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REVIEW ARTICLE

Impact of Bariatric Surgery on Male Sex Hormones and Sperm Quality: a Systematic Review and Meta-Analysis

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Abstract

This systematic review and meta-analysis aims to establish the effects of bariatric surgery on male sex hormones, sperm parameters, and sexual function. We searched MEDLINE, EMBASE, Web of Science, and Scopus from database inception through June 2018. Articles were eligible for inclusion if they examined the effect of bariatric surgery on male sex hormones and sperm parameters in patients with obesity. Primary outcomes of interest were sex hormones and sperm quality. Secondary outcome was sexual function (International Index of Erectile Function (IIEF) score). Pooled estimates were calculated using random effects meta-analysis. A total of 28 cohort studies with 1022 patients were identified from 3896 potentially relevant citations. Both free and calculated testosterone levels were significantly increased after bariatric surgery (mean difference (MD) − 7.47 nM, 95% CI − 8.62 to − 6.31, $p < 0.001$ and MD − 0.05 nM, 95% CI − 0.07 to − 0.02, $p < 0.001$, respectively). Consistent with the increase in testosterone, LH, FSH, and SHBG levels were also significantly increased after surgery. In contrast, free and total estradiol and prolactin levels were significantly decreased after bariatric surgery. From studies that reported the IIEF score, bariatric surgery led to a significant increase in erectile function after surgery (MD − 0.46, 95% CI − 0.89 to − 0.02, $p = 0.04$). However, bariatric surgery did not affect sperm quality, DHEA, androstenedione, and inhibin B levels. Sustained weight-loss induced by bariatric surgery had a significant effect on increasing male sex hormones and decreasing female sex hormones in male patients with obesity. However, sperm quality and function were not improved after surgery.

Keywords Bariatric surgery · Testosterone · Estrogen · Sex hormones · Sperm quality · Erectile function

Introduction

Obesity is a global health epidemic, affecting over 400 million adults worldwide [1]. Individuals with obesity often experience endocrine alterations [2] and report deficits in sexual functioning and sexual satisfaction [3]. The effects of obesity on male reproduction are less documented than in the female [2, 4]. Nonetheless, obese men experience lower

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testosterone levels, lower sexual satisfaction, and reduced fertility compared to men of normal weight [2, 3, 5]. It is estimated that the odds of male infertility increase by 10% for every 9 kg a man is overweight [6]. While semen quality has declined over the past 50 years [7, 8], obesity has doubled in prevalence since 1980 [9].

Mechanistically, increased male body mass index (BMI) is associated with diminished androgen production and the peripheral aromatization of androgens to estrogens by excess adipose tissue [10, 11]. This results in reduced plasma concentrations of sex hormone binding globulin (SHBG), testosterone, and increased levels of estrogen which disrupt the negative feedback loop of the hypothalamic pituitary gonadal (HPG) axis, reduce Sertoli cell function, and lead to a persistent hypogonadal state in men [2, 5, 10, 12, 13]. Male obesity and hypogonadism are also connected in a vicious cycle, in which low testosterone favors further weight gain, and weight gain induced hypogonadism [14]. Furthermore, increased scrotal adiposity can elevate temperatures within the scrotum, inducing apoptosis of actively dividing germ cells and reducing sperm counts [15–17].

Lifestyle-induced weight loss has a beneficial effect on testosterone levels, and may lead to improvements in semen quality; however, the maintenance of weight loss is difficult [18]. Bariatric surgery is the most effective treatment for sustained weight loss in obese patients and is frequently performed in individuals with sexual deficits from infertility, with one study finding that 51% of women and 36% of men undergoing bariatric surgery reported a sexual dysfunction [19]. Because women undergo the vast majority of bariatric surgeries, studies examining outcomes in women are common, and bariatric surgery has been demonstrated to improve female fertility and reduce pregnancy complications, with the Royal College of Obstetricians and Gynecologists recommending it as a "last resort" [20]. In comparison, the effects of bariatric surgery on semen parameters and sex hormones in men are still currently unclear, because, while improvements in sex-life quality and corrections in hormonal profiles have been identified [21, 22], irreversible azoospermia after RYGB has also been reported [23].

The literature on the effect of bariatric surgery on male sex hormones and sperm quality is considerable and has not been comprehensively reviewed and meta-analyzed. As the prevalence of both male infertility and bariatric surgery increases, knowledge of how surgical intervention affects fertility outcomes may better inform patient and surgeon decisions on pursuing bariatric surgery. This systematic review and meta-analysis aims to establish the effects of bariatric surgery on male sex hormones, sperm parameters, and sexual function.

Methods

Search Strategy

We searched the following databases covering the period from database inception through June 2018: MEDLINE, EMBASE, Web of Science, and Scopus. Search strategy included keywords such as "bariatric surgery," "sex hormones," "sperm quality," "sexual function," and similar phrases (complete list of search terms available on Supplementary Table 1). We also searched the references of published studies and searched gray literature manually to ensure that relevant articles were not missed. This systematic review and meta-analysis is reported in accordance with the Preferred Reporting items for Systematic Reviews and Meta-Analyses (PRISMA) [24].

Eligibility Criteria and Data Abstraction

Articles were eligible for inclusion if the studies examined the effect of bariatric surgery on male sex hormones or sperm parameters in obese patients. We included both single-arm studies (effect of bariatric surgery on sex hormones and sperm parameters before and after surgery without a comparator) and double-arm studies (bariatric surgery versus placebo or medical therapy). However, there were no double-arm studies identified in the current literature. Exclusion criteria were as follows: (1) case-series/reports, expert opinions, basic science, and review articles (2) non-human studies, (3) studies including patients with permanent loss of sexual function, (4) studies not reporting outcomes of female and male population separately, (5) non-English studies, and (6) studies including less than five patients.

At least two reviewers independently screened the searched titles, abstracts, and full texts following the inclusion and exclusion criteria. Reviewers were not blinded to authors, institution, or the journal where the manuscript was published. Discrepancies that occurred at the title and abstract screening stages were resolved by automatic inclusion to ensure that all relevant papers were not missed. Discrepancies at the full-text stage were resolved by consensus between two reviewers and if disagreement persisted, a third reviewer was consulted. Two reviewers independently conducted data abstraction onto a standardized spreadsheet designed a priori. The following data were abstracted from included studies: study characteristics (author, country, year of publication, study design, funding source, study design), patient demographics (mean age at time of surgery, number of patients included, comorbidities, mean weight and mean BMI before and after surgery, total body weight loss (TBWL), estimated weight loss (EWL), and estimated BMI loss (EBML)), follow-up time points, type of bariatric surgery, and outcomes. Disagreement between reviewers were also solved by consensus or by a third reviewer.

Outcomes Assessed and Risk of Bias Assessment

Articles included in the systematic review and meta-analysis had to report at least one of the primary outcomes of interest before and after surgery, which included: (1) sex hormones (luteinizing hormone (LH), follicle stimulating hormone (FSH), total estradiol (E2), free E2, total testosterone, free or calculated free testosterone (free testosterone), dehydroepiandrosterone (DHEA), androstenedione, sex hormone-binding globulin (SHBG), prolactin, inhibin B) and (2) sperm quality (sperm volume (ml), sperm concentration (mill/ml), % total motility, % normal morphology, % progressive motility). Secondary outcome was sexual function (International Index of Erectile Function score (IIEF) questionnaire). Some IIEF questionnaires were out of 25 or 75 points [25, 26]. As a result, we converted the 75-point questionnaire into 25 in order to meta-analyze the outcome. Methodological Index for Non-Randomized Studies (MINORS) tool was used to assess the risk of bias for individual studies [27].

Statistical Analysis

All statistical analysis and meta-analysis were performed on Cochrane Review Manager 5.3 (London, United Kingdom) with a level of significance set at p of < 0.05. All outcomes were continuous in nature. We performed pairwise meta-analyses using a DerSimonian and Laird random effects model for continuous variables. Pooled effect estimates were obtained by calculating the mean difference (MD) in outcomes along with their respective 95% confidence intervals (CI) to confirm the effect size estimation. In addition, mean and standard deviation was estimated for studies that only reported median and interquartile range using the estimation method proposed by Wan et al. [28]. Assessment of heterogeneity was completed using the inconsistency (I^2) statistic. We considered I^2 higher than 50% to represent considerable heterogeneity. In addition, we performed subgroup analyses based on different types of bariatric surgery.

Results

Study Characteristics

From 3896 potentially relevant citations identified, 28 studies were eligible for inclusion (21 prospective cohort, 4 retrospective cohort, 2 randomized controlled trials, and 1 cross-sectional study) (Fig. 1). All studies investigated the effect of bariatric surgery on male sex hormones and/or sperm parameters before and after surgery. Included studies were conducted between 1998 and 2018 with median follow-up time period of 12 months (range, 6 to 60 months) across all outcome measurements. For studies reporting more than a single time point, we chose to analyze the time point closest to 12 months. The weighted mean age of the patients at the time of surgery was 42.43 ± 5.31 years. The weighted mean BMI at baseline was 47.42 ± 7.67 kg/m^2 and 34.59 ± 4.79 kg/m^2 at follow-up, with a mean absolute percent reduction of 27.06% after surgery. Different types of bariatric procedures conducted in the included studies were Roux-en-Y gastric bypass (RYGB; 20 studies), laparoscopic adjustable gastric banding (LAGB; 7 studies), sleeve gastrectomy (SG; 10 studies), vertical banded gastroplasty (VBG; 2 studies), and biliopancreatic diversion (BPD; 6 studies). Study characteristics of included studies in this systematic review are reported in detail in Table 1.

Sex Hormones

From 28 studies included, 16 studies reported LH ($n = 418$), 14 for FSH ($n = 347$), 17 for total estradiol ($n = 431$), 2 for free estradiol ($n = 38$), 23 for total testosterone ($n = 652$), 15 for free testosterone ($n = 399$), 3 for prolactin ($n = 95$), and 15 for SHBG ($n = 375$). Both total and free testosterone levels (Fig. 2a, b) were significantly increased after bariatric surgery (MD − 7.47 nM, 95% CI − 8.62 to − 6.31, $p < 0.00001$ and MD − 0.08 nM, 95% CI − 0.11 to − 0.04, $p = 0.0001$ respectively). In contrast, free and total estradiol levels (Fig. 2c, d) were significantly decreased after bariatric surgery (MD 0.45 pmol/L, 95% CI 0.09 to 0.81, $p = 0.02$ and MD 22.63 pmol/L, 95% CI 14.89 to 30.37, $p < 0.00001$ respectively).

Consistent with the increase in testosterone levels, LH, FSH, and SHBG levels were also significantly increased after bariatric surgery (Fig. 3a–c) (MD − 0.90 IU/L, 95% CI − 1.33 to − 0.47, $p < 0.00001$ and MD − 1.21 IU/L, 95% CI − 1.78 to − 0.63, $p < 0.0001$ and MD − 20.41 nM, 95% CI − 25.71 to − 15.12, $p < 0.00001$ respectively). In addition, following the trend of estradiol decrease, prolactin levels were also significantly decreased after bariatric surgery (Fig. 3d) (MD 1.43 ng/ml, 95% CI 0.09 to 2.77, $p < 0.0001$). However, bariatric surgery did not significantly affect DHEA, androstenedione, and inhibin B levels after surgery (Supplementary Figs. 1A-C). All sex hormone meta-analyses results had considerable heterogeneity ($I^2 > 50\%$).

Sperm Quality and Erectile Function

Sperm parameters were reported in a limited number of studies. Three studies reported sperm volume, sperm concentration, % total motility, and % normal morphology ($n = 75$), and two studies reported % progressive motility ($n = 69$). All sperm parameters showed no significant difference before

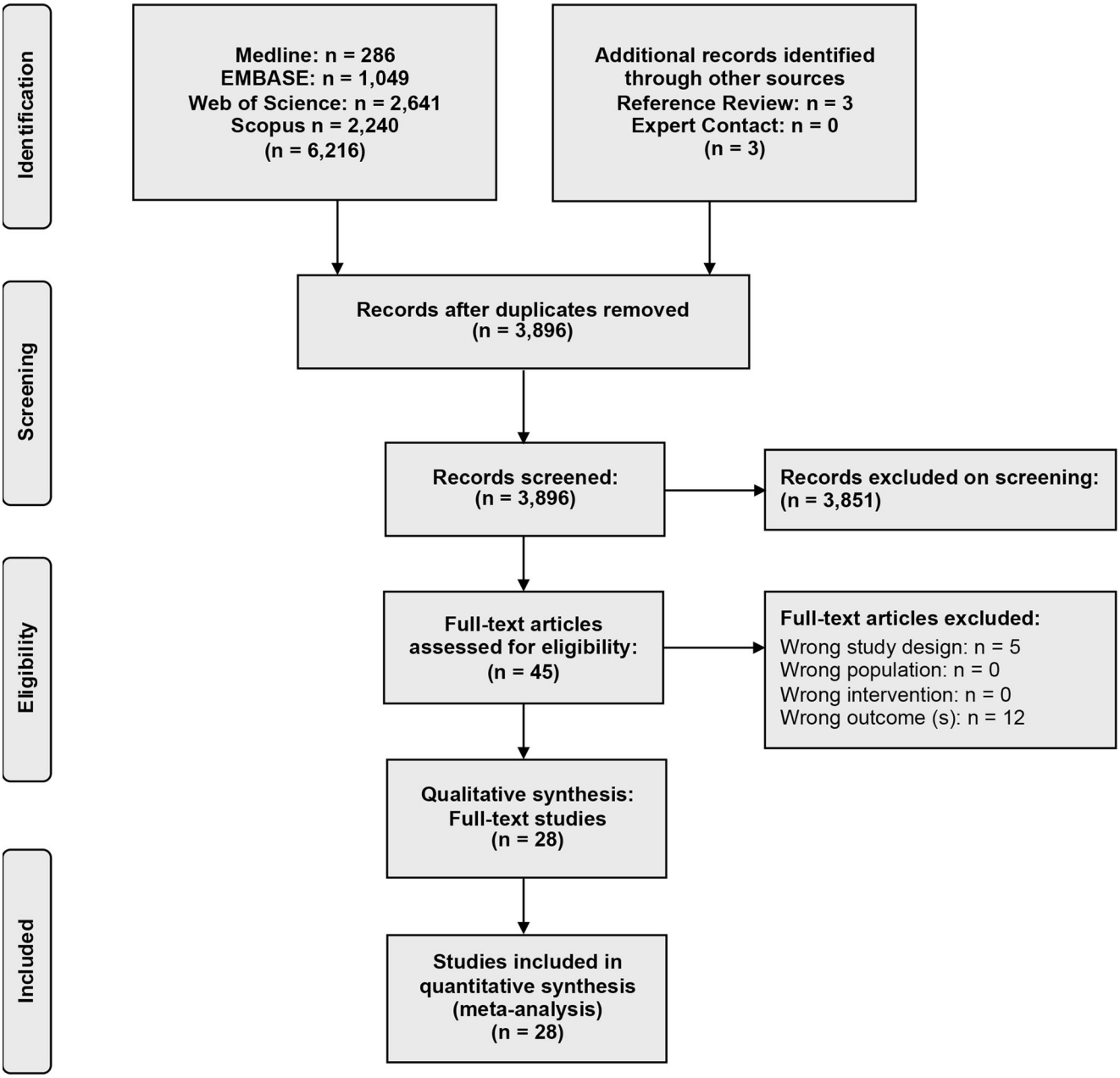

Fig. 1 PRISMA Diagram—transparent reporting of systematic reviews and meta-analysis flow diagram outlining the search strategy results from initial search to included studies

and after bariatric surgery (Fig. 4a–e). From five studies that reported IIEF, bariatric surgery led to a small, but statistically significant increase in erectile function after surgery (Supplementary Fig. 1D) (MD −0.46, 95% CI −0.89 to −0.02, $p = 0.04$; $I^2 = 70\%$).

Subgroup Analysis

The majority of the included studies (18/28; 64.28%) had performed more than one type of bariatric surgery and did not report separate outcomes for specific bariatric surgeries. Due to the most common surgery being RYGB, we decided to a conduct a subgroup analysis of all outcomes with ten studies that conducted RYGB only. Subgroup analysis with RYGB only did not change the significance in outcomes that were shown to be significant in the initial analysis (data not shown). The only outcome that became significant after subgroup analysis was normal sperm morphology, which decreased after bariatric surgery (Supplementary Fig. 2) (MD 3.45%, 95% CI −0.06 to 6.95, $p = 0.05$; 2 studies). Subgroup analysis of common bariatric procedures such as SG or BPD were not conducted as only few studies exclusively performed these surgeries.

Table 1 Study characteristics (*RCT*, randomized controlled trial; *VBG*, vertical banded gastroplasty; *BPD*, biliopancreatic diversion; *RYGB*, Roux-en-Y gastric bypass; *SG*, sleeve gastrectomy; *LAGB*, laparoscopic adjustable gastric banding; *BMI*, body mass index)

Study	Study design	Surgery	*n*	Mean age	Follow-up (months)	Pre-op weight (kg)	Post-op weight (kg)	Pre-BMI (mean ± SD) (kg/m^2)	Post-BMI (mean ± SD) (kg/m^2)	Funding
Bastounis 1998 [21]	Prospective	VBG	19	34.7 ± 7.7	12	179 ± 22	109 ± 20.5	57.1 ± 7.4	34.7 ± 6.5	NR
Mingrone 2002 [29]	Cross-sectional	BPD	15	30–45	12	151.8 ± 17.1	99.7 ± 7	48 ± 5.4	30.4 ± 3.5	Public
Globerman 2005 [30]	Prospective	VBG	17	38.2 ± 2.5	11.6 ± 1.4	137.4 ± 5.1	99.2 ± 5.4	44.3 ± 1.7	31.6 ± 1.5	Public
Alagna 2006 [31]	Prospective	BPD	20	21–63	12 ± 1	132.1 ± 36.9	93.5 ± 21	47.3 ± 13.1	33.5 ± 7	NR
Hammoud 2009 [22]	Retrospective	RYGB	22	48.9 ± 1.2	24	333 ± 7.1	NR	46.2 ± 0.9	29.6 ± 1.2	Public
Reis 2010 [32]	RCT	RYGB	10	36.7 ± 11.5	24	168.6 ± 28.2	94.5 ± 22.1	55.7 ± 7.8	31 ± 5.3	NR
Ranasinghe 2010 [33]	Retrospective	LAGB	34	52.8 ± 9.33	31.79 ± 22.27	145.6 ± 28.31	123.3 ± 23.15	47.3 ± 12.67	38.4 ± 6.18	Private
Pellitero 2012 [34]	Prospective	RYGB, SG	33	40.5 ± 9.9	12	157.9 ± 23.5	NR	50.3 ± 6.1	31.5 ± 4.7	Public
Woodard 2012 [35]	Prospective	RYGB	64	48.1 ± 1.3	12	154.3 ± 3.3	NR	48.2 ± 1.5	39.2 ± 1	Public
Botella-Carretero 2013 [36]	Prospective	BPD, RYGB, LAGB	20	40 ± 10.34	6 to 24	145.03 ± 21.61	107.24 ± 20.8	47.05 ± 5.99	35 ± 6.57	Public
Facchiano 2013 [37]	Prospective	LAGB, RYGB, BPD	20	40.5 (27.2–46.7)	6	NR	NR	43.6 (40.9–48.7)	34.8 (31.7–40.5)	Public
Ippersiel 2013 [38]	Prospective	RYGB, SG	21	40 (33–53)	12	138.6 (129.2–151.3)	98.9 (84.9–111.9)	45.3 ± 5.6	31 ± 4.2	Public
Luconi 2013 [39]	Prospective	BPD, RYGB, LAGB	24	42.5 (31.2–46.7)	12	139.2 (125.9–164)	104 (91.8–120.5)	43.9 (40.8–53.8)	34 (30.3–39.5)	Public
Mora 2013 [40]	Prospective	RYGB, SG	39	43.5 (19.7–60.7)	12	144.13 ± 26.42	94.75 ± 17.93	46.9 ± 7.77	30.88 ± 5.04	Public
Aarts 2014 [41]	Prospective	LAGB, RYGB	24	43.5 ± 2	12	152 ± 4.8	114.9 ± 3.5	46.1 ± 1.3	34.8 ± 0.8	NR
Mihalca 2014 [42]	Prospective	SG	28	43.07 ± 9.56	6	NR	NR	50.1 ± 11.19	35.87 ± 7.02	Public
Samavat 2014 (hypogonadism) [43]	Prospective	RYGB, LAGB, BPD, SG	42	42.3 ± 11.6	12	148.4 ± 26.1	101.8 ± 24.1	46.6 ± 7.4	32.2 ± 6.8	Public
Samavat 2014 (osteocalcin) [44]	Prospective	RYGB	76	42 ± 11	9	146.6 ± 24.5	110.6 ± 23.1	46.7 ± 6.9	35.3 ± 6.2	Public
Legro 2015 [45]	Prospective	RYGB	6	37.5 (30–40)	12	166 ± 36	111 ± 30	48 ± 7	32 ± 7	Public
Sarwer 2015 [19]	Prospective	RYGB	31	48 (24–64)	12	149.3 (111.4–228.2)	NR	45.1 (37.3–64.6)	NR	Public
Bekaert 2015 [46]	Cross-sectional	RYGB	14	51 ± 12	24	NR	NR	45 ± 8	34 ± 8	Public
Kun 2015 [47]	Retrospective	RYGB	39	45.2 ± 12.3	12	NR	NR	41.2 ± 8.5	32.1 ± 7.3	Public
BoonchayaAnant 2016 [48]	Prospective	RYGB, SG	29	31 ± 8	6	168.3 ± 35	126.2 ± 25.5	56.9 ± 11.7	42.9 ± 9	Public
El Bardisi 2016 [49]	Prospective	SG	46	37 (29–44)	12	NR	NR	71.4 (42.9–96.2)	46.9 (32.2–76.9)	Public

Table 1 (continued)

Study	Study design	Surgery	*n*	Mean age	Follow-up (months)	Pre-op weight (kg)	Post-op weight (kg)	Pre-BMI (mean ± SD) (kg/m^2)	Post-BMI (mean ± SD) (kg/m^2)	Funding
Gao 2018 [50]	Prospective	SG	30	33 ± 9.5	6	125 ± 18.1	96 ± 15.2	40.2 ± 5.2	30.8 ± 4.4	Public
Liu 2018 [51]	Retrospective	RYGB	39	46.05 ± 9.71	12	NR	NR	32.81 ± 4.04	25.41 ± 3.36	Public
Pham 2018 [52]	RCT (sub-analysis)	RYGB, SG	24	51.7	60	NR	NR	36.7	NR	Public and Private
Samavat 2018 [53]	Prospective	RYGB	23	38 ± 9	6	144.9 ± 27.3	110.2 ± 21	45.8 ± 7.4	34.7 ± 5.3	Public

Risk of Bias Assessment

The mean MINORS score of included studies was 12.40 ± 1.08, which indicates a fair quality of evidence for non-randomized studies [27]. A comprehensive list of MINORS for included studies are available in Table 2. In brief, all 28 studies had a clearly stated objective with unbiased assessment of study endpoint. Most of the studies included consecutive patients (24/28 studies) with prospective collection of data (24/28), had an established protocol prior to the study (20/28 studies), and had less than 5 to 10% of loss to follow-up (20/28 studies). The mean follow-up was longer than 12 months in 6/28 studies. However, most studies lacked a prospective calculation of study size (4/28 studies).

Discussion

We have conducted the most comprehensive systematic review and meta-analysis on the effect of bariatric surgery on fertility including sperm parameters and sex hormones in male patients with obesity. Males who underwent bariatric surgery experienced significant increases in total and free testosterone, SHBG, LH, and FSH, with corresponding decreases in total and free estradiol levels and prolactin levels after surgery. In line with the improvements in male sex hormone levels, erectile function also significantly increased after bariatric surgery. However, sperm parameters including sperm volume, concentration, motility, and morphology did not significantly change after bariatric surgery, although a limited number of studies reported these parameters.

The link between weight loss after bariatric surgery and improvements in male sex hormones and erectile function is likely multifactorial [54]. It is possible that a reduction in visceral and subcutaneous fat after bariatric surgery reduces the conversion of testosterone to estradiol that is catalyzed by aromatase, an enzyme commonly found in visceral adipose tissue [14, 55, 56]. This would lead to the increased levels of testosterone and decreased levels of estradiol described in the present review, as well as reduced feedback inhibition of LH and FSH secretion by the pituitary glands [57, 58]. A higher LH level would further improve testosterone secretion by Leydig cells of the testis [5, 59]. The massive loss of adipose tissue also reduces the production of many pro-inflammatory cytokines and adipokines including leptin, which typically inhibits testosterone synthesis by Leydig cells [60–62]. Furthermore, insulin resistance and increased insulin levels have been shown to suppress levels of LH, SHBG, and testosterone while bariatric surgery is known to reduce insulin resistance and decrease insulin levels [29, 63, 64]. Previous studies have attributed erectile dysfunction to low testosterone levels and vascular endothelial dysfunction associated with the pro-inflammatory state of obesity [65]. Massive weight

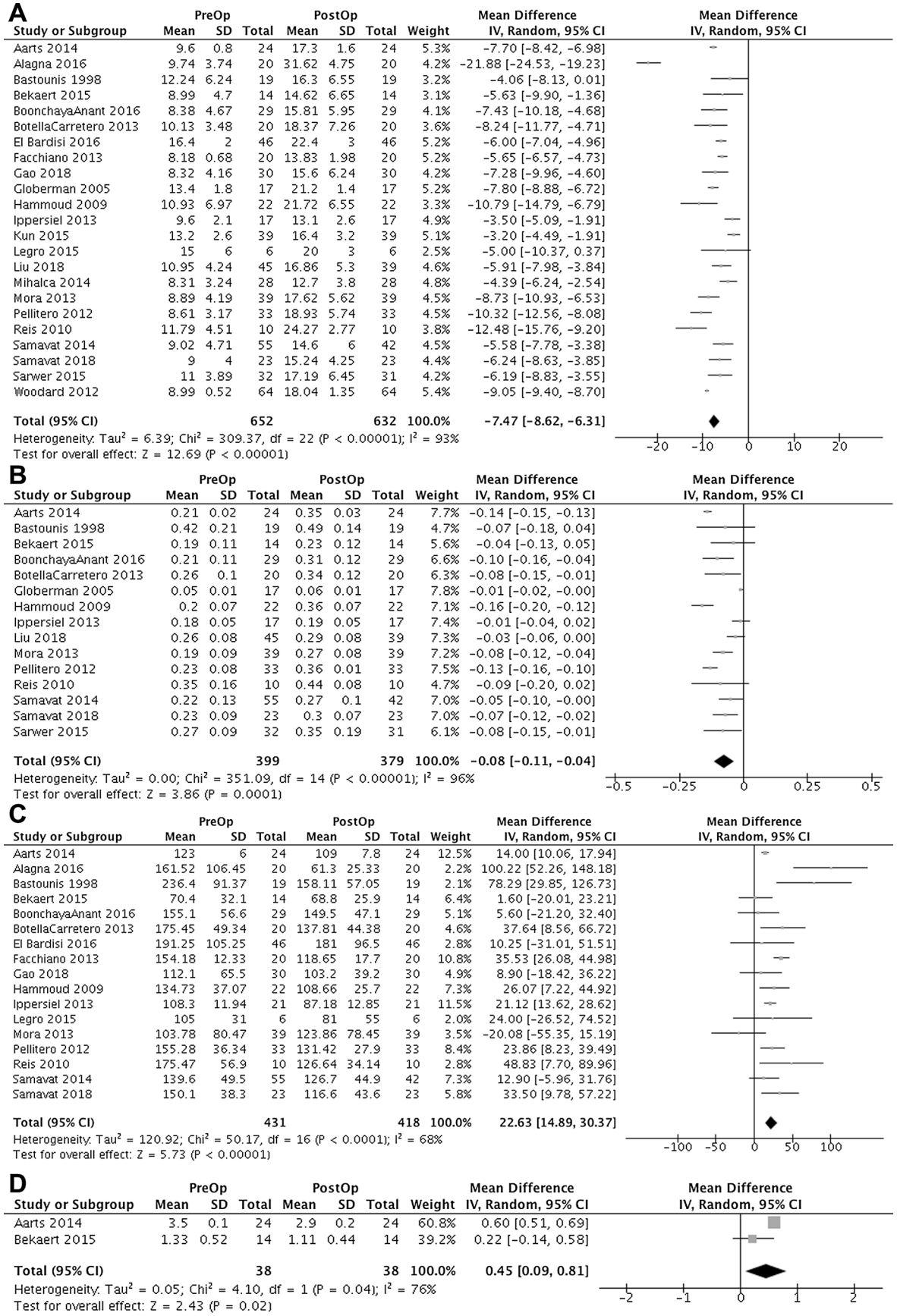

Fig. 2 Forest plot of sex hormones. **a** Total testosterone (nM). **b** Free testosterone (nM). **c** Total estradiol (pmol/L). **d** Free estradiol (pmol/L)

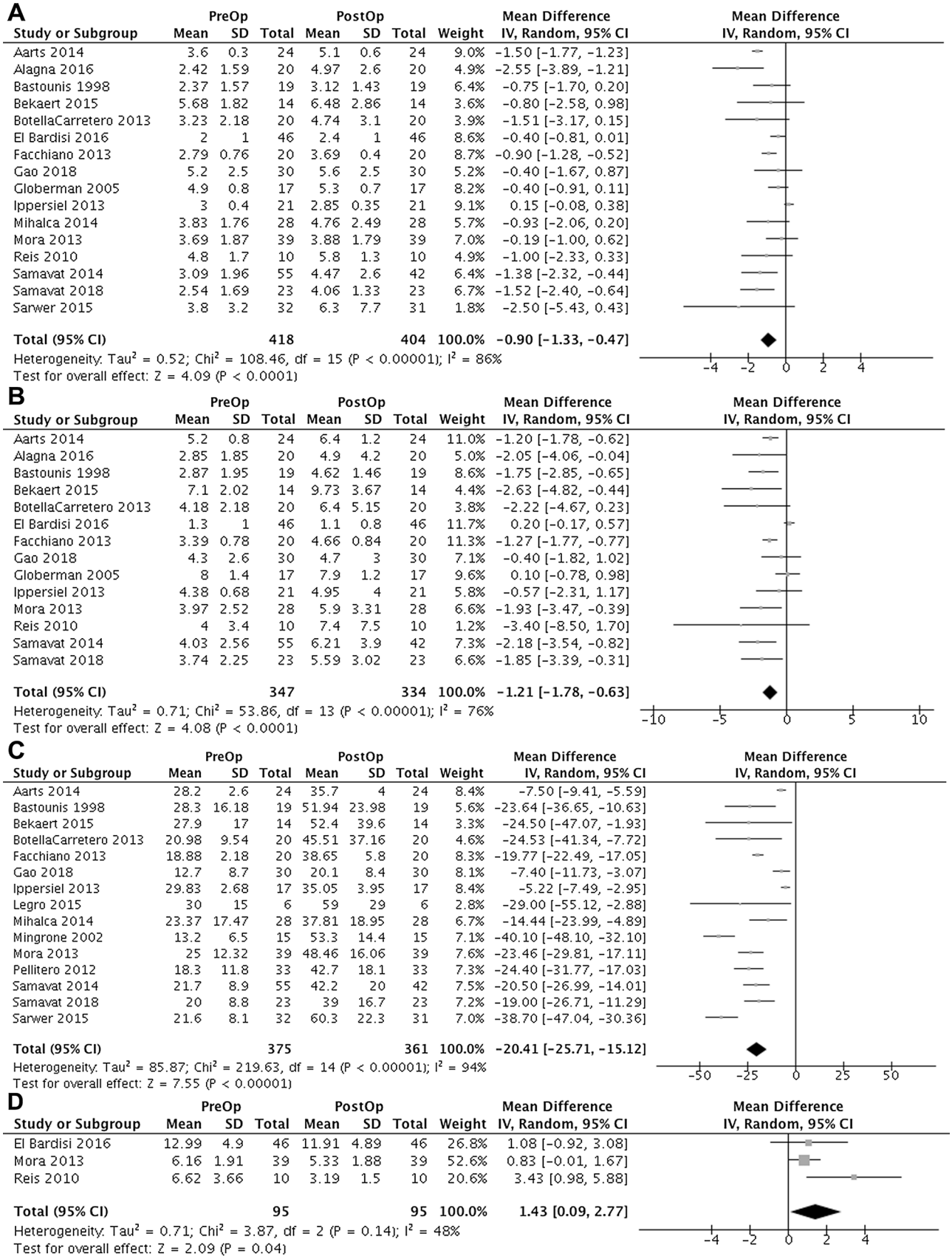

Fig. 3 Forest plot of sex hormones continued. **a** Luteinizing hormone (IU/L). **b** Follicle-stimulating hormone (IU/L). **c** Sex hormone-binding globulin (nM). **d** Prolactin (ng/ml)

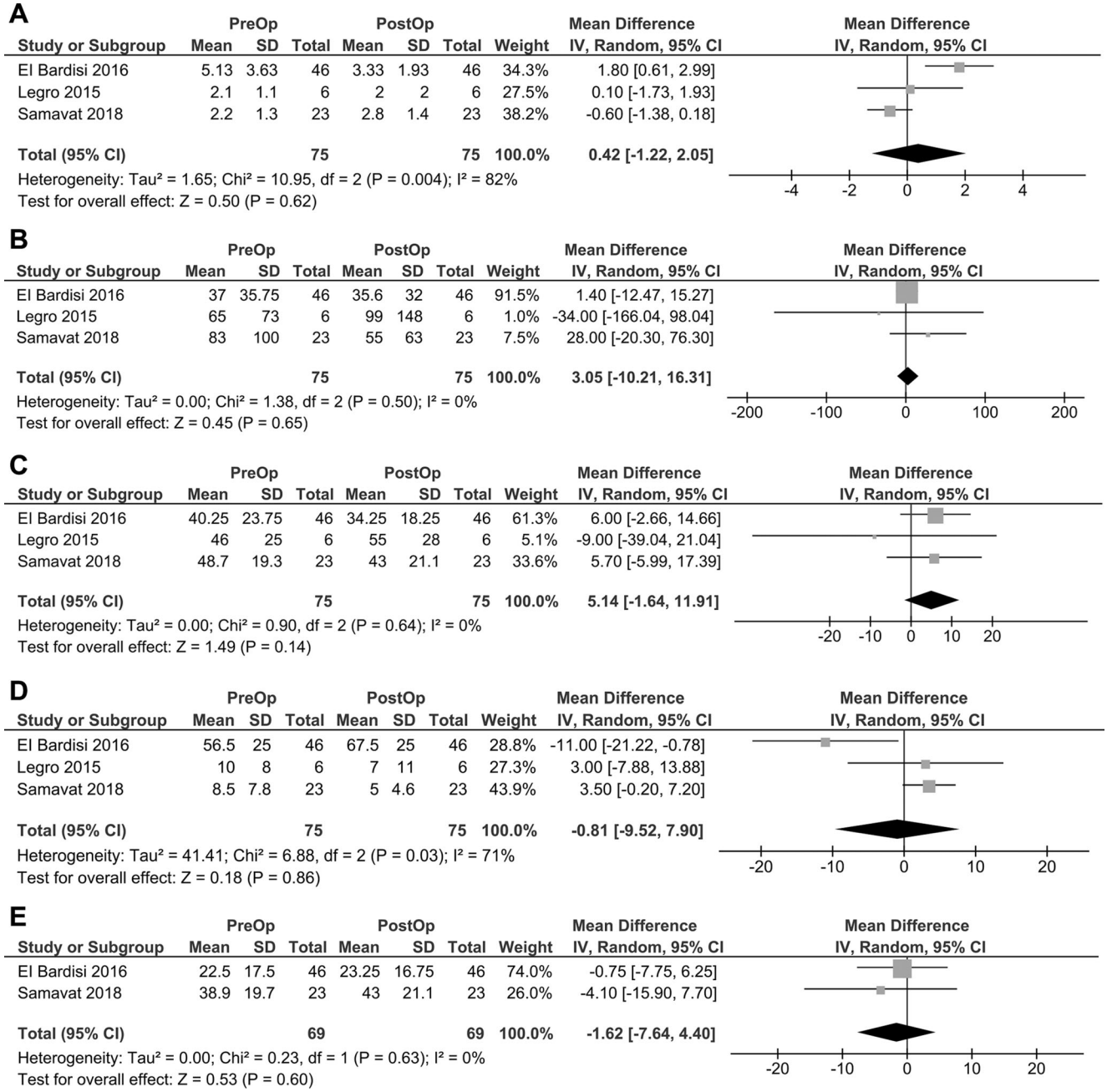

Fig. 4 Forest plot of sperm quality. **a** Volume (ml). **b** Concentration (mill/ml). **c** % Total motility. **d** % Normal morphology. **e** % Progressive motility

loss after bariatric surgery also reduces the obesity-related inflammatory state and increase testosterone levels, explaining the increase in erectile function [66, 67].

Although one might expect sperm parameters to improve following bariatric surgery, no significant changes in sperm parameters were found in the present review, and several cases of worsened sperm parameters have been reported in the literature [23, 68]. This may be because any positive hormonal changes after bariatric surgery are counterbalanced by nutritional malabsorption and insufficiencies. Nutritional imbalances caused by selective food maldigestion and malabsorption have been commonly reported in the bariatric surgery literature and may disrupt GnRH secretion and lead to reproductive disorders [69–71]. Furthermore, nutritional deficits of iron, calcium, and vitamins required for spermatogenesis may lead to worsened sperm parameters [70, 72]. Alternatively, liposoluble toxic substances including endocrine disruptors may accumulate because of massive weight loss after bariatric surgery and contribute to deficits in spermatogenesis [23, 73]. A case series by di Frega et al. of six males with normal sex hormone levels who underwent RYGB reported non-obstructive azoospermia with complete spermatogenic arrest at 12–15 months [23]. As a result, the authors suggested the spermatogenic dysfunction was caused by nutritional

Table 2 MINORS assessment of included studies

Study	MINORS criteria								
	A clearly stated aim	Inclusion of consecutive patients	Prospective collection of data	End points appropriate to the aims of the study	Unbiased assessment of the study endpoint	Follow-up period appropriate to the aim of the study	Loss to follow-up less than 5%	Prospective calculation of the study size:	Total
Bastounis 1998 [21]	1	1	2	2	2	2	2	0	12
Mingrone 2002 [29]	2	0	2	2	2	2	1	0	11
Globerman 2005 [30]	2	2	2	2	2	2	1	0	13
Alagna 2006 [31]	2	1	2	2	2	2	1	0	12
Hammoud 2009 [22]	2	1	1	2	2	2	2	0	12
Reis 2010 [32]	2	0	2	2	2	2	2	0	12
Ranasinghe, 2010 [33]	2	1	1	2	2	2	2	0	12
Pellitero 2012 [34]	2	0	2	2	2	2	1	0	11
Woodard 2012 [35]	2	2	2	2	2	2	1	0	13
Botella-Carretero 2013 [36]	2	2	2	2	2	1	2	2	15
Facchiano 2013 [37]	2	2	2	2	2	1	0	2	13
Ippersiel 2013 [38]	2	2	2	2	2	2	0	0	12
Luconi 2013 [39]	2	2	2	2	2	2	0	0	12
Mora 2013 [40]	2	2	2	2	2	2	0	0	12
Aarts 2014 [41]	2	1	2	2	2	2	2	0	13
Mihalca 2014 [42]	2	2	2	2	2	1	0	0	11
Samavat 2014 [43, 44]	2	2	2	2	2	2	1	0	13
Legro 2015 [45]	2	1	2	2	2	2	0	2	13
Sarwer 2015 [19]	2	1	2	2	2	2	2	0	13
Bekaert 2015 [46]	2	1	2	2	2	2	0	0	11
Kun 2015 [47]	2	2	1	2	2	2	2	0	13
BoonchayaAnant 2016 [48]	2	1	2	2	2	1	1	0	11
El Bardisi 2016 [49]	2	2	2	2	2	2	1	0	13
Gao 2018 [50]	2	2	2	2	2	1	1	0	12
Liu 2018 [51]	2	2	0	2	2	2	1	0	11
Pham 2018 [52]	2	2	2	1	2	2	2	0	13
Samavat 2018 [53]	2	2	2	2	2	1	2	0	13

The items are scored 0 (not reported), 1 (reported but inadequate), or 2 (reported and adequate). The global ideal score is 16 for non-comparative studies

deficiencies rather than hormonal dysfunctions. Another series of three patients by Sermondade et al. found worsened sperm parameters in three patients after 3 months; however, deficits in one patient reversed after 24 months [68]. Consistent with these studies, the results of our subgroup analysis for RYGB found significantly worsened sperm morphology after surgery, further suggesting the effect of intestinal bypass on malabsorption of micronutrients. However, this subgroup analysis was limited to two studies and few patients.

A previous systematic review and meta-analysis by Wen et al. found similar improvements in sex hormone levels in males after bariatric surgery [74]. However, the review did not investigate changes in sperm parameters, analyzed fewer sex hormones, and included fewer patients. The key strengths of our review include its broad evaluation of sex hormones ranging from testosterone to SHBG. To our knowledge, this systematic review is also the first to evaluate sperm parameters, the most accurate measurement of male fertility. The results of this review should be interpreted within the context of its limitations. First, while sperm parameters were evaluated, sperm DNA fragmentation was not assessed, and the chromatin integrity of sperm was not determined. Second, the limited time frame of included studies may not allow for the evaluation of long-term effects of massive weight loss on sex hormones and sperm parameters. Third, heterogeneity between included studies was high for all outcomes except sperm concentration, sperm total motility, sperm progressive motility, IIEF, androstenedione, and prolactin. This heterogeneity may be because of the varying study designs, different patient populations, different types of bariatric surgery, and the small sample sizes of included studies. Fourth, IIEF was a self-reported patient questionnaire, and is subject to response bias in which patients may underreport erectile dysfunction due to embarrassment. Fifth, the bulk of this review's claim that bariatric surgery may improve male fertility rests on the outcome of improved levels of male sex hormones. However, sex hormones levels can be impacted by various factors including age, genetics, circadian rhythms, comorbid conditions, and lifestyle [75–77]. Considering the heterogeneity between included studies, there exists the potential for sex hormone levels to be an inaccurate representation of overall male fertility. Finally, nearly all studies were observational in nature with no comparators, and only two RCTs were identified from the literature.

Conclusions

Bariatric surgery appears to be effective in increasing male sex hormones and decreasing female sex hormones in obese male patients. However, our review also suggests that bariatric surgery has no benefits on sperm parameters. Long-term comparative studies or adequately powered randomized controlled trials are warranted to further examine the impact of bariatric surgery on male sex hormones and sperm quality.

Compliance with Ethical Standards

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

Ethical Approval Statement For this type of study formal consent is not required.

Informed Consent Statement Does not apply.

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