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ORIGINAL CONTRIBUTIONS

Learning Curves of Laparoscopic Roux-en-Y Gastric Bypass and Sleeve Gastrectomy in Bariatric Surgery: a Systematic Review and Introduction of a Standardization

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Abstract

Background The most commonly performed bariatric procedures are laparoscopic Roux-en-Y gastric bypass (RYGB) and sleeve gastrectomy (LSG). Impact of learning curves on operative outcome has been well shown, but the necessary learning curves have not been clearly defined. This study provides a systematic review of the literature and proposes a standardization of phases of learning curves for RYGB and LSG.

Methods A systematic literature search was performed using PubMed, Web of Science, and CENTRAL databases. All studies specifying a number or range of approaches to characterize the learning curve for RYGB and LSG were selected.

Results A total of 28 publications related to learning curves for 27,770 performed bariatric surgeries were included. Parameters used to determine the learning curve were operative time, complications, conversions, length of stay, and blood loss. Learning curve range was 30–500 (RYGB) and 30–200 operations (LSG) according to different definitions and respective phases of learning curves. Learning phases described the number of procedures necessary to achieve predefined skill levels, such as competency, proficiency, and mastery.

Conclusions Definitions of learning curves for bariatric surgery are heterogeneous. Introduction of the three skill phases competency, proficiency, and mastery is proposed to provide a standardized definition using multiple outcome variables to enable better comparison in the future. These levels are reached after 30–70, 70–150, and up to 500 RYGB, and after 30–50, 60–100, and 100–200 LSG. Training curricula, previous laparoscopic experience, and high procedure volume are hallmarks for successful outcomes during the learning curve.

Keywords Learning curve · Obesity surgery · Laparoscopy · Roux-en-Y gastric bypass · Sleeve gastrectomy · Competency · Proficiency · Mastery

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Abbreviations

ASMBS	American Society for Metabolic & Bariatric Surgery
BMI	Body mass index
CUSUM	Cumulative sum analysis
LSG	Laparoscopic sleeve gastrectomy
RYGB	Laparoscopic Roux-en-Y gastric bypass
IFSO	International Federation for the Surgery of Obesity and Metabolic Disorders
LOS	Length of hospital stay
NOS	Newcastle-Ottawa Scale

Introduction

The World Health Organization has formally recognized obesity as a global health epidemic since 1997 [1]. In 2016, nearly 40% of the global adult population was characterized as overweight or obese [2]. Bariatric surgery has proven to be a long-term effective treatment of morbid obesity and to improve obesity-related comorbidities and quality of life [3–7]. Laparoscopic Roux-en-Y gastric bypass (RYGB) and laparoscopic sleeve gastrectomy (LSG) are currently the most commonly performed bariatric procedures [8]. In 2016, a total of 609,897 bariatric surgeries (30.1% RYGB and 53.6% LSG) were performed worldwide [8]. LSG was introduced more recently than RYGB, and its increased worldwide popularity has made it a meaningful alternative to RYGB for weight loss operations with low morbidity and minimal mortality [9, 10].

The laparoscopic method is the gold standard for bariatric surgery with its immanent advantages compared to open surgery [11–15]. However, laparoscopic bariatric surgery requires advanced laparoscopic skills and is more complex due to the amount of intraabdominal fatty tissue in these patients. Thus, to perform safe bariatric surgery and avoid perioperative complications, the learning curve of surgeons requires attention [16–19].

The learning curve phenomenon is a concept first described in aircraft manufacturing by T.P. Wright in 1936. It states that performance improves with time and experience, which increases productivity [20]. The idea of a learning curve has since then been adopted in medicine and surgery [21]. Subramonian et al. defines it as "the time taken and/or the number of procedures an average surgeon needs to be able to perform a procedure independently with a reasonable outcome" [22]. Michel defines the learning curve as a graphic representation of the relationship between experience with a procedure or technique and an outcome variable such as operation time, complication rate, LOS, or mortality [23]. Three components have been generally described in the graphical representation of the learning curve of surgical practice. The first component begins with a starting point and slow initial progress characterized by getting comfortable with the surgical technique and a focus on patient safety. The second component represents the slope of the curve, with more fluidity and faster improvement of tasks during practice but also eventually taking up more difficult or complex cases. The third component is described as the plateau, where the curve stabilizes, and experience is achieved in a particular task and also complex cases can be mastered [24, 25]. Learning curves in surgery have some specific factors that complicate the clear definition and comparability between studies. These include but are not limited to gradual surgeon autonomy in cases that are mentored or proctored, the role of team training, previous operative experience, and general technical skill of surgeons, i.e., novice surgeons versus experienced surgeons learning a new procedure or operative approach, but also patient-related factors such as patient selection and case difficulty [26–28]. All these factors contribute to the heterogeneity of learning curves in the available literature and have to be taken into account when discussing learning curves and defining training and introduction of new procedures.

The learning curve for bariatric surgery has been a topic of ongoing discussion and investigation [18, 29–32]. Therefore, the need for a systematic review that identifies, appraises, and synthesizes research-based evidence was seen. The aim of the present study was to assess learning curves reported for RYGB and LSG, to identify the decisive parameters for these learning curves, and to provide the basis for uniform definitions and standardized reporting of learning curves.

Materials and Methods

Systematic Literature Search Methodology

This review complies with the recommendations of the Cochrane Handbook for Systematic Reviews and Interventions [33] and is reported in line with the PRISMA guidelines [34]. A protocol was developed a priori and published on PROSPERO 2018 CRD42018105905. The systematic literature search was performed using PubMed, Web of Science, and CENTRAL databases. The search terms were connected with Boolean operators and used in combination with medical subject headings (MeSH). The full search strategy was as follows: "((laparoscopy[mesh]) OR (minimally invasive surgical procedures[mesh]) OR (laparoscopy[Tiab] OR (laparoscopic[Tiab] AND surgery[Tiab]) OR "robotic surgery"[Tiab] OR "da vinci surgery"[Tiab] OR "minimal* invasive surgery"[Tiab] OR"minimal* invasive surgeries"[Tiab]

OR ”minimally invasivetechnique”[Tiab] OR “minimally invasive techniques”[Tiab])) AND ((education[mesh]) OR (training[tiab] OR education[tiab]))”.

The systematic literature search included contributions listed in the above-mentioned databases until December 2017. No language restrictions were applied. Cross-referencing and manual search of the bibliographies of eligible publications was actively performed until April 2019 to identify further relevant studies for the review.

Study Selection and Data Extraction

Selection of relevant articles was performed in stages. Two of the authors independently screened the title and abstracts of all retrieved references. Duplicates were deleted before further review. Studies considered irrelevant were discarded. Full-text articles for each of the selected abstracts were analyzed. In cases where clarification was needed, a consensus was reached through either discussion or a third reviewer. For data extraction, a dedicated spreadsheet was used which was pretested on five studies to proof its suitability. Details of the selection process are illustrated in the PRISMA flow diagram (Fig. 1).

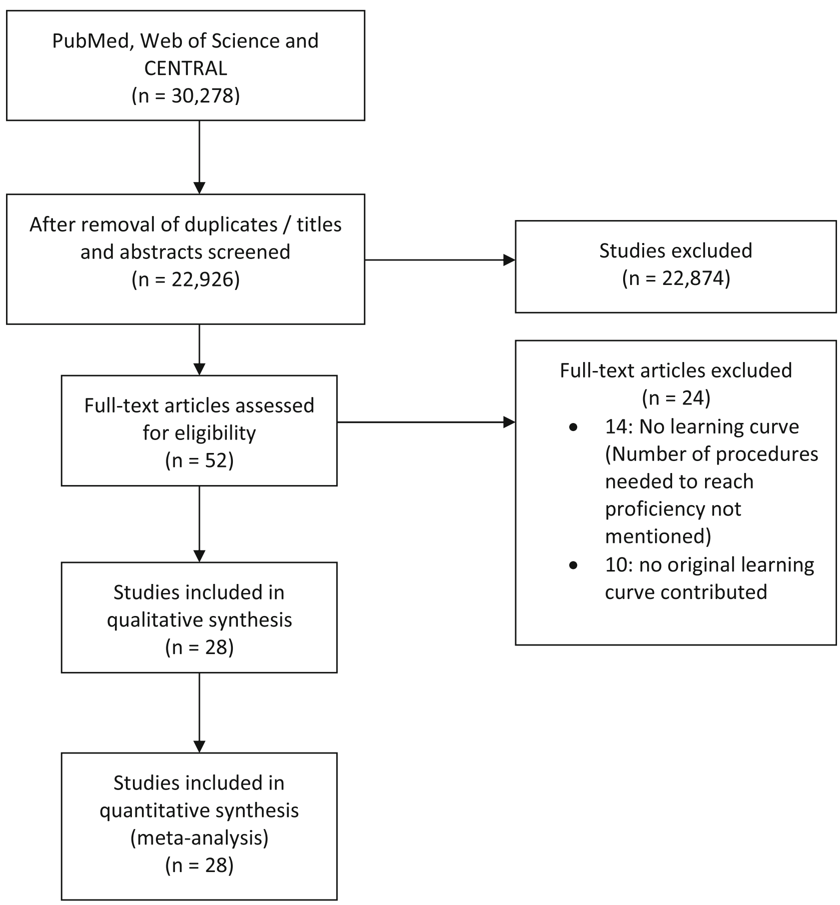
Inclusion and Exclusion

Eligible for inclusion were studies specifying a number or range of procedures to characterize the learning curve for RYGB and LSG. All parameters used and described in each study for learning curve determination were included. Exclusion criteria were (1) studies based on a different bariatric procedure, (2) articles that did not provide a specific case number or range at which the learning curve was attained, and (3) articles which compared preexisting learning curves. Abstracts and further material not associated with a full-text manuscript such as congress abstracts were only included in the systematic review when sufficient data concerning the characteristics of the learning curve were available, but were used carefully in further discussion. Studies reporting on experimental or cadaveric models were excluded.

Outcome Parameters

The primary outcome was the number of procedures needed to reach learning phases for the bariatric procedure. Secondary aims of the review were to define different phases of learning curves and to identify the outcome variables that are used to define learning curves.

Fig. 1 PRISMA flow diagram



Quality Assessment

Newcastle-Ottawa Scale was used for quality assessment of all non-randomized studies in the systematic review [35]. Three domains—(1) selection, (2) comparability, and (3) exposure—were rated with a maximum total score of nine stars.

Results

A total of 22,926 studies were obtained from the systematic literature search. After screening of the titles and abstracts, 52 full-text articles were assessed for eligibility and 28 studies published between 2003 and 2019 were finally included. Detailed information on the screening process can be found in Fig. 1.

Study Characteristics

From the 28 studies, 22 studies [17–19, 36–54] evaluated RYGB (78.6%), while six studies [55–60] evaluated LSG (21.4%). A total of 27,869 patients underwent bariatric surgery in the included studies (23,974 RYGB (86%) and 3895 LSG (14%)). Table 1 provides general information on the studies included.

Table 1 List of included studies with general information organized by author and procedure, Newcastle-Ottawa-Scale for quality assessment

Author	Country	Study period	No. of surgeons	No. of patients	Procedure	NOS		
						Selection (4)	Comparability (2)	Outcome (3)
Abu-Hilal et al. [36]	UK	04/2004–04/2005	3	100	RYGB	3	1	2
Agrawal et al. [37]	UK	03/2010–03/2011	1	74	RYGB	2	1	0
Ali et al. [38]	USA	07/2000–06/2003	Surgeons: 3; Fellows: 5	611	RYGB	2	1	2
Andrew et al [39]	Canada	02/2002–01/2004	1	201	RYGB	3	2	2
Ballesta-López et al. [40]	Spain	09/2000–07/2004	2	600	RYGB	2	2	3
Doumouras et al. [41]	Canada	04/2009–05/2015	29	11684	RYGB	3	2	3
El-Kadre et al. [42]	Brazil	08/1999–12/2011	*n/a*	2281	RYGB	2	2	3
Geubbels et al. [43]	Netherlands	12/2007–07/2012	4	713	RYGB	4	1	3
Huang et al. [44]	Taiwan	08/2005–02/2007	1	100	RYGB	2	2	1
Jacobsen et al. [45]	Norway	09/2005–12/2010	Surgeons; Trainees: 3	2000	RYGB	3	1	2
Lublin et al. [18]	USA	02/2001–11/2002	2	100	RYGB	2	2	2
Nguyen et al. [46]	USA	*n/a*	1	150	RYGB	2	2	2
Oliak et al. [18]	USA	04/1999–08/2001	1	225	RYGB	2	2	3
Pournaras et al. [47]	UK	01/2004–08/2008	2[a]	300	RYGB	3	2	2
Schauer et al. [19]	USA	07/1997–09/2001	2	150	RYGB	2	2	2
Shen et al. [48]	Taiwan	03/2009–08/2009	1	60	RYGB	3	2	1
Shikora et al. [49]	USA	03/1998–04/2004	*n/a*	750	RYGB	2	2	3
Shin et al. [50]	USA	04/2003–09/2003	1	100	RYGB	2	1	2
Sovik et al. [51]	Norway	06/2004–10/2007	2	292	RYGB	3	1	2
Suter et al. [52]	Switzerland	06/1999–08/2001	*n/a*	107	RYGB	1	1	2
van Rijswijk et al. [53]	Netherlands	12/2007–01/2016	Surgeon: 4; Resident: 3	3051	RYGB	3	1	2
Victorzon et al. [54]	Finland	05/2006–03/2011	3	325	RYGB	2	2	2
Carandina et al. [60]	France	05/2013–04/2016	1	99	LSG	2	1	2
Major et al. [55]	Poland	04/2009–10/2017	6	500	LSG	4	1	3
Prevot et al. [56]	France	11/2004–07/2007	1	84	LSG	2	1	2
Sánchez-Santos et al. [57]	Spain/Portugal	2006–2012	*n/a*	2882	LSG	2	1	2
Zachariah et al. [58]	Taiwan	02/2007–03/2012	*n/a*	228	LSG	2	1	3
Zacharoulis et al. [59]	Greece	08/2006–08/2010	2	102	LSG	3	2	2

RYGB Roux-en-Y gastric bypass, *LSG* laparoscopic sleeve gastrectomy, *NOS* Newcastle-Ottawa scale, *n/a* data not available

[a] Second surgeon started after 156 RYGB

Demographics

The female population ranged from 58.3 to 90%, predominating in all included studies. The age of patients varied from 14 to 74 years with a median of 41.5 years. Preoperative body mass index (BMI) varied from overweight to superobese, with the lowest BMI being 26 kg/m^2 and the highest BMI at 97 kg/ m^2, the median was 47.2. Patients' demographic data was not mentioned in 11 studies [41–47, 54, 56, 57, 59]. There were no significant differences between patient populations during and after the learning curve reported in most studies. Only in one study, there was a statistically significant difference of increasing BMI of operated patients between the first and third of learning phases, potentially implying an uptake of more complex cases with increasing experience. Overall demographics are shown in Table 2.

Surgeon Experience and Analysis

The present review included studies with surgeons, fellowship graduates, and trainees with varying levels of experience. Several studies (42%) included surgeons with advanced laparoscopic experience, but without or limited bariatric experience [17, 18, 36, 42, 44–47, 51, 54, 59, 60]. Seven surgeons (25%) had advanced laparoscopic experience plus laparoscopic bariatric surgery experience [37, 43, 48, 50, 53, 56, 58], while three surgeons had open bariatric surgery experience [39, 51, 53]. Fellowship graduates with limited laparoscopic experience (21%) were included in six studies [17, 38, 41, 43, 45, 53]. Data for surgeon experience was not available in six studies [19, 40, 49, 52, 55, 57]. Nine studies [18, 37, 39, 40, 44, 46, 48, 56, 60] described the learning curve of a single surgeon (32%), while experience of two surgeons was

Table 2 Demographic data as provided in the original articles

Author	Year	Gender (female, %)	Age[a] (years)	Pre-op BMI[a] (kg/m^2)
Abu-Hilal et al. [36]	2007	90	42 (19–64)[b]	45 (26–63)[b]
Agrawal et al. [37]	2011	85.1	45.1 (25–66)	47.7 (36–57)
Ali et al. [38]	2010	86	42 (15–67)	48.9 (36–86)
Andrew et al. [39]	2006	80.1	37 ± 9	49.2 ± 8,3
Ballesta-López et al. [40]	2005	79	38.7 ± 11	44.4 ± 7.6
Doumouras et al. [41]	2017	83.3	44.6 ± 10.4	n/a
El-Kadre et al. [42]	2013	71.3	37.5 (14–71)	45.15 (34–97)
Geubbels et al. [43]	2015	81.5	42.1 ± 10.1	42.6 (35–67.6)[b]
Huang et al. [44]	2008	66	31.2 ± 7.2 (17–58)	43 ± 7.5 (35–63.3)
Jacobsen et al. [45]	2012	78	41.5 (17–73)	42.9 (28.7–68.3)
Lublin et al. [17]	2005	83	42 (18–67)	48.7 (36–68)
Nguyen et al. [46]	2003	89	40 ± 8 (22–59)	47 ± 5 (39–61)
Oliak et al. [18]	2003	78	40 (21–69)	51 (36–86)
Pournaras et al. [47]	2010	78.7	44.2 ± 10.4	50 ± 6.7
Schauer et al. [19]	2003	78.7	44.3	55[c]
Shen et al. [48]	2016	58.3	34.2 (18–61)	41.5 (32.6–64.9)
Shikora et al. [49]	2005	85	41.6 (14–69)	47 (32–86)
Shin et al. [50]	2005	90	42.6 (22–62)	47.6 (36–71.8)
Sovik et al. [51]	2009	76	40 ± 9.5	46.7 ± 5.3
Suter et al. [52]	2003	76.6	39.7 (19–58)	48.6 (37.8–69.7)
van Rijswijk et al. [53]	2018	83.9	43.5 ± 10.6	43.4 ± 5
Victorzon et al. [54]	2012	63.7	45 ± 10.8 (19–67)	47.5 ± 7.8 (31.5–91)
Carandina et al. [60]	2019	87.7	36 ± 10.3 (17–61)	42.3 ± 6 (35.3–74.6)
Major et al. [55]	2017	66	40 (33–49)[b]	44.8 (34–76.4)[b]
Prevot et al. [56]	2014	85	40 ± 11	47.7 ± 7
Sánchez-Santos et al. [57]	2016	67.1	43.8 ± 11.6	47.2 ± 8.7
Zachariah et al. [58]	2013	63.6	34.6 ± 10.1 (18–62)	37.4 ± 4.7 (32–65.7)
Zacharoulis et al. [59]	2012	80.4	40 (18–62)[b]	45.4 (35–61)[b]

Pre-op BMI pre-operative body mass index, *n/a* data not available

[a] In mean ± standard deviation (range)

[b] In median (range)

[c] In 22%, a BMI over 55 was reported

analyzed in six studies [17, 19, 40, 47, 51, 59]. Multiple-surgeon experience was observed in the remaining ten studies, which varied between 3 and 29 surgeons [36, 38, 41–43, 45, 53–55, 57]. Three studies did not mention the number of participating surgeons [49, 52, 58] (Table 1). Studies were carried out as single-center studies, except one study [57], where 29 different hospitals were part of a multicenter study. A mentoring relationship between trainees and experienced surgeons was described in three studies (10%) [38, 45, 53].

Definition of the Learning Curve

In this review, outcome variables, phases, and plateaus were heterogeneous, and the definition of bariatric learning curves varied throughout the studies. The learning curve was frequently defined as the number of procedures performed necessary to reach competency [17, 49, 53], proficiency [46, 48, 59], or mastery [41, 42, 56]. Major et al. used the term expert level to describe the learning curve [55]. Van Rijswijk et al. were the only ones that described all three phases (competency, proficiency, and mastery) as part of the learning curve [53]. Most of the studies defined the learning curve by a plateau of outcome variables [18, 37, 39, 40, 43, 44, 51, 57, 58]. Schauer et al. defined the endpoint of the learning curve when technical complications became comparable to open RYGB [19]. The included studies mainly defined this plateau as a stabilized improvement [18, 39–42, 48] and/or significant decrease [17, 44, 56–58] of the most influential outcome variables to achieve a predefined skill level in the given procedure. There was a similarity between all studies regarding findings and conclusions after overcoming the learning curve, regardless of the number of procedures needed.

Factors for the Determination of the Learning Curve

From all parameters included, operative time, complication rate, estimated blood loss, conversion to open surgery, and LOS were reported most often. Other parameters that were investigated but showed no meaningful differences were readmission, re-operation, excess weight loss, and resolution of comorbidities. Parameters that showed significant changes and helped to determine the learning curve were named main parameters. The two most-used parameters by the analyzed studies were operative time and complication rate. All except two studies [38, 57] used operative time, of which 22 used it as the main parameter. Perioperative complications were also used in 26 of our reviewed studies and were absent in two [36, 56]. Nineteen studies used complication rate as a main parameter. The combination of these two main parameters was analyzed in 24 studies (86%) [17–19, 37, 39–55, 58–60]. LOS was used in 16 studies (57%) [17, 19, 37, 40, 42, 44, 46, 48–51, 54, 57–60] as a parameter of the learning curve, but determining the learning curve only in 5. Conversion from laparoscopic to open surgery was a used parameter in 11 studies (39%) [17, 19, 37, 38, 42, 44, 47, 48, 50, 52], yet only once found as a main parameter of the learning curve. Four studies described the estimated blood loss during the operation (14%) [17, 19, 49, 60], though it was never used as a main parameter. Operative time and complication rate were not only the most used (93%), but most important parameters to determine the learning curve in this review. These parameters decreased significantly by the time the plateau for RYGB and LSG was reached. Twelve studies defined the number of procedures needed to achieve plateau using only one parameter [36–38, 43, 45, 50, 52, 53, 55–58]. On the other hand, there were 16 studies (57%) that indicated an improvement of two or more parameters while achieving plateau [17–19, 39–42, 44, 46–49, 51, 54, 59, 60] (Table 3).

Phases of the Learning Curve

Learning phases serve to describe different levels of skill during the learning curve. The model of acquisition of skills explained by Dreyfus has five distinct phases: novice, competence, proficiency, expertise, and mastery [61]. Because of prior laparoscopic experience and insufficient differentiation between the last two phases, the novice and expertise phase were respectively not reported in the included studies. Three phases were primarily described: competency, proficiency and mastery. The aim of most included studies was to find the number of procedures necessary to achieve one of these predefined skill levels. The total number of consecutive procedures in each study was divided into different groups to compare parameters during the learning curve. Each study defined the number of patient groups based on the past literature about the bariatric learning curve or used retrospective statistical analysis of outcome variables to divide the patients in groups [40, 44, 49, 58]. Studies had different numbers of patient groups that were used to define an adequate number of procedures for each phase. This was done to compare parameters between groups and to identify changes in the learning curve for RYGB or LSG. The first analyzed group of patients directly correlated with the first phase of the learning curve in 14 studies [18, 36–40, 47–50, 54, 56, 58, 60] and consisted of the number of procedures necessary to achieve an improvement in one or more parameters.

The first phase of the learning curve is generally described as improvement of operative parameters, especially operative time while most importantly focusing on patient safety. The skill level of competency has frequently been used for this phase. For the second phase, the further reduction of postoperative complications and stabilization of operative time is characteristic. Proficiency best fits the description of this second phase. Patient selection was applied in some studies [17, 43, 49, 62], where certain patient characteristics were avoided until sufficient experience was gained. As the surgeons acquire experience and operative skills, case difficulty also rises, present usually only during the second or even third phase [42]. When operative time and complication rate plateau, even with more complicated cases, mastery is achieved which defines the third phase [41]. Although competency, proficiency, and mastery were the phases described in this review, this concept was neither well differentiated nor standardized before and is a simpler and more pragmatic adaption from the Dreyfus model, as well as the IDEAL stages for introduction of new surgical techniques together with the available data from the literature identified in this systematic review [63]. The number of surgeries necessary to overcome any phase of the learning curves for both RYGB and LSG varied between 30 and 500.

Out of the 22 RYGB studies analyzed herein, the number of procedures required to reach plateau, excluding mastery, in one or two main parameters ranged from 30 to 150. A clear differentiation between competency and proficiency was mostly not described. Two of the 22 (9%) studies for RYGB patients concluded that in order to master a RYGB procedure, a surgeon needs 500 procedures [41, 42]. As for LSG, to safely reduce operative time, approximately 30 to 50 procedures were needed, defining competency, whereas to reach proficiency, 60 to 100 LSG were required [57–60]. Two studies assessed mastery level for surgeons with contrasting prior experience and plateau. Novices took 100 to 200 procedures to reach mastery [55]. On the other hand, a specialized bariatric surgeon was reported to need 30 LSG to achieve mastery [55, 56]. The numerical digit that was most often included in the learning curve throughout all studies was 100, being present in 13 studies.

Table 4 summarizes main findings of all included studies. This includes details about each learning curve, the number of patient groups and cases analyzed, previous experience of every surgeon, fellow, resident or trainee, and the number of procedures needed to reach different phases according to main parameters used, which are specified in a small conclusion of each study.

Table 3 Parameters used to assess the learning curve

Author	Time	Blood loss	Complications	Conversions	LOS
Abu-Hilal et al. (2007) [36]	X[a]				
Agrawal et al. (2011) [37]	X		X[a]	X	X
Ali et al. (2010) [38]			X[a]	X	
Andrew et al. (2006) [39]	X[a]		X[a]		
Ballesta-López et al. (2005) [40]	X[a]		X		X[a]
Doumouras et al. (2017) [41]	X[a]		X[a]		
El-Kadre et al. (2013) [42]	X[a]		X[a]	X	X
Geubbels et al. (2015) [43]	X[a]		X		
Huang et al. (2008) [44]	X[a]		X[a]	X	X
Jacobsen et al. (2012) [45]	X[a]		X		
Lublin et al. (2005) [17]	X[a]	X	X[a]	X	X
Nguyen et al. (2003) [46]	X[a]		X[a]		X[a]
Oliak et al. (2003) [18]	X[a]		X[a]		
Pournaras et al. (2010) [47]	X[a]		X[a]	X[a]	
Schauer et al. (2003) [19]	X[a]	X	X[a]	X	X
Shen et al. (2016) [48]	X[a]		X[a]	X	X
Shikora et al. (2005) [49]	X[a]	X	X[a]		X
Shin et al. (2005) [50]	X[a]		X	X	X
Sovik et al. (2009) [51]	X[a]		X		X[a]
Suter et al. (2003) [52]	X		X[a]	X	
van Rijswijk et al. (2018) [53]	X[a]		X		
Victorzon et al. (2012) [54]	X[a]		X[a]		X[a]
Carandina et al. (2019) [60]	X[a]	X	X[a]	X	X
Major et al. (2017) [55]	X		X[a]		
Prevot et al. (2014) [56]	X[a]				
Sánchez-Santos et al. (2016) [57]			X[a]		X
Zachariah et al. (2013) [58]	X		X[a]		X
Zacharoulis et al. (2012) [59]	X[a]		X	X	X[a]

LOS Length of hospital stay

[a] Main parameters that defined the learning curve

Table 4 Characteristics of the learning curves

Author	Procedure	Groups and cases	Previous experience	Conclusion	LC
Abu-Hilal et al. (2007) [36]	RYGB	Group 1: 1–50; Group 2: 51–100	Advanced experience in laparoscopic surgery	Using a two-surgeon technique, operative time throughout the first and second 50 cases was lower than in single-surgeon studies.	50
Agrawal et al. (2011) [37]	RYGB	Group 1: 1–74	Advanced experience in laparoscopic and bariatric surgery	The learning curve can be safely reduced with an adequate surgeon experience in advanced laparoscopic courses and bariatric surgical fellowships. 75–100 cases are sufficient to achieve minimal perioperative complications.	75–100
Ali et al. (2010) [38]	RYGB	Group 1: Surgeon 1: 98; Surgeon 2: 72; Surgeon 3: 102; Surgeon 4: 127; Surgeon 5: 121	Minimally invasive and bariatric surgery fellowship graduates	An average of 100 cases over the course of 1 year of advanced fellowship training was sufficient to allow fellowship graduates to achieve quality outcomes in practice.	72–127
Andrew et al. (2006) [39]	RYGB	Group 1: 1–67; Group 2: 68–134; Group 3: 135–201	Experience in open bariatric surgery	Operative time and anastomotic stricture rates plateaued in phase 2, after approximately 70 cases.	67–70
Ballesta-López et al. (2005) [40]	RYGB	Group 1: 1–100; Group 2: 101–200; Group 3: 201–300; Group 4: 301–400; Group 5: 401–500; Group 6: 501–600	*n/a*	Operative time and LOS significantly decreased in group 2, after the first 100 patients.	100
Doumouras et al. (2017) [41]	RYGB	Group 1: 1–75; Group 2: 76–150 Group 3: 151–225; Group 4: 226–300; Group 5: 301–375; Group 6: 376–450; Group 7: 451–525; Group 8: 526–600 Group 9: > 600	Fellowship-trained bariatric surgeons	Risk-adjusted all-cause morbidity and operative time did not plateau until group 7/ phase 3, approximately 500 cases. This finding was likely caused by an increase in technical skill as surgeon cumulative volume was also significantly correlated with decreased operative times.	500
Author	Procedure	Phases and Procedures	Previous experience	Conclusion	LC
El-Kadre et al. (2013) [42]	RYGB	22 Group with 100 procedures each	Advanced experience in laparoscopic surgery	Operating time was reduced after 100 RYGB; risks of adverse outcome were significantly reduced after a long learning curve of 500 consecutive procedures.	500
Geubbels et al. (2015) [43]	RYGB	Surgeon 1: 5 Group, 239 procedures; Surgeon 2: 4 Group, 186 procedures; Surgeon 3: 4 Group, 200 Procedures; Surgeon 4: 2 Group, 88 Procedures (50 procedures each group)	Surgeon 1 and 3 had previous laparoscopic bariatric experience while Surgeon 2 and 4 had not.	For every individual surgeon, the operative time decreased significantly per 50 cases within the first 150 cases. After the first 150 procedures, the operative time seemed to plateau for Surgeon 1, 2 and 3.	150
Huang et al. (2008) [44]	RYGB	Group 1: 1–50; Group 2: 51–100	4 years of experience in laparoscopic surgery	Reduction in operative time and complication rate reached plateau after 50 cases.	50
Jacobsen et al. (2012) [45]	RYGB	20 Groups: 100 procedures each	Advanced experience in laparoscopic and bariatric surgery + 3 trainees	Operative time declined significantly from the first 100 to the last 100 cases. Complication rate increased slightly during the period of the learning curves, but was still low and not significant.	100
Lublin et al. (2005) [17]	RYGB	Surgeon A (primary surgeon) operated with surgeon B assisting (Stage 1: 1–20). Surgeon B learned RYGB in stages: exposure and jejuno-jejunostomy (Stage 2: 21–45), gastric pouch (Stage 3:46-63), gastro-jejunostomy (Stage 4: 64–84), and sequence all steps (Stage 5: 85–100).	Surgeon A: Advanced experience in laparoscopic surgery; Surgeon B: Basic laparoscopic skills	Operative time variation and complications decreased in stage 4, after 80 RYGB.	80–100

Table 4 (continued)

Author	Procedure	Groups and cases	Previous experience	Conclusion	LC
Nguyen et al. (2003) [46]	RYGB	Group 1: 1–75; Group 2: 76–150	Advanced experience in laparoscopic surgery	Early operative experience of the surgeon was a major factor associated with not only a longer operative time but also with a higher rate of major complications, reoperations, and a longer LOS.	75
Author	Procedure	Phases and Procedures	Previous experience	Conclusion	LC
Oliak et al. (2003) [18]	RYGB	Group 1: 1–75; Group 2: 76–150; Group 3: 151–225	Advanced experience in laparoscopic surgery	Complication rate and operative time decline in phase 2 after approximately 75 procedures.	75
Pournaras et al. (2010) [47]	RYGB	Group 1: 1–100; Group 2: 101–200; Group 3: 201–300	Advanced experience in laparoscopic surgery	Complication rate, conversion rate and operative time improved in phase 2, after the first 100 patients.	100
Schauer et al. (2003) [19]	RYGB	Group 1: 1–50; Group 2: 51–100; Group 3: 101–150	*n/a*	Operative time and complications decreased 50% after 100 cases.	100
Shen et al. (2016) [48]	RYGB	Group 1: 1–30; Group 2: 31–60	Advanced experience in laparoscopic and bariatric surgery	Complication rate considerably decreased and operative time plateaued in phase 2, after achieving proficiency with 30 cases.	30
Shikora et al. (2005) [49]	RYGB	Group 1: 1–100; Group 2: 101– 750	*n/a*	There was reduction of complication rate and operative time by 50% in group 2, after the first 100 cases.	100
Shin et al. (2005) [50]	RYGB	Group 1: 1–50; Group 2: 51–100	Advanced experience in laparoscopic and bariatric surgery	The learning curve can be safely reduced to 50 cases with an adequate surgeon experience in advanced laparoscopic courses and proctorship and creation of a high-volume bariatric practice.	50
Sovik et al. (2009) [51]	RYGB	Group 1: first 40; Group 2: last 40; Surgeon A: 1–140, Surgeon B: 1–152	Surgeon A: Advanced experience in laparoscopic surgery and open bariatric surgery; Surgeon B: Basic laparoscopic surgery	For both surgeons, operative time and LOS were significantly reduced, leveling out after 100 procedures. Postoperative complications were reduced throughout the study period but did not plateau.	100
Author	Procedure	Phases and Procedures	Previous experience	Conclusion	LC
Suter et al. (2003) [52]	RYGB	Group 1: 1–107	*n/a*	The learning curve is steep and long, involving > 100 cases. Therefore, the learning curve has not yet been surpassed with this series of 107 patients.	100–150
van Rijswijk et al. (2018) [53]	RYGB	Group 1: 1–70; Group 2: > 70	Surgeons: Advanced experience in laparoscopic surgery and open bariatric surgery; Residents: Basic laparoscopic skills	If the learning curve of surgical residents would solely be based on operative time, it would not differ from the learning curve of senior surgeons.	50–100

RYGB Roux-en-Y gastric bypass, *LSG* laparoscopic sleeve gastrectomy, *LC* learning curve, *LOS* length of hospital stay, *n/a* data not available

Morbidity and Mortality

Morbidity and mortality were measured in all 28 studies. The mortality range for RYGB was 0–1.2%, and for LSG, it was 0–1%. Medians were 0.1 and 0.2, respectively. No differences were reported between mortality during the learning curve and afterwards. The total morbidity for RYGB ranged between 1.4 and 31.3%, and for LSG, the range was 4.4–11.7%. Medians were 15.8 and 8.9, respectively. Considering the reported perioperative complications, the most important surgery-related complications indicated in these studies were leaks: mean 1.7% (range 0–5.7%), stenosis: mean 1% (range 0–6.7%), hemorrhage: mean 1.7% (range 0–5.8%), and occlusions: mean 0.8% (range 0–3.5%). Other non-specified complications occurred in a range of 0 to 15.4% (median 6.5). Two studies did not indicate any specific complications, only overall morbidity [41, 43]. Two other studies reported leaks as the only complication [36, 56]. Mortality rates were recorded in each study except one [41]. Morbidity and mortality are shown in Table 5. Morbidity, represented as complication rate, was divided into learning curve and post-learning curve to show differences between phases in Table 6. A significantly higher complication rate was shown in the learning curve compared to post-learning curve in 11 studies [17–19, 41, 44, 46, 48, 54, 55, 58, 60]. Additionally, operative time was also included in this table and was always higher during the learning curve than post-learning curve, except for one study [58].

Discussion

The purpose of the present study was to analyze the literature on learning curves in bariatric surgery, specifically RYGB and LSG, with the aim of identifying the amount of surgeries

Table 5 Overall morbidity and mortality at the end of each study

Author	Leaks (%)	Hemorrhage (%)	Occlusion (%)	Stenosis (%)	Other (%)	Total (%)	Mortality (%)
Abu-Hilal et al. (2007) [36]	3.0	n/a	0	0	n/a	10.0	0
Agrawal et al. (2011) [37]	0.0	0	1.4	0	0	1.4	0
Ali et al. (2010) [38]	4.0	0.2	3.1	2.9	12.6	23.1	0.7
Andrew et al (2006) [39]	4.0	1.5	3.5	6.0	12.3	27.3	0.5
Ballesta-López et al. (2005) [40]	5.7	1.8	1.2	5.7	5.1	19.5	1.2
Doumouras et al. (2017) [41]	n/a	n/a	n/a	n/a	n/a	10.1	n/a
El-Kadre et al. (2013) [42]	0.7	0.6	0.4	0	0	1.7	0.4
Geubbels et al. (2015) [43]	n/a	n/a	n/a	n/a	n/a	9.4	0
Huang et al. (2008) [44]	4.0	1.0	0	10.0	9.0	24.0	0
Jacobsen et al. (2012) [45]	0.5	1.1	0.3	0	0.8	2.8	0.1
Lublin et al. (2005) [17]	1.0	0	3.0	1.0	3.0	8.0	0
Nguyen et al. (2003) [46]	0.6	3.3	3.3	0	6.8	14.0	0
Oliak et al. (2003) [18]	0.4	2.6	2.2	2.2	13.0	20.4	0.8
Pournaras et al. (2010) [47]	1.0	3.3	1.3	0.3	1.9	7.8	0.3
Schauer et al. (2003) [19]	4.7	4.0	2.0	6.7	13.9	31.3	0
Shen et al. (2016) [48]	5.0	1.7	0	3.3	6.7	16.7	0
Shikora et al. (2005) [49]	1.7	5.0	1.6	0.8	5.9	15.0	0.3
Shin et al. (2005) [50]	1.0	1.0	1.0	6.0	11.0	20.0	1.0
Sovik et al. (2009) [51]	1.4	5.8	0	0.3	7.2	14.7	0
Suter et al. (2003) [52]	5.4	2.8	0	1.8	10.3	20.5	0.9
van Rijswijk et al. (2018) [53]	1.0	3.3	0	1.4	10.9	16.6	0
Victorzon et al. (2012) [54]	1.2	1.8	0.6	0	15.4	19.1	0.3
RYGB—ranges	0–5.7	0–5.8	0–3.5	0–6.7	0–15.4	1.4–31.3	0–1.2
Carandina et al. (2019) [60]	2	1	3	1	3	10	0
Major et al. (2017) [55]	0.8	0.8	0	0.2	5.6	7.6	0
Prevot et al. (2014) [56]	3.4	0	0.8	0	6.0	10.2	0
Sánchez-Santos et al. (2016) [57]	2.8	2.4	n/a	n/a	6.5	11.7	0.5
Zachariah et al. (2013) [58]	1.3	0	0	1.3	1.8	4.4	0.4
Zacharoulis et al. (2012) [59]	3.9	2	0	1.9	0	7.8	1.0
LSG—ranges	0.8–3.9	0–2.4	0–3	0–1.9	0–6.5	4.4–11.7	0–0.5

Table 6 Comparison between learning curve and post-learning curve

Author	*N*	LC	Operative time (mean ± SD)			Complication rate (*N* (%))		
			LC	Post-LC	*P* value	LC	Post-LC	*P* value
Abu-Hilal et al. (2007) [36]	100	50	127 (90–240)[b]	105(80–210)[b]	0.009	n/a	10 (10)[c]	n/a
Agrawal et al. (2011) [37]	74	75–100	160 (115–247)[c]	n/a	n/a	1 (1.4)[c]	n/a	n/a
Ali et al. (2010) [38]	611	72–127	n/a	n/a	n/a	93 (18.6)	141 (23.1)[a]	NS
Andrew et al. (2006) [39]	201	67–70	145 ± 30	118 ± 23	0.01	(19.4)	(11.9)	NS
Ballesta-López et al. (2005) [40]	600	100	166	109	n/a	21 (29.2)	10 (14)	n/a
Doumouras et al. (2017) [41]	11684	500	170.6	125.9	0.001	(11.3)	(7.7)	0.01
El-Kadre et al. (2013) [42]	2281	500	119	90	0.001	(2.5)	(1.75)	n/a
Geubbels et al. (2015) [43]	713	150	n/a	n/a	n/a	n/a	n/a	n/a
Huang et al. (2008) [44]	100	50	217 ± 51	105 ± 38	0.001	(15)	(3)	0.05
Jacobsen et al. (2012) [45]	2000	100	102	54	0.001	n/a	n/a	NS
Lublin et al. (2005) [17]	100	80–100	246 ± 70	183 ± 42	0.001	8 (12)	0 (0)	0.05
Nguyen et al. (2003) [46]	150	75	250 ± 77[c]	n/a	0.01	9 (12)	1 (1)	0.03
Oliak et al. (2003) [18]	225	75	189	125	0.001	24 (32)	11 (15)	0.01
Pournaras et al. (2010) [47]	300	100	163 ± 53	119 ± 37	0.01	15 (15)	9 (4.5)	NS
Schauer et al. (2003) [19]	150	100	311	237	0.05	36 (36)	11 (n/a)	0.05
Shen et al. (2016) [48]	60	30	120 (80–440)[b]	80 (50–150)[b]	0.01	8 (26.7)	2 (6.7)	0.038
Shikora et al. (2005) [49]	750	100	212	132	n/a	26 (26)	87 (13)	n/a
Shin et al. (2005) [50]	100	50	113 (54–238)[b]	73 (39–145)[b]	0.0001	16 (32)	4 (8)	NS
Sovik et al. (2009) [51]	292	100	164 ± 75	66 ± 21	0.001[d]	8 (20)	6 (15)	NS[d]
Suter et al. (2003) [52]	107	100–150	185 (110–355)[b, c]	n/a	n/a	22 (20.5)[c]	n/a	n/a
van Rijswijk et al. (2018) [53]	3051	50–100	57 (50–67)[b]	n/a	n/a	27 (12,9)	n/a	n/a
Victorzon et al. (2012) [54]	325	108	110 ± 30	82 ± 24	0.001	9 (8)	6 (3)	0.05
Carandina et al. (2019) [60]	99	30–60	109 (85–180)	82 (50–120)	0.001	7 (10.6)	0 (0)	0.02
Major et al. (2017) [55]	500	100–200	130 (100–160)[b]	80 (65–96)[b]	0.001	13 (13)	5 (5)	0.011
Prevot et al. (2014) [56]	84	30	139	93	0.01	n/a	n/a	n/a
Sánchez-Santos et al. (2016) [57]	2882	100	n/a	n/a	n/a	34 (11.7)[c]	n/a	n/a
Zachariah et al. (2013) [58]	228	50	52 ± 19	63 ± 29	0.012	4 (8)	3 (1.68)	0.022
Zacharoulis et al. (2012) [59]	102	68	105 (60–240)[b]	83 (50–200)[b]	0.003	(7.8)[c]	n/a	n/a

LC learning curve, *Post-LC* post learning curve, *SD* standard deviation, *RYGB* Roux-en-Y gastric bypass, *LSG* laparoscopic sleeve gastrectomy, *N* procedures, *NS* not significant, *n/a* no data available

[a] Mentors were considered as post-LC

[b] Median (range)

[c] Data represents the whole study, not LC or post-LC

[d] Data represents learning curve from surgeon A

needed to overcome learning curves. There was great heterogeneity in definitions of learning curves and phases of the bariatric learning curve. In the included studies, the range for learning curves of RYGB was 30–500, and for LSG, it was 30–200 procedures, respectively. Therefore, further analysis was performed to suggest a uniform definition of the learning curve with the three phases competency, proficiency, and mastery. The learning curve can be assessed using several outcome measures that can be divided in two groups: variables of patient outcome and variables of surgical efficiency [64]. Complication rates and operative time play a significant role for each group, respectively, and represent the main parameters in the determination of the bariatric learning curve.

As a general concept, the learning curve can be defined as the entire learning process measuring outcomes versus experience until the individual gathers enough experience to reach a plateau. The number of procedures needed to reach plateau for RYGB and LSG varied largely in the present systematic review, because of the wide range of definitions of learning curves and plateaus and parameters used to describe it. RYGB is considered a more advanced surgical procedure [65, 66] and has a longer learning curve [67, 68], which is also shown in the present review. Most RYGB studies indicated that approximately 100 procedures were necessary to reach proficiency or at least to achieve a significant decrease in operative time and/or complication rate whereas two studies concluded that, to significantly reduce and maintain operative time and complications even with complicated cases, 500 RYGBs were needed [41, 42]. On the contrary, the learning curve for LSG was shorter with a range of 30 to 200 operations needed. Considering the absence of an anastomosis and the shorter operative time, LSG is accepted as a simpler procedure [69]. Data concerning the learning curve for LSG were more limited, given its later introduction to the surgical armamentarium compared to RYGB. However, most studies only report a number of cases to reach a certain level of safety or outcomes, rather than a rate that needs to be performed constantly over several years. As mentioned by Shikora et al., surgeons at high volume hospitals often have the opportunity to learn procedures in a shorter period of time [49]. Courcoulas et al. found that patients of surgeons performing only ten or less bariatric procedures per year had a higher risk of adverse outcomes compared to patients of surgeons with higher annual volume [70]. Similar results were reported regarding the hospital volume in general [70, 71]. Birkmeyer et al. evaluated the surgical skills of 20 bariatric surgeons using videos of them performing a procedure. Surgical skill was strongly related to annual procedural volume. Those in the bottom quartile had lower annual volumes of RYGB or any bariatric procedures compared to the surgeons in the top quartile. The higher volume surgeons had less complications [65]. Further studies evaluating the impact of annual rates of the two main bariatric procedures per surgeon and institution on patient outcomes are needed.

It is important to clarify that the number of procedures described as the learning curve refers to the acquisition of a predefined skill level. Dreyfus' model of skill acquisition has been modified and adapted by Peña to more clinical situations [72]. As such, we propose to integrate this model with the acquisition of surgical skills in bariatric surgery and predefine a three-phase model during the learning curve. The first objective is to reach competency, described as the first phase, where guidelines are learned, procedures are performed with safety levels comparative to averages. A competent surgeon can consciously plan and carry out a task, but lacks flexibility and speed in carrying them out [73]. This phase normally correlates with the number of procedures at which the ASMBS awards privileges for bariatric surgery [74]. Competency was also frequently described when variables of surgical efficiency reached plateau. Proficiency on the other hand represents the second phase, where the surgeon has memorized principles to solve problems and to determine the appropriate action, using intuition to recognize specific situations in a holistic manner. Often, expert-derived benchmarks including parameters of patient outcome are used to predefine this phase. The final phase is related to more complex cases; mastery is achieved when the experienced surgeon swiftly carries out tasks, adapts to various circumstances with absorbed awareness, and makes intuitive decisions with stable outcomes significantly superior to the average [72]. This model can be fairly adapted to the RYGB studies, suggesting approximate values for the three phases: competency [50], proficiency (100), and mastery (500). As evaluated by Bokhari et al. using the cumulative sum analysis method (CUSUM), the learning curve for robotic-assisted laparoscopic colorectal surgery consists of three phases. The first phase represents a negative slope that indicates shorter operative time. Phase 2 plateau represents increased competence or proficiency. Increased operative time in the post-learning curve was attributed to a greater proportion of more technically challenging cases in phase 3 [75]. Although there were fewer studies for LSG, competency was mostly reached between 30 and 50, proficiency around 60 to 100, and mastery needed 100 to 200 procedures depending on prior laparoscopic and bariatric experience. Case mix and previous expertise in advanced laparoscopic and bariatric surgery might lead to shorter learning curves since one study stated that a specialist bariatric surgeon needed only 30 procedures to accomplish mastery [56]. Definitions may, however, have been heterogeneous.

In the present study, operative time and complication rates were the determining outcome variables of bariatric learning curve in most studies, representing surgical efficiency and patient outcome. Operative time was the most frequently used parameter to determine the learning curve, used in 22 of the 28 included studies. Although simple to measure, the complexity of the entire surgery is undermined by this parameter in terms of assessing the learning curve. However, external factors such as patient, surgical team variability and institutional dynamics can also affect operative time [76]. It is noteworthy to recall that normally, when a single parameter is taken as the decisive outcome measure for the learning curve, the number of procedures necessary to reach plateau is lower than when using multiple parameters. Time alone may not be the most important factor to measure safety and quality outcomes [25]. In just over half of the included studies, two or more parameters were used to define the learning curve. The combination of operative time and complication rates is important, but to truly identify relevant benchmarks for outcome in bariatric surgery it is necessary to focus also on procedure specific and clinically relevant outcomes [77]. Recently, most important perioperatively measured outcome parameters for bariatric surgery have been validated; these are mortality, severe and mild postoperative complications, readmissions and prolonged LOS [78]. Important mid- and long-term outcomes include weight-loss, improvement of comorbidities, quality of life, and avoidance of further surgeries or hospitalizations. With international benchmark outcomes, these can be used to assess proposed skill levels and create a standardized evaluation tool for bariatric surgical quality assessments taking into account also external factors.

For further appraisal of the learning curve, it is essential to use appropriate analytical tools. CUSUM is a visual representation of a trend of series of consecutive procedures adjusted to the mean value. The risk-adjusted CUSUM is designed to detect change in performance associated with rate of adverse outcome while considering individual patient risk [79]. As described in the study of the learning curve of robotic RYGB by Renaud et al., multifactorial analysis can be achieved with risk-adjusted CUSUM and permits the identification of cut-off points of variance for a specific variable [80]. By this means, benchmark outcome parameters can be used to detect different phases in the learning curve of bariatric surgery. By defining different levels of skill and quality of outcome for each described learning phases with benchmark outcomes and by use of CUSUM analysis, standardized learning models, and strategies for homogenous and global collection of data during the bariatric learning process can be achieved in the future. This will enable to better understand and improve bariatric surgical training and thus to improve patient safety and outcomes in the future. The present study will facilitate such development through standardization of learning curves.

Laparoscopic skills and prior bariatric surgery experience influence the individual learning curve for RYGB and LSG [81, 82]. Birkmeyer et al. found that years of experience in laparoscopic and/or bariatric surgery had no direct relation to surgical skill, but instead this was strictly related to procedural volume. However, the included surgeons had long been practicing and were past the initial learning curves [65]. The surgeons evaluated in the present review had varying previous surgical experience. In studies with a mentoring program, the learning curve of surgical residents did not differ from the learning curve of senior surgeons. On the other hand, previous studies have shown that surgeons with advanced laparoscopic experience and/or laparoscopic fellowships tended to have shorter learning curves regarding complications and operative time in bariatric surgery [83, 84], additional studies showed a rapid safety improvement during the early phases of the learning curve in comparison to the later phases after the learning curve [85, 86]. These findings are supported in the present review, where surgeons with advanced experience in laparoscopic and bariatric surgery tended to need a lower number of procedures to overcome the learning curve for RYGB and LSG. In addition, with the aim of shortening the bariatric learning curve, several studies focused on the development of different programs, including bariatric fellowships [66, 84, 87, 88], laparoscopic bariatric workshops [89], systematic training programs [90], task-based approaches [91], bariatric assessment tools, simulation-based training [30, 92], laparoscopic skills evaluation [67], proctorships and mentorships [29, 93]. A well-structured bariatric training curriculum has a positive effect on the learning curve and on patient safety [29, 66, 83, 84, 87–90, 94, 95].

It is yet to be determined if there is a difference in learning curves, if surgeons would specialize in only one procedure rather than learning both simultaneously. However, the majority of surgeons need to master multiple bariatric procedures in order to meet the patients' specific needs. Accurately determining the learning curve for RYGB or LSG separately seems difficult, since they are not completely independent from each other in case both are performed by the same surgeons. Furthermore, the performance of several laparoscopic procedures in a similar or identical anatomical area, a concept also known as "index procedures", will have a positive influence on the learning curve of each of the procedures. Comparative studies are challenging due to the common practice of surgeons performing both procedures but may answer this question more thoroughly.

Even though the exact relation between surgical experience and shorter learning curves is still a matter of debate and depends also on individual talent, a surgeon's previous experience and a well-structured training curriculum are hallmarks in the challenge of mastering the complexity of laparoscopic bariatric surgery.

Limitations

Variation in regard to the definition of learning curve, plateau, phases, and parameters used in included studies brought heterogeneity to this review, demonstrating the considerable heterogeneity of included studies. Also, different statistical methods to obtain results and the lack of prospective randomized trials did not allow a meta-analysis for the ideal assessment of the bariatric learning curve. After appraising included studies and their limitations, we highlight the need for the application of standardized definition of learning curves and key aspects, like outcome variables, surgeon's prior training and experience, learning phases and plateaus. For future studies, we therefore defined and recommend reporting the three phases of competency, proficiency and mastery with adequate statistical analysis focusing on various outcomes that can be used for benchmarking. Due to the heterogeneity and subjectivity in definitions, further differentiation and more studies are needed to confirm the range of numbers required by surgeons with different previous operative training to reach the proposed levels.

Conclusion

In conclusion, this systematic review of 28 studies demonstrates that operative time and post-operative complications have been used as main outcome variables to establish learning curves in bariatric surgery. Due to the heterogeneity of the studies included that resulted in great variation, the introduction of a learning curve model with three phases was established based on the available data. For RYGB, the required procedure numbers were 30 to 70 for competency, 70 to 150 for proficiency, and up to 500 for mastery. For LSG, required procedures ranged between 30 and 50 for competency, between 60 and 100 for proficiency, and between 100 and 200 for mastery. Well-established training curricula, previous experience with laparoscopic skills, and high procedure volume are key aspects for a successful and safe mastering of the learning curve of bariatric surgery. For future assessment of the bariatric learning curve, multiple procedure relevant outcome measures should be evaluated using appropriate statistical methods, thereby accomplishing a deeper and more holistic understanding in future studies.

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Compliance with Ethical Standards

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

Ethical Approval and Informed Consent For this type of study, formal consent and ethical approval is not required.

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