop duodeno-ileostomy with gastric plication, SADI-S single-anastomosis duodeno-jejunal bypass with sleeve gastrectomy, LDJB-SG loop duodeno-jejunal bypass with sleeve gastrectomy, LDS single anastomosis loop duodenal switch, SADI-S single-anastomosis duodeno-ileal bypass with sleeve gastrectomy

\*Data about 100 patients: in the first 50 cases, the anastomosis was performed at 200 cm from the ileocecal valve; in the last 50 cases, this length was enlarged to 250 cm

#The cohort described in this study is a subgroup of the previous study

lesser curvature, i.e., the right gastric artery and the supraduodenal vessels.

#### *The Choice of the Position of the Duodeno-Enterostomy*

As in all malabsorptive operations, the critical issue in SAPPP is the position of the duodeno-enterostomy, determining the type of omega switch: duodeno-jejunal or duodeno-ileal. In D-SAPPP, the ileocaecal junction is identified, and the common channel is measured upward. Its length is 250 cm for Sanchez-Pernaute et al. (200 cm in the initial version) [11–14] and 300 cm for Morales et al. [15], for Vilallonga et al. [16], and for Cottam et al. [20]. In P-SAPPP, the ligament of Treitz is identified and the biliopancreatic limb measured downward at 200 cm for Huang et al. [8, 17] and between 150 and 250 cm according to the BMI value for Lee et al. [9, 19].

In order to account for inter-individual differences, Karcz and Grueneberger propose a different strategy. After duodenal division, the table is tilted to the horizontal position and the surgeon moves to the left side of the patient. The entire length of the small bowel is measured and the position of the of the duodeno-enterostomy is determined to be aboral to the Treitz ligament, one third of total small bowel length in case of duodeno-jejunostomy, and two thirds for duodeno-ileostomy [22, 23].

#### *The Duodeno-Enterostomy*

The selected loop is ascended antecolically and an isoperistaltic duodeno-jejunal anastomosis is performed, either mechanical side-to-side or hand-sewn end-to-side. The anastomosis is tested for leaks with methylene blue instillation through the nasogastric tube and/or through an air leak test. A drain is routinely left.

#### *The Closure of the Petersen's Space*

In SAPPP, there is not mesenteric defect, but a Petersen's space is always present between the caudal surface of the transverse mesocolon and the loop irrespective of the type of duodeno-enterostomy, representing a potential space for internal hernia formation. Since this space is very large and its closure difficult, most authors do not close it advocating a very low probability of internal hernia. Only Huang et al. report to systematically close the Petersen defect with a continuous suture [8, 17].

### **Postoperative Complications**

No postoperative mortality was observed in any series. In one of their articles, Sanchez-Pernaute et al. cite the case of one patient who died 3 months after surgery from progressive

respiratory insufficiency, without reporting any link to surgical complications [11].

Three intraoperative complications were reported as follows: Grueneberger et al. described an intestinal perforation upon insertion of the first trocar in a patient with previous gastric banding [22]; Morales et al. reported two small bowel lesions but did not specify how they produced [15]. No lesion during duodenal dissection has been reported. Cottam et al. reported the case of a patient with a miscounted common channel of 160 cm complaining of postoperative diarrhea. When that patient was converted to a 450-cm common channel, the diarrhea settled [20]. The rate of major postoperative complications (grades III and IV according to Clavien-Dindo classification [24]), was nil both in the series of Grueneberger et al. [22] and Cottam et al. [20], 2 % in the series by Sanchez-Pernaute et al. [12, 14], 3.3 % for Huang et al. [17], 3.4 % in the series of Lee et al. [9, 19], and 6 % for Morales et al. [15]. With regard to leaks, nine cases were reported as follows: Sanchez-Pernaute et al. described three leaks: two from the SG and one from the duodeno-ileal anastomosis, and all of them successfully treated conservatively [12, 14]; Morales et al. reported six leaks: three from the SG (in two cases requiring reoperation) and three from the duodenal stump (one necessitating surgery) [15]. If we consider the total number of 462 patients, the total leak rate of 1.9 % was therefore quite low, 1.1 % for the SG, 0.6 % for the duodenal stump, and 0.2 % for the duodeno-enteral anastomosis. Nine cases of postoperative bleeding were reported: four by Lee et al. (one necessitating surgery, the others only transfusions) [19]; two by Sanchez-Pernaute et al. (one managed by endoscopic coagulation and one requiring reoperation) [12, 14]; two by Huang et al. (managed by transfusions) [17]; and one by Morales et al. (necessitating surgery) [15]. Bleeding rate was 1.9 % in the whole patients' population. Three cases of early sleeve stricture requiring reoperation were reported as follows: Lee et al. described a case of conversion to RYGB [19], Huang et al. reported a case managed by laparoscopic stricturoplasty [17], and Morales et al. reported a case necessitating reoperation but the type of surgical management was not specified [15].

### **Long-Term Complications**

Clinical malnutrition with asthenia, edema, and hypoalbuminemia was reported by Sanchez-Pernaute et al. in five patients [12, 14]. They described four cases among the first 50 patients (8 %), having a common limb of 2 m; two patients underwent revision to Roux-en-Y DS with a 3-m alimentary limb and a 2-m common channel by dividing the bowel in the efferent loop just distal to the duodeno-ileostomy and bringing this end to the afferent (biliopancreatic) limb 1 m proximal to the duodeno-ileostomy. The authors considered this hypoalbuminemia rate to be excessively high and decided to change



**Table 3** Main series of single anastomosis pylorus preserving procedures: results concerning weight loss, evolution of comorbidities, and long-term complications

Authors, year (country)	Procedure	FU (mo)	WL (%)	EWL (%)	T2DM rem (%)	HT rem (%)	Dyslip rem (%)	Other comorb rem (%)	Long-term complications
P-SAPPP Grüneberger et al., 2014 (Germany) [22]	Primary DJOS-SG or revisional DJOS-GP after AGB (2 patients)	6	NR	47	-	-	-	-	6 GERD 5 PPI treatments 1 flatulence 1 dumping 1 diarrhea 2 marginal ulcers
Lee et al., 2015 (Taiwan) [19]	Primary SADJB-SG	12 (26 patients)	NR	87 ± 15	93§	>90	>90	NR	1 trocar site hernia requiring reoperation 7 de novo GERD NR
Huang et al., 2016 (Taiwan) [17]	Primary LDJB-SG	12	16	NR	53§	67	44	NR	4GERD 9 PPI treatments 5 flatulences 2 diarrheas 1 sleeve stricture requiring endoscopic dilation 1 dilated fundus requiring reoperation, 4 nausea 1 de novo GERD 1 diarrhea 1 miscounted small bowel requiring reoperation 1 internal hernia requiring reoperation
D-SAPPP Morales et al., 2012 (Chile) [15]	Primary SADI-S	NR	NR	NR	NR	NR	NR	NR	5 clinical hypoalbuminemia in 3 cases requiring reoperation
Grüneberger et al., 2014 (Germany) [22]	Revisional DJOS-SG and DJOS-GP (after AGB 2 patients, after RYGB 2 patients)	6	NR	50	89*	89	NR	-	
Cottam et al., 2015 (USA) [20]	Primary LDS	18	41	NR	NR	NR	NR	GERD 97 (preop 63)	
Sanchez-Pernaute et al., 2013 and 2015 (Spain) [12, 14]	Primary or revisional SADI-S (after SG 21 patients, after RYGB 1 patient, after VBG 3 patients)	36 (19 patients) 60 (25 diabetic patients)	60	95	76 at 36 mo, 52 at 60 mo@	55 (control 95)	improvement 80	SAS 88	
Sanchez-Pernaute et al., 2013 and 2015 (Spain) [13, 14]#	Revisional SADI-S after SG	21 (2-46)	NR	72	89@	60 (control 90)	40 (improvement 100)	NR	0

Values are expressed as mean (eventually with range) or median + SD

NR not reported; rem: remission, FU follow-up, WL weight loss, EWL excess weight loss, T2DM type 2 diabetes mellitus, HT hypertension, SAS sleep apnea syndrome, AGB adjustable gastric banding, SG sleeve gastrectomy, RYGB Roux-en-Y gastric bypass, VBG vertical banded gastroplasty, P-SAPPP proximal single-anastomosis pylorus-preserving procedures, D-SAPPP distal single-anastomosis pylorus-preserving procedures, DJOS-SG pylorus-preserving loop duodeno-jejunoileostomy with sleeve gastrectomy, DJOS-GP pylorus-preserving loop duodeno-jejunoileostomy with gastric plication, DJOS-SG pylorus-preserving loop duodeno-ileostomy with sleeve gastrectomy, DJOS-GP pylorus-preserving loop duodeno-ileostomy with gastric plication, SADI-S single-anastomosis duodeno-jejunal bypass with sleeve gastrectomy, LDJB-SG loop duodeno-jejunal bypass with sleeve gastrectomy, LDS single-anastomosis loop duodenal switch, SADI-S single-anastomosis duodeno-ileal bypass with sleeve gastrectomy, GERD gastro-esophageal reflux disease

§ T2DM remission defined as HbA1c <6.5 %

\*No clear definition of T2DM remission

@ T2DM remission defined as HbA1c <6 % without antidiabetic medication for >1 year

#The cohort described in this study is a subgroup of the previous study

the common limb length to 250 cm thereafter. After this change, only one more patient needed reoperation, consisting on the division of the duodeno-ileal anastomosis and the performance of a new one 1-m proximal. In the series by Cottam et al., with a common channel of 300 cm no patient presented protein malnutrition [20]. Flatulence and diarrhea, which represent a common and major concern after BPD/DS, were not reported as clinically relevant by Sanchez-Pernaute et al. or by Cottam et al. [12, 14, 20]. In the series by Sanchez-Pernaute et al. the average number of daily bowel movements was 2.3 [12, 14]. Only Grueneberger reported flatulence rates as high as 55.6 and 71.4 % in case of DIOS and DJOS, respectively. Correspondent rates of diarrhea were 66.7 and 28.6 %. Nevertheless, the series included only 16 patients with a follow-up of only 6 months [22]. A surprising data from the series by Grueneberger is the GERD rate as high as 44.4 and 85.7 % in case of DIOS and DJOS, with 100 and 71.4 % of patients under PPI treatment, respectively [22]. Huang et al. similarly showed a significantly increased incidence of erosive esophagitis (30 to 65 %) and reflux symptoms (0 to 20 %) after LDJB-SG [17]. On the other hand, Cottam et al. reported 34 patients taking acid-reducing medications preoperatively and only one at 1 year after surgery [20]. Gruenegerber et al. reported the only case of occasional dumping-related symptoms [22]. Lee et al. reported the only two cases of marginal ulcers necessitating medical treatment [19].

Cottam et al. reported a stricture managed through endoscopic dilation and a dilated gastric fundus requiring reoperation [20]. With regard to internal hernia, a single case was described by Summerhays et al. 2 months after conversion from RYGB to LDS [21]. They found the entire afferent limb underneath the anastomosis and over to the right side of the abdominal cavity, creating a partial bowel obstruction. After reduction, they sutured the omentum to the mesentery of the small bowel to keep the afferent limb in place.

## Weight Loss

### *P-SAPPP*

Grueneberger et al. [22] reported a 47 % excess weight loss (EWL) at 6 months, while Lee et al. [19] showed a median EWL of 87 % at 12 months (26 patients out of 89 having completed the 1 year FU). The other Taiwanese paper by Huang et al. reported a mean WL of 16 % at 12 months in a series of 30 diabetic patients with a BMI as low as 28 (range 21–34) [17].

### *D-SAPPP*

Grueneberger et al. [22] showed a 50 % EWL at 6 months, while Cottam et al. [20] reported a 41 % WL at 18 months. The only available mid-term data were reported in the series

by Sanchez-Pernaute et al. [12, 14]. Analyzing their first 100 patients, they reported a 95 % EWL at 3 years (19 patients having completed the 3 years FU) [14]. In another paper describing the results on 97 obese diabetic patients, results are equivalent at 5 years with a 98 and a 63 % WL (25 patients having completed the 5 years FU). In the FU, six patients failed to reach a 50 % EWL (6.1 %) [12]. In another paper, Sanchez-Pernaute et al. reported the results of SADI performed as a second step after SG in 16 patients, showing a mean EWL of 72 % at 2 years after surgery [13].

## Evolution of Diabetes

### *P-SAPPP*

Lee et al. reported a 93 % type 2 diabetes mellitus (T2DM) remission rate at 1 year, defining remission as HbA1c <6.5 % [19]. Huang et al. reported a lower remission rate of 53.3 % at 1 year, the main negative prognostic factor being T2DM duration [17]. This difference is in accord with other studies in the literature, showing that remission of T2DM appears to be less in patients with a lower BMI compared to those with a higher BMI [25–27].

### *D-SAPPP*

In the paper on the 97 obese diabetic patients operated on for SADI-S, Sanchez-Pernaute et al. defined T2DM remission when HbA1c was maintained <6 % without antidiabetic medication for >1 year. Overall remission rates were 71.6, 77, 75.8, 63.3, and 52 % at 1, 2, 3, 4, and 5 years, respectively. Most patients who achieved remission (89 %) acquired it in the first postoperative year. After an initial remission, only four patients recurred in the first 5 years. Diabetes duration and the need of preoperative insulin therapy were significantly associated with a lower remission rate on multivariate analysis [12].

Concerning SADI as a second step, Sanchez-Pernaute showed a complete remission of T2DM in eight out of nine patients at a mean FU of 21 months (2–46), with only one patient continuing treatment with one daily dose of metformin [13].

## Evolution of Other Comorbidities

### *P-SAPPP*

Remission rates at 1 year for hypertension and dyslipidemia were reported by Huang et al. at 67 and 44 %, respectively [17]. Lee et al. reported higher remission rates >90 % [19].

*D-SAPPP*

Sanchez-Pernaute et al. reported hypertension control (remission and improvement) in 98 % of their first 100 patients, with complete remission in 58 % [14]. In another paper describing the results on 97 obese diabetic patients, results were equivalent with 96 % control rate and 52 % remission rate [12]. Concerning SADI as a second step, remission was observed in 60 % and improvement in 30 % of cases [13]. Concerning SAS, Sanchez-Pernaute et al. showed 88 % remission in their first 100 patients. When they analyzed dyslipidemia, improvement rate was reported as high as 80 % [14]. Concerning SADI as a second step, dyslipidemia improved in all cases, with absolute normalization of all parameters in 40 % of the cases [13]. GERD was analyzed in only one paper by Cottam et al. They took into consideration only the use of acid-reducing medications without endoscopic or pH studies. Nevertheless, they reported 34 patients taking acid-reducing medications preoperatively and one at 1 year after surgery. Such favorable results were referred by the authors to the aggressive attitude in the diagnosis hiatal hernia preoperatively and its intra-operative treatment [20].

**Discussion**

Following the epidemics of obesity, the number of bariatric procedures performed worldwide increases each year [1, 10]. Recently, a novel technique combining the advantages of pylorus preservation and single-loop reconstruction was introduced into bariatric surgery by Sanchez-Pernaute et al., aiming to decrease the operative complexity of a preexisting effective surgical procedure like BPD/DS. They described the single anastomosis duodeno-ileal bypass with sleeve resection (SADI-S) [7], which was followed by several variants that we collectively named single anastomosis pylorus-preserving procedures (SAPPP).

Since only retrospective series were found with a short- or mid-term FU, only preliminary conclusions can be drawn about SAPPP at present. Only the series of SADI-S by Sanchez-Pernaute team, providing mid-term outcomes about more than 100 patients, allows more reliable conclusions [11–14]. Available data allow stating that SAPPP appear as promising since they are safe in terms of short-term complications and show good results in the short-term concerning WL and comorbidities resolution. The SG is performed in a standard fashion by all authors in the different variants of SAPPP. Only Grueneberger et al. proposed to perform a gastric plication in case of previous gastric banding and relevant perigastric scar tissue in order to minimize operative risk [22]. Nevertheless, such a precaution is likely to be excessive, as the overall rates of leak and bleeding were both 1.9 %, thus low when compared to series of SG as a standing-alone procedure

[28]. Furthermore, the gastric plication is a controversial procedure and there is no strong evidence that it results in less immediate complications compared to the standard SG. The most critical issue in the surgical technique is the position of the duodeno-ileostomy in D-SAPPP, since the length of the common limb must be adequate to determine malabsorption but at the same time, protein malnutrition must be avoided. With a common channel of 200 cm, clinical malnutrition rate was 8 % in the series by Sanchez-Pernaute et al., and it reduced to 1 % when the length was enlarged to 250 cm [7, 11–14, 22]. Cottam et al. reported no case of malnutrition with a common channel length of 300 cm [20]. Another attitude was adopted by Grueneberger et al. [22] in order to account for inter-individual differences as the total small intestinal length is highly variable and ranges between 4 and nearly 10 m [29, 30]. They decided to place the duodeno-ileostomy after two thirds of the small intestine, leaving a common channel of one third. Given a range of small bowel length of 6–9 m, the two thirds position of the duodenal anastomosis leaves a mean common channel length of 245 cm. Therefore, their final technique was similar to that already described by Sanchez-Pernaute et al. and Cottam et al., at the price of a prolongation of the operation time, with the associated theoretical risk of accidental lesions during small bowel manipulation. In P-SAPPP, the position of the duodeno-jejuno-stomy is likely to play a minor role as the length of the biliopancreatic limb does not probably influence long-term results, as already shown in RYGB where no difference was found between long- and short-limb techniques [31, 32]. Moreover, the rationale who led Huang [8] and Lee [9] to develop SADJB-SG was different from that of Sanchez-Pernaute et al. in developing SADI-S. The former aimed to allow an endoscopic access to the remnant stomach taking into account the high incidence of gastric cancer in Asian countries and to add duodenal exclusion to SG in order to achieve a higher rate of diabetes remission [33–36]. This difference is evident when the cohorts by Huang and Lee are compared with those issued by the other Western series: mean BMI was 28–35 vs 37–48 kg/m<sup>2</sup>, while the rate of diabetic patients was 87–100 vs 18–58 % [9, 11–14, 19, 20, 22]. Lee et al. measured the biliopancreatic limb between 150 and 250 cm according to the BMI value [9, 19], Huang et al. chose a standard length of 200 cm [8, 17], while Grueneberger et al. achieved a similar result calculating one third of the total bowel length, corresponding at a mean value of 235 cm [22].

Concerning postoperative complications, mortality rate was nil in SAPPP and the rate of major postoperative complications (grades III and IV according to Clavien-Dindo classification [24]) ranged between 0 and 6 %. Among 462 patients, five leaks were detected at the level of the SG (1.1 %), three from the duodenal stump (0.6 %), and only one at the level of the duodeno-enteral anastomosis (0.3 %); in three cases, a reoperation was performed [12, 14, 15]. Nine cases of

postoperative gastric bleeding were reported (bleeding rate 1.9 %), three of them requiring reoperation and one managed by endoscopic coagulation [12, 14, 15, 17, 19].

Analyzing the literature, postoperative mortality rates were reported at 0–1.4 % for BPD/DS [37–43], at 0.04–0.16 % for RYGB [39, 44, 45], and at 0.08–0.2 % for SAGB [6, 46]. Leak rates were reported at 1–3.6 % for BPD/DS [37, 38, 40–43], 1–1.8 % for RYGB [44, 45], and at 0.6–1.6 % for SAGB [6, 46]. Therefore, SAPPP can be considered as safe with a low rate of immediate postoperative complications in the hands of experienced bariatric surgeons.

While postoperative morbidity and mortality of SAPPP may be considered globally due to the relative homogeneity in the surgical technique, the different malabsorptive characteristics of P-SAPPP and D-SAPPP pushed us to analyze their outcomes separately, to compare them in a reliable manner to the other bariatric techniques. Indeed, D-SAPPP can be compared to BPD/DS, while P-SAPPP can be compared to RYGB and SAGB. Concerning WL, outcomes of SAPPP are likely to be satisfactory, at least in the short and mid-term.

Analyzing P-SAPPP, Lee et al. reported a median 87 % EWL at 1 year FU [19], which indicates better results than those reported for the RYGB at 2 years (58 % EWL) by Buchwald [2] and those reported by Rutledge for SAGB [6] at 1 year (68 % EWL).

Cottam et al. showed a mean 41 % WL at 18 months [20] and Sanchez-Pernaute et al. a mean 95 % EWL (60 % WL) 5 years after surgery for D-SAPPP [12, 14]. In the series by Sanchez-Pernaute et al., EWL was 80 % by the first 6 postoperative months and reached a mean value of 100 % at 18 months and was maintained for the following years [12, 14]. These results indicate that the D-SAPPP leads to a higher EWL than the BPD/DS that results in an EWL ranging between 66 and 76 % [37, 38, 40, 42]. In the study by Hess et al., a maximum WL was obtained by the third postoperative year and then patients regained some lost weight and reached a plateau of 75 % EWL in the long term [40]. In the series by Sanchez-Pernaute, patients reached a greater EWL nadir earlier, maybe in reason of the greater gastric restriction. A greater rate of absorption should be expected with SADI-S compared to DS, because the common channel is longer, but this has not been observed. However, SADI-S patients had a lower number of daily bowel movements (2.3 versus 3.2) [12, 14, 40], which could be explained by the lower amount of bile salts reaching the colon [47].

One main reason for the growing interest for SAPPP is the potential indication of these procedures in case of SG failure, which represents a rising issue. Concerning the two-step SADI-S as reported by Sanchez-Pernaute et al., the mean 72 % EWL at 21 months [13] can be compared to the short and midterm outcomes of some small series of conversion of SG into BPD/DS, RYGB, and revisional SG: EWL is 73–80, 65–66, and 43–58 %, respectively [48–51].

Protein malnutrition is a major concern after any type of BPD, as shown by Scopinaro [52]. Clinical malnutrition with asthenia, edema, and hypoalbuminemia was reported by Sanchez-Pernaute et al. in five patients [12, 14]. They described four cases among the first 50 patients (8 %), with a 4 % surgical revision rate. After increasing the common limb length from 200 to 250 cm, only one more patient needed reoperation (1 % revision rate). In the series by Cottam et al., with a common channel of 300 cm, no patient presented protein malnutrition [20]. These data seem promising when compared to the 0.5 and 3.6 % revision rates of DS for persistent hypoalbuminemia or severe diarrhea reported by Marceau [42] and Hess [40], respectively.

Analyzing the efficacy on T2DM with regard to P-SAPPP, Lee et al. reported a 93 % remission rate at 1 year [19]. In the paper on obese diabetic patients only, Sanchez-Pernaute showed remission rates for SADI-S of 71.6 and 52 % at 1 and 5 years, respectively, with only four patients recurring in the first 5 years [12]. Comparison among different studies and different techniques is difficult because of the huge variations in the severity of the populations included and because of the great heterogeneity in criteria used to define improvement or remission [53, 54]. Nevertheless, results seem particularly promising. Concerning the evolution of the other comorbidities, available data show excellent results with hypertension control in about 90 % of patients and complete remission in about 60 %. Dyslipidemia was improved in 80 % of the cases and 40 % of patients showed complete remission. SAS remission rate was as high as 90 %.

Evolution of GERD after SAPPP was analyzed in the series by Cottam et al., Grueneberger et al., and Huang et al. Cottam et al. reported a 97 % remission rate which they referred to their aggressive attitude for the diagnosis of hiatal hernia preoperatively and its treatment intra-operatively. Nevertheless, they took into consideration only the use of acid-reducing medications without endoscopic or pH studies [20]. On the other hand, Grueneberger et al. showed GERD rates as high as 44.4 and 85.7 % in case of DIOS and DJOS, with 100 and 71.4 % of patients under PPI treatment, respectively [22]. Huang et al. similarly showed a significantly increased incidence of erosive esophagitis (30 to 65 %) and reflux symptoms (0 to 20 %) after LDJB-SG. In the latter study, all patients underwent endoscopic surveillance within the first year [17]. Concerning GERD after SG, the literature is discordant and the subject is still matter of debate [55]. About SAPPP, we could speculate that the duodenal mobilization, together with the disruption of anatomical antireflux mechanisms due to the SG, could aggravate GERD. Nevertheless, the scarcity of available data does not allow to drive any conclusion.

Some advantages of SAPPP related to the post-pyloric reconstruction are shared with DS including the absence of dumping syndrome and the very low rate of marginal ulcers. Only two cases of marginal ulcer were reported by Lee et al.,

i.e., a total rate of 0.4 % [9–19]. In the most recent series of RYGB marginal ulcer rate ranges between 1 and 16 % [44, 56–58], while in SAGB it is reported around 2 % [6, 46]. Other theoretical advantages of SAPP are related to the single-loop reconstruction which eliminates one anastomosis: the reduction in the operation duration and anesthesia time, the reduction in the probability of postoperative leak, and as the mesentery is not opened, there is a lower probability of internal hernia. On the other hand, the expected rate of internal hernia after an RY procedure is variable, from 1 to 16 % [59, 60], and recently the results of a Swedish randomized multicentric trial supported the routine closure of the mesenteric defects in RYGB [61]. Indeed, the absence of IH after SAGB in long-term follow-up is one of the advantages lauded by those advocating SAGB over RYGB [6, 62]. Nevertheless, cases of IH after SAGB have recently been reported [63, 64]. In these cases, a volvulation of the small bowel along the anastomotic loop axis was observed. The only case of IH after SAPP was described by Sumerhays and Cottam [21] in a patient having been converted from RYGB to LDS 2 months before: they found a rolling of the entire afferent limb through the defect with bowel obstruction. The authors maintained that the adhesions related to the previous surgery played a role in the formation of this internal hernia. The omentum was sutured to the mesentery of the small bowel to keep the afferent limb in place. Although the rate of internal hernia is very low after single-loop reconstruction, given the few cases reported and the short FU, no conclusion can be drawn on the systematic non-closure of the defect.

In conclusion, SAPP appear today as promising techniques with an excellent profile in terms of safety and reproducibility. Preliminary results concerning WL and comorbidities improvement on the short term are good, but larger series with a longer follow-up are necessary to draw definitive conclusions.

#### Compliance with Ethical Standards

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

**Ethical Statement** This article does not contain any studies with human participants or animals performed by any authors.

**Consent Statement** For this type of study formal consent is not required.

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