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REVIEW

The bariatric surgery and weight losing: a meta-analysis in the long- and very long-term effects of laparoscopic adjustable gastric banding, laparoscopic Roux-en-Y gastric bypass and laparoscopic sleeve gastrectomy on weight loss in adults

Mahdieh Golzarand[1] · Karamollah Toolabi[2] · Roya Farid[3]

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Abstract
Background Several studies have been investigated to find the long-term effect of bariatric surgery on weight loss; nevertheless, a meta-analysis can detailedly demonstrate the effect of bariatric surgery on weight in morbidly obese patients. This study aimed to assess the long- and very long-term effects of laparoscopic adjustable gastric banding (LAGB), laparoscopic Roux-en-Y gastric bypass (LRYGB), and laparoscopic sleeve gastrectomy (LSG) on weight loss in adults.
Methods An electronic search using PubMed, Scopus, and Google scholar databases was performed for all English-language articles up to May 15, 2016 with no publication date restriction. Outcome was long-term (≥5–10 years) and very long-term (≥10 years) weight reduction that reported as the mean %EWL and changes in BMI from baseline.
Results Eighty articles with 87 arms were included in this meta-analysis. The excess weight loss percentage (%EWL) was 47.94% and 47.43% after LAGB at ≥5 and ≥10 years, respectively. After LRYGB the %EWL was 62.58% at ≥5 years and 63.52% at ≥10 years. It was 53.25% at ≥5 years after LSG. Results of subgroup analyses have indicated that LRYGB leads to higher %EWL in America and Asia compared with Europe. Meta-regression analyses have shown that there is no significant association between %EWL and baseline age, BMI and length of follow-up after three procedures. However, there is a positive association between gender and %EWL after LRYGB ($\beta = 1.24$). No publication bias was found.
Conclusions These findings suggest that LRYGB is an effective procedure in morbidly obese patients that leads to sustainable weight loss over the long- and very long-term periods in compared with LAGB and LSG.

Keywords Laparoscopic adjustable gastric banding · Laparoscopic Roux-en-Y gastric bypass · Laparoscopic sleeve gastrectomy · Weight · Bariatric surgery

✉ Karamollah Toolabi
tolabika@tums.ac.ir

[1] School of Nutritional Sciences and Dietetics, Tehran University of Medical Sciences, Tehran, Iran

[2] Department of Surgery, Imam Khomeini Hospital, Tehran University of Medical Sciences, Keshavarz Blvd., Tehran, P.O.Box 13145-158, Iran

[3] Department of Social Sciences and Health, Durham University, Durham, UK

Obesity (body mass index [BMI] ≥ 30 kg/m^2) is a worldwide public health issue. It is associated with increased risk of diabetes mellitus, cardiovascular disease (CVD), sleep apnea, osteoarthritis, cognitive dysfunction, some cancers, non-alcoholic fatty liver disease, and gallbladder disease which together lead to 2.5 million deaths per year worldwide [1]. Based on the National Health and Nutritional Examination Survey (NHNES) report in 2011–2012, 34.9% of adults (36.1% of women and 33.5% of men) suffer from obesity in the USA [2]. Management of obesity involves non-surgical and surgical approaches. Non-surgical intervention including diet therapy, pharmaceutical therapy, and lifestyle modification are conventional approaches used to treat obesity [3]. However, these interventions are ineffective in treating morbid obesity (BMI ≥ 40 kg/m^2) over the long-term periods (≥5 years) [1]. In comparison with the non-surgical approach, surgical techniques, referred to as bariatric surgery, are effective method in treating morbid

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obesity and its related co-morbidities in the long-term periods [4, 5].

National Institutes of Health (NIH) guidelines recommend bariatric surgery for patients with BMI ≥ 40 or ≥35 kg/m^2 with co-morbidity. Laparoscopic adjustable gastric banding (LAGB), laparoscopic Roux-en-Y gastric bypass (LRYGB), and laparoscopic sleeve gastrectomy (LSG) are the three most common procedures in managing morbid obesity [5, 6]. In addition, several studies have investigated the long-term effects of bariatric surgery on weight loss which suggested weight reduction after bariatric surgery varies based on ethnic group [4]. Consequently, there is a need to conduct a meta-analysis to elucidate the effect of bariatric surgery on weight in morbidly obese patients. A meta-analysis on 28 studies (including 7383 patients) showed that excess weight loss (%EWL) was 49.4% (95% CI 44.9–54.0) after LAGB and 62.6% (95% CI 58.6–66.6) after LRYGB [6]. Buchwald et al. conducted a meta-analysis on 91 studies (including 22,094 patients) showing %EWL to be 47.4% (95% CI 40.6–54.2) and 61.5% (95% CI 56.8–66.5) after AGB and RYGBP, respectively [1]. An updated meta-analysis is necessary for two reasons; first, the previous meta-analyses pooled studies with short-term (<2 years), mid-term (2–5 years), and long-term (≥5 years) follow-up periods; thus, their findings do not provide an accurate estimate of long- and very long-term weight reduction after bariatric surgery. Second, some previous meta-analyses included studies that used open bariatric surgery. Therefore, this meta-analysis of existing literature which aimed to assess long- and very long-term weight reduction after LAGB, LRYGB, and LSG in adults has been conducted.

Materials and methods

The various literature reviews of studies that investigated long-term weight reduction after LRYGB, LAGB, or LSG has been used. The electronic search using PubMed, Scopus, and Google scholar databases was performed for all English-language articles up to May 15, 2016 although there was no publication date restriction. Search terms used were as follows: "body weight," "weight loss," "weight gain," "weight change," "fat mass," "body fat," "lean mass," "fat free mass," "adipose tissue," "gastric bypass," "sleeve gastrectomy," "gastric banding," "bariatric surgery," and "Roux-en-Y gastric bypass." In addition, a list of references of review articles was checked for any relevant articles.

Study selection

The two researchers (M.G and K.T) screened retrieved articles independently and selected relevant studies by title and abstract, then full text. These studies were included if they were prospective, retrospective or randomized clinical trials (≥5 years follow-up), used LRYGB, LAGB, or LSG. Also their BMI were more than 40 or 35 kg/m^2 with co-morbidity and more than 37 or >32 kg/m^2 in Asian population. The participants' mean age was ≥19 years at baseline, reported %EWL or BMI at 5 years or more after surgery.

This study benefits letters, comments, case reports, reviews, or animal studies. Exclusion criteria included adolescents, lactating women, patients with previous bariatric surgery, Prader–Willi syndrome, kidney disease and cardiac or kidney transplantation, studies of laparotomy bariatric surgery techniques, other bariatric surgery procedures (i.e., biliopancreatic diversion, vertical gastric banding, duodenal switch, gastric plication, mini gastric bypass or banded gastric bypass), intragastric balloon therapy, studies did not report %EWL or BMI at 5 years or more after surgery and also studies with less than 5 years' follow-up. If studies reported %EWL or BMI over a mean or median of follow-up periods (<5 years' follow-up to >5 years' follow-up), they were removed. To avoid overlapping, kin relationships were identified and recent studies were included. In cases reported %EWL or BMI at several different intervals, only the %EWL or BMI at the longest follow-up duration has been used.

Extraction of data

The two researchers (M.G and K.T) reviewed included studies and extracted data based on a data collection form. We extracted baseline sample size, age, gender ratio, baseline BMI and weight, geographic location, type of surgery, number of participants at the end of the study, %EWL or BMI at 5 years or more after surgery, duration of follow-up, bougie size, length of alimentary limb, and biliopancreatic limb.

Definition

Surgical techniques included LRYGB, LAGB, or LSG

Outcome was long-term (≥5–10 years) and very long-term (≥10 years) weight reduction that reported as the mean %EWL and changes in BMI from baseline. %EWL was defined: [(basal weight − final weight) × 100]/(basal weight − ideal weight).

Statistical analysis

All statistical analyses were performed using Stata software version 12 (StataCrop. College Station, Texas, USA). To calculate pooled effect size and 95% confidence interval (95% CI), long- and very long-term %EWL and changes in BMI from baseline were used. Random-effects model meta-analyses were conducted if there was heterogeneity. The heterogeneity of studies using *I*-squared (I^2) and Tau-squared (τ^2) statistics were assessed. To assess the effect of predefined source of heterogeneity including age, gender, baseline BMI, duration of follow-up, bougie size, length of alimentary limb and biliopancreatic limb on the %EWL, and changes in BMI from the baseline, this paper used meta-regression analyses and subgroup analysis to assess the effect of geographic location on %EWL. Egger's regression symmetry was used to investigate publication bias.

Results

The flow chart of the study selection process is presented in Fig. 1. Initially, several articles were screened; 19,680 articles (11,470 from PubMed, 8207 from Scopus, 5806 from Google Scholar and 3 from the reference list of review articles). Of those, 10,866 articles were retrieved for title and abstract assessment (8814 were excluded due to duplicated articles). Based on title and abstract, 10,480 articles were excluded. Of the remaining 486 articles, 406 did not meet the inclusion and exclusion criteria so were removed and

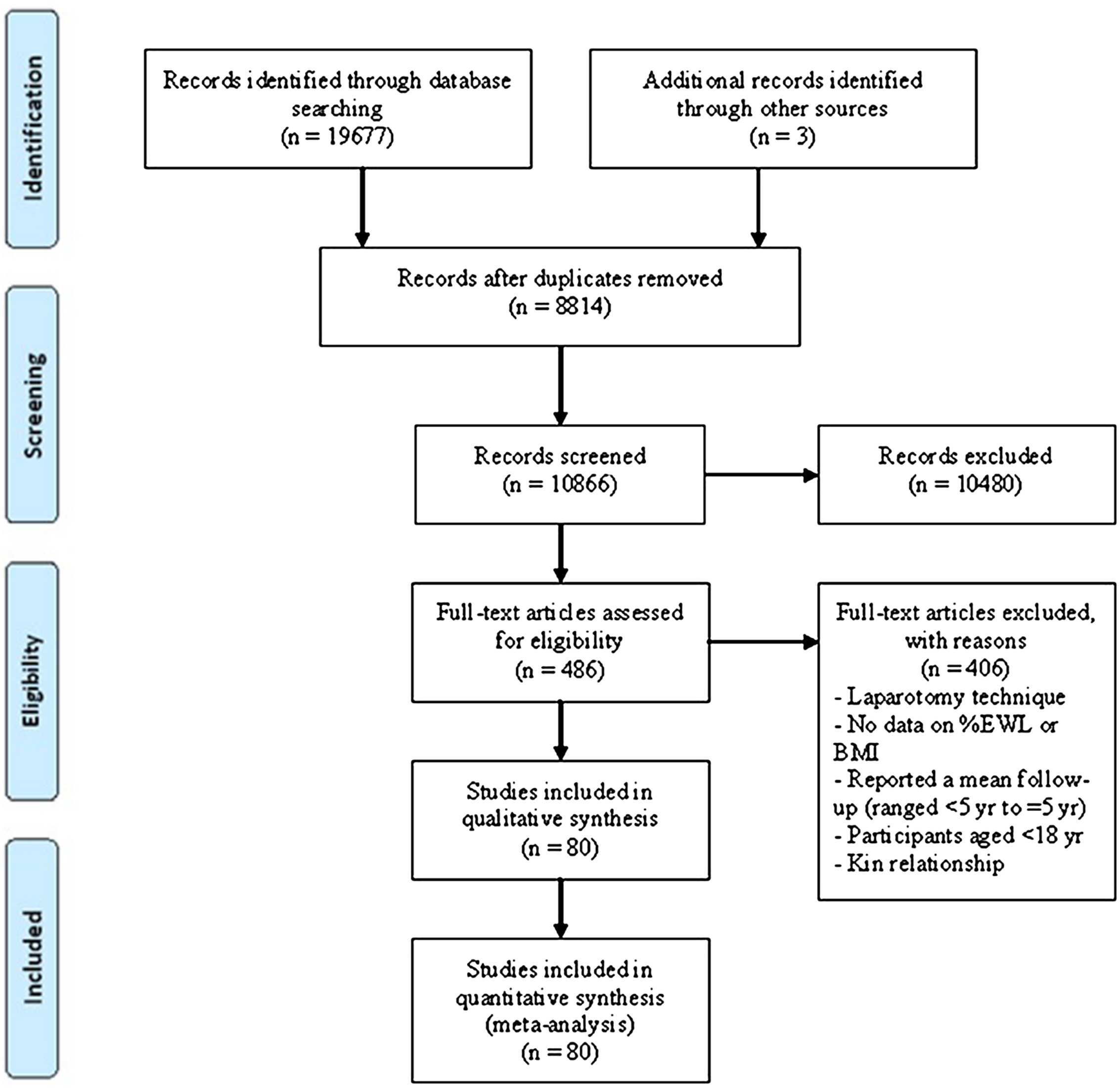

Fig. 1 Flow chart of study selection process

80 articles with 87 arms (5825 persons) were included in this meta-analysis.

Weight reduction after LAGB

Forty-four [7–50] studies including 3040 persons reported long- and very long-term %EWL and changes in BMI from baseline after LAGB. The mean age of patients was 42.7 ± 8.4 years and 73.6 ± 13.2% of patients were women. Mean weight and BMI at baseline were 125.6 ± 14.9 kg and 45.7 ± 4.9 kg/m^2, respectively. The forty-four included studies were conducted in America ($n = 11$), Asia ($n = 4$), Europe ($n = 23$), and Oceania ($n = 6$). The Eggers' regression symmetry test indicated no significant publication bias among studies ($P = 0.52$).

Long-term %EWL was pooled for 42 studies [7–20, 22–31, 33–50], and very long-term %EWL was pooled for 15 studies [7, 9, 10, 14, 18, 22, 26, 29, 33, 35, 36, 42, 45, 46, 48]. Thirty [9–11, 15, 16, 18–24, 26–32, 34, 35, 38, 41–44, 46–48, 50] and 10 studies [9, 10, 18, 22, 26, 29, 35, 42, 46, 48] reported the long- and very long-term changes in BMI from baseline, respectively. The forest plot of long-term %EWL after LAGB is presented in Fig. 2. Over the long-term periods, the %EWL was 47.94% (95% CI 45.31–50.57, $P < 0.001$) and BMI reduced by −11.09 kg/m^2 (95% CI −12.43 to −9.74, $P < 0.001$) from baseline (Table 1). The mean %EWL was 47.43% (95% CI 37.46–57.40, $P < 0.001$) (Fig. 3), and changes in BMI from baseline were −9.69 kg/m^2 (95% CI −11.32 to −8.06, $P < 0.001$) (Table 1) during the very long-term follow-up periods.

Sensitivity analysis indicated two [36, 43] and four studies [7, 14, 33, 35] that affected the long- and very long-term %EWL, respectively. After exclusion of these studies, the long-term %EWL remained unchanged (48.30%, 95% CI 47.22–48.84, $P < 0.001$); however, the mean %EWL over the very long-term follow-up decreased (43.69%, 95% CI 38.66–48.72, $P < 0.001$).

After subgroup analysis based on geographic location, the mean %EWL was 41.74% (95% CI 40.36–43.13, $P < 0.001$) in America, 55.95% (95% CI 55.70–56.21, $P < 0.001$) in Europe, 48.24% (95% CI 42.64–53.84, $P < 0.001$) in Asia, and 46.70% (95% CI 46.57–46.83, $P < 0.001$) in Oceania (Table 2).

Meta-regression analysis on %EWL is presented in Fig. 4. Findings from meta-regression show that there is no

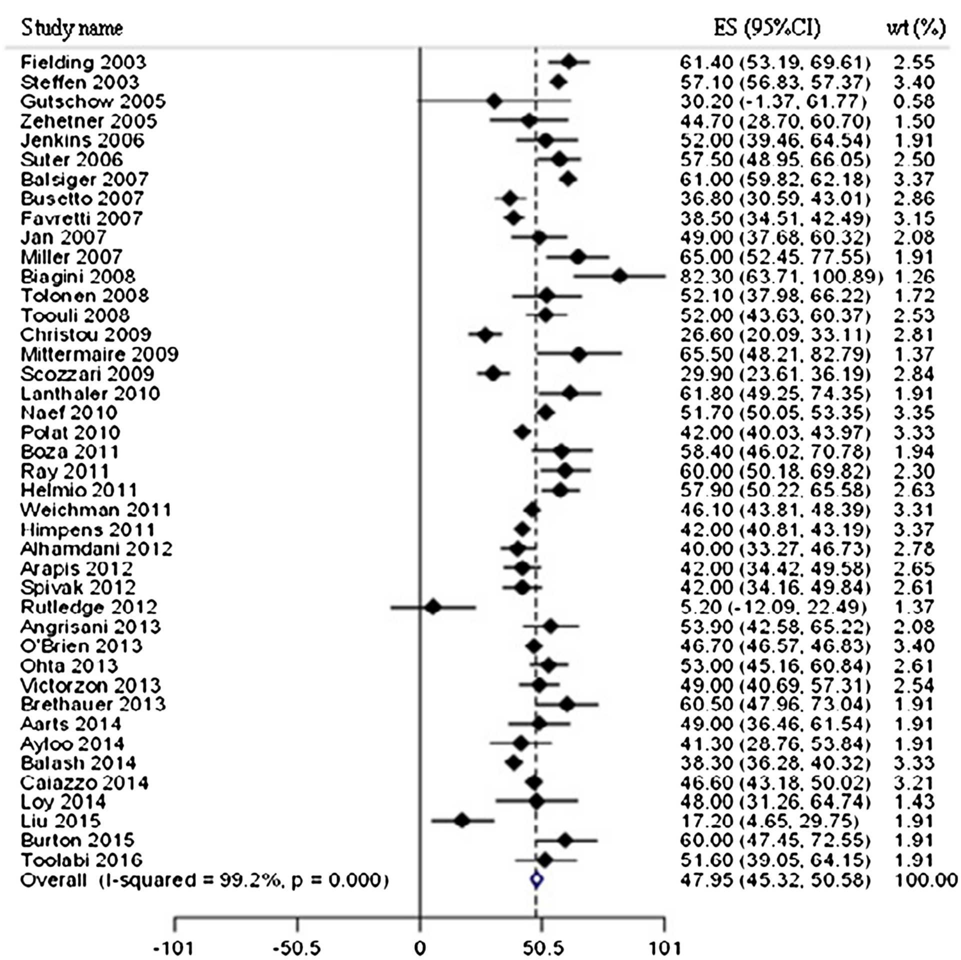

Fig. 2 Forest plot of effect of LAGB on the long-term (≥5 year) %EWL

Table 1 Long- and very long-term changes in BMI from baseline after LAGB, LRYGB, and LSG

Changes in BMI	Participants (n)	ES (95% CI)	*P* value	I^2 (%)	τ^2
LAGB					
Long-term	2664	−11.09 (−12.43 to −9.74)	<0.001	86.3	10.17
Very long-term	364	−9.69 (−11.32 to −8.06)	<0.001	51.7	2.94
LRYGB					
Long-term	1427	−13.75 (−14.78 to −12.72)	<0.001	92.3	3.88
Very long-term	27	−14.75 (−17.93 to −11.57)	<0.001	60.4	3.28
LSG					
Long-term	1114	−11.32 (−12.87 to −9.77)	<0.001	98.9	9.13
Very long-term	–	–	–	–	–

LAGB laparoscopic gastric banding, *LRYGB* laparoscopic Roux-en-Y gastric bypass, *LSG* laparoscopic sleeve gastrectomy, *ES* effect size

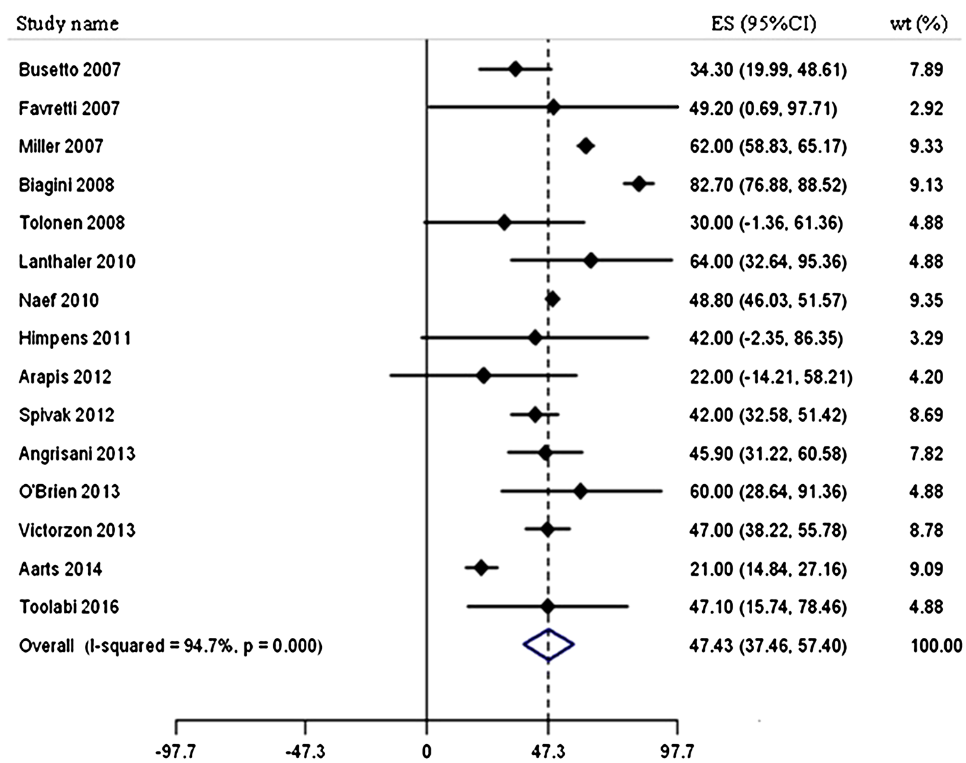

Fig. 3 Forest plot of effect of LAGB on the very long-term (≥10 year) %EWL

significant association between %EWL and age ($\beta = -0.34$, $P = 0.23$), duration of follow-up ($\beta = -0.40$, $P = 0.55$), gender ($\beta = 0.10$, $P = 0.64$), and baseline BMI ($\beta = 0.05$, $P = 0.89$).

Weight reduction after LRYGB

Twenty-three studies [3, 9, 19, 20, 27, 42, 51–67] including 1671 persons reported long- and very long-term %EWL and changes in BMI from baseline after LRYGB. The mean age of patients was 40.8 ± 5.2 years and 79.4 ± 7.8% of patients were women. Mean weight and BMI at baseline were 134.7 ± 15.6 kg and 47.2 ± 15.6 kg/m^2, respectively. The twenty-two selected studies were conducted in America ($n = 12$), Asia ($n = 1$), and Europe ($n = 10$). No significant publication bias was found (Eggers' regression symmetry test = 0.32). This study pooled long-term %EWL and changes in BMI from baseline for 19 studies [3, 9, 19, 20, 27, 42, 52, 54–58, 60–65, 67] and 17 studies [3, 9, 19, 20, 27, 42, 51–55, 59, 60, 62, 64, 66, 67], respectively. Only three studies [9, 42, 57] reported very long-term %EWL and two studies [9, 42] reported very long-term changes in BMI from baseline. The forest plot of long- and very long-term %EWL after LRYGB is illustrated in Figs. 5 and 6, respectively. The pooled effect size of %EWL was 62.58% (95% CI 58.33–66.82, $P < 0.001$) at ≥5 years and 63.52%

Table 2 Long- and very long-term changes in BMI after LAGB, LRYGB, and LSG

Procedure	America	Asia	Europe	Oceania
LAGB				
%EWL	41.74 (40.36–43.13)	48.24 (42.64–53.84)	55.95 (55.70–56.21)	46.70 (46.57–46.83)
P value	<0.001	<0.001	<0.001	<0.001
I-squared (%)	89.4	92.1	98.1	83.5
LRYGB				
%EWL	60.10 (55.35–64.84)	61.91 (60.50–63.31)	56.68 (54.69–58.66)	–
P value	<0.001	<0.001	<0.001	–
I-squared (%)	92.1	0.0	67.1	–
LSG				
%EWL	57.10 (52.26–61.93)	51.95 (51.00–52.91)	55.72 (53.88–57.57)	40.00 (34.71–45.28)
P value	<0.001	<0.001	<0.001	<0.001
I-squared (%)	76.4	89.9	0.0	0.0

LAGB laparoscopic gastric banding, *LRYGB* laparoscopic Roux-en-Y gastric bypass, *LSG* laparoscopic sleeve gastrectomy

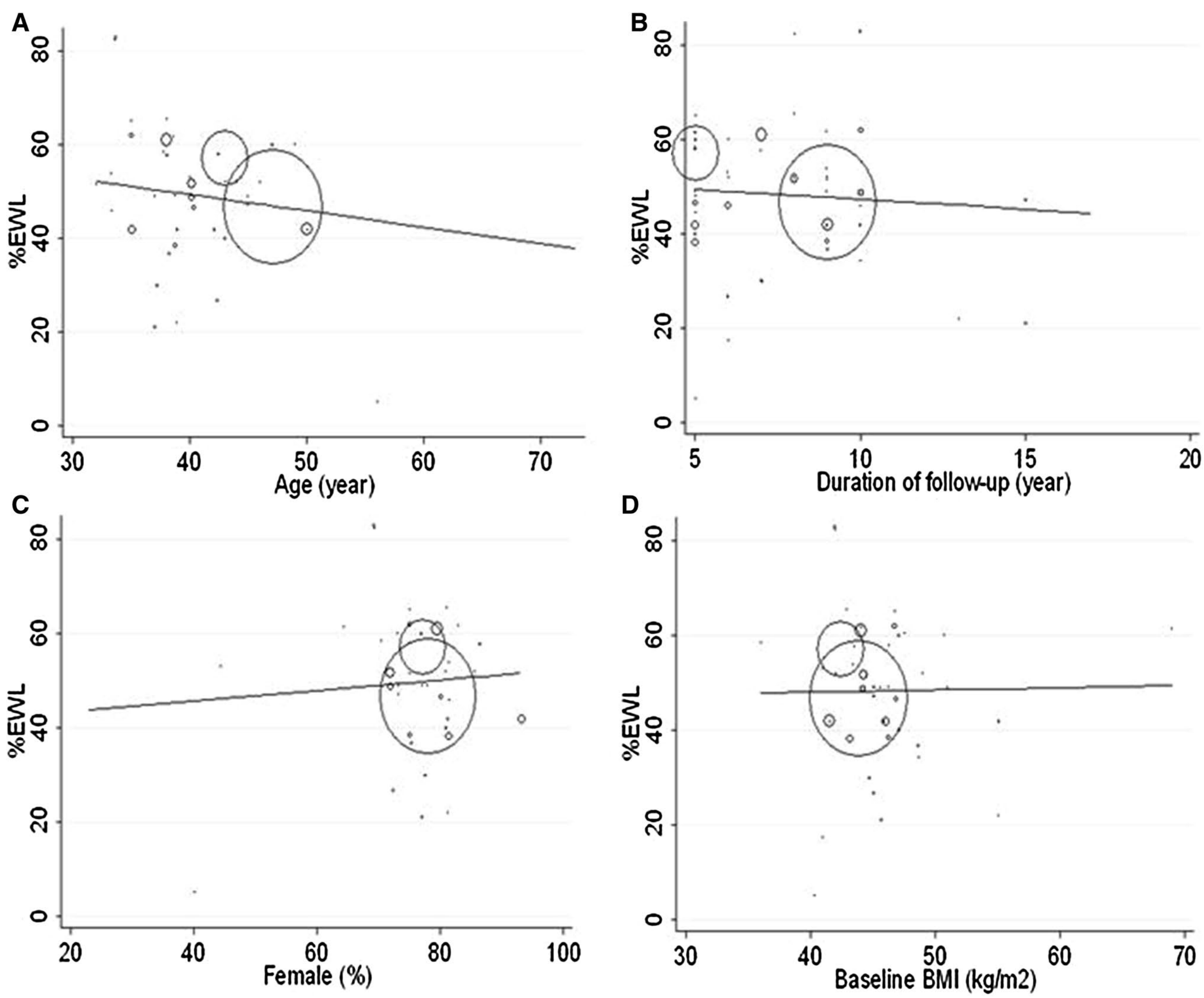

Fig. 4 Meta-regression analysis of effect of **A** baseline age, **B** duration of follow-up, **C** female (%) and **D** baseline BMI on %EWL after LAGB. Size of the *circles* corresponds to the weight of each study

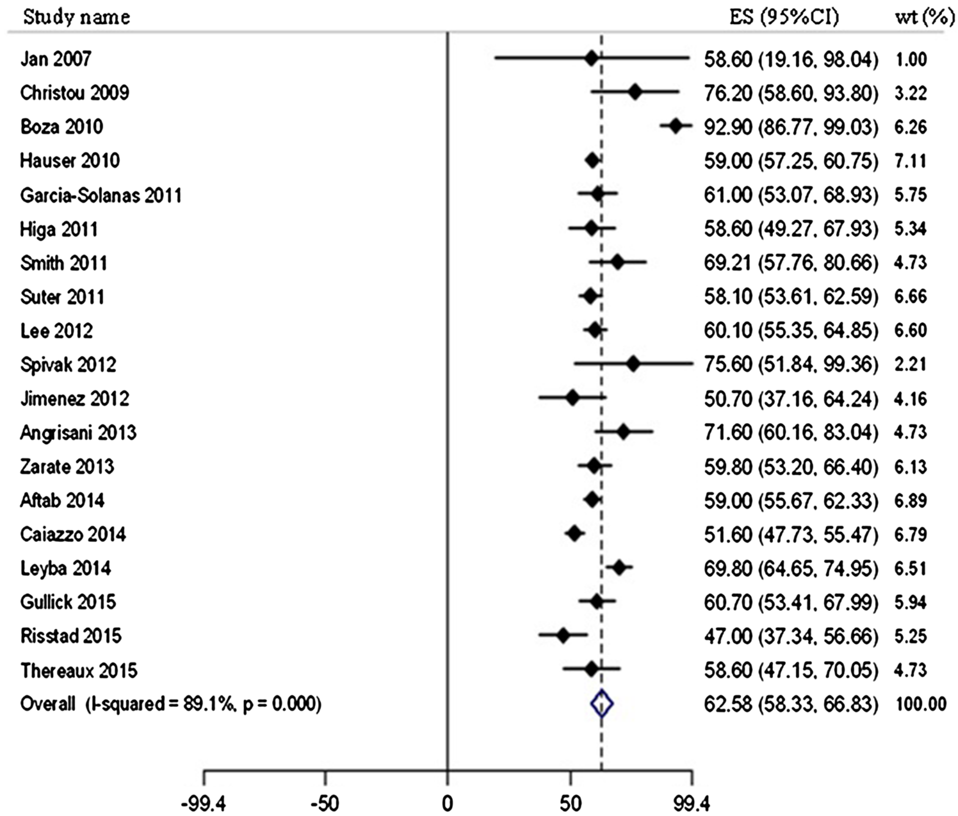

Fig. 5 Forest plot of effect of LRYGB on the long-term (≥5 year) %EWL

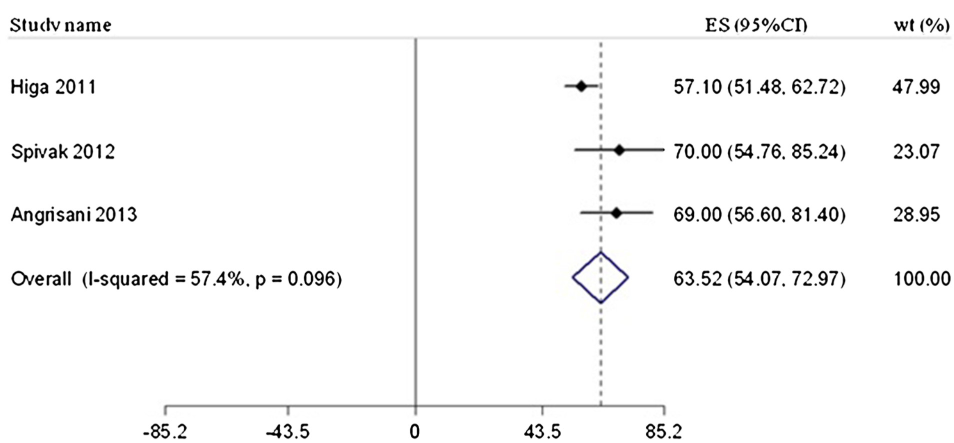

Fig. 6 Forest plot of effect of LRYGB on the very long-term (≥10 year) %EWL

(95% CI 54.07–72.97, $P < 0.001$) at ≥10 years. Changes in BMI from baseline were −13.75 kg/m^2 (−14.78 to −12.72, $P < 0.001$) and −14.75 kg/m^2 (−17.92 to −11.57, $P < 0.001$) over the long- and very long-term follow-up periods, respectively (Table 1). Sensitivity analysis indicated that no study significantly affected the pooled effect size.

The effect of geographic location on the %EWL is shown in Table 2. The mean %EWL was 61.91% (95% CI 60.50–63.31, $P < 0.001$), 56.33% (95% CI 54.1–58.55, $P < 0.001$) and 60.10% (95% CI 55.35–64.84, $P < 0.001$) in America, Europe, and Asia, respectively.

Meta-regression analysis on %EWL is presented in Fig. 7. Results of meta-regression indicate that gender is significantly associated with %EWL ($\beta = 1.24$, $P = 0.004$). There is no significant association between %EWL and age ($\beta = -0.74$, $P = 0.17$), duration of follow-up ($\beta = 0.77$, $P = 0.52$), baseline BMI ($\beta = -0.88$, $P = 0.05$), biliopancreatic limb ($\beta = 0.53$, $P = 0.16$), and alimentary limb ($\beta = -0.08$, $P = 0.69$).

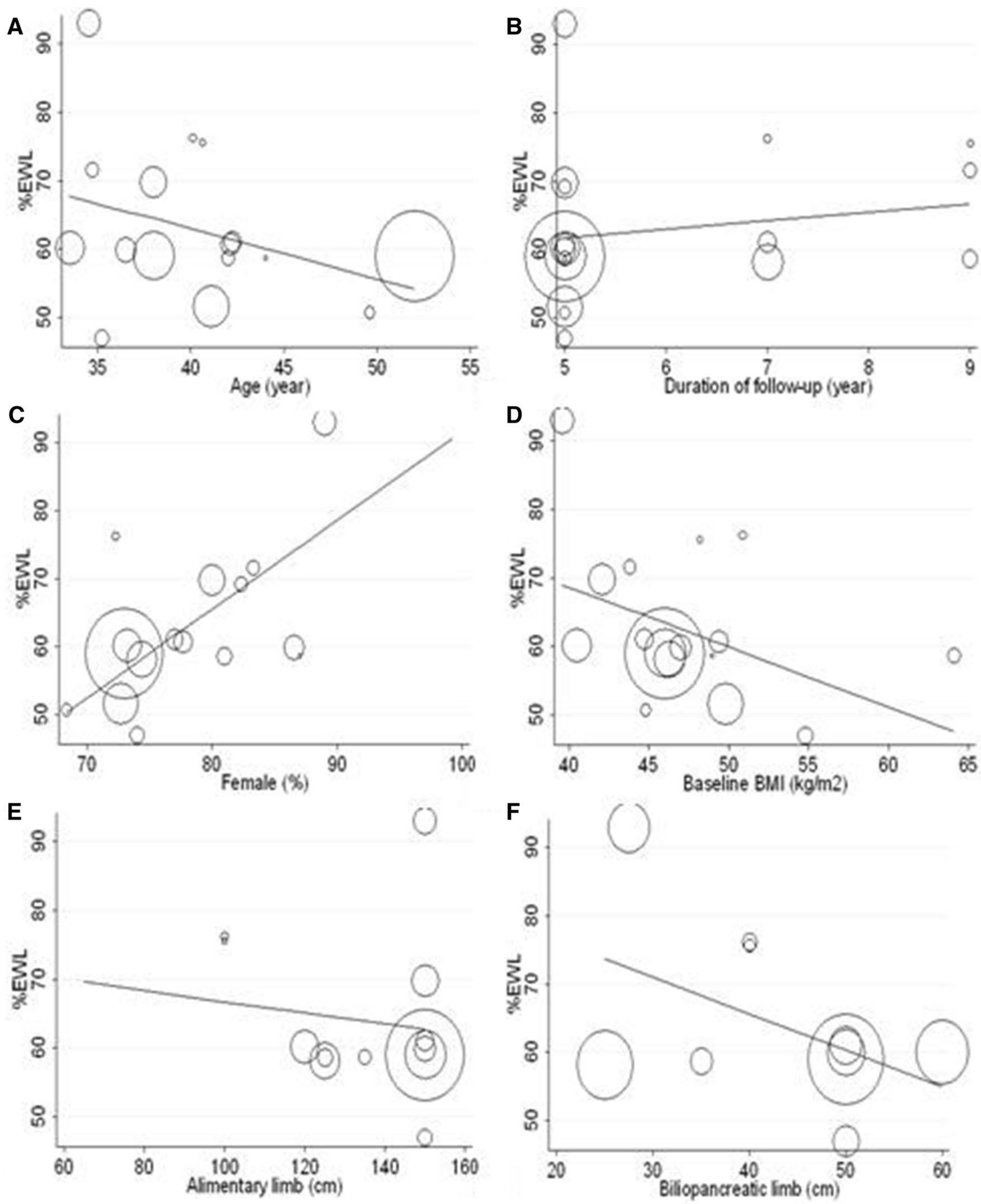

Fig. 7 Meta-regression analysis of effect of **A** baseline age, **B** duration of follow-up, **C** female (%), **D** baseline BMI, **E** alimentary limb and **F** biliopancreatic limb on %EWL after LRYGB. Size of the *circles* corresponds to the weight of each study

Weight reduction after LSG

Twenty studies [16, 61, 68–85] including 1114 persons reported long-term %EWL and changes in BMI from baseline after LSG. In this respect, no study on very long-term %EWL and changes in BMI was found. Mean age of patients was 46.4 ± 11.2 years and 67.3 ± 12.6% of patients were women. Mean weight and BMI at baseline were 126.2 ± 16.7 kg and 47.3 ± 7.1 kg/m^2, respectively. The twenty studies were conducted in America (n = 6), Asia (n = 4), Europe (n = 8), Africa (n = 1), and Oceania (n = 1). The Egger's symmetry test showed no significant publication bias among studies (P = 0.65).

Sixteen studies [16, 61, 68–79, 84, 85] were pooled for long-term %EWL and 15 studies [16, 68–71, 74, 76, 77, 79–85] for long-term changes in BMI from baseline. The forest plot of long-term %EWL after LSG is presented in Fig. 8. The mean %EWL was 53.25% (95% CI 50.27–56.18, $P<0.001$). At ≥5 years after LSG, BMI reduced by −11.32 kg/m^2 (95% CI −12.87 to −9.77, $P<0.001$) (Table 1). Sensitivity analysis showed that one study affected pooled effect size. After exclusion of Kular et al. [77], the %EWL remained unchanged.

Based on geographic location, the %EWL was 57.1% (95% CI 52.26–61.93, $P<0.001$) in America, 55.72% (95% CI 53.88–57.57, $P<0.001$) in Europe, 51.95% (95% CI 51.00–52.92, $P<0.001$) in Asia, and 40% (95% CI 34.71–45.28, $P<0.001$) in Oceania (Table 2).

Meta-regression analysis on %EWL is presented in Fig. 9. In this figure, there are no significant association between %EWL and age ($\beta=0.15$, $P=0.38$), duration of follow-up ($\beta=-0.03$, $P=0.98$), gender ($\beta=-0.21$, $P=0.07$), baseline BMI ($\beta=-0.42$, $P=0.13$), and bougie size ($\beta=-0.12$, $P=0.75$).

Discussion

Bariatric surgery is an effective approach used to treat morbid obesity which causes long-term sustained weight loss and remission of co-morbidities such as diabetes mellitus, dyslipidemia, hypertension, and sleep apnea.

Data on the most effective bariatric procedure to maintain %EWL over the long-term periods unconfirmed [7, 86]. In any case, it seems that meta-analysis is a way to provide beneficial knowledge regarding assessing long- and very long-term weight reduction after LAGB, LRYGB and LSG. The results of the study suggested that the mean %EWL at ≥5 years was 47.9%, 62.5%, and 53.2% after LAGB, LRYGB, and LSG, respectively. The mean %EWL at ≥10 years after LAGB and LRYGB is the same as the mean %EWL at ≥5 years. In addition, there was a significant positive association between gender and %EWL after LRYGB but no LAGB and LSG. However, there is no significant association between age, baseline BMI and duration of follow-up and %EWL after LAGB, LRYGB, and LSG. Bougie size and length of biliopancreatic and alimentary limb had no association with %EWL after LSG and LRYGB, respectively. Also, the results showed that effectiveness of LAGB, LRYGB, and LSG is equal in Europe, while in America and Asia, LRYGB achieves more weight loss than LAGB.

In 2008, Buchwald et al. have reported that the global number of AGB, RYGB, and SG performed was 42%, 40%, and 4.5%, respectively [87]. However, in a recent survey, Angrisani et al. have reported that the most performed procedures were RYGB (45%), SG (37%), and AGB (10%) worldwide in 2013 [88]. Previous studies have indicated that AGB was a popular procedure in Europe, Australia, and South America [13–15]. In USA, RYGB was performed routinely until 2001; however, after Food and Drug Administration's (FDA) approved the AGB, number of this

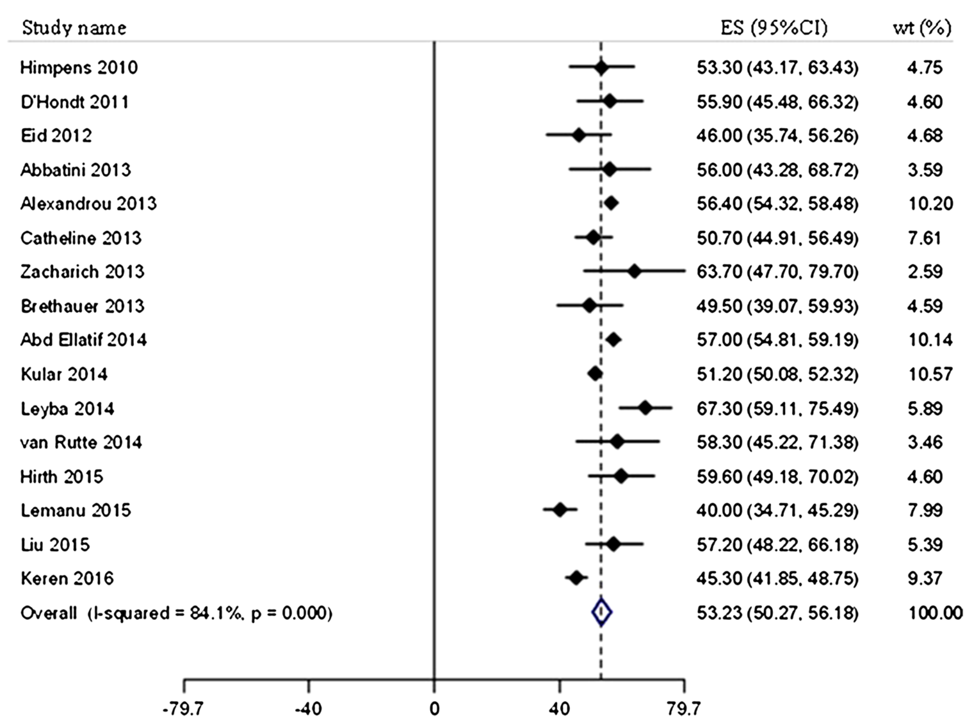

Fig. 8 Forest plot of effect of LSG on the long-term (≥5 year) %EWL

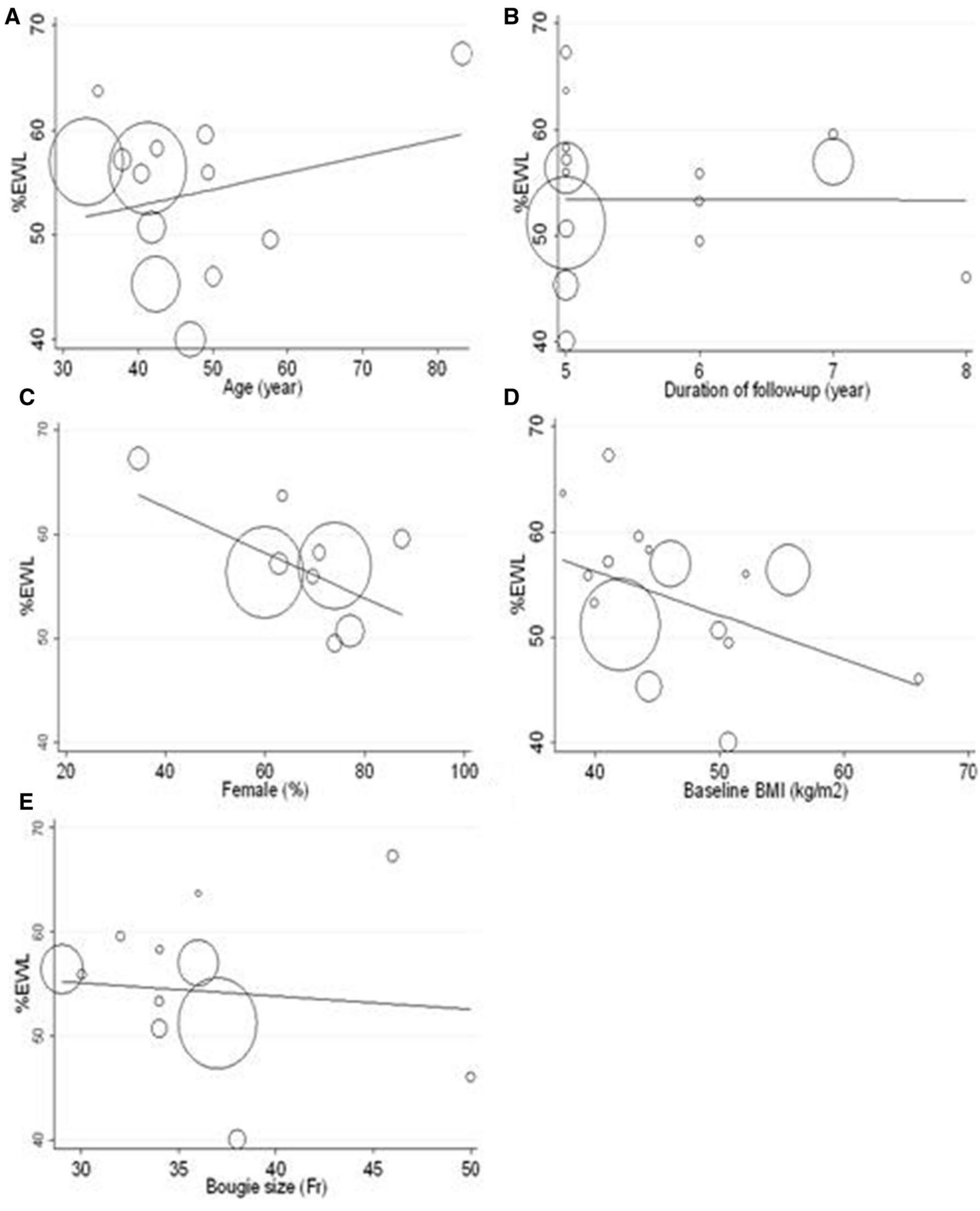

Fig. 9 Meta-regression analysis of effect of **A** baseline age, **B** duration of follow-up, **C** female (%), **D** baseline BMI, and **E** bougie size on %EWL after LSG. Size of the circles corresponds to the weight of each study

surgery elevated significantly [20, 55]. Recently, number of AGB performed has a descending trend in Europe and USA due to poor weight loss in compared with RYGB and SG [3, 7, 20, 89]. In contrary, total number of SG is increasing in USA and Europe due to simple procedure, low risk, and good outcome [7, 86]. Based on a new survey, SG is the most performed surgery in Asia (49%) and USA/Canada (43%) and RYGB (65%) is commonly performed in South America. In Europe, both of RYGB (38%) and SG (37%) are the most popular procedures among surgeons and patients [88].

The findings prove previous meta-analysis which indicated that people who underwent LRYGB lose more weight than those who underwent LSG and both LRYGB, and also LSG promotes weight loss more effectively than does LAGB [90–92]. Garb et al., in a meta-analysis of 28 studies (including 7383 patients) with follow-up ranging from 11 to 91 months, indicated that the mean %EWL was 49.4% (95% CI 44.9–54.0) after LAGB and 62.6% (95% CI 58.6–66.6) after LRYGB [6]. In another meta-analysis of 91 studies (including 22,094 patients), Buchwald et al. showed that %EWL was 47.4% (95% CI 40.6–54.2) and 61.5% (95% CI 56.8–66.5) after AGB and RYGBP, respectively [1]. Li et al. conducted a meta-analysis on 18 studies (including 455 patients), with follow-up ranging from 1.5 to 60 months, reporting that LRYGB leads to more weight loss in comparison with LSG (7.24 kg, 95% CI 3.81–0.67) [93]. In a meta-analysis of 21 studies including 18,766, Zhang et al. indicated that the effect of LRYGB is the same as LSG over the short term but over mid-term the effectiveness of LRYGB is superior to LSG [94]. In contrast with this study, these meta-analyses included studies with follow-up of less than 5 years that could not estimate long-term effect of bariatric surgery on weight loss in morbidly obese patients.

To sum up, previous studies have stated that weight loss may be associated with geographic location and race [94–96]. The result of the present study, in terms of subgroup analysis, indicated that LRYGB is more effective than LAGB for reducing weight in America (61.9 vs. 41.7%) and Asia (60.1 vs. 48.2%); however, in Europe the effectiveness of LRYGB is equal to LAGB (56.3 vs. 55.9%). In contrast, the effect of LSG on weight loss is the same in America, Asia, and Europe. Studies have indicated that weight reduction after bariatric surgery is dependent on ethnic and race [4, 55]. The differences in weight loss among ethnic groups may be related to ethnic/race-related differences in metabolism, dietary intake, and dietary habits among these groups [55]. No previous meta-analyses have investigated %EWL based on region. Therefore, further studies are required to confirm it.

The findings demonstrated that long-term %EWL is independent of baseline BMI and age after LAGB, LRYGB, and LSG. In addition, there was no significant association between %EWL and length of follow-up after LAGB, LRYGB, and LSG that confirmed sustainability of weight loss after these procedures. Consistent with the results of the study, Attiah et al. in a meta-regression analysis of 22 studies (including 4206) reported that %EWL had no association with duration of follow-up, age, and baseline BMI [97]. The present findings indicated that long-term %EWL is independent of gender after LAGB and LSG; moreover, there is a positive association between %EWL and gender (%female) after LRYGB.

Results of the present study have shown that there is no association between bougie size and long-term weight loss. The effect of bougie size on weight reduction is controversial [98, 99]. Some studies have reported that there is no association between bougie size and short-term weight loss [100–102]. In contrary, the smaller bougie size (<40 Fr) results in greater weight loss than bigger bougie size (50–60 Fr) over long-term periods [69, 73]. International Sleeve Gastrectomy Expert Panel Consensus Statement has suggested that bougie size should be 32–36 Fr in order to good weight loss outcome [103]. It is possible that low number of studies that performed big bougie size (15%) is responsible for lack of association between bougie size and %EWL in the current study. Recently, some investigations have stated that bougie size had no effect on weight loss, in opposite, the volume of remnant gastric is an important predictor of weight reduction and maintenance of %EWL after SG [100, 104]. However, further investigations are required to confirm association between remnant volume and weight loss after SG.

We found no association between %EWL and length of alimentary limb and biliopancreatic limb. The best limb length in order to long-term weight loss is on debate [105]. Negaard et al. have indicated that long-limb resulted in greater weight loss in compared with short-limb [106]. However, some studies did not find significant differences in %EWL between long-limb and short-limb length [105, 107–109]. Length of limb bypass significantly varies among studies and dependent on initial BMI [107]. Orci et al. in a systematic review have been stated that long-limb length leads to greater weight reduction in super obese patients (BMI > 50 kg/m^2) than non-super obese patients (BMI ≤ 50 kg/m^2) [110]. In the current study, no observed association between limb bypass and %EWL may be related to the same limb bypass (150–200 cm) among included studies.

There were several strengths and limitations. The strength of this study was that it offered a comprehensive literature review to identify all studies that have reported %EWL or BMI ≥ 5 years after bariatric surgery. In the present study, we excluded studies with follow-up of less than 5 years to estimate the effectiveness of LAGB, LRYGB, and LSG over long-term periods. In addition, the results of this meta-analysis apply to obese adults with a BMI ≥ 40 kg/m^2 or ≥35 kg/m^2 with co-morbidities.

The main limitation of the present study was lack of studies comparing LAGB versus LRYGB (n = 5), LAGB versus LSG (n = 1), and LRYGB versus LSG (n = 1) that leads to fail comparing long-term effectiveness of these procedures together. Moreover, some included studies had a small sample size that may have affected pooled effect size.

In summary, the study investigated the long- and very long-term effect of LAGA, LRYGB, and LSG on weight loss in morbidly obese patients. The findings suggest that LRYGB is an effective procedure in morbidly obese patients that leads to sustainable weight loss over the long- and very long-term periods in compared with LAGB and LSG.

Compliance with ethical standards

Disclosure Drs. Mahdieh Golzarand, Karamollah Toolabi and Mrs. Roya Farid have no conflict of interest or financial ties to disclose.

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