This document is the Accepted Manuscript version of a Published Work that appeared in final form in Obesity Reviews, 22 July 2020.
Online version: https://onlinelibrary.wiley.com/doi/abs/10.1111/obr.13082
DOI: https://doi.org/10.1111/obr.13082

Type of article: Systematic review and meta-analysis

Title: Male adiposity, sperm parameters and reproductive hormones: An updated systematic review and collaborative meta-analysis

Running title: Male adiposity, sperm parameters and sex hormones

Authors:

Albert Salas-Huetos [1,2,3,4,*], Leila Maghsoumi-Norouzabad [5,6,†], Emma R. James [4,7,†], Douglas T. Carrell [4,7], Kenneth I. Aston [4], Timothy G. Jenkins [4,8], Nerea Becerra-Tomás [1,2,3], Ahmad Zare Javid [5,6], Reza Abed [9], Pedro Javier Torres [10,11], Eugenia Mercedes Luque [10,11], Nicolás David Ramírez [10,11], Ana Carolina Martini [10,11,12,‡], Jordi Salas-Salvadó [1,2,3,13,‡,*]

Affiliations:

1. Universitat Rovira i Virgili, Departament de Bioquímica i Biotecnologia, Unitat de Nutrició, Reus, Spain.
2. Institut d'Investigació Sanitària Pere Virgili (IISPV), Reus, Spain.
3. Centro de Investigación Biomédica en Red Fisiopatología de la Obesidad y la Nutrición (CIBEROBN), Institute of Health Carlos III, Madrid, Spain
4. Andrology and IVF Laboratory, Division of Urology, Department of Surgery, University of Utah School of Medicine, Salt Lake City, UT, USA.
5. Department of Nutrition, School of Allied Medical Sciences, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran.
6. Nutrition and Metabolic Diseases Research Center, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran.

7. Department of Human Genetics, University of Utah School of Medicine, Salt Lake City, UT, USA.
8. Department of Physiology and Developmental Biology, Brigham Young University, Provo, UT, USA.
9. Aras Hospital, Iran Social Security Organization, Parsabad, Ardabil, Iran.
10. Instituto de Fisiología, Facultad de Ciencias Médicas (FCM), Universidad Nacional de Córdoba. Santa Rosa 1085, Córdoba, Argentina.
11. Instituto de Investigaciones en Ciencias de la Salud (INICSA), Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICET)-FCM, Argentina.
12. Established investigator from CONICET, Argentina.
13. University Hospital of Sant Joan de Reus, Nutrition Unit, Reus, Spain.

†. These authors should be considered similar in author order.

‡. These authors should be considered similar in author order.

* Corresponding authors.

Corresponding authors information:

Dr. Albert Salas-Huetos

Address: Andrology and IVF Laboratory, Division of Urology, Department of Surgery, University of Utah School of Medicine, 84180 Salt Lake City, UT, USA.

Contact: +1 (385) 210-5534

Dr. Jordi Salas-Salvadó

Address: Human Nutrition Unit, Biochemistry and Biotechnology Department, Faculty of Medicine and Health Sciences, Universitat Rovira i Virgili (URV) and Pere Virgili Institute for Health Research (IISPV), 43201 Reus, Spain.

Contact: +34 977 759 213

Authors emails and ORCIDs:

Albert Salas-Huetos: albert.salas@utah.edu, 0000-0001-5914-6862

Leila Maghsoumi-Norouzabad: l.maghsumi55@gmail.com, 0000-0002-0674-5025

Emma R. James: emma.james@utah.edu, 0000-0001-5680-2131

Douglas T. Carrell: douglas.carrell@hsc.utah.edu, 0000-0002-6471-2803

Kenneth I. Aston: ki.aston@hsc.utah.edu, 0000-0001-6459-2103

Timothy G. Jenkins: tim_jenkins@byu.edu, 0000-0003-1171-4482

Nerea Becerra-Tomás: nerea.becerra@urv.cat, 0000-0002-4429-6507

Ahmad Zare Javid: ahmaddjavid@gmail.com, 0000-0001-7119-7582

Reza Abed: r.abed55@gmail.com, 0000-0002-1358-5728

Pedro Javier Torres: pedrojtorres011@hotmail.com.ar, 0000-0002-7825-5623

Eugenia Mercedes Luque: eugenialu@gmail.com, 0000-0001-9726-9046

Nicolás David Ramírez: nicoramireznr94@gmail.com, 0000-0001-9762-5637

Ana Carolina Martini: acmartini2000@yahoo.com, 0000-0003-3063-5640

Jordi Salas-Salvadó: jordi.salas@urv.cat, 0000-0003-2700-7459

ABSTRACT

The present updated systematic review and meta-analysis aims to summarize the evidence from published studies with low risk for any important bias (based on methodological quality assessment) investigating the potential associations of adiposity with sperm quality and reproductive hormones. We conducted a systematic search of the literature published in MEDLINE-PubMed and EMBASE through June 2019. Based on the criteria in our review, 169 eligible publications were used for data abstraction. Finally, 60 articles were included in the qualitative analysis and 28 in the quantitative analysis. Our systematic review results indicated that overweight and/or obesity were associated with low semen quality parameters (i.e. semen volume, sperm count and concentration, sperm vitality and normal morphology) and some specific reproductive hormones (e.g. inhibin B, total testosterone, and sex hormone–binding globulin). Overweight and/or obesity were also positively associated with high estradiol concentrations. Meta-analysis indicated that overweight and/or obesity categories were associated with lower sperm quality (i.e. semen volume, sperm count and concentration, sperm vitality, total motility and normal morphology), and underweight category was likewise associated with low sperm normal morphology. In conclusion, our results suggest that maintaining a healthy body weight is important for increasing sperm quality parameters and potentially male fertility.

Keywords: BMI; adiposity; sperm parameters; sex hormones; systematic review; meta-analysis

INTRODUCTION

Infertility is defined as the inability to have a child after at least one year of regular unprotected sexual intercourse. It is reported that about 15 percent of couples across the world are suffering from infertility [1].

There are several causes for infertility, however, about half of the causes are attributed to the male partner. Infertility can be caused by a variety of factors, such as anatomical abnormalities including varicocele, ductal obstructions, or ejaculatory disorders. However, more than 25% of infertile men have idiopathic infertility [2,3], defined as the absence of specific abnormalities in semen parameters [4]. The etiology of suboptimal semen quality is not well understood, but oxidative stress and several genetic, physiological, environmental, and nutritional factors are suggested [5].

There is increasing evidence showing the important role of nutrition on quality of sperm. Recent studies suggested that nutrition, in terms of both macro- and micro-nutrient intake, plays a key role in normal reproductive function indicating that high energy intake, elevated intake of saturated fatty acids, trans fatty acids, and sodium along with low consumption of antioxidant-rich foods such as fruits and vegetables, may result in an impaired reproductive system, affecting the structure of sperm, as well as fetal and offspring health [6–10].

Underweight and overweight/obesity have been reported to be associated with an increased risk of infertility through sex hormones and seminogram alterations. Because several studies in humans have investigated the links between adiposity (BMI or waist-circumference) and sperm parameters, several systematic reviews and meta-analysis have been conducted [11–13] suggesting an association between excess of adiposity and several sperm parameters. However, these meta-analyses were conducted some years ago, in some cases in specific populations, and frequently included low-quality studies, therefore, the associations are controversial. These controversies are commonly attributed to limitations that are inherent in human studies such as confounding factors and other limitations that are absent from animal-controlled studies. In fact, there are a wide variety of studies in animal models indicating detrimental effects of obesity-induced fat-rich diets in spermatogenesis function [14–16]. Importantly, some well-controlled animal studies indicate that a diet-induced reversion to normal weight in not sufficient to reverse the effects of an unhealthy diet on semen parameters [16]. Both types of studies, human observational studies and animal experimental studies highlight the necessity of new, updated systematic reviews and meta-analysis to create a consensus in the topic.

The aim of the present systematic review and meta-analysis was to update and summarize the high-quality evidence from published human observational studies investigating the potential associations between adiposity categories (underweight, overweight and obesity), and seminogram parameters or sex-related hormones implicated in male reproductive function.

METHODS

Data Sources and Searches

We followed the Cochrane Handbook of Systematic Reviews guidelines. The protocol has been registered (PROSPERO 2019: CRD42019121920) in the PROSPERO registry (http://www.crd.york.ac.uk/PROSPERO).

We performed a systematic search of the literature published in MEDLINE-PubMed database (http://www.ncbi.nlm.nih.gov/pubmed), EMBASE database (https://www.embase.com/#search), and a manual search of a reference list of retrieved articles through June 2019, in accordance with the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [17,18] and Meta-analyses Of Observational Studies in Epidemiology (MOOSE) statements [19].

For literature searches, a combination of terms as both Medical Subject Headings (MeSH) and keywords was used. The search terms for this study included "male (in)fertility" related keywords, and terms related to "weight/obesity" such as: male infertility OR asthenozoospermia OR oligozoospermia OR oligoasthenozoospermia OR oligoasthenoteratozoospermia OR teratozoospermia OR spermatogenesis OR semen quality OR sperm DNA damage OR varicocele AND obesity OR abdominal obesity OR metabolic syndrome OR overweight OR body mass index OR BMI OR body weight OR fat mass OR body fat. The complete search strategy and filters applied are available in **Supplemental Appendix 1**.

Eligibility criteria and study selection

Four authors in the field of male fertility and nutrition screened the titles and abstracts of all articles for eligibility (AS-H, LMN, ERJ, and RA). The accessible case-control, cross-sectional and observational prospective and retrospective studies, in which fertile/infertile men were well-defined with sperm disorders, sperm DNA damage, or idiopathic infertility, were included in this review. In addition, studies were selected with the primary outcomes of semen quality (volume, motility, morphology, sperm count or concentration, sperm DNA damage or chromatin integrity and sex hormonal level). We excluded randomized clinical trials, animal studies, review articles, varicocele studies, and studies of low quality. After primary screening (assessing the scope of study) and evaluating the quality in accordance with inclusion/exclusion criteria, the full text of selected articles was obtained (**Supplemental Table 1**).

Data extraction

The following information was extracted from each study: author/s, year of publication, location, age (years), infertility status, sample size, study design, exposure, primary and secondary outcomes, and conclusion. After extracting the data, in order to minimize any errors, they were double checked by the authors regarding any discrepancies.

Quality assessment

The quality of selected observational (cross-sectional, retrospective, prospective and case-controls) studies was assessed and scored on a six-point scale by three authors (AS-H, LMN, and RA) in parallel [20]. The discrepancies were re-evaluated altogether. We assessed the quality of individual studies using the following criteria (0, 0.5 or 1 point per criterion): (i) study participation; (ii) study attrition; (iii) prognostic factor measurement; (iv) confounding measurement and account; (v) outcome measurement; and (vi) analysis. Studies with a score between 0 and 3 points were considered low-quality studies (excluded) and studies with a score > 3 were considered as moderate to high quality studies (included for subsequent analysis).

Statistical analysis (meta-analysis)

Meta-analyses were performed only using the latest World Health Organization [21] BMI categories: <18.5 (underweight), 18.5-24.9 (normal weight), 25.0-29.9 (overweight, or pre-obesity), 30.0-34.9 (class I obesity), 35-39.9 (class II obesity) and ≥40.0 (morbid obesity, or class III obesity) kg/m^2.

Participants with a BMI between 18.5-24.9 kg/m^2 were considered as the reference category, except in few cases, where the normal weight was considered 20-24.9 kg/m^2 [22–25]. In the studies with only some categories encompassed in the last WHO-BMI categorization the meta-analysis were done only with these categories (for example: Luque *et al.,* 2017 [22] has WHO categories for overweight and obesity but not for underweight). When only one subcategory of obesity was reported in a paper (BMI>30.0), the values where computed in the first obesity category (class I obesity -or more-) (for example: Aggerholm *et al.*, 2008 [26]). In a few cases, only two subcategories of obesity were shown (BMI>30-34.9 and BMI>35); in those cases the values in the highest category where computed in the second obesity category (class II obesity -or more-) (for example: Belloc *et al.*, 2014 [27]).

Meta-analysis was conducted only with the studies included in the qualitative synthesis with seminogram data (semen volume, sperm count and concentration, sperm vitality, sperm total and progressive motility, and/or normal morphology) through the use of Doing Meta-Analysis in R [28] and Meta-Essentials v.1.4 [29] platforms in accordance with the Cochrane guidelines [30,31].

To calculate the effect size (ES) and 95% confidence intervals (95% CIs), the mean and standard deviation (SD) were obtained from patient characteristics data of each study. The ES describes the difference between all aforementioned unhealthy BMI categories (underweight, overweight, class I obesity, class II obesity, and morbid obesity, or class III obesity) and healthy-normal weight. Positive values indicated that the specific unhealthy BMI category has better seminogram parameters than normal weight, whereas negative ES indicates poorer seminogram parameters. In the case of prospective studies [32] baseline values were used. In most of the cases, these values were directly obtained from the main data of the article (or supplemental data) and in few cases the values were obtained through a request to the corresponding authors [22,33,34]. When necessary, estimated mean and SD values were calculated with the median and interquartile rank (IQR) [35]. The main values for meta-analysis calculations were obtained by the primary author (AS-H) and were checked by three independent authors (PJT, EML, and NDR). Random-effects models were used to obtain summary effects and inter-study variation when ≥5 studies were compared (fixed-effects models were used if number of study comparisons were <5 [36]). Statistical significance was set at p-value<0.05 (two-way). Heterogeneity between the studies was evaluated via a chi-square test and the I^2 index with the significance level set at $p<0.10$. I^2 values <50% were deemed moderate, ≥50% to <75% were deemed substantial, and ≥75% were deemed of considerable heterogeneity. Tests for funnel plot asymmetry were used only when there were at least 10 studies included in the meta-analysis, as well as, “trim and fill” method, in order to identify and correct for funnel plot asymmetry arising from publication bias [31].

Sensitivity analyses were performed in two different ways when ≥5 studies were included in the meta-analysis 1) changing meta-analysis models (random to fixed models) and, 2) systematic exclusion of one study at a time and recalculating summary effect sizes.

RESULTS

Study characteristics

The number of articles identified after a primary search was 2,237 (**Figure 1**). After analyzing the results, we immediately excluded 565 records because they were duplicated (n=337); they were conference papers (n=223), or comments, replies or letters (n=5). The remaining 1,672 records were evaluated based on their title and abstract, and 1,518 articles were excluded based on the scope of the study. One hundred and fifty-four articles (based on the inclusion and exclusion criteria) with full texts were selected for quality assessment. Fourteen additional manuscripts were included after a complimentary search of the citation lists. We also included one recently published study obtained by contacting the corresponding authors of all studies included in the meta-analysis, assigned as '(Ramírez *et al.*, 2020)[23]' study. Therefore, the inclusion/exclusion criteria and quality scores were assessed in 169 full-text articles. One hundred nine of these articles were excluded based on inclusion/exclusion criteria (n=24), quality assessment threshold (n=13) or other reasons (reviews, n=28; data not found, n=2; no English papers, n=10; conference papers, n=23; comments, replies, or letters, n=5; corrigendums, n=1; or randomized clinical trials, n=3). After considering all eligibility parameters and the PICOS table (**Supplemental Table 1**), 60 high-quality articles were used for data abstraction. Finally, 28 articles were included in the quantitative synthesis because seminogram data were displayed and/or subsequently obtained (exclusion reasons: insufficient data, n=18; non-WHO based BMI categories included, n=5; lack of data in normal weight individuals, n=3; lack of BMI data, n=2; and articles with only hormonal data, n=4).

Qualitative synthesis

The summary of articles analyzing the associations between semen quality, reproductive hormone levels and different exposures related with underweight, normal weight, overweight and obesity data were condensed in **Table 1**.

We identified a total of 54 studies reporting the association between BMI and sperm quality parameters, and 29 studies reporting some associations between BMI and reproductive hormones. The majority of exposure associations are reported with BMI data (58/60), however, some studies also reported other exposures (e.g. body fat, waist circumference, metabolic syndrome, waist-to-height ratio or waist-to-hip ratio).

The articles included subjects from all continents but Antarctica, with 30 countries represented: Argentina, Australia, Austria, Brazil, China, Czech Republic, Denmark, Egypt, Estonia, Finland, France, Georgia, Germany, Hungary, Iceland, India, Iran, Italy, Netherlands, New Zealand, Nigeria, Norway, Pakistan, Saudi Arabia, Sweden, Taiwan, Tunisia, Turkey, United Kingdom, USA. The age of the participants ranged between 16 and 66 years.

Even though all of the studies included in the systematic review have cross-sectional data (reporting baseline characteristics) and these data were used to perform the meta-analysis, when possible, different study types were identified: 8 retrospective, 8 prospective and 44 cross-sectional studies. The mean quality assessment score for all included studies was 4.3/6 (range: 3.5-5.5).

Globally, our systematic review results indicated that overweight or obesity (based in BMI-WHO) was associated with reduced semen quality parameters (i.e. semen volume, sperm count and concentration, sperm vitality and motility, and normal morphology) and disruption of some specific reproductive hormones (i.e inhibin B, total testosterone, and sex hormone–binding globulin). However, overweight and/or obesity were associated with high peripheral concentrations of estradiol. In the case of all other measured parameters (i.e. free testosterone, prolactin, follicle-stimulating hormone, luteinizing hormone, testosterone/luteinizing hormone ratio, progressive sperm motility, and DNA fragmentation index) the associations are, in some cases, contradictory (**Table 1 and Table 2**). Even though not all the studies considered possible confounding factors for the analysis, the vast majority adjusted for age due to age-associated increases in risk of obesity.

Quantitative synthesis: association between BMI categories and seminogram parameters

The present meta-analysis includes a total of 28 eligible studies with BMI and seminogram data [22–27,32–34,37–55].

Figure 2A-G shows the summary associations (combined effect size) between BMI categories and each seminogram parameter considered.

Figure 2A shows the summary associations (combined effect size) between BMI categories and semen volume. The comparisons between each BMI category and semen volume were shown in supplemental figures (**Supplemental Figures 1-5**). Compared to individuals with normal weight, those with class I obesity and class II obesity had a lower semen volume (ES; 95% confidence interval) (-0.31; -0.58 to -0.03; p-value=0.018, and -0.72; -1.07 to -0.36; p<0.001, respectively). This association was not observed in the case of class III obesity category, where heterogeneity was moderately high (I^2<50%, p=0.140). For the other BMI categories there was evidence of considerable and significant heterogeneity between the studies (I^2>85%, p<0.001). The visual evaluation of funnel plot and “trim and fill” test were performed for the meta-analysis with at least 10 studies included, and no substantial changes in the ES and heterogeneity (<10% of changes in heterogeneity) were detected in semen volume outcomes.

Figure 2B shows the summary associations between BMI categories and sperm count. The comparisons between each BMI category and sperm count are shown in supplemental figures (**Supplemental Figures 6-10**). Compared to the individuals with normal weight, sperm count was lower in the cases of class II obesity and class III obesity categories (-0.66; -0.91 to -0.42; p<0.001, and -0.20; -0.98 to 0.57; p=0.001, respectively). Except for class III obesity category, where heterogeneity was moderate (I^2=61%, p=0.110) there was evidence of considerable and significant heterogeneity between the studies for the other BMI categories (I^2>90, p<0.001). Funnel plots and "trim and fill" tests indicated that no substantial changes in heterogeneity were detected.

Figure 2C shows the summary associations between BMI categories and sperm concentration. The comparisons between each BMI category and sperm concentration were shown in supplemental figures (**Supplemental Figures 11-15**). Compared to individuals with normal weight, only those with class III obesity had decreased sperm concentrations (-0.18; -0.42 to 0.06; p=0.002). In that case, the heterogeneity was classified as substantial (I^2=71.3%, p=0.015) for class II obesity and moderate (I^2<50%, p=0.272) for class III obesity. The other categories were classified with high heterogeneity (I^2>90, p<0.001). Funnel plots and "trim and fill" tests indicated that no substantial changes in heterogeneity were detected.

Figure 2D shows the summary associations between BMI categories and sperm vitality. The comparisons between each BMI category and sperm vitality were shown in supplemental figures (**Supplemental Figures 16-19**). The meta-analysis comparing individuals with underweight and normal weight could not be performed due to too few studies being identified. We found that, compared to individuals with normal weight, those with overweight, class I obesity and class III obesity categories had a decrease in sperm vitality percentages (-0.81; -1.59 to -0.03; p=0.012, -0.76; -1.65 to 0.13; p=0.027, and -3.16; -4.82 to -1.51; p<0.001, respectively). Evidence of significant, considerable heterogeneity (I^2>85%, p<0.001) was observed for all analyzed categories. In that outcome, no funnel plots and "trim and fill" tests were applied because fewer than 10 studies were included in the meta-analysis.

Figure 2E shows the summary associations between BMI categories and total motility. The comparisons between each BMI category and total motility are shown in supplemental figures (**Supplemental Figures 20-24**). We only found a decrease in total sperm motility in individuals with class III obesity as compared with individuals with normal weight (-0.37; -0.61 to -0.12;

p<0.001). This was also the only comparison with moderate heterogeneity (I^2<50%, p=0.188). Funnel plots and “trim and fill” tests indicated that no substantial changes in heterogeneity were detected.

Figure 2F shows the summary associations between BMI categories and progressive motility. The comparisons between each BMI category and sperm progressive motility are shown in supplemental figures (**Supplemental Figures 25-28**). In the case of progressive motility, no significant associations were found for any adiposity categories analyzed. Except for individuals in underweight category, where heterogeneity was very low (I^2=0%, p=0.889), there was evidence of considerable and significant heterogeneity between the studies for the other considered BMI categories (I^2>90, p<0.001). Funnel plots and “trim and fill” tests indicated that no substantial changes in heterogeneity were detected. However, for the overweight category, “trim and fill” tests resulted in a non-significant change of the ES from a negative association without the adjustment (-0.26; -0.57 to 0.05) to a positive association after the adjustment and imputation of six data points (0.02; 0.01 to 0.04) (**Supplemental Figure 26**).

Finally, **Figure 2G** shows the summary associations between BMI categories and normal sperm morphology. The comparisons between each BMI category and morphology are shown in supplemental figures (**Supplemental Figures 29-33**). We found that individuals with underweight, class II obesity and class III obesity were associated with a decrease in spermatozoa with normal morphology (-0.98; -1.40 to -0.56; p<0.001, -0.57; -0.82 to -0.32; p<0.001, and -0.31; -0.56 to -0.05; p<0.001, respectively). Except for class III obesity category, where heterogeneity was substantial (I^2=63%, p=0.068) there was evidence of considerable heterogeneity between the studies for the other BMI categories (I^2>90, p<0.001). Finally, funnel plots and “trim and fill” tests indicated that no substantial changes in heterogeneity were detected.

Figure 2H is a summary of the data and was generated to illustrate significant associations between BMI class and seminogram parameter while considering direction of change. This was done by plotting statistical significance (-log10 p-value) against combined effect size on the y-axis and x-axis, respectively.

Sensitivity analyses

Fixed models

The use of fixed models (instead of random models), in the meta-analyses with ≥5 studies, substantially modified the significance of some results but maintained the same associations described in **Figure 2** with the exception of the sperm volume category (normal vs. underweight) and sperm total motility (normal vs. overweight). In the other cases, the association direction is the same but becomes statistically significant. This is observed in the case of semen volume (overweight), sperm count (underweight, overweight and class I obesity), sperm concentration (underweight, and class I obesity), total and progressive motility (class I obesity) and normal morphology (class I obesity), but not in vitality. The results showed that random models are stricter than fixed models, as expected, in meta-analyses with more than 5 studies (see **Supplementary Figures 34-50**).

Systematic exclusion of one study at time

Some changes in results were identified by systematic exclusion of one study at a time in the meta-analyses with ≥5 studies (see **Supplementary Table 2**). The results showed that the ES of semen volume in the underweight group changed to a significant negative association when we eliminated data from Qin et al., 2007 [48]. Removing the study by Qin *et al.*, 2007 [48] also explained the heterogeneity in this comparison. Moreover, results showed that the ES of semen volume in the group with overweight changed to a significant negative association when we eliminated data from Alshahrani et al., 2016 [55], while the outcome of other groups was not qualitatively changed with or without any study.

Removing the study by Qin et al., 2007 [48] explained the heterogeneity for sperm count in underweight group (passing form considerable heterogeneity to moderate). In the same sperm quality variable, the results showed that the ES in the group with overweight changed to a significant negative association when we eliminated data from Qin et al., 2007 [48]. Moreover, the results showed that the ES in the group with obesity (or class I obesity) changed to a significant negative association when we eliminated data from Aggerholm et al., 2008 and/or Shayeb et al., 2011 [26,50].

Similarly, removing the study by Qin et al., 2007 [48] explained the heterogeneity for sperm concentration in the underweight group (passing form considerable heterogeneity to moderate), while the ES outcome and heterogeneity of other groups was not qualitatively changed with or without any study.

The results showed that the ES of sperm vitality in the group with obesity (or class I obesity) changed to non-significant negative association when we eliminated data from Taha et al., 2016 [51].

In the case of total motility, neither heterogeneity nor ES associations were qualitatively changed with or without any study. However, in progressive motility the results showed that the ES in the group with overweight changed to a significant negative association when we eliminated data from Bandel et al., 2015; Belloc et al., 2014; Keskin et al., 2017 and/or Ma et al., 2019 [27,34,37,44] and in the group with obesity (or class I obesity) when we eliminated data from Bandel et al., 2015; Hammiche et al., 2012; Keskin et al., 2017; Ma et al., 2019 and/or Taha et al., 2016 [34,37,43,44,51].

Finally, the results showed that the ES of sperm normal morphology only in the group with obesity (or class I obesity) changed to a significant negative association when we eliminated data from Qin et al., 2007 [48].

DISCUSSION

The present systematic review and meta-analysis of observational studies provides the most comprehensive analysis to date of the associations between male adiposity and sperm quality or sex-related hormones. These data suggest that there is an association between weight status and sperm and hormonal parameters suggesting that weight loss could improve sperm parameters, and therefore, may improve not only assisted reproduction outcomes and live-birth rate, but also natural conception. However, it's important to note that well designed studies investigating the impact of weight loss on improving semen parameters and reproductive outcomes are scarce. Our systematic review results indicated that overweight and/or obesity were associated with low semen quality parameters (e.g. semen volume, sperm count and concentration, sperm vitality and normal morphology) and the peripheral concentrations of some specific reproductive hormones (e.g. inhibin B, total testosterone, and sex hormone–binding globulin). However, overweight and/or obesity were associated with higher levels of estradiol. Our meta-analysis indicated that overweight/obesity categories were associated with lower sperm quality (e.g. semen volume, sperm count and concentration, sperm vitality, total motility and normal morphology) and underweight category was associated with reduced normal sperm morphology.

There have been several systematic reviews and meta-analyses performed in the last 10 years to investigate the association between adiposity and seminogram parameters but all of them had limitations which restrict their interpretation and/or applicability (see **Supplemental Table 3**). Aggerholm *et al.* [26] found no significant relationship between sperm count and BMI. This finding was further confirmed by Pauli *et al.* study in 2008 [56], in which no relationship was observed between BMI and semen parameters. In a meta-analysis by MacDonald and collaborators [13], considering very strict inclusion and exclusion criteria, similarly there was no evidence obtained to support the association between BMI and sperm concentration or total sperm count. In several studies, the observed effects on sperm concentration were not significant and the sperm quantity and quality were within the normal range among men with overweight and obesity. There was no association between BMI and semen parameters according to many recent studies. Therefore, although there is some existing support for the suggestion that obesity affects reproductive potential, several studies indicate no connection between BMI and semen parameters.

Although the first systematic review and meta-analysis found no evidence of association between BMI and semen parameters [13], in the next three meta-analyses, a potential association between overweight/obesity and different indices of semen quality was reported [11,12,57]. All of the systematic reviews with meta-analyses analyzing the association between excess of adiposity and seminogram were published in 2017 or before [11–13,57], with the exception of one that analyzed the association between low BMI and seminogram without sperm morphology analysis [58]. In that study, a relationship between low BMI and semen quality was reported, suggesting that low BMI is a harmful factor for male infertility. With the exception of the Campbell et al., study [57], including 31 studies in the systematic review and only 5 in the meta-analysis, the other meta-analyses did not evaluate the quality of the studies included in their analysis, therefore the conclusions were weakened. In addition, the majority did not explore heterogeneity due to limited number of studies based upon their entry criteria or did not explore the certainty of the evidence. In addition, new evidence has accumulated since most recent published systematic review and meta-analysis. These newer studies were included in the present review. Our search in the MEDLINE-PubMed and EMBASE databases showed that since the most recent meta-analysis was published, at least three new epidemiologic studies have been reported in the case of participants with overweight/obesity and two in the case of underweight. Our study took into consideration all of the aforementioned limitations of the already published meta-analyses, being the most comprehensive and updated systematic review and meta-analysis on this topic, including comparisons between individuals with normal weight with those with underweight, overweight and with different types of obesity as measured by BMI.

Obesity may affect male fertility directly or indirectly through several possible mechanisms including alterations in hormonal profiles, increased scrotal temperature due to increased scrotal adiposity, increased production of ROS and inflammatory mediators, and epigenetic changes including methylation of sperm DNA and modification of non-coding RNAs [59–62].

In fact, our qualitative systematic review results indicated that overweight and/or obesity were associated with reduced peripheral levels of some specific reproductive hormones (e.g. inhibin B, total testosterone, and sex hormone–binding globulin) subsequently resulting in hypogonadism. Generally, men with obesity present secondary hypogonadism, characterized by abnormal hypothalamic-pituitary levels and difficulties maintaining testicular function due to insufficient levels of gonadotropin [63], as also has been seen in the results of our qualitative systematic review. Men with obesity also display a marked decrease in SHBG concentrations which is the principal reason for the concomitant decrease in total testosterone observed in available studies. Nevertheless, free and total testosterone levels are not always reduced in men with overweight/obesity [63–67]. Despite having low total testosterone concentrations, men with obesity may still have free testosterone within the reference range, and therefore, hypogonadism symptoms are not observed [68]. The ratio of Testosterone/LH may be an important measure to demonstrate the secondary nature of the obesity hypogonadism. Unfortunately, this ratio was measured in only one of the included studies [38] and in this case, an association with overweight or obesity categories was not observed.

It has also been suggested that increased scrotal temperatures due to increased scrotal adiposity may impair spermatogenesis impacting semen parameters [69], and may induce an increase in sperm DNA fragmentation [70]. However, in a recent meta-analysis it was concluded that there is insufficient data to demonstrate a positive association between BMI and sperm DNA fragmentation [71]. It was suggested that excess levels of leptin in obesity, induced by increased secretion from adipose tissue, may have damaging effects on the production of sperm and androgens by Leydig cells [72], however this has not been confirmed. Moreover, it is suggested that obesity may stimulate sperm abnormalities through the increased production of ROS and inflammatory mediators impairing testicular and epididymal tissues directly [73,74]. In fact, elevated levels of inflammatory mediators including TNF-α and IL-6 and decreased levels of vascular endothelial growth factor (VEGF) in the seminal plasma of males with obesity was observed, which may affect semen quality [75].

Moreover, our qualitative analysis also indicated that overweight and/or obesity were associated with higher levels of estradiol, and this deserves a special discussion. New data suggested that estradiol levels measured in male serum by immunoassay cannot be considered reliable, and the use of mass spectrometric estradiol measurements are strongly recommended [76,77]. In fact, using mass spectrometric estradiol measurements, it has been shown that peripheral estradiol levels in men with obesity are actually low [78] and increased only upon extreme obesity [79,80].

Therefore, it is suggested that obesity may alter the systemic and local environment necessary for spermatogenesis and sperm maturation in the epididymis and may result in poor sperm quality including decreased sperm motility, abnormal morphology of sperm, impaired acrosome reaction, altered membrane lipids and increased DNA damage [81]. Furthermore, some recent studies indicate that epigenetic changes including changes in sperm DNA methylation and modification of non-coding RNAs may be a consequence of increased adiposity [59,62].

In fact, men with obesity are more likely to experience infertility, reduced live birth per ART cycle, and increased absolute risk of non-viable pregnancies [57]. A recent systematic review and meta-analysis including eleven studies revealed that elevated male BMI was associated with a significant reduction in clinical pregnancy rates, and live birth rates per IVF-ICSI treatment cycle, suggesting that male BMI could be an important factor influencing these outcomes potentially through the aforementioned mechanisms [57].

It is possible that weight loss may be an effective treatment approach in obesity linked with male infertility. In fact, it was found that men who reduced their body weight by adhering to a healthy diet and exercise, had increased levels of androgen and inhibin B, improved semen parameters, increased sex hormone binding globulin (SHBG) and decreased serum concentrations of insulin and leptin [82]. Moreover, a preliminary prospective double-armed study recently found that large-scale weight loss following bariatric surgery was also associated with an improvement in some semen parameters [83]. However, the body of literature for controlled trials on the potential benefits of losing weight on sperm parameters, and especially on reproductive potential, is relatively small and controversial [84]. Therefore additional studies are needed to draw strong conclusions in this area [85–87]. It is noteworthy that the extent to which semen parameter improvements associated with weight loss are accompanied by concomitant improvements in reproductive potential need to be further studied since most infertile men have normal sperm quality. However, considering the increasing prevalence of obesity and decreasing male fertility, it is suggested that clinicians should have increased awareness of the effects of obesity on fertility and the underlying mechanisms in order to appropriately counsel patients and provide more effective treatments.

Strengths and limitations

The present study has some strengths that should be highlighted. We used a comprehensive systematic search strategy in multiple databases to identify all available studies published in this field and we only included studies of high quality. Nevertheless, the present systematic review and meta-analysis also has some limitations that need to be addressed. First, the clinical significance of the observed changes in the seminogram is uncertain, and certainty depends on whether the patient has a normal borderline normal (considering WHO 2010 categorization [88]) or abnormal seminogram. Second, we could not perform a publication bias assessment for most of the outcomes because fewer than 10 study comparisons were available. Moreover, in the vast majority of the performed meta-analyses, the inter-study heterogeneity was considerable, and although the exclusion of Qin et al., 2007[48] explained the observed heterogeneity in the semen volume, sperm count and sperm concentration analyses, it remained unexplained for the other outcomes. Finally, the possibility for residual confounding and reverse causation inherent to the design of the included studies could not be ruled out. As a consequence, future research in this field is critical to better understand the impacts of adiposity on male fertility and the mechanisms underlying adiposity-associated male subfertility.

CONCLUSIONS

In conclusion, the present systematic review and meta-analysis of observational studies provides the most updated and comprehensive analysis to date of the associations between male adiposity and sperm quality and/or sex hormones. The meta-analysis results indicate that overweight/obesity is associated with lower sperm quality (e.g. semen volume, sperm count and concentration, sperm vitality, total motility and normal morphology) and underweight is associated with reduced normal sperm morphology. These results suggest that overweight/obesity prevention should be considered at an early age to avoid deleterious effects on reproductive health. Since observational studies can prove associations but not demonstrate causation, the associations summarized in the present study need to be confirmed with large prospective cohort studies of high quality, especially in the context of well-designed randomized clinical trials. Additional studies are warranted to elucidate the potential benefits of weight loss for improving reproductive potential in individuals with obesity.

Contributions

Conceptualization: AS-H, and LM-N. Methodology: AS-H, and NB-T. Formal analysis: AS-H, LM-N, ERJ, RA, PJT, EML, and NDR. Writing—Original Draft Preparation: AS-H, and JS-S. Writing—Review and Editing: LM-N, ERJ, DTC, KIA, TGJ, NBT, AZJ, RA, PJT, EML, NDR, and ACM. Visualization: AS-H, and ERJ. Supervision: NB-T, ACM, and JS-S. All authors made substantial contributions in writing and editing the manuscript before submission.

Conflict of interest

The authors report no financial or commercial conflicts of interest.

Acknowledgements

J.S-S. gratefully acknowledges the financial support by ICREA under the ICREA Academia program.

Funding

This study did not receive any financial support.

REFERENCES

1. Datta J, Palmer MJ, Tanton C, et al. Prevalence of infertilityand help seeking among 15 000 women and men. *Hum Reprod*. 2016;31(9):2108-2118. doi:10.1093/humrep/dew123

2. Siddiq FM, Sigman M. A new look at the medical management of infertility. *Urol Clin North Am*. 2002;29(4):949-963. doi:10.1016/S0094-0143(02)00085-X

3. Jungwirth A, Giwercman A, Tournaye H, et al. European association of urology guidelines on male infertility: The 2012 update. *Eur Urol*. 2012;62:324-332. doi:10.1016/j.eururo.2012.04.048

4. Cooper TG, Noonan E, Eckardstein S Von, et al. World Health Organization reference values for human semen characteristics. *Hum Reprod*. 2010;16(3):231-245. doi:10.1093/humupd/dmp048

5. Auger J, Eustache F, Andersen AG, et al. Sperm morphological defects related to environment, lifestyle and medical history of 1001 male partners of pregnant women from four European cities. *Hum Reprod*. 2001;16(12):2710-2717.

6. Salas-Huetos A, Bulló M, Salas-Salvadó J. Dietary patterns, foods and nutrients in male fertility parameters and fecundability: a systematic review of observational studies. *Hum Reprod Update*. 2017;23(4):371-389. doi:10.1093/humupd/dmx006

7. Salas-Huetos A, Rosique-Esteban N, Becerra-Tomás N, Vizmanos B, Bulló M, Salas-Salvadó J. The Effect of Nutrients and Dietary Supplements on Sperm Quality Parameters: A Systematic Review and Meta-Analysis of Randomized Clinical Trials. *Adv Nutr An Int Rev J*. 2018;9(6):833-848. doi:10.1093/advances/nmy057

8. Gaskins AJ, Chavarro JE. Diet and fertility: a review. *Am J Obstet Gynecol*. 2017;(September):1-11. doi:10.1016/j.ajog.2017.08.010

9. Salas-Huetos A, James ER, Aston KI, Jenkins TG, Carrell DT. Diet and sperm quality: Nutrients, foods and dietary patterns. *Reprod Biol*. 2019;19(3):219-224. doi:10.1016/j.repbio.2019.07.005

10. Giahi L, Mohammadmoradi S, Javidan A, Sadeghi MR. Nutritional modifications in male infertility: A systematic review covering 2 decades. *Nutr Rev*. 2016;74(2):118-130. doi:10.1093/nutrit/nuv059

11. Sermondade N, Faure C, Fezeu L, et al. BMI in relation to sperm count: An updated systematic review and collaborative meta-analysis. *Hum Reprod Update*. 2013;19(3):221-231. doi:10.1093/humupd/dms050

12. Guo D, Wu W, Tang Q, et al. The impact of BMI on sperm parameters and the metabolite changes of seminal plasma concomitantly. *Oncotarget*. 2017;8(30):48619-48634. doi:10.18632/oncotarget.14950

13. MacDonald AA, Herbison GP, Showell M, Farquhar CM. The impact of body mass index on semen parameters and reproductive hormones in human males: A systematic review with meta-analysis. *Hum Reprod Update*. 2009;16(3):293-311. doi:10.1093/humupd/dmp047

14. Rato L, Alves MG, Cavaco JE, Oliveira PF. High-energy diets: A threat for male fertility? *Obes Rev*. 2014;15(12):996-1007. doi:10.1111/obr.12226

15. Crean AJ, Senior AM. High-fat diets reduce male reproductive success in animal models: A systematic review and meta-analysis. *Obes Rev*. 2019;20(6):921-933. doi:10.1111/obr.12827

16. Crisóstomo L, Rato L, Jarak I, et al. A switch from high-fat to normal diet does not restore sperm quality but prevents metabolic syndrome. *Reproduction*. 2019;158(4).

17. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *J Clin Epidemiol*. 2009;62(10):e1-34. doi:10.1016/j.jclinepi.2009.06.006

18. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med*. 2009;6(7):e1000097. doi:10.1371/journal.pmed.1000097

19. Stroup DF, Berlin JA, Morton SC, et al. Meta-analysis of Observational Studies: A Proposal for Reporting. *JAMA*. 2000;283(15):2008-2012.

20. Hayden JA, Cote P, Bombardier C. Evaluation of the quality of prognosis studies in systematic reviews. *Ann Intern Med*. 2006;144(6):427-437. doi:144/6/427 [pii]

21. WHO. *Obesity: Preventing and Managing the Global Empidemic*.; 2000.

22. Luque EM, Tissera A, Gaggino MP, et al. Body mass index and human sperm quality: Neither one extreme nor the other. *Reprod Fertil Dev*. 2017;29(4):731-739. doi:10.1071/RD15351

23. Ramírez N, Molina R, Tissera A, et al. Recategorisation of body mass index to achieve andrological predictive power: a study in more than 20,000 patients. *Reprod Fertil Dev*. 2020. doi:10.1071/RD19429

24. Thomsen L, Humaidan P, Bungum L, Bungum M. The impact of male overweight on semen quality and outcome of assisted reproduction. *Asian J Androl*. 2014;16(5):787. doi:10.4103/1008-682x.133321

25. Jensen TK, Andersson AM, Jørgensen N, et al. Body mass index in relation to semen quality and reproductive hormones among 1,558 Danish men. *Fertil Steril*. 2004;82(4):863-870. doi:10.1016/j.fertnstert.2004.03.056

26. Aggerholm AS, Thulstrup AM, Toft G, Ramlau-Hansen CH, Bonde JP. Is overweight a risk factor for reduced semen quality and altered serum sex hormone profile? *Fertil Steril*. 2008;90(3):619-626. doi:10.1016/j.fertnstert.2007.07.1292

27. Belloc S, Cohen-Bacrie M, Amar E, et al. High body mass index has a deleterious effect on semen parameters except morphology: Results from a large cohort study. *Fertil Steril*. 2014;102(5):1268-1273. doi:10.1016/j.fertnstert.2014.07.1212

28. Harrer M, Cuijpers P, Furukawa TA, Ebert DD. *Doing Meta-Analysis in R: A Hands-on Guide*. PROTECT Lab; 2019. https://bookdown.org/MathiasHarrer/Doing_Meta_Analysis_in_R/.

29. Suurmond R, Hak T. Introduction, comparison , and validation of Meta-Essentials: A free and simple tool for meta-analysis. *Res Syntesis Methods*. 2017;8(July):537-553. doi:10.1002/jrsm.1260

30. O'Connor D, Green S, Higgins JP. *Cochrane Handbook for Systematic Reviews of Interventions*. Version 5. Wiley-Blackwell; 2008. doi:10.1002/9780470712184.ch5

31. Higgins JP, Green S, eds. *Cochrane Handbook for Systematic Reviews of Interventions*. Version 5. The Cochrane Collaboration; 2011. www.handbook.cochrane.org.

32. Ferigolo PC, Ribeiro de Andrade MB, Camargo M, et al. Sperm functional aspects and enriched proteomic pathways of seminal plasma of adult men with obesity. *Andrology*. 2019;7(3):341-349. doi:10.1111/andr.12606

33. Andersen JM, Rønning PO, Herning H, Bekken SD, Haugen TB, Witczak O. Fatty acid composition of spermatozoa is associated with BMI and with semen quality. *Andrology*. 2016;4(5):857-865. doi:10.1111/andr.12227

34. Ma J, Wu L, Zhou Y, et al. Association between BMI and semen quality: An observational study of 3966 sperm donors. *Hum Reprod*. 2019;34(1):155-162. doi:10.1093/humrep/dey328

35. Hozo SP, Djulbegovic B, Hozo I. Estimating the mean and variance from the median, range, and the size of a sample. *BMC Med Res Methodol*. 2005;10(5):13. doi:10.1186/1471-2288-5-13

36. Murad MH, Montori VM, Ioannidis JPA, Prasad K, Cook DJ, Guyatt G. Fixed-Effects and Random-Effects Models. In: Guyatt G, Rennie D, Meade MO, Cook DJ, eds. *Users' Guides to the Medical Literature: A Manual for Evidence-Based Clinical Practice, 3rd Ed*. New York, NY: McGraw-Hill Education; 2015. http://jamaevidence.mhmedical.com/content.aspx?aid=1127444211.

37. Bandel I, Bungum M, Richtoff J, et al. No association between body mass index and sperm DNA integrity. *Hum Reprod*. 2015;30(7):1704-1713. doi:10.1093/humrep/dev111

38. Chavarro JE, Toth TL, Wright DL, Meeker JD, Hauser R. Body mass index in relation to semen quality, sperm DNA integrity, and serum reproductive hormone levels among men attending an infertility clinic. *Fertil Steril*. 2010;93(7):2222-2231. doi:10.1016/j.fertnstert.2009.01.100

39. Ehala-Aleksejev K, Punab M. The different surrogate measures of adiposity in relation to semen quality and serum reproductive hormone levels among Estonian fertile men. *Andrology*. 2015;3(2):225-234. doi:10.1111/andr.12002

40. Eisenberg ML, Kim S, Chen Z, Sundaram R, Schisterman EF, Buck Louis GM. The relationship between male BMI and waist circumference on semen quality: Data from the LIFE study. *Hum Reprod*. 2014;29(2):193-200. doi:10.1093/humrep/det428

41. Fariello RM, Pariz JR, Spaine DM, Cedenho AP, Bertolla RP, Fraietta R. Association between obesity and alteration of sperm DNA integrity and mitochondrial activity. *BJU Int*. 2012;110(6):863-867. doi:10.1111/j.1464-410X.2011.10813.x

42. Hadjkacem Loukil L, Hadjkacem H, Bahloul A, Ayadi H. Relation between male obesity

and male infertility in a Tunisian population. *Andrologia*. 2015;47(3):282-285. doi:10.1111/and.12257

43. Hammiche F, Laven JSE, Twigt JM, Boellaard WPA, Steegers EAP, Steegers-Theunissen RP. Body mass index and central adiposity are associated with sperm quality in men of subfertile couples. *Hum Reprod*. 2012;27(8):2365-2372. doi:10.1093/humrep/des177

44. Keskin MZ, Budak S, Aksoy EE, et al. Investigation of the effect of body mass index (BMI) on semen parameters and male reproductive system hormones. *Arch Ital di Urol e Androl*. 2017;89(3):219-221. doi:10.4081/aiua.2017.3.219

45. Koloszár S, Fejes I, Závaczki Z, Daru J, Szöllosi J, Pál A. Effect of body weight on sperm concentration in normozoospermic males. *Arch Androl*. 2005;51(4):299-304. doi:10.1080/01485010590919701

46. Oliveira JBA, Petersen CG, Mauri AL, et al. Association between body mass index and sperm quality and sperm DNA integrity. A large population study. *Andrologia*. 2018;50(3):1-10. doi:10.1111/and.12889

47. Martini AC, Tissera A, Estofán D, et al. Overweight and seminal quality: A study of 794 patients. *Fertil Steril*. 2010;94(5):1739-1743. doi:10.1016/j.fertnstert.2009.11.017

48. Qin DD, Yuan W, Zhou WJ, Cui YQ, Wu JQ, Gao ES. Do reproductive hormones explain the association between body mass index and semen quality? *Asian J Androl*. 2007;9(6):827-834. doi:10.1111/j.1745-7262.2007.00268.x

49. Rybar R, Kopecka V, Prinosilova P, Markova P, Rubes J. Male obesity and age in relationship to semen parameters and sperm chromatin integrity. *Andrologia*. 2011;43(4):286-291. doi:10.1111/j.1439-0272.2010.01057.x

50. Shayeb AG, Harrild K, Mathers E, Bhattacharya S. An exploration of the association between male body mass index and semen quality. *Reprod Biomed Online*. 2011;23(6):717-723. doi:10.1016/j.rbmo.2011.07.018

51. Taha EA, Sayed SK, Gaber HD, et al. Does being overweight affect seminal variables in fertile men? *Reprod Biomed Online*. 2016;33(6):703-708. doi:10.1016/j.rbmo.2016.08.023

52. Vignera S La, Condorelli RA, Vicari E, Calogero AE. Negative effect of increased body weight on sperm conventional and nonconventional flow cytometric sperm parameters. *J Androl*. 2012;33(1):53-58. doi:10.2164/jandrol.110.012120

53. Wang E-Y, Huang Y, Du Q-Y, Yao G-D, Sun Y-P. Body mass index effects sperm quality: a retrospective study in Northern China. *Asian J Androl*. 2017;19(2):234. doi:10.4103/1008-682x.169996

54. Dupont C, Faure C, Sermondade N, et al. Obesity leads to higher risk of sperm DNA damage in infertile patients. *Asian J Androl*. 2013;15(5):622-625. doi:10.1038/aja.2013.65

55. Alshahrani S, Ahmed AF, Gabr AH, Abalhassan M, Ahmad G. The impact of body mass index on semen parameters in infertile men. *Andrologia*. 2016;48(10):1125-1129. doi:10.1111/and.12549

56. Pauli EM, Legro RS, Demers LM, Kunselman AR, Dodson WC, Lee PA. Diminished paternity and gonadal function with increasing obesity in men. *Fertil Steril*. 2008;90(2):346-351. doi:10.1016/j.fertnstert.2007.06.046

57. Campbell JM, Lane M, Owens JA, Bakos HW. Paternal obesity negatively affects male fertility and assisted reproduction outcomes: A systematic review and meta-analysis. *Reprod Biomed Online*. 2015;31(5):593-604. doi:10.1016/j.rbmo.2015.07.012

58. Guo D, Xu M, Zhou Q, et al. Is low body mass index a risk factor for semen quality? A PRISMA-compliant meta-analysis. *Med (United States)*. 2019;98(32). doi:10.1097/MD.0000000000016677

59. Soubry A, Guo L, Huang Z, et al. Obesity-related DNA methylation at imprinted genes in human sperm: Results from the TIEGER study. *Clin Epigenetics*. 2016;8(1):1-11. doi:10.1186/s13148-016-0217-2

60. Nätt D, Kugelberg U, Casas E, et al. Human sperm displays rapid responses to diet. *PLoS Biol*. 2019;17(12):e3000559. doi:10.1371/journal.pbio.3000559

61. Bodden C, Hannan AJ, Reichelt AC. Diet-Induced Modification of the Sperm Epigenome Programs Metabolism and Behavior. *Trends Endocrinol Metab*. 2019;0(0):1-19. doi:10.1016/j.tem.2019.10.005

62. Craig JR, Jenkins TG, Carrell DT, Hotaling JM. Obesity, male infertility, and the sperm epigenome. *Fertil Steril*. 2017;107(4):848-859. doi:10.1016/j.fertnstert.2017.02.115

63. Carrageta DF, Oliveira PF, Alves MG, Monteiro MP. Obesity and male hypogonadism: Tales of a vicious cycle. *Obes Rev*. 2019;20(8):1148-1158. doi:10.1111/obr.12863

64. Mohr BA, Bhasin S, Link CL, O'Donnell AB, McKinlay JB. The Effect of changes in adiposity on testosterone levels in older men: Longitudinal results from the Massachusetts male aging study. *Eur J Endocrinol*. 2006;155(3):443-452. doi:10.1530/eje.1.02241

65. Basaria S. Male hypogonadism. *Lancet*. 2014;383(9924):1250-1263. doi:10.1016/S0140-6736(13)61126-5

66. Vermeulen A, Kaufman JM, Deslypere JP, Thomas G. Attenuated luteinizing hormone (LH) pulse amplitude but normal LH pulse frequency, and its relation to plasma androgens in hypogonadism of obese men. *J Clin Endocrinol Metab*. 1993;76(5):1140-1146. doi:10.1210/jcem.76.5.8496304

67. Dhindsa S, Bhatia V, Dhindsa G, Chaudhuri A, Gollapudi G, Dandona P. The Effects of Hypogonadism on Body Composition and Bone Mineral Density in Type 2 Diabetic Patients. *Diabetes Care*. 2007;30(7):1860. doi:10.2337/dc07-0337.S.D.

68. Antonio L, Wu FCW, O'Neill TW, et al. Low free testosterone is associated with hypogonadal signs and symptoms in men with normal total testosterone. *J Clin Endocrinol Metab*. 2016;101(7):2647-2657. doi:10.1210/jc.2015-4106

69. Palmer NO, Bakos HW, Fullston T, Lane M. Impact of obesity on male fertility, sperm function and molecular composition. *Spermatogenesis*. 2012;2(4):253-263. doi:10.4161/spmg.21362

70. Shiraishi K, Takihara H, Matsuyama H. Elevated scrotal temperature, but not varicocele grade, reflects testicular oxidative stress-mediated apoptosis. *World J Urol*. 2010;28(3):359-364. doi:10.1007/s00345-009-0462-5

71. Sepidarkish M, Maleki-Hajiagha A, Maroufizadeh S, Rezaeinejad M, Almasi-Hashiani A, Razavi M. The effect of body mass index on sperm DNA fragmentation: a systematic review and meta-analysis. *Int J Obes*. 2020. doi:10.1038/s41366-020-0524-8

72. Isidori AM, Caprio M, Strollo F, et al. Leptin and androgens in male obesity: Evidence for leptin contribution to reduced androgen levels. *J Clin Endocrinol Metab*. 1999;84(10):3673-3680. doi:10.1210/jc.84.10.3673

73. Manna P, Jain SK. Obesity, Oxidative Stress, Adipose Tissue Dysfunction, and the Associated Health Risks: Causes and Therapeutic Strategies. *Metab Syndr Relat Disord*. 2015;13(10):423-444. doi:10.1089/met.2015.0095

74. Adewoyin M, Ibrahim M, Roszaman R, et al. Male Infertility: The Effect of Natural Antioxidants and Phytocompounds on Seminal Oxidative Stress. *Diseases*. 2017;5(1):9. doi:10.3390/diseases5010009

75. Fan W, Xu Y, Liu Y, Zhang Z, Lu L, Ding Z. Obesity or overweight, a chronic inflammatory status in male reproductive system, leads to mice and human subfertility. *Front Physiol*. 2018;8(JAN):1-11. doi:10.3389/fphys.2017.01117

76. Ohlsson C, Nilsson ME, Tivesten Å, et al. Comparisons of immunoassay and mass spectrometry measurements of serum estradiol levels and their influence on clinical association studies in men. *J Clin Endocrinol Metab*. 2013;98(6):1097-1102. doi:10.1210/jc.2012-3861

77. Stanczyk FZ, Jurow J, Hsing AW. Limitations of Direct Immunoassays for Measuring Circulating Estradiol Levels in Postmenopausal Women and Men in Epidemiologic Studies. *Cancer Epidemiol Biomarkers Prev*. 2010;19(4):903-906. doi:10.1158/1055-9965.EPI-10-0081

78. Dhindsa S, Batra M, Kuhadiya N, Dandona P. Oestradiol concentrations are not elevated in obesity-associated hypogonadotrophic hypogonadism. *Clin Endocrinol (Oxf)*. 2014;80(3):464. doi:10.1111/cen.12236

79. Aarts E, Van Wageningen B, Loves S, et al. Gonadal status and outcome of bariatric surgery in obese men. *Clin Endocrinol (Oxf)*. 2014;81(3):378-386. doi:10.1111/cen.12366

80. Pellitero S, Olaizola I, Alastrue A, et al. Hypogonadotropic Hypogonadism in Morbidly Obese Males Is Reversed After Bariatric Surgery. *Obes Surg*. 2012;22(12):1835-1842. doi:10.1007/s11695-012-0734-9

81. Liu Y, Ding Z. Obesity, a serious etiologic factor for male subfertility in modern society. *Reproduction*. 2017;154(4):R123-R131. doi:10.1530/REP-17-0161

82. Di Vincenzo A, Busetto L, Vettor R, Rossato M. Obesity, Male Reproductive Function and Bariatric Surgery. *Front Endocrinol (Lausanne)*. 2018;9(December):1-9. doi:10.3389/fendo.2018.00769

83. Samavat J, Cantini G, Lotti F, et al. Massive Weight Loss Obtained by Bariatric Surgery

Affects Semen Quality in Morbid Male Obesity: a Preliminary Prospective Double-Armed Study. *Obes Surg*. 2018;28(1):69-76. doi:10.1007/s11695-017-2802-7

84. Legro RS. Effects of obesity treatment on female reproduction: results do not match expectations. *Fertil Steril*. 2017;107(4):860-867. doi:10.1016/j.fertnstert.2017.02.109

85. Kaukua J, Pekkarinen T, Sane T, Mustajoki P. Health-related quality of life in WHO Class II-III obese men losing weight with very-low-energy diet and behaviour modification: A randomised clinical trial. *Int J Obes*. 2002;26(4):487-495. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed5&NEWS=N&AN=2002145189.

86. Jaffar M, Ashraf M. Does weight loss improve fertility with respect to semen parameters and reproductive hormones? results from a large cohort study. *Reprod Health*. 2011;8:24. http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L617484001.

87. Håkonsen L, Thulstrup A, Aggerholm A, et al. Does weight loss improve semen quality and reproductive hormones? results from a cohort of severely obese men. *Reprod Health*. 2011;8(1):1-8. doi:10.1186/1742-4755-8-24

88. World Health Organization. *WHO Laboratory Manual for the Examination and Processing of Human Semen*. Vol 5th ed. Geneva: World Health Organization; 2010.

89. Al-Ali BM, Gutschi T, Pummer K, et al. Body mass index has no impact on sperm quality but on reproductive hormones levels. *Andrologia*. 2014;46(2):106-111. doi:10.1111/and.12051

90. Al Omrani B, Al Eisa N, Javed M, Al Ghedan M, Al Matrafi H, Al Sufyan H. Associations of sperm DNA fragmentation with lifestyle factors and semen parameters of Saudi men and its impact on ICSI outcome. *Reprod Biol Endocrinol*. 2018;16(1):1-6. doi:10.1186/s12958-018-0369-3

91. Amjad S, Baig M, Zahid N, Tariq S, Rehman R. Association between leptin, obesity, hormonal interplay and male infertility. *Andrologia*. 2019;51(1):1-7. doi:10.1111/and.13147

92. Bieniek JM, Kashanian JA, Deibert CM, et al. Influence of increasing body mass index on semen and reproductive hormonal parameters in a multi-institutional cohort of subfertile men. *Fertil Steril*. 2016;106(5):1070-1075. doi:10.1016/j.fertnstert.2016.06.041

93. Christofolini J, Barros RAS de A, Ghirelli Filho M, Christofolini DM, Bianco B, Barbosa CP. Is there any relation between anthropometric indices and decrease in seminal parameters? *Einstein (São Paulo)*. 2014;12(1):61-65. doi:10.1590/s1679-45082014ao2781

94. Dubeux VT, Renovato T, Esteves AC, André L, De Oliveira A, Penna IA. The impact of obesity on male fecundity: A Brazilian study. *J Bras Reprod Assist*. 2016;20(3):137-141. doi:10.5935/1518-0557.20160031

95. Duits FH, Van Wely M, Van Der Veen F, Gianotten J. Healthy overweight male partners of subfertile couples should not worry about their semen quality. *Fertil Steril*. 2010;94(4):1356-1359. doi:10.1016/j.fertnstert.2009.05.075

96. Ehala-Aleksejev K, Punab M. The effect of metabolic syndrome on male reproductive health: A cross-sectional study in a group of fertile men and male partners of infertile couples. *PLoS One*. 2018;13(3):1-11. doi:10.1371/journal.pone.0194395

97. Fejes I, Koloszar S, Szollosi J, Zavaczki Z, Pal A. Is semen quality affected by male body fat distribution? *Andrologia*. 2005;37(5):155-159. doi:10.1111/j.1439-0272.2005.00671.x

98. Foresta C, Di Mambro A, Pagano C, Garolla A, Vettor R, Ferlin A. Insulin-like factor 3 as a marker of testicular function in obese men. *Clin Endocrinol (Oxf)*. 2009;71(5):722-726. doi:10.1111/j.1365-2265.2009.03549.x

99. Hajshafiha M, Ghareaghaji R, Salemi S, Sadegh-Asadi N, Sadeghi-Bazargani H. Association of body mass index with some fertility markers among male partners of infertile couples. *Int J Gen Med*. 2013;6:447-451. doi:10.2147/IJGM.S41341

100. Hammoud AO, Wilde N, Gibson M, Parks A, Carrell DT, Meikle AW. Male obesity and alteration in sperm parameters. *Fertil Steril*. 2008;90(6):2222-2225. doi:10.1016/j.fertnstert.2007.10.011

101. Hofny ERM, Ali ME, Abdel-Hafez HZ, et al. Semen parameters and hormonal profile in obese fertile and infertile males. *Fertil Steril*. 2010;94(2):581-584. doi:10.1016/j.fertnstert.2009.03.085

102. Hofstra J, Loves S, van Wageningen B, Ruinemans-Koerts J, Janssen I, de Boer H. High prevalence of hypogonadotropic hypogonadism in men referred for obesity treatment. *Neth J Med*. 2008;66(3):103-109.

103. Kort HI, Massey JB, Elsner CW, et al. Impact of body mass index values on sperm quantity and quality. *J Androl*. 2006;27(3):450-452. doi:10.2164/jandrol.05124

104. Lu JC, Jing J, Dai JY, et al. Body mass index, waist-to-hip ratio, waist circumference and waist-to-height ratio cannot predict male semen quality: a report of 1231 subfertile Chinese men. *Andrologia*. 2015;47(9):1047-1054. doi:10.1111/and.12376

105. Macdonald AA, Stewart AW, Farquhar CM. Body mass index in relation to semen quality and reproductive hormones in New Zealand men: a cross-sectional study in fertility clinics. *Hum Reprod*. 2013;28(12):3178-3187. doi:10.1093/humrep/det379

106. Magnusdottir E V., Thorsteinsson T, Thorsteinsdottir S, Heimisdottir M, Olafsdottir K. Persistent organochlorines, sedentary occupation, obesity and human male subfertility. *Hum Reprod*. 2005;20(1):208-215. doi:10.1093/humrep/deh569

107. Ozdemir E, Tokmak A, Tuzluoglu A, et al. The impact of obesity on semen parameters and hormone levels in infertile men. *Med Sci | Int Med J*. 2016;5(3):780. doi:10.5455/medscience.2016.05.8436

108. Ramaraju G, Teppala S, Prathigudupu K, Kalagara M, Kota M, Cheemakurthi R. Association between obesity and sperm quality. *Andrologia*. 2017;50:1-12. doi:10.1111/and.12888

109. Ramlau-Hansen CH, Hansen M, Jensen CR, Olsen J, Bonde JP, Thulstrup AM. Semen quality and reproductive hormones according to birthweight and body mass index in childhood and adult life: two decades of follow-up. *Fertil Steril*. 2010;94(2):610-618.

doi:10.1016/j.fertnstert.2009.01.142

110. Relwani R, Berger D, Santoro N, et al. Semen parameters are unrelated to BMI but vary with SSRI use and prior urological surgery. *Reprod Sci*. 2011;18(4):391-397. doi:10.1177/1933719110385708

111. Rufus O, James O, Michael A. Male obesity and semen quality: Any association? *Int J Reprod Biomed*. 2018;16(4):285-290. doi:10.29252/ijrm.16.4.285

112. Sallmén M, Sandler DP, Hoppin JA, Blair A, Baird DD. Reduced fertility among overweight and obese men. *Epidemiology*. 2006;17(5):520-523. doi:10.1097/01.ede.0000229953.76862.e5

113. Sekhavat L, Moein MR. The effect of male body mass index on sperm parameters. *Aging Male*. 2010;13(3):155-158. doi:10.3109/13685530903536643

114. Stewart TM, Liu DY, Garrett C, Jørgensen N, Brown EH, Baker HWG. Associations between andrological measures, hormones and semen quality in fertile Australian men: Inverse relationship between obesity and sperm output. *Hum Reprod*. 2009;24(7):1561-1568. doi:10.1093/humrep/dep075

115. Tsao CW, Liu CY, Chou YC, Cha TL, Chen SC, Hsu CY. Exploration of the association between obesity and semen quality in a 7630 male population. *PLoS One*. 2015;10(3):1-13. doi:10.1371/journal.pone.0119458

116. Wen-Hao T, Xin-Jie Z, Lu-Lin M, et al. Correlation between body mass index and semen quality in male infertility patients. *Turkish J Med Sci*. 2015;45(6):1300-1305. doi:10.3906/sag-1408-7

117. Winters SJ, Wang C, Abdelrahaman E, Hadeed V, Dyky MA, Brufsky A. Inhibin-B levels in healthy young adult men and prepubertal boys: Is obesity the cause for the contemporary decline in sperm count because of fewer sertoli cells? *J Androl*. 2006;27(4):560-564. doi:10.2164/jandrol.05193

118. Yamaçake KGR, Cocuzza M, Torricelli FCM, et al. Impact of body mass index, age and varicocele on reproductive hormone profile from elderly men. *Int Braz J Urol*. 2016;42(2):365-372. doi:10.1590/S1677-5538.IBJU.2014.0594

TABLES

Table 1. Summary of studies reporting the associations between semen quality, hormone levels and different exposures related with adiposity (i.e. BMI, waist circumference, metabolic syndrome, waist-to-height ratio or waist-to-hip ratio). Table is organized in alphabetical order by first author surname.

Reference (First author name/year/location)	Population studied	Age (years)	Study design	Exposure	Outcomes	Principal conclusion	Adjustment variables	Score >3	Included in systematic review?	Included in meta-analysis?
(Aggerholm et al., 2008)[26]/Denmark	2,139 men	18-66	Cross-sectional	BMI	Sperm quality (semen volume, sperm count and concentration, and total motility) and reproductive hormones (T, FSH, LH, SHBG, E2 and Inhibin B)	Men with overweight had a slightly lower adjusted sperm concentration and total sperm count than did men with a normal BMI, but no reduction in sperm count was observed among the men with obesity. The T and inhibin B serum concentrations were 25%-32% lower in men with obesity in comparison with normal-weight men, whereas the E2 concentration was 6% higher in men with obesity.	Age and abstinence time	5	Yes	Yes
(Al-Ali et al., 2014)[89]/Austria and Germany	2,110 men	31.8 (±6.6)	Cross-sectional	BMI	Sperm quality (sperm concentration, total sperm motility, and normal sperm morphology) and reproductive hormones (T, FSH, LH, and PRL)	BMI did not have significant significantly independent association with any of the assessed sperm quality parameters, whereas BMI was significantly associated with LH, T and PRL hormone values.	ND/NA	4	Yes	No. Insufficient data
(Al Omrani et al., 2018)[90]/Saudi Arabia	94 couples	23-55	Retrospective (cross-sectional data)	BMI	Sperm quality (semen volume, total sperm count and concentration, vitality, total motility and, normal sperm morphology), sperm DNA fragmentation, fertilization rate and pregnancy outcome	The BMI was positively correlated with moderate DFI category.	ND/NA	3.5	Yes	No. Insufficient data

(Alshahrani et al., 2016)[55]/Saudi Arabia	439 men	≥18	Prospective (cross-sectional data)	BMI	Sperm quality (semen volume, total sperm count and concentration, total motility, and normal morphology)	Sperm concentration was the only semen parameter that was inversely associated with BMI in infertile men.	ND/NA	4	Yes	Yes
(Amjad et al., 2019)[91]/Pakistan	313 (178 infertile and 135 fertile men)	Infertile=33.74±5.67; Fertile=37.65±6.12	Cross-sectional	BMI and BF	Reproductive hormones (T, FSH, LH, SHBG)	FSH, LH, T and SHBG concentrations were significantly lower in obesity as compared to normal weight and overweight categories (BMI).	ND/NA	5	Yes	No. Only hormonal data.
(Andersen et al., 2016)[33]/Norway	166 men	22–61	Cross-sectional	BMI	Sperm quality (sperm count and concentration, progressive sperm motility, normal sperm morphology, and vitality), sperm DNA integrity analysis, and reproductive hormones (T, SHBG, inhibin B, and AMH)	BMI was negatively associated with sperm concentration, total sperm count, progressive sperm motility, normal sperm morphology, and percentage of vital spermatozoa. A negative relationship was observed between BMI and T, SHBG, inhibin B and AMH.	Age, abstinence time and time to semen analysis	4	Yes	Yes
(Bandel et al., 2015)[37]/Sweden	1,503 men	27.9 (±10.9)	Cross-sectional	BMI	Sperm quality (semen volume, sperm concentration, and total and progressive motility) and sperm DNA fragmentation (SCSA).	High BMI was not associated with impaired sperm DNA integrity as assessed by SCSA.	Age, smoking, and abstinence time	5	Yes	Yes
(Belloc et al., 2014)[27]/France	10,665 men	37.1 (±6.1)	Cross-sectional	BMI	Sperm quality (pH, semen volume, sperm count and concentration, total and progressive motility, viability, and normal morphology)	Increased BMI was associated with decreased semen quality, affecting volume, concentration, and motility. The percentage of normal forms was not decreased.	Age and abstinence time	5.5	Yes	Yes
(Bieniek et al., 2016)[92]/USA	4,440 men	36.1 (±7.6)	Cross-sectional	BMI	Sperm quality (semen volume, sperm concentration, total motility, normal morphology) and reproductive hormones (gonadotropins, T, E2, and PRL)	On multivariate analyses, BMI had weak but significant negative correlations with ejaculate volume, sperm concentration and morphology. Testosterone had a significant negative correlation, whereas E2 conversely demonstrated a positive relationship with these parameters.	Age and study centre	5	Yes	No. Insufficient data

(Chavarro et al., 2010)[38]/USA	483 male partners of subfertile couples	36.3 (±5.4)	Cross-sectional	BMI	Sperm quality (semen volume, sperm motility and sperm morphology), sperm DNA fragmentation and reproductive hormones (T, E2, SHBG, inhibin B, T:LH ratio)	BMI was positively related to E2 levels and inversely related to T and SHBG levels. There was a strong inverse relation between BMI and inhibin B levels and a lower T:LH ratio among men with a BMI ≥ 35 kg/m^2. BMI was unrelated to sperm concentration, motility, or morphology. Ejaculate volume decreased steadily with increasing BMI levels. Men with BMI ≥ 35 kg/m^2 had a lower total sperm count than normal weight men. Sperm with high DNA damage were significantly more numerous in men with obesity than in normal-weight men.	Age, ethnicity, abstinence time, smoking history, intakes of alcohol and caffeine, history of undescended testes and history of groin injury	5	Yes	Yes
(Christofolini et al., 2014)[93]/Brazil	118 male partners of subfertile couples	35.59 (±7.47)	Cross-sectional	BMI and WC	Sperm quality (semen volume, sperm concentration, progressive sperm motility)	No significant difference was found in the sperm quality relative to the BMI or WC	ND/NA	3.5	Yes	No. Insufficient data
(Dubeux et al., 2016)[94]/Brazil	153 men with infertility	ND	Cross-sectional	BMI and WC	Sperm quality (sperm count and concentration, sperm motility and sperm morphology)	No association between obesity and semen alterations in a population of infertile men.	ND/NA	4	Yes	No. Insufficient data
(Duits et al., 2010)[95]/The Netherlands	1,401 male partners of subfertile couples	36.4 (±6.5)	Cross-sectional	BMI	Sperm quality (semen volume, sperm count and concentration, total motility, normal morphology, and total motile sperm count)	Semen quality was not significantly associated with BMI.	ND/NA	5	Yes	No. Insufficient data
(Dupont et al., 2013)[54]/France	330 male partners of subfertile couples	37.6±6.2	Cross-sectional	BMI	Sperm quality (total sperm count, sperm motility and sperm morphology) and sperm DNA fragmentation	Using the TUNEL assay, an increased rate of sperm DNA damage in men with obesity was reported.	Age and smoking	4	Yes	Yes
(Ehala-Aleksejev and Punab, 2015)[39]/Estonia	260 male partners of pregnant women	21–57	Cross-sectional	BMI, BF%, WC and WHtR	Sperm quality (semen volume, sperm count and concentration, total motility, normal morphology), and reproductive hormones (T, FSH, LH, E2, and SHBG)	This study shows that semen quality is affected by central adiposity. Quartile analysis revealed that all adiposity markers were negatively related to SHBG and total testosterone levels. After adjustment for covariates, a high BF%, WC and WHtR	Age, abstinence time and alcohol use	5	Yes	Yes

						were negatively associated with total sperm count. The BF% was also negatively related to semen volume. These significant associations occurred in those individuals with a BF% ≥ 23.4%, WC > 98 cm and WHtR > 0.54.				
(Ehala-Aleksejev and Punab, 2018)[96]/Estonia	Fertile=238, male partners of subfertile couples=2,642	Fertile 32.0 (±6.1) and male partners of subfertile couples 32.6 (±5.7)	Cross-sectional	MS	Sperm quality (semen volume, sperm concentration, total sperm count, motile spermatozoa, normal morphology), and reproductive hormones (T, FSH, LH, and E2)	Except for testosterone, MS has no independent effect on major fertility parameters in different subgroups of men.	Age, alcohol use, smoking and total testes volume	5	Yes	No. Lack of BMI data
(Eisenberg et al., 2014)[40]/USA	501 male partners of subfertile couples	31.8±4.8	Cross-sectional	BMI, WC	Sperm quality (semen volume, total sperm count and concentration, total motility, vitality, and normal morphology), and DNA fragmentation index	Ejaculate volume showed a linear decline with increasing BMI and WC. Similarly, the total sperm count showed a negative linear association with WC. No significant relationship was seen between body size (i.e. BMI or WC) and semen concentration, motility, vitality, morphology or DNA fragmentation index. The percentage of men with abnormal volume, concentration and total sperm increased with increasing body size. No relationship between physical activity and semen parameters was identified.	Age, college education and serum cotinine (smoking)	5	Yes	Yes
(Fariello et al., 2012)[41]/Brazil	305 male patients	27-42	Cross-sectional	BMI	Sperm quality (sperm count and concentration, total sperm motility and sperm normal morphology), sperm DNA fragmentation, and sperm mitochondrial activity	Mitochondrial activity was lower in the group with obesity. Compared to the normal weight group, the percentage of sperm with DNA damage was higher in the group with obesity than the other BMI groups.	ND/NA	4	Yes	Yes

(Fejes et al., 2005)[97]/Hungary	81 men with infertility	23.7–52.2	Cross-sectional	Weight, WC and HC, WHtR	Sperm quality (semen volume, sperm count and concentration, total and progressive motility) and reproductive hormones (T, FSH, LH, PRL, E2, and SHBG)	The waist/hip ratio was correlated with several reproductive hormone levels. Although both the waist circumference and hip circumference correlated with the semen characteristics, the waist/hip ratio did not.	ND/NA	4	Yes	No. Lack of BMI data
(Ferigolo et al., 2019)[32]/Italy	47 male volunteers	20-50	Prospective (cross-sectional data)	BMI	Sperm quality (semen volume, sperm count and concentration, progressive motility and normal morphology), sperm DNA fragmentation, acrosome integrity, and mitochondrial activity.	Men with obesity presented decreased non-progressive motility, morphology, acrosome integrity, mitochondrial activity, and increased sperm DNA fragmentation.	ND/NA	5	Yes	Yes
(Foresta et al., 2009)[98]/Italy	31 men with obesity and 64 age-matched men without obesity	22–49, 24–47	Cross-sectional	BMI	Plasma concentrations of INSL3, T, SHBG, E2, LH, FSH, fT	Men with obesity had significantly lower plasma concentrations of T, SHBG, fT and INSL3, and higher levels of E2 with respect to men without obesity. Significant negative correlation between BMI and INSL3, and a positive correlation between INSL3 and T was reported. This study showed for the first time that INSL3 levels decrease with obesity.	ND/NA	3.5	Yes	No. Only hormonal data.
(Hadjkacem Loukil et al., 2015)[42]/Tunisia	98 men	32.74 (±6.96)	Cross-sectional	BMI	Sperm quality (sperm concentration) and reproductive hormones (T, FSH, LH, and PRL)	Male obesity is not associated with the incidence of sperm concentration.	ND/NA	3.5	Yes	Yes
(Hajshafiha et al., 2013)[99]/Iran	159 male partners in subfertile couples	ND	Cross-sectional	BMI	Sperm quality (sperm concentration, total motility and normal morphology) and reproductive hormones (T, FSH, LH, PRL, E2, and SHBG)	BMI was not associated with sperm count, sperm morphology, and sperm motility. BMI was not significantly correlated with some hormone levels, such as LH, prolactin, and LH/FSH ratio. However, a statistically significant association was observed between BMI and E2, SHBG, and also the T/E2 ratio.	ND/NA	5	Yes	No. Insufficient data

(Håkonsen et al., 2011)[87]/Denmark	43 men	20-59	Prospective (cross-sectional data, pilot cohort)	BMI and weight loss	Sperm quality (sperm count and concentration, total motility and sperm normal morphology), sperm DNA integrity, and reproductive hormones (T, LH, FSH, E2, SHBG, AMH, and inhibin B)	BMI was inversely associated with sperm concentration, total sperm count, sperm morphology and motility, as well as T and Inhibin B and positively associated to E2. 15% total weight loss was associated with an increase in total sperm count, semen volume, testosterone, SHBG and AMH. The group with the largest weight loss had a statistically significant increase in total sperm count and normal sperm morphology.	Age, abstinence time, smoking, season, diseases in the reproductive organs, spillage at semen sampling, fever, and time to semen analysis	5	Yes	No. Non-WHO based BMI categories
(Hammiche et al., 2012)[43]/Netherlands	450 men of subfertile couples	22-60	Cross-sectional	BMI, WC	Sperm quality (semen volume ,sperm concentration, progressive motility and total motile sperm count)	Overweight was negatively associated with the percentage of progressive motility type A and positively associated with the percentage of immotility type C. Obesity was negatively associated with ejaculate volume, sperm concentration and total motile sperm count. WC ≥102 cm, a measure for central adiposity, was inversely associated with sperm concentration and total motile sperm count.	Age, ethnicity, active and passive smoking, alcohol, medication use, and folate status	4.5	Yes	Yes
(Hammoud et al., 2008)[100]/USA	472 men of subfertile couples	32.8 (±0.3)	Retrospective (cross-sectional data)	BMI	Sperm quality (progressive motile sperm count), and oligozoospermia (%)	The incidence of oligozoospermia increased with increasing BMI. The prevalence of a low progressively motile sperm count was also greater with increasing BMI.	ND/NA	4	Yes	No. Insufficient data
(Hofny et al., 2010)/[101]/Egypt	42 fertile men with obesity and 80 infertile oligozoospermic men with obesity	Fertile=29.79 (±1.1); Infertile=29.35 (±0.9)	Prospective (cross-sectional data)	BMI	Sperm quality (sperm count, total motility and normal morphology) and reproductive hormones (T, FSH, LH, PRL, and E2)	The BMI had significant positive correlation with abnormal sperm morphology, LH, serum leptin and significant negative correlation with sperm concentration, sperm motility, serum T.	ND/NA	4	Yes	No. Insufficient data
(Hofstra et al., 2008)[102]/Netherlands	160 men with obesity	43.3 ± 0.8	Cross-sectional	BMI	Total and calculated free testosterone (T and fT)	T and fT levels were inversely related to BMI. T was subnormal in 57.5% and free	Age	5	Yes	No. Lack of data in normal

						testosterone in 35.6% of the subjects. The group of men with IHH was more obese, had higher HbA1 C levels and had a 2.6 higher risk for cardiovascular disease. Decreased libido and erectile dysfunction were 7.1 and 6.7 times as common in IHH as in eugonadal men with obesity.				weight individuals
(Jensen et al., 2004)[25]/Denmark	1,558 young men	Mean age=19	Cross-sectional	BMI	Sperm quality (semen volume,sperm concentration and count, sperm motility, and sperm morphology), testis size and reproductive hormones (FSH, LH, SHBG, T, E2 and Inhibin B)	Men with a BMI <20 kg/m^2 had a reduction in sperm concentration and total sperm count of 28.1% and 36.4%, respectively, and men with a BMI >25 kg/m^2 had a reduction in sperm concentration and total sperm count of 21.6% and 23.9%, respectively, compared to men with BMI between 20-25 kg/m^2. Serum T, SHBG, and inhibin B, all are lower with increasing BMI, whereas free androgen index and E2 increased with increasing BMI. Serum FSH was higher among slim men.	Age, abstinence time, smoking, time to semen analysis, research centre, diseases in reproductive organs, still in school, and cryptorchidism	5	Yes	Yes
(Keskin et al., 2017)[44]/Turkey	454 men consulting for infertility	ND	Retrospective (cross-sectional data)	BMI	Sperm quality (semen volume, sperm concentration, total and progressive motility, total progressive motile sperm count, normal morphology) and reproductive hormones (T, FSH, LH, PRL and E2)	There were no statistically significant differences in all variables between adiposity groups.	ND/NA	3.5	Yes	Yes
(Koloszár et al., 2005)[45]/Hungary	274 men with normozoospermia	26±4.9	Cross-sectional	BMI	Sperm quality (semen volume, sperm count and concentration, total motility and normal morphology) and reproductive hormones (T, FSH, LH, PRL, E2, and SHBG)	Sperm concentration was significantly lower in the group with obesity than in the following groups of BMI: 17-20, 20-25 and 25-30. In the group with obesity, sperm count decreased with aging. It was concluded that obesity is associated with a lower sperm	ND/NA	4	Yes	Yes

						count in case of normozoospermia men.				
(Kort et al., 2006)[103]/Georgia	520 men	26–45	Cross-sectional	BMI	Sperm quality (semen volume, sperm concentration, total motility, normal sperm morphology), and DNA fragmentation index	Linear regression revealed a significant and negative relationship between BMI and the total number of normal-motile sperm cells. ANOVA revealed a significant difference in the total number of normal-motile sperm cells among the different BMI categories. Linear regression revealed a significant and positive relation between BMI and DFI. Men presenting with a BMI >25 kg/m^2 had fewer chromatin-intact normal-motile sperm cells per ejaculate.	ND/NA	4	Yes	No. Insufficient data
(Lu et al., 2015)[104]/China	1,132 men with infertility	29.07 (±4.83)	Cross-sectional	BMI, WC, WHR and WHtR	Sperm quality (sperm count and concentration, total and progressive motility, normal morphology and total normal-progressively motile sperm count), and reproductive hormones (T, LH, FSH, E2 and SHBG)	BMI, WC, WHR and WHtR were positively related to sperm concentration, total sperm count, progressive motility, sperm motility and normal sperm morphology. BMI, WHR, WC and WHtR were negatively related to serum T and SHBG levels.	ND/NA	5	Yes	No. Non-WHO based BMI categories
(Luque et al., 2017)[22]/Argentina	4,860 men of subfertile couples	18-65	Retrospective (cross-sectional data)	BMI	Sperm quality (semen volume, sperm count and concentration, total motility, vitality and normal morphology), reactive spermatozoa (HOS test) and spermatozoa with mature nuclei, and percentages of oligozoospermia, asthenozoospermia and teratozoospermia.	Sperm concentration, total sperm count, and total motility were significantly lower in the underweight and morbid obesity groups compared with normal weight, overweight and obese groups. Moreover, the percentage of morphologically normal spermatozoa was decreased in the morbid obesity group compared with the other groups. Men in the morbid obesity category had an increased risk (2.3- to 4.9-fold greater) of suffering oligozoospermia and teratozoospermia.	ND/NA	4	Yes	Yes
(Ma et al., 2019[34]/China	3,966 sperm donors	28.5 (±5.5)	Cross-sectional	BMI	Sperm quality (semen volume, sperm count and concentration, total and progressive	Underweight was significantly associated with reduction in sperm concentration, total sperm number and total motile	Age, ethnicity, education ,	4	Yes	Yes

					motility, and total motile sperm count)	sperm count. Overweight was significantly associated with reduction in semen volume, total sperm number and total motile sperm count.	smoking, marital status, abstinence period and season			
(Macdonald et al., 2013)[105]/New Zealand	511 men attending fertility clinic	36.8	Cross-sectional	BMI	Sperm quality (semen volume, sperm count and concentration, total sperm motility, normal sperm morphology) and reproductive hormones (T, LH, FSH, E2, and SHBG)	No statistically significant differences or correlation between sperm concentration and total sperm count in relation to BMI were reported. Normal sperm morphology increased with increasing BMI. The multiple linear regression analysis showed that BMI had a marginally significant effect on normal sperm morphology. Statistically significant relationships between BMI and total testosterone, and SHBG were reported. No significant relationships were found for FSH, LH, and E2.	ND/NA	4.5	Yes	No. Insufficient data
(Magnusdottir et al., 2005)/[106]/Iceland	25 men with poor semen quality, 20 men with normal semen quality and idiopathic subfertility and 27 men with normal semen	30-45	Cross-sectional	BMI	Sperm quality (semen volume, sperm count and concentration, progressive motility, and progressively motile sperm count)	Men with poor semen quality were three times more likely to be obese than men with normal semen quality. There was also a significant negative correlation between semen quality parameters and BMI among men with normal semen quality.	ND/NA	4	Yes	No. Insufficient data
(Martini et al., 2010)[47]/Argentina	794 men of subfertile couples	34.9 (±0.2)	Prospective (cross-sectional data)	BMI	Sperm quality (semen volume, sperm concentration, total and progressive motility, normal morphology, and viability), reactive spermatozoa (HOS test), nuclear maturity, and levels of seminal T.	Multivariate analysis showed a negative association between BMI and total and rapid motility. No associations were found between BMI and sperm concentration, semen volume, normal morphology, reactive spermatozoa, nuclear maturity or seminal T levels.	ND/NA	4	Yes	Yes
(Oliveira et al., 2018)[46]/Brazil	1,824 men	37.9 ± 6.6	Cross-sectional	BMI	Sperm quality (semen volume, total sperm count and	High BMI was negatively associated with sperm concentration, vitality, motility	ND/NA	4.5	Yes	Yes

					concentration, vitality, motile sperm, and normal sperm morphology), the percentages of sperm DNA, sperm chromatin packaging/ underprotamination, mitochondrial damage and apoptosis	and morphology. Conversely, high BMI was not associated with impaired sperm DNA integrity, as assessed by DNA fragmentation, nor sperm protamination and sperm apoptosis. Increased BMI was associated with increased spermatozoa mitochondrial damage.				
(Ozdemir et al., 2016)[107]/Turkey	257 men with infertility	22-42	Prospective (cross-sectional data)	BMI	Sperm quality (semen volume, sperm count and concentration, progressive motility, total progressively motile sperm count, and nomal morphology), and reproductive hormones (T, FSH, LH, E2, PRL, and TSH)	Semen volume was significantly higher in individuals with obesity compared with individuals without obesity. Serum T and T/E2 ratio were statistically significantly lower in the obese group. Serum E2 levels were significantly higher in individuals with obesity compared with individuals without obesity.	ND/NA	4	Yes	No. Lack of data in normal weight individuals
(Pauli et al., 2008)[56]/USA	87 adult men	19–48	Prospective (cross-sectional data)	BMI and skinfold thickness	Sperm quality (semen volume, sperm concentration, total motility, and normal morphology) and reproductive hormones (inhibin B, FSH, LH, T, and fT)	There was no correlation between BMI or skinfold thickness and semen parameters. BMI was negatively correlated with T, FSH, and inhibin B levels and were positively correlated with E2 concentrations. Testosterone levels also negatively correlated with skinfold thickness. Inhibin B level correlated significantly with sperm motility.	ND/NA	3.5	Yes	No. Insufficient data
(Qin et al., 2007)[48]/China	990 fertile men	38.9(±9.7)	Cross-sectional	BMI	Sperm quality (semen volume, sperm count and concentration, total motility and normal morphology), and reproductive hormones (T, LH, FSH, and E2)	Men with underweight had low sperm concentration, total sperm count and percentage of normal sperm forms compared with men with men with normal weight. Reproductive hormones cannot explain the association between BMI and semen quality.	Age, study centre, diseases in reproductive organs, smoking, alcohol intake, period of abstinence and reproduct	4	Yes	Yes

							ive hormones			
(Ramaraju et al., 2017)[108]/India	1,285 men attending fertility clinic	34.5 (±4.7)	Retrospective (cross-sectional data)	BMI	Sperm quality (semen volume, sperm count and concentration, total and progressive motility, and normal morphology), oligozoospermia, teratozoospermia and asthenozoospermia.	Men with obesity had lower semen volume, number, concentration and motility compared with men with men with normal weight.	Age, smoking, and diabetes status	5	Yes	No. Lack of data in normal weight individuals
(Ramírez et al., 2020)[23]/Argentina	20,563 men of subfertile couples	35.75(±6.16)	Retrospective (cross-sectional data)	BMI	Sperm quality (semen volume, sperm count and concentration, total motility and rapid motility, and normal morphology), and HOST test.	Having a BMI below 20 kg/m2 or above 32 kg/m2 might be detrimental for semen quality, and this negative association is more obvious in morbid obesity. They propose a recategorization of the BMI to achieve andrological predictive power. The smallest summatory in sperm abnormalities were found at BMI=27kg/m$^{2.}$	ND/NA	5	Yes	Yes
(Ramlau-Hansen et al., 2010)[109]/Denmark	347 men	16-19	Retrospective (cross-sectional data)	BMI, birth weight	Sperm quality (semen volume, sperm count and concentration, vitality, total motility, and normal morphology), and reproductive hormones (SHBG, T, FSH, LH, and inhibin B)	Neither childhood BMI, birth weight, nor adulthood BMI was significantly associated with semen quality. Men with the 33% highest childhood BMI had 15% lower SHBG, 8% lower T, and 16% lower FSH than men with the 33% lowest childhood BMI. Men with high adulthood BMI had 14% lower T, 9% lower inhibin B, 31% lower SHBG, and 20% higher E2 than men with low adulthood BMI.	Season, history of diseases of the reproductive organs, smoking, maternal smoking during pregnancy, abstinence time, spillage during collection, time to semen analysis	4	Yes	No. Non-WHO based BMI categories
(Relwani et al., 2011)/[110]/USA	530 men attending fertility clinics	18-50	Prospective (cross-sectional data)	BMI	Sperm quality (semen volume, sperm concentration, total motility, normal morphology), and	No consistent relationships were reported between BMI and sperm concentration, motility, or morphology, although the testosterone	ND/NA	4	Yes	No. Non-WHO based BMI

					reproductive hormones (T, FSH, LH, E2, and SHBG)	levels trended downward with increasing BMI.				categories
(Rufus et al., 2018)[111]/Nigeria	206 men of subfertile couples	≥20	Cross-sectional	BMI	Sperm quality (sperm concentration and count, total motility, and normal morphology), oligozoospermia, azoospermia, asthenozoospermia, teratozoospermia, and oligoasthenoteratozoospermia.	There was no statistically significant difference in the semen quality as well as the pattern of semen parameter abnormalities between males with normal and elevated BMI.	ND/NA	4	Yes	No. Insufficient data
(Rybar et al., 2011)[49]/Czech Republic	153 men of subfertile couples	31.5 (±6.2)	Cross-sectional	BMI	Sperm quality (semen volume, sperm concentration, total motility and normal morphology) and sperm chromatin integrity	No consistent relationships were observed between BMI and semen parameters or sperm chromatin integrity.	ND/NA	4	Yes	Yes
(Sallmén et al., 2006)[112]/Finland	1,329 couples with an attempt at pregnancy	25-54	Cross-sectional	BMI	Prevalence of Infertility	Adjusting for potential confounders, a 3-unit increase in male BMI was associated with infertility risk.	Age, smoking, alcohol, solvent and pesticide exposure, state of residence	4.5	Yes	No. Insufficient data
(Sekhavat and Moein, 2010)[113]/Iran	852 normal, healthy men	25-50 y	Cross-sectional	BMI	Sperm quality (sperm count and concentration, total motility, and normal morphology)	Sperm concentration of men with overweight and obesity was lower than subjects with normal BMI. Total sperm count and sperm motility in men with overweight and obesity were significantly lower than men with normal BMI. Sperm morphology in study adiposity groups was similar. The results revealed a significant inverse correlation between BMI and sperm parameters.	ND/NA	4	Yes	No. Insufficient data
(Shayeb et al., 2011)[50]/United Kingdom	2,035 men	25-40	Cross-sectional	BMI	Sperm quality (semen volume, sperm concentration, total motility, and normal morphology)	Men with obesity are more likely to have lower semen volume and fewer morphologically normal spermatozoa than men with normal BMI	Age, smoking, alcohol intake, abstinence period	5	Yes	Yes

							and social deprivation			
(Stewart et al., 2009)[114]/Australia	225 men	21–46	Cross-sectional	BMI	Sperm quality (sperm count and concentration) and reproductive hormones (FSH, LH, SHBG, T, and Inhibin B)	Compared with those with BMI < 30, subjects with obesity had significantly lower total sperm count and inhibin B but not FSH.	ND/NA	4	Yes	No. Only hormonal data.
(Taha et al., 2016)[51]/Egypt	165 fertile men	32-44	Cross-sectional	BMI	Sperm quality (semen volume, sperm count and concentration, total and progressive motility, normal morphology, and vitality), seminal reactive oxygen species (ROS), and sperm DNA fragmentation	Fertile men with obesity had significantly lower sperm concentration, progressive sperm motility and sperm normal morphology, with significantly higher seminal ROS and sperm DNA fragmentation compared with fertile normal-weight men and overweight men. BMI was negatively correlated with sperm concentration, progressive sperm motility, normal sperm morphology, sperm vitality, but positively correlated with sperm DNA fragmentation percentage and seminal ROS. Increased BMI was found to affect semen parameters negatively even in fertile men.	ND/NA	4	Yes	Yes
(Thomsen et al., 2014)[24]/Sweden	612 men of subfertile couples	32.8 (±5.1)	Cross-sectional	BMI	Sperm quality (sperm count and concentration, progressive and total sperm motility), and sperm DNA fragmentation (SCSA)	No statistically significant effect of male BMI was seen on conventional semen parameters or on SCSA-results.	ND/NA	4	Yes	Yes
(Tsao et al., 2015)[115]/Taiwan	7630 healthy male individuals	≥18	Cross-sectional	BMI, WC, HC, WHR, WHtR and BF%	Sperm quality (sperm concentration, total and progressive motility, and normal morphology)	Total sperm motility, progressive motility, normal sperm morphology and sperm concentration showed a statistically linear decline with increasing BMI. Sperm concentration showed a significantly negatively linear association with BMI, and normal sperm morphology showed an inverse	Age, triglyceride, cholesterol, C-Reactive Protein, prolactin and smoking duration	4.5	Yes	No. Non-WHO based BMI categories

						association with BMI and waist-to-height ratio. The prevalence of abnormal total sperm motility, progressive motility, and normal sperm morphology and sperm concentration increased with increasing age. Lower normal sperm morphology and sperm concentration were associated with increasing body adiposity. No relationship between obesity and sperm motility was identified.				
(Vignera et al., 2012)[52]/Italy	150 men (general population)	20-48	Cross-sectional	BMI	Sperm quality (semen volume, sperm count and concentration, progressive motility, vitality and nomal morphology), reproductive hormones (T, FSH, LH, E2, and SHBG), mitochondrial membrane potential, chromatin compactness, and sperm DNA fragmentation.	Men with overweight and obesity had significantly lower sperm progressive motility and normal forms than controls. They also had a significantly higher percentage of spermatozoa with low mitochondrial membrane potential. Men with obesity, but not men with overweight showed a lower percentage of viable spermatozoa. A significant increased percentage of spermatozoa with abnormal chromatin compactness was found in both, men with overweight and men with obesity, whereas only men with obesity had a significantly higher number of spermatozoa with DNA fragmentation compared with controls.	ND/NA	4	Yes	Yes
(Wang et al., 2017)[53]/China	2,384 men	29-36	Retrospective (cross-sectional data)	BMI	Sperm quality (semen volume, sperm count and concentration, total and progressive motility, and normal morphology)	The results clearly indicated lower sperm quality (total sperm count, sperm concentration, motile sperm, relative amounts of type A motility, and progressive motility sperm) in men with overweight and obesity than in those with normal BMI.	ND/NA	4.5	Yes	Yes
(Wen-Hao et al., 2015)[116]/China	617 men with infertility	32.0 (±5.2)	Cross-sectional	BMI	Sperm quality (semen volume, sperm count and concentration, progressive motility,	BMI was negatively correlated with sperm motility, although they did not correlate with semen volume, total sperm	ND/NA	3.5	Yes	No. Insufficient data

					and nomal morphology)	number, concentration, and rate of sperm with normal morphology.				
(Winters et al., 2006)[117]/USA	74 African American and Caucasian young, and 48 African American and Caucasian boys	18-24 and 5-9 (in two different cohorts)	Cross-sectional	BMI	Reproductive hormones (T, fT, Inhibin-B, SHBG, E, LH, FSH)	Inhibin-B levels declined with increasing obesity in young adult men. Sex hormone–binding globulin and total testosterone, but not free testosterone, were also lower with increasing BMI; serum follicle-stimulating hormone and luteinizing hormone levels were unaffected by obesity. In prepubertal boys, by contrast, inhibin-B was unaffected by obesity.	Age	3.5	Yes	No. Only hormonal data.
(Yamaçake et al., 2016)[118]/Brasil	875 men who were screened for prostate cancer	61.0 (±6.0)	Cross-sectional	BMI	Reproductive hormones (T, fT, FSH, LH, and SHBG)	Patients with obesity had lower levels of T, fT, and SHBG compared to underweight or normal weight patients.	ND/NA	3.5	Yes	No. Insufficient data

Abbreviations: Anti-Müllerian hormone (AMH), Analysis of variance (ANOVA), Area under the curve (AUC), Assisted reproductive technology (ART), Body fat (BF), Body mass index (BMI), DNA fragmentation index (DFI), estradiol (E2), follicle-stimulating hormone (FSH), free testosterone (fT), Hemoglobin A1c (HbA1c), Hypoosmotic Swelling Test (HOS), human chorionic gonadotropin (hCG), human prolactin (hPRL), Hyaluronan-binding assay (HA), insulin resistance insulin-like factor 3 (INSL3), isolated hypogonadotropic hypogonadism (IHH), luteinizing hormone (LH), Metabolic syndrome (MS), No data/No adjustment (ND/NA), obstructive sleep apnea (OSA), sex hormone-binding globulin (SHBG), testosterone (T), thyroid stimulating hormone (TSH), time to pregnancy (TTP), very-low-energy diet (VLED), waist circumference (WC), waist-to-height ratio (WHtR), waist-to-hip ratio (WHR).

Table 2. Summary of studies reporting associations between BMI and sperm DNA fragmentation and reproductive hormones. Data and measurements are highly heterogeneous, precluding meta-analysis. Table is organized in descending order by year of publication.

Study	Association between BMI categories (overweight and obesity) and sperm DNA fragmentation and reproductive hormonal parameters									
	Sperm DNA fragmentation	**Inhibin B**	**Total testosterone**	**Free testosterone**	**Sex hormone-binding globulin**	**Prolactin**	**Estradiol**	**Follicle-stimulating hormone**	**Luteinizing hormone**	**Testosterone/ Luteinizing hormone ratio**
(Jensen et al., 2004)[25]	ND	Negative	Negative	ND	Negative	ND	Positive	None	None	ND
(Fejes et al., 2005)[97]	ND	ND	Negative	ND	Negative	None	ND	ND	ND	ND
(Kort et al., 2006)[103]	Positive	ND	ND	ND	ND	ND	ND	ND	ND	ND
(Winters et al., 2006)[117]	ND	Negative	Negative	None	Negative	ND	None	None	None	ND
(Aggerholm et al., 2008)[26]	ND	Negative	Negative	ND	Negative	ND	None	None	None	ND
(Hofstra et al. 2008)[102]	ND	ND	Negative	Negative	None	ND	None	None	None	ND
(Pauli et al., 2008)[56]	ND	Negative	Negative	None	ND	ND	Positive	Negative	None	ND
(Foresta et al., 2009)[98]	ND	ND	Negative	Negative	Negative	ND	Positive	None	None	ND
(Stewart et al., 2009)[114]	ND	Negative	Negative	ND	Negative	ND	ND	None	ND	ND
(Chavarro et al., 2010)[38]	ND	Negative	Negative	ND	Negative	None	Positive	None	None	None
(Hofny et al., 2010)[101]	ND	ND	Negative	ND	ND	Positive	None	None	Positive	ND
(Ramlau-Hansen et al., 2010)[109]	ND	Negative	Negative	ND	Negative	ND	Positive	None	None	ND
(Rybar et al., 2011)[49]	None	ND	ND	ND	ND	ND	ND	ND	ND	ND
(Vignera et al., 2012)[52]	ND	ND	None	ND	Positive	ND	Positive	None	None	ND
(Dupont et al., 2013)[54]	Positive	ND	ND	ND	ND	ND	ND	ND	ND	ND

(Hajshafiha et al., 2013)[99]	ND	ND	Negative	ND	Negative	None	Negative	None	None	ND
(MacDonald et al., 2013)[105]	ND	ND	Negative	Negative	Negative	ND	None	None	None	ND
(Al-Ali et al., 2014)[89]	ND	ND	Negative	ND	ND	None	ND	None	Negative	ND
(Eisenberg et al., 2014)[40]	None	ND	ND	ND	ND	ND	ND	ND	ND	ND
(Thomsen et al., 2014)[24]	None	ND	ND	ND	ND	ND	ND	ND	ND	ND
(Bandel et al., 2015)[37]	Negative	ND	ND	ND	ND	ND	ND	ND	ND	ND
(Ehala-Aleksejev and Punab, 2015)[39]	ND	ND	Negative	ND	Negative	ND	None	None	None	ND
(Hadjkacem Loukil et al., 2015)[42]	ND	ND	None	ND	ND	None	ND	None	None	ND
(Lu et al., 2015)[104]	ND	ND	Negative	ND	Negative	ND	None	None	None	ND
(Alshahrani et al., 2016)[55]	ND	ND	None	ND	ND	None	ND	None	None	ND
(Andersen et al., 2016)[33]	None	ND	ND	ND	ND	ND	ND	ND	ND	ND
(Bieniek et al., 2016)[92]	ND	ND	Negative	ND	ND	None	Positive	ND	None	ND
(Ozdemir et al., 2016)[107]	ND	ND	Negative	ND	ND	ND	Positive	None	None	ND
(Taha et al., 2016)[51]	Positive	ND	ND	ND	ND	ND	ND	ND	ND	ND
(Yamaçake et al., 2016)[118]	ND	ND	Negative	Negative	Negative	ND	ND	None	None	ND
(Keskin et al., 2017)[44]	ND	ND	Positive	ND	ND	Positive	None	None	None	ND
(Amjad et al., 2019)[91]	ND	ND	Negative	ND	Negative	ND	ND	Negative	Negative	ND
(Ferigolo et al., 2019)[32]	Positive	ND	ND	ND	ND	ND	ND	ND	ND	ND

Abbreviations: ND, No data.

FIGURE CAPTIONS

Figure 1. Flow chart of the literature search and selection process.

Figure 2. **A-G.** Summary associations (combined effect size) between BMI categories and each seminogram parameter. **H.** Plot showing seminogram parameters that are associated with BMI class by using statistical significance (-log10 p-value) versus combined effect size on the y-axis and x-axis, respectively. Colored shapes represent significant associations. The horizontal dotted line represents the significance threshold. The vertical dotted line represents an ES of 0, where anything to the left of the line shows a negative change, and anything to the right of the line shows a positive change.

SUPPLEMENTAL TABLES

Supplemental Table 1. PICOS criteria for inclusion and exclusion of studies.

Supplemental Table 2. Sensitivity analysis data by systematic exclusion of one study at a time (only available for analyses of more than 5 studies).

APPENDIX

Appendix S1. Search strategy for the literature published between the earliest available online indexing year and June 2019 in MEDLINE-Pubmed and EMBASE databases.

SUPPLEMENTAL FIGURE CAPTIONS

Supplemental Figure 1. Association between underweight BMI and normal weight in semen volume.

Supplemental Figure 2. Association between overweight BMI and normal weight in semen volume and corresponding Funnel plot and “trim and fill” test analyzing the heterogeneity of the studies.

Supplemental Figure 3. Association between obese (or obese I) BMI and normal weight in semen volume and corresponding Funnel plot and “trim and fill” test analyzing the heterogeneity of the studies.

Supplemental Figure 4. Association between obese II (or more) BMI and normal weight in semen volume.

Supplemental Figure 5. Association between obese III BMI and normal weight in semen volume.

Supplemental Figure 6. Association between underweight BMI and normal weight in sperm count.

Supplemental Figure 7. Association between overweight BMI and normal weight in sperm count and corresponding Funnel plot and “trim and fill” test analyzing the heterogeneity of the studies.

Supplemental Figure 8. Association between obese (or obese I) BMI and normal weight in semen volume and corresponding Funnel plot and “trim and fill” test analyzing the heterogeneity of the studies.

Supplemental Figure 9. Association between obese II (or more) BMI and normal weight in sperm count.

Supplemental Figure 10. Association between obese III BMI and normal weight in sperm count.

Supplemental Figure 11. Association between underweight BMI and normal weight in sperm concentration.

Supplemental Figure 12. Association between overweight BMI and normal weight in sperm concentration and corresponding Funnel plot and “trim and fill” test analyzing the heterogeneity of the studies.

Supplemental Figure 13. Association between obese (or obese I) BMI and normal weight in sperm concentration and corresponding Funnel plot and “trim and fill” test analyzing the heterogeneity of the studies.

Supplemental Figure 14. Association between obese II (or more) BMI and normal weight in sperm concentration.

Supplemental Figure 15. Association between obese III BMI and normal weight in sperm concentration.

Supplemental Figure 16. Association between overweight BMI and normal weight in sperm vitality.

Supplemental Figure 17. Association between obese (or obese I) BMI and normal weight in sperm vitality.

Supplemental Figure 18. Association between obese II (or more) BMI and normal weight in sperm vitality.

Supplemental Figure 19. Association between obese III BMI and normal weight in sperm vitality.

Supplemental Figure 20. Association between underweight BMI and normal weight in sperm total motility.

Supplemental Figure 21. Association between overweight BMI and normal weight in sperm total motility and corresponding Funnel plot and “trim and fill” test analyzing the heterogeneity of the studies.

Supplemental Figure 22. Association between obese (or obese I) BMI and normal weight in sperm total motility and corresponding Funnel plot and “trim and fill” test analyzing the heterogeneity of the studies.

Supplemental Figure 23. Association between obese II (or more) BMI and normal weight in sperm total motility.

Supplemental Figure 24. Association between obese III BMI and normal weight in sperm total motility.

Supplemental Figure 25. Association between underweight BMI and normal weight in sperm progressive motility.

Supplemental Figure 26. Association between overweight BMI and normal weight in sperm progressive motility and corresponding Funnel plot and “trim and fill” test analyzing the heterogeneity of the studies.

Supplemental Figure 27. Association between obese (or obese I) BMI and normal weight in sperm progressive motility and corresponding Funnel plot and “trim and fill” test analyzing the heterogeneity of the studies.

Supplemental Figure 28. Association between obese II (or more) BMI and normal weight in sperm progressive motility.

Supplemental Figure 29. Association between underweight BMI and normal weight in sperm normal morphology.

Supplemental Figure 30. Association between overweight BMI and normal weight in sperm normal morphology and corresponding Funnel plot and "trim and fill" test analyzing the heterogeneity of the studies.

Supplemental Figure 31. Association between obese (or obese I) BMI and normal weight in sperm normal morphology and corresponding Funnel plot and "trim and fill" test analyzing the heterogeneity of the studies.

Supplemental Figure 32. Association between obese II (or more) BMI and normal weight in sperm normal morphology.

Supplemental Figure 33. Association between obese III BMI and normal weight in sperm normal morphology.

Supplemental Figure 34. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between underweight BMI and normal weight in semen volume.

Supplemental Figure 35. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between overweight BMI and normal weight in semen volume and corresponding Funnel plot and "trim and fill" test analyzing the heterogeneity of the studies.

Supplemental Figure 36. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between obese (or obese I) BMI and normal weight in semen volume and corresponding Funnel plot and "trim and fill" test analyzing the heterogeneity of the studies.

Supplemental Figure 37. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between underweight BMI and normal weight in sperm count.

Supplemental Figure 38. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between overweight BMI and normal weight in sperm count and corresponding Funnel plot and "trim and fill" test analyzing the heterogeneity of the studies.

Supplemental Figure 39. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between obese (or obese I) BMI and normal weight in sperm count and corresponding Funnel plot and "trim and fill" test analyzing the heterogeneity of the studies.

Supplemental Figure 40. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between underweight BMI and normal weight in sperm concentration.

Supplemental Figure 41. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between overweight BMI and normal weight in sperm concentration and corresponding Funnel plot and "trim and fill" test analyzing the heterogeneity of the studies.

Supplemental Figure 42. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between obese (or obese I) BMI and normal weight in sperm concentration and corresponding Funnel plot and "trim and fill" test analyzing the heterogeneity of the studies.

Supplemental Figure 43. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between overweight BMI and normal weight in sperm vitality.

Supplemental Figure 44. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between obese (or obese I) BMI and normal weight in sperm vitality.

Supplemental Figure 45. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between overweight BMI and normal weight in sperm total motility and corresponding Funnel plot and "trim and fill" test analyzing the heterogeneity of the studies.

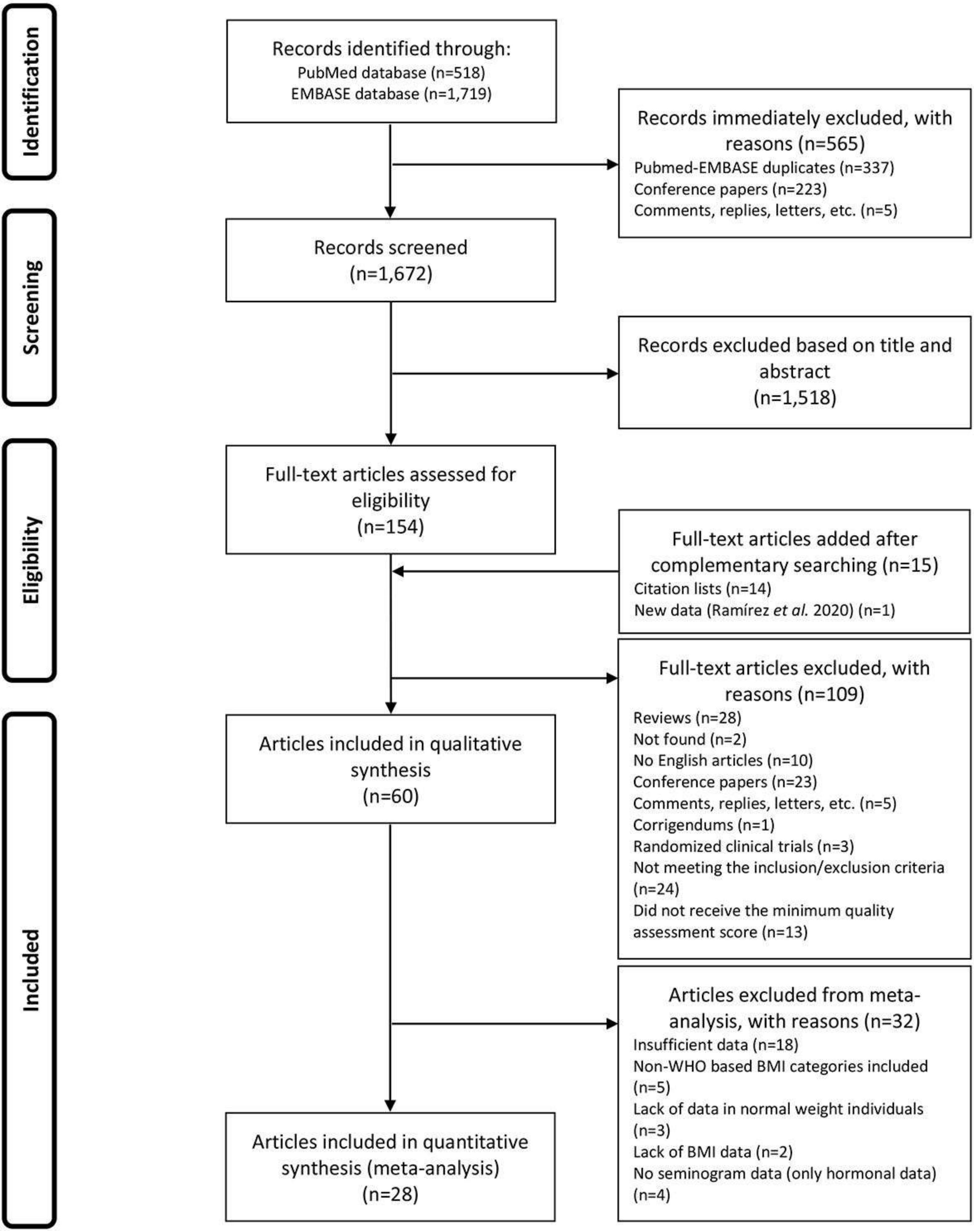
Supplemental Figure 46. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between obese (or obese I) BMI and normal weight in sperm total motility and corresponding Funnel plot and "trim and fill" test analyzing the heterogeneity of the studies.

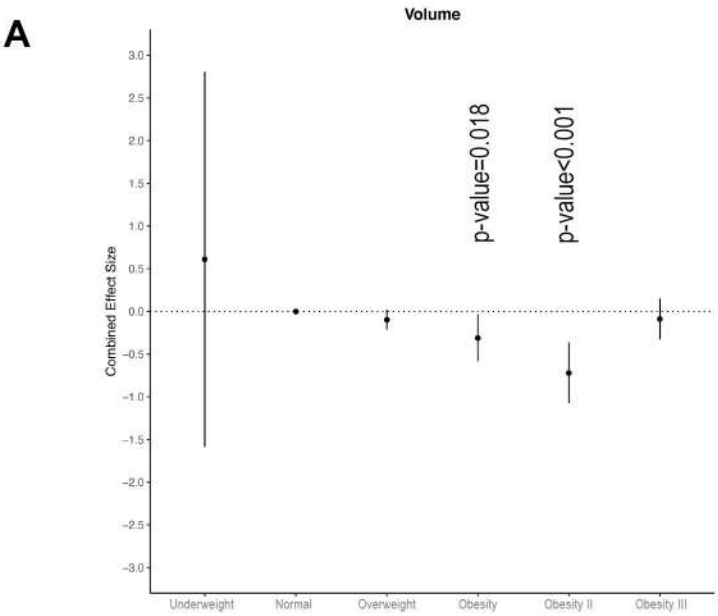
Supplemental Figure 47. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between overweight BMI and normal weight in sperm progressive motility and corresponding Funnel plot and "trim and fill" test analyzing the heterogeneity of the studies.

Supplemental Figure 48. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between obese (or obese I) BMI and normal weight in sperm progressive motility and corresponding Funnel plot and "trim and fill" test analyzing the heterogeneity of the studies.

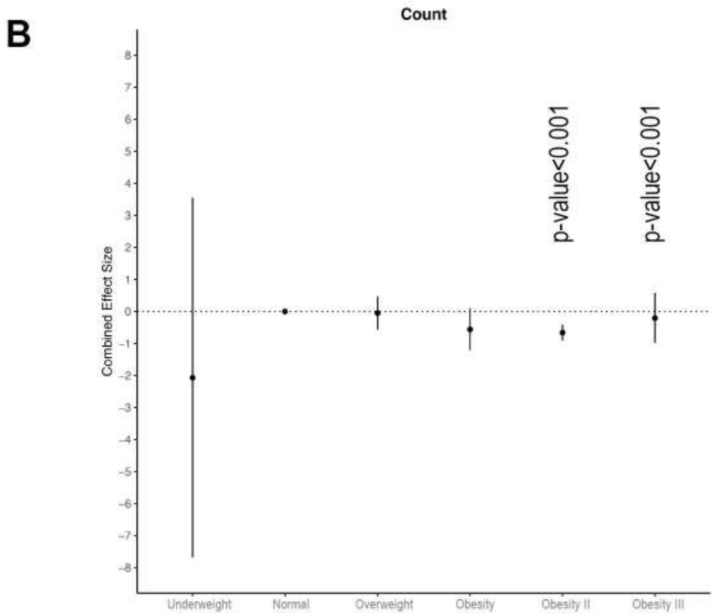
Supplemental Figure 49. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between overweight BMI and normal weight in sperm normal morphology and corresponding Funnel plot and “trim and fill” test analyzing the heterogeneity of the studies.

Supplemental Figure 50. Sensitivity analysis by changing meta-analysis models (random to fixed models) showing the association between obese (or obese I) BMI and normal weight in sperm normal morphology and corresponding Funnel plot and “trim and fill” test analyzing the heterogeneity of the studies.

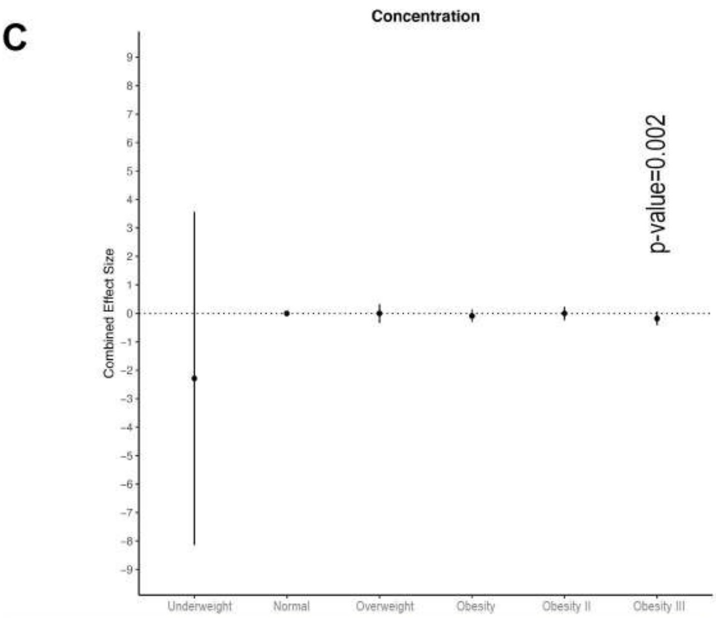

Identification
Screening
Eligibility
Included
Records identified through:
PubMed database (n=518)
EMBASE database (n=1,719)
Records immediately excluded, with reasons (n=565)
Pubmed-EMBASE duplicates (n=337)
Conference papers (n=223)
Comments, replies, letters, etc. (n=5)
Records screened
(n=1,672)
Records excluded based on title and abstract
(n=1,518)
Full-text articles assessed for eligibility
(n=154)
Full-text articles added after complementary searching (n=15)
Citation lists (n=14)
New data (Ramírez *et al.* 2020) (n=1)
Full-text articles excluded, with reasons (n=109)
Reviews (n=28)
Not found (n=2)
No English articles (n=10)
Conference papers (n=23)
Comments, replies, letters, etc. (n=5)
Corrigendums (n=1)
Randomized clinical trials (n=3)
Not meeting the inclusion/exclusion criteria (n=24)
Did not receive the minimum quality assessment score (n=13)
Articles included in qualitative synthesis
(n=60)
Articles excluded from meta-analysis, with reasons (n=32)
Insufficient data (n=18)
Non-WHO based BMI categories included (n=5)
Lack of data in normal weight individuals (n=3)
Lack of BMI data (n=2)
No seminogram data (only hormonal data) (n=4)
Articles included in quantitative synthesis (meta-analysis)
(n=28)



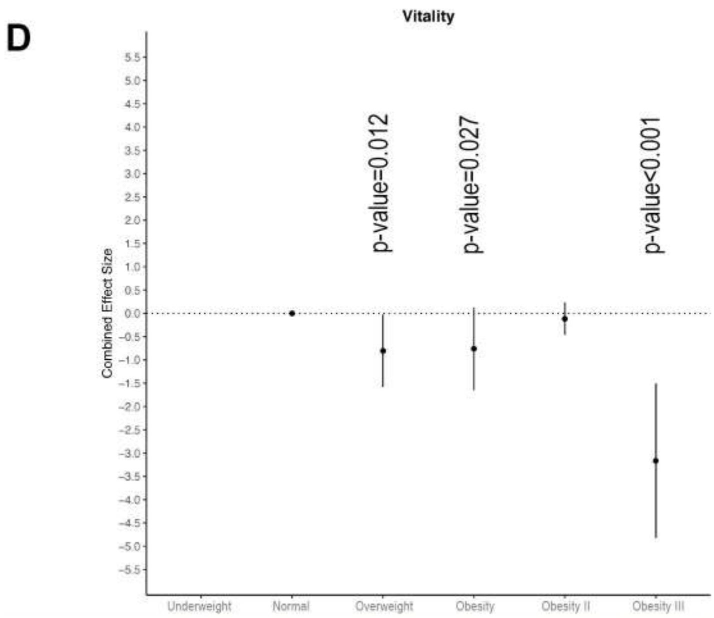
	Underweight	Normal	Overweight	Obesity	Obesity II	Obesity III
Studies	6	REF	20	18	3	3
Individuals	2687	REF	26580	3077	209	334
Model	Random	REF	Random	Random	Fixed	Fixed
Heterogeneity p-value	**<0.001**	REF	**<0.001**	**<0.001**	**<0.001**	0.139988105
Heterogeneity I²	99.18%	REF	86.28%	91.83%	97.43%	49.14%



	Underweight	Normal	Overweight	Obesity	Obesity II	Obesity III
Studies	5	REF	16	15	4	2
Individuals	1970	REF	22956	3781	241	277
Model	Random	REF	Random	Random	Fixed	Fixed
Heterogeneity p-value	**<0.001**	REF	**<0.001**	**<0.001**	**<0.001**	0.109787231
Heterogeneity I²	99.62%	REF	98.87%	97.77%	94.83%	60.90%

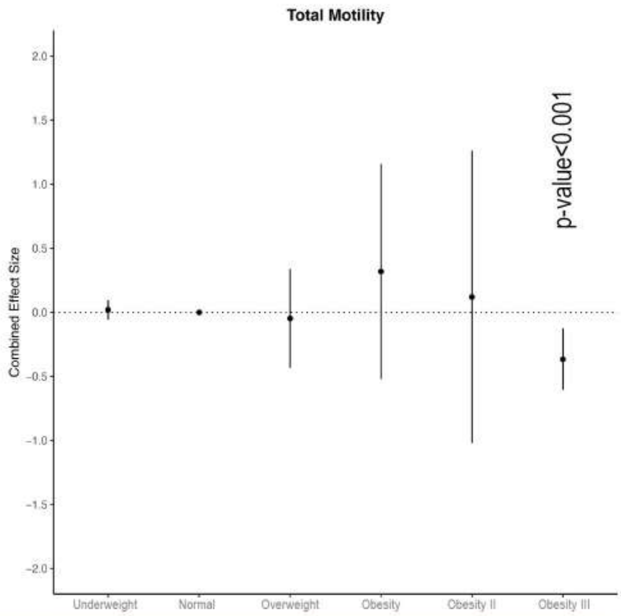


	Underweight	Normal	Overweight	Obesity	Obesity II	Obesity III
Studies	6	REF	26	24	4	3
Individuals	2002	REF	27829	4011	281	334
Model	Random	REF	Random	Random	Fixed	Fixed
Heterogeneity p-value	**<0.001**	REF	**<0.001**	**<0.001**	**0.014980764**	0.271831679
Heterogeneity I²	99.59%	REF	98.24%	92.67%	71.34%	23.23%



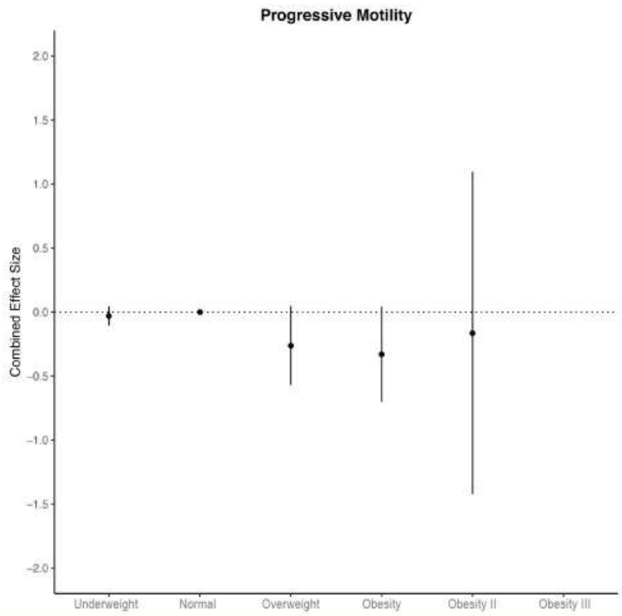
	Underweight	Normal	Overweight	Obesity	Obesity II	Obesity III
Studies	ND	REF	7	6	3	2
Individuals	ND	REF	7636	1561	201	90
Model	ND	REF	Random	Random	Fixed	Fixed
Heterogeneity p-value	ND	REF	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Heterogeneity I²	ND	REF	99.71%	96.76%	85.67%	99.89%

E



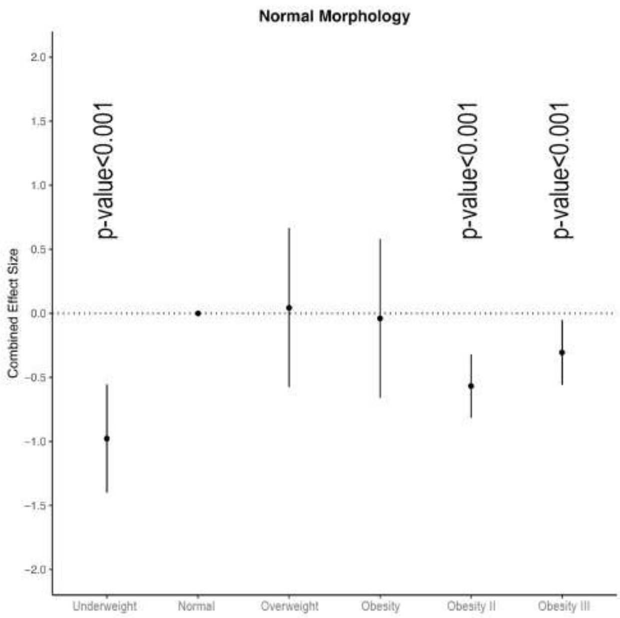
	Underweight	Normal	Overweight	Obesity	Obesity II	Obesity III
Studies	4	REF	16	13	2	3
Individuals	1902	REF	25943	2943	137	333
Model	Fixed	REF	Random	Random	Fixed	Fixed
Heterogeneity p-value	**<0.001**	REF	**<0.001**	**<0.001**	**<0.001**	0.188021691
Heterogeneity I²	99.66%	REF	98.60%	98.56%	93.45%	40.16%

F



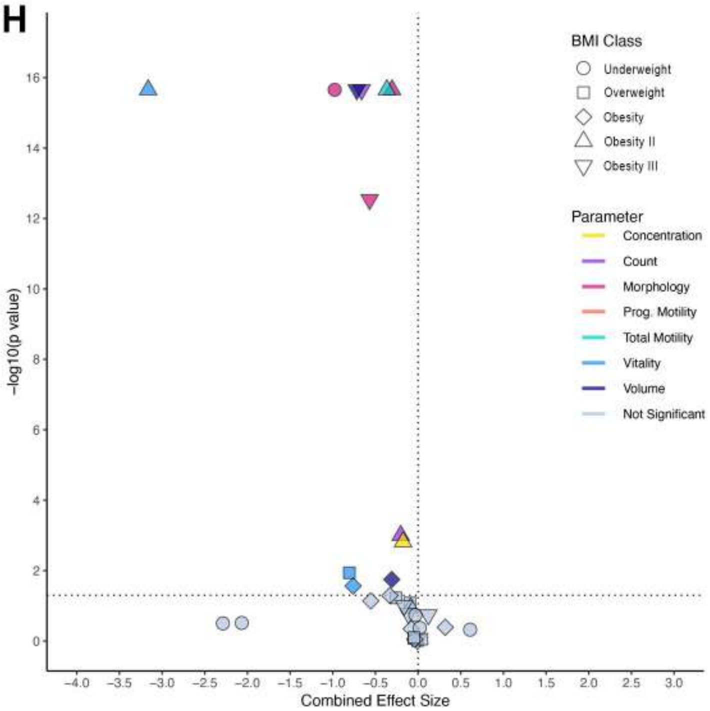
	Underweight	Normal	Overweight	Obesity	Obesity II	Obesity III
Studies	4	REF	11	12	2	ND
Individuals	1937	REF	11379	2237	110	ND
Model	Fixed	REF	Random	Random	Fixed	ND
Heterogeneity p-value	0.889459213	REF	**<0.001**	**<0.001**	**<0.001**	ND
Heterogeneity I²	0.00%	REF	93.62%	91.00%	91.25%	ND

G



	Underweight	Normal	Overweight	Obesity	Obesity II	Obesity III
Studies	3	REF	18	16	4	3
Individuals	137	REF	18310	2229	240	302
Model	Fixed	REF	Random	Random	Fixed	Fixed
Heterogeneity p-value	**<0.001**	REF	**<0.001**	**<0.001**	**<0.001**	0.068353377
Heterogeneity I²	99.78%	REF	98.88%	96.03%	96.42%	62.73%

H



Supplemental Table 1. Population, Intervention, Comparator Outcome, Study design (PICOS) criteria for a systematically searched.

Patients	Well-defined fertile/infertile men.
Interventions	No treatments: Cross-sectional data or baseline data.
Comparators	Control group (fertile males).
Outcomes	Primary outcomes: Semen volume, ejaculate pH, total sperm count or concentration, sperm vitality, sperm motility (progressive or total motility), sperm morphology. Secondary outcomes: Acrosome resistance, sperm DNA fragmentation (SDF) or damage, sperm chromatin integrity (SCI), sperm reactive oxygen species (ROS), sperm aneuploidies, sperm function parameters, or hormonal levels.
Study design	Inclusion: Case-control, cross-sectional, observational prospective or retrospective studies. Exclusion: Animal or *in-vitro* studies, reviews, editorials, opinions, randomized clinical trial, and case-reports articles.

Supplemental Table 2. Sensitivity analysis by systematic exclusion of one study at a time (only available for analyses of ≥5 studies)[a].

Removal of	ES	95% CI	P-value*	I² (%)	P-heterogeneity**	Comment
			Semen volume – Underweight *vs* normal weight			
Overall	0.61	(-1.59, 2.81)	0.47	99.2	<0.001	**-**
Bandel et al. 2015[1]	0.82	(-2.00, 3.64)	0.42	99.3	<0.001	-
Belloc et al. 2014[2]	0.81	(-2.02, 3.64)	0.43	99.3	<0.001	-
Ma et al. 2019[3]	0.76	(-2.10, 3.63)	0.46	99.3	<0.001	**-**
Qin et al. 2007[4]	-0.16	(-0.25, -0.06)	<0.001	5.2	0.37	Heterogeneity was explained and ES becomes significant
Shayeb et al. 2011[5]	0.76	(-2.09, 3.62)	0.46	99.3	<0.001	**-**
Wang et al. 2017[6]	0.75	(-2.12, 3.62)	0.47	99.3	<0.001	**-**
			Semen volume – Overweight *vs* normal weight			
Overall	-0.10	(-0.21, 0.02)	0.08	86.3	<0.001	-
Alshahrani et al. 2016[7]	-0.11	(-0.22, 0.00)	0.03	85.4	<0.001	Influential study, ES becomes significant
Bandel et al. 2015[1]	-0.10	(-0.23, 0.02)	0.08	86.8	<0.001	-
Belloc et al. 2014[2]	-0.10	(-0.23, 0.03)	0.10	86.9	<0.001	-
Chavarro et al. 2010[8]	-0.07	(-0.16, 0.03)	0.13	81.1	<0.001	-
Ehala-Aleksejev et al. 2015[9]	-0.10	(-0.22, 0.02)	0.09	87.0	<0.001	-
Eisenberg et al. 2014[10]	-0.09	(-0.21, 0.03)	0.11	86.9	<0.001	-
Fariello et al. 2012[11]	-0.10	(-0.22, 0.02)	0.09	87.0	<0.001	-
Hammiche et al. 2012[12]	-0.06	(-0.15, 0.02)	0.12	78.9	<0.001	-
Jensen et al. 2004[13]	-0.10	(-0.23, 0.02)	0.08	86.9	<0.001	-
Keskin et al. 2017[14]	-0.10	(-0.22, 0.03)	0.10	87.0	<0.001	-
Luque et al. 2017[15]	-0.09	(-0.22, 0.03)	0.12	86.4	<0.001	-
Ma et al. 2019[3]	-0.10	(-0.23, 0.03)	0.10	87.0	<0.001	-
Martini et al. 2010[16]	-0.10	(-0.22, 0.02)	0.09	87.0	<0.001	-
Oliveira et al. 2018[17]	-0.11	(-0.23, 0.02)	0.07	86.5	<0.001	-
Qin et al. 2007[4]	-0.10	(-0.23, 0.02)	0.08	86.9	<0.001	-

Ramírez et al. 2020[18]	-0.10	(-0.23, 0.03)	0.11	86.8	<0.001	-
Rybar et al. 2011[19]	-0.10	(-0.22, 0.03)	0.10	87.0	<0.001	-
Shayeb et al. 2011[5]	-0.10	(-0.23, 0.02)	0.08	86.7	<0.001	-
Vignera et al. 2012[20]	-0.10	(-0.22, 0.02)	0.09	87.0	<0.001	-
Wang et al. 2017[6]	-0.10	(-0.23, 0.02)	0.08	86.7	<0.001	-
Semen volume – Obesity (or obesity I) *vs* normal weight						
Overall	-0.31	(-0.58, -0.03)	0.02	91.8	<0.001	-
Alshahrani et al. 2016[7]	-0.32	(-0.61, -0.03)	0.02	92.3	<0.001	-
Bandel et al. 2015[1]	-0.33	(-0.62, -0.03)	0.02	92.3	<0.001	-
Belloc et al. 2014[2]	-0.32	(-0.62, -0.03)	0.02	92.3	<0.001	-
Chavarro et al. 2010[8]	-0.29	(-0.58, 0.00)	0.04	91.9	<0.001	-
Ehala-Aleksejev et al. 2015[9]	-0.24	(-0.48, 0.00)	0.04	89.8	<0.001	-
Eisenberg et al. 2014[10]	-0.27	(-0.56, 0.01)	0.04	91.3	<0.001	-
Fariello et al. 2012[11]	-0.31	(-0.60, -0.02)	0.03	92.3	<0.001	-
Ferigolo et al. 2019[21]	-0.31	(-0.60, -0.02)	0.02	92.3	<0.001	-
Hammiche et al. 2012[12]	-0.22	(-0.43, 0.00)	0.03	85.3	<0.001	-
Keskin et al. 2017[14]	-0.32	(-0.61, -0.02)	0.02	92.3	<0.001	-
Ma et al. 2019[3]	-0.33	(-0.62, -0.04)	0.02	92.0	<0.001	-
Martini et al. 2010[16]	-0.32	(-0.62, -0.03)	0.02	92.3	<0.001	-
Oliveira et al. 2018[17]	-0.33	(-0.62, -0.04)	0.02	92.1	<0.001	-
Qin et al. 2007[4]	-0.32	(-0.61, -0.03)	0.02	92.3	<0.001	-
Rybar et al. 2011[19]	-0.34	(-0.62, -0.06)	0.01	92.2	<0.001	-
Shayeb et al. 2011[5]	-0.32	(-0.61, -0.02)	0.02	92.3	<0.001	-
Vignera et al. 2012[20]	-0.33	(-0.61, -0.04)	0.02	92.3	<0.001	-
Wang et al. 2017[6]	-0.33	(-0.62, -0.04)	0.02	92.1	<0.001	-
Sperm count – Underweight *vs* normal weight						
Overall	-2.07	(-7.68, 3.55)	0.31	99.6	<0.001	-
Belloc et al. 2014[2]	-2.53	(-10.63, 5.56)	0.32	99.7	<0.001	-
Ma et al. 2019[3]	-2.56	(-10.66, 5.54)	0.32	99.7	<0.001	-

Qin et al. 2007[4]	-0.10	(-0.33, 0.13)	0.18	44.0	0.15	Heterogeneity was explained
Shayeb et al. 2011[5]	-2.61	(-10.62, 5.41)	0.30	99.7	<0.001	-
Wang et al. 2017[6]	-2.62	(-10.65, 5.41)	0.30	99.7	<0.001	-
Sperm count – Overweight *vs* normal weight						
Overall	-0.05	(-0.57, 0.47)	0.84	98.9	<0.001	-
Aggerholm et al. 2008[22]	-0.02	(-0.59, 0.54)	0.92	98.9	<0.001	-
Andersen et al. 2016[23]	-0.03	(-0.58, 0.53)	0.92	98.9	<0.001	-
Belloc et al. 2014[2]	-0.05	(-0.61, 0.51)	0.85	98.9	<0.001	-
Chavarro et al. 2010[8]	-0.02	(-0.58, 0.54)	0.94	98.9	<0.001	-
Dupont et al. 2013[24]	-0.05	(-0.61, 0.51)	0.85	98.9	<0.001	-
Ehala-Aleksejev et al. 2015[9]	0.01	(-0.53, 0.55)	0.97	98.9	<0.001	-
Eisenberg et al. 2014[10]	-0.04	(-0.60, 0.52)	0.88	98.9	<0.001	-
Hammiche et al. 2012[12]	0.00	(-0.54, 0.55)	0.99	98.9	<0.001	-
Jensen et al. 2004[13]	0.00	(-0.56, 0.55)	0.99	98.9	<0.001	-
Ma et al. 2019[3]	-0.05	(-0.61, 0.51)	0.85	98.9	<0.001	-
Qin et al. 2007[4]	-0.26	(-0.45, -0.07)	0.004	95.3	<0.001	Influential study, ES becomes significant
Ramírez et al. 2020[18]	-0.05	(-0.62, 0.51)	0.84	98.9	<0.001	-
Shayeb et al. 2011[5]	-0.07	(-0.63, 0.49)	0.79	98.9	<0.001	-
Thomsen et al. 2014[25]	-0.05	(-0.61, 0.51)	0.84	98.9	<0.001	-
Vignera et al. 2012[20]	-0.06	(-0.61, 0.50)	0.83	98.9	<0.001	-
Wang et al. 2017[6]	-0.04	(-0.60, 0.53)	0.89	98.9	<0.001	-
Sperm count – Obesity (or obesity I) *vs* normal weight						
Overall	-0.55	(-1.21, 0.11)	0.07	97.8	<0.001	-
Aggerholm et al. 2008[22]	-0.66	(-1.33, 0.01)	0.03	97.4	<0.001	Influential study, ES becomes significant
Andersen et al. 2016[23]	-0.58	(-1.29, 0.13)	0.08	97.9	<0.001	-
Belloc et al. 2014[2]	-0.59	(-1.31, 0.13)	0.08	97.9	<0.001	-
Chavarro et al. 2010[8]	-0.53	(-1.24, 0.19)	0.11	97.8	<0.001	-
Dupont et al. 2013[24]	-0.48	(-1.17, 0.21)	0.14	97.7	<0.001	-
Ehala-Aleksejev et al.	-0.49	(-1.18, 0.21)	0.13	97.8	<0.001	-

2015[9]						
Eisenberg et al. 2014[10]	-0.57	(-1.29, 0.14)	0.09	97.9	<0.001	**-**
Ferigolo et al. 2019[21]	-0.59	(-1.30, 0.12)	0.07	97.9	<0.001	**-**
Hammiche et al. 2012[12]	-0.53	(-1.24, 0.18)	0.11	97.8	<0.001	**-**
Ma et al. 2019[3]	-0.61	(-1.32, 0.11)	0.07	97.9	<0.001	**-**
Qin et al. 2007[4]	-0.31	(-0.70, 0.09)	0.10	96.6	<0.001	**-**
Shayeb et al. 2011[5]	-0.63	(-1.33, 0.06)	0.048	97.6	<0.001	Influential study, ES becomes significant
Thomsen et al. 2014[25]	-0.60	(-1.31, 0.11)	0.07	97.9	<0.001	**-**
Vignera et al. 2012[20]	-0.59	(-1.30, 0.12)	0.08	97.9	<0.001	**-**
Wang et al. 2017[6]	-0.58	(-1.30, 0.14)	0.08	97.9	<0.001	**-**
Sperm concentration – Underweight *vs* normal weight						
Overall	-2.29	(-8.14, 3.56)	0.31	99.6	<0.001	**-**
Bandel et al. 2015[1]	-2.77	(-10.36, 4.82)	0.31	99.7	<0.001	-
Belloc et al. 2014[2]	-2.73	(-10.35, 4.88)	0.32	99.7	<0.001	-
Ma et al. 2019[3]	-2.76	(-10.40, 4.89)	0.32	99.7	<0.001	-
Qin et al. 2007[4]	-0.05	(-0.24, 0.14)	0.45	44.4	0.126	Heterogeneity was explained
Shayeb et al. 2011[5]	-2.71	(-10.33, 4.90)	0.32	99.7	<0.001	**-**
Wang et al. 2017[6]	-2.81	(-10.40, 4.78)	0.30	99.7	<0.001	**-**
Sperm concentration – Overweight *vs* normal weight						
Overall	-0.01	(-0.34, 0.32)	0.96	98.2	<0.001	-
Aggerholm et al. 2008[22]	0.01	(-0.34, 0.35)	0.98	98.3	<0.001	-
Alshahrani et al. 2016[7]	-0.01	(-0.35, 0.34)	0.97	98.3	<0.001	-
Andersen et al. 2016[23]	-0.01	(-0.35, 0.34)	0.97	98.3	<0.001	-
Bandel et al. 2015[1]	-0.01	(-0.35, 0.34)	0.97	98.3	<0.001	-
Belloc et al. 2014[2]	-0.01	(-0.35, 0.34)	0.96	98.3	<0.001	-
Chavarro et al. 2010[8]	-0.02	(-0.36, 033)	0.92	98.3	<0.001	-
Ehala-Aleksejev et al. 2015[9]	0.03	(-0.30, 0.36)	0.85	98.3	<0.001	-
Eisenberg et al. 2014[10]	-0.04	(-0.38, 0.30)	0.81	98.3	<0.001	-
Fariello et al. 2012[11]	0.00	(-0.34, 0.34)	1.00	98.3	<0.001	-

Hadjkacem-Loukil et al. 2015[26]	0.01	(-0.33, 0.35)	0.96	98.3	<0.001	-
Hammiche et al. 2012[12]	0.05	(-0.28, 0.37)	0.77	98.1	<0.001	-
Jensen et al. 2004[13]	0.02	(-0.32, 0.36)	0.89	98.2	<0.001	-
Keskin et al. 2017[14]	-0.01	(-0.35, 0.33)	0.95	98.2	<0.001	-
Koloszar et al. 2005[27]	0.00	(-0.35, 0.34)	0.99	98.3	<0.001	-
Luque et al. 2017[15]	-0.01	(-0.36, 0.33)	0.95	98.3	<0.001	-
Ma et al. 2019[3]	-0.01	(-0.36, 0.33)	0.95	98.3	<0.001	-
Martini et al. 2010[16]	-0.01	(-0.35, 0.34)	0.96	98.3	<0.001	-
Oliveira et al. 2018[17]	0.00	(-0.35, 0.34)	0.98	98.3	<0.001	-
Qin et al. 2007[4]	-0.14	(-0.31, 0.02)	0.08	94.3	<0.001	-
Ramírez et al. 2020[18]	-0.01	(-0.36, 0.33)	0.95	98.3	<0.001	-
Rybar et al. 2011[19]	-0.01	(-0.35, 0.34)	0.96	98.3	<0.001	-
Shayeb et al. 2011[5]	0.00	(-0.35, 0.34)	0.98	98.3	<0.001	-
Taha et al. 2016[28]	-0.01	(-0.35, 0.33)	0.96	98.3	<0.001	-
Thomsen et al. 2014[25]	-0.01	(-0.35, 0.34)	0.97	98.3	<0.001	-
Vignera et al. 2012[20]	-0.01	(-0.35, 0.33)	0.96	98.3	<0.001	-
Wang et al. 2017[6]	0.01	(-0.34, 0.35)	0.97	98.3	<0.001	-
Sperm concentration – Obesity (or obesity I) *vs* normal weight						
Overall	-0.08	(-0.30, 0.14)	0.45	92.7	<0.001	-
Aggerholm et al. 2008[22]	-0.11	(-0.33, 0.12)	0.33	92.2	<0.001	-
Alshahrani et al. 2016[7]	-0.08	(-0.31, 0.15)	0.47	93.0	<0.001	-
Andersen et al. 2016[23]	-0.09	(-0.32, 0.14)	0.43	93.0	<0.001	-
Bandel et al. 2015[1]	-0.09	(-0.32, 0.14)	0.44	93.0	<0.001	-
Belloc et al. 2014[2]	-0.08	(-0.31, 0.15)	0.48	93.0	<0.001	-
Chavarro et al. 2010[8]	-0.11	(-0.33, 0.11)	0.30	92.5	<0.001	-
Ehala-Aleksejev et al. 2015[9]	-0.06	(-0.28, 0.17)	0.59	92.8	<0.001	-
Eisenberg et al. 2014[10]	-0.11	(-0.34, 0.11)	0.28	92.4	<0.001	-
Fariello et al. 2012[11]	-0.06	(-0.29, 0.16)	0.56	92.9	<0.001	-
Ferigolo et al. 2019[21]	-0.08	(-0.31, 0.15)	0.45	93.0	<0.001	-

Hadjkacem-Loukil et al. 2015[26]	-0.09	(-0.32, 0.14)	0.41	93.0	<0.001	-
Hammiche et al. 2012[12]	-0.01	(-0.18, 0.16)	0.91	89.5	<0.001	-
Keskin et al. 2017[14]	-0.09	(-0.32, 0.15)	0.45	93.0	<0.001	-
Koloszar et al. 2005[27]	-0.05	(-0.28, 0.17)	0.63	92.6	<0.001	-
Ma et al. 2019[3]	-0.09	(-0.32, 0.14)	0.42	92.8	<0.001	-
Martini et al. 2010[16]	-0.08	(-0.32, 0.15)	0.45	93.0	<0.001	-
Oliveira et al. 2018[17]	-0.06	(-0.29, 0.17)	0.57	92.1	<0.001	-
Qin et al. 2007[4]	-0.11	(-0.33, 0.11)	0.30	92.8	<0.001	-
Rybar et al. 2011[19]	-0.09	(-0.32, 0.14)	0.41	93.0	<0.001	-
Shayeb et al. 2011[5]	-0.10	(-0.33, 0.13)	0.37	92.3	<0.001	-
Taha et al. 2016[28]	-0.06	(-0.29, 0.16)	0.56	92.9	<0.001	-
Thomsen et al. 2014[25]	-0.09	(-0.32, 0.15)	0.44	93.0	<0.001	-
Vignera et al. 2012[20]	-0.08	(-0.31, 0.15)	0.48	93.0	<0.001	-
Wang et al. 2017[6]	-0.07	(-0.30, 0.16)	0.55	92.4	<0.001	-
Sperm vitality – Overweight *vs* normal weight						
Overall	-0.81	(-1.59, -0.03)	0.01	99.7	<0.001	-
Andersen et al. 2016[23]	-0.89	(-1.82, 0.05)	0.02	99.8	<0.001	-
Belloc et al. 2014[2]	-0.94	(-1.82, -0.05)	0.006	99.5	<0.001	-
Eisenberg et al. 2014[10]	-0.69	(-1.60, 0.21)	0.049	99.8	<0.001	-
Luque et al. 2017[15]	-0.56	(-1.28, 0.15)	0.04	96.8	<0.001	-
Martini et al. 2010[16]	-0.93	(-1.83, -0.03)	0.008	99.8	<0.001	-
Oliveira et al. 2018[17]	-0.91	(-1.83, 0.01)	0.01	99.8	<0.001	-
Taha et al. 2016[28]	-0.70	(-1.61, 0.21)	0.049	99.8	<0.001	-
Sperm vitality – Obesity (or obesity I) *vs* normal weight						
Overall	-0.76	(-1.65, 0.13)	0.03	96.8	<0.001	-
Andersen et al. 2016[23]	-0.86	(-1.97, 0.24)	0.03	97.4	<0.001	-
Belloc et al. 2014[2]	-0.91	(-2.01, 0.18)	0.02	96.3	<0.001	-
Eisenberg et al. 2014[10]	-0.47	(-1.21, 0.28)	0.08	92.4	<0.001	-
Martini et al. 2010[16]	-0.89	(-2.00, 022)	0.03	97.4	<0.001	-

Oliveira et al. 2018[17]	-0.84	(-2.01, 0.33)	0.046	97.3	<0.001	-
Taha et al. 2016[28]	-0.59	(-1.58, 0.40)	0.10	96.8	<0.001	Influential study, ES becomes non-significant
Sperm total motility – Overweight *vs* normal weight						
Overall	-0.05	(-0.43, 0.34)	0.79	98.6	<0.001	-
Aggerholm et al. 2008[22]	-0.12	(-0.50, 0.26)	0.51	98.0	<0.001	-
Belloc et al. 2014[2]	-0.05	(-0.47, 0.37)	0.80	98.7	<0.001	-
Chavarro et al. 2010[8]	-0.11	(-0.50, 0.27)	0.53	98.6	<0.001	-
Dupont et al. 2013[24]	0.04	(-0.32, 0.40)	0.81	98.5	<0.001	-
Ehala-Aleksejev et al. 2015[9]	-0.09	(-0.49, 0.31)	0.63	98.7	<0.001	-
Jensen et al. 2004[13]	-0.05	(-0.47, 0.37)	0.79	98.7	<0.001	-
Keskin et al. 2017[14]	-0.06	(-0.47, 0.35)	0.76	98.7	<0.001	-
Luque et al. 2017[15]	-0.05	(-0.47, 0.37)	0.79	98.7	<0.001	-
Ma et al. 2019[3]	-0.05	(-0.47, 0.36)	0.78	98.7	<0.001	-
Martini et al. 2010[16]	-0.05	(-0.46, 0.37)	0.81	98.7	<0.001	-
Oliveira et al. 2018[17]	-0.04	(-0.46, 0.38)	0.84	98.7	<0.001	-
Qin et al. 2007[4]	0.08	(-0.23, 0.38)	0.59	97.7	<0.001	-
Ramírez et al. 2020[18]	-0.05	(-0.47, 0.37)	0.80	98.7	<0.001	-
Rybar et al. 2011[19]	-0.04	(-0.46, 0.37)	0.82	98.7	<0.001	-
Shayeb et al. 2011[5]	-0.06	(-0.47, 0.36)	0.77	98.7	<0.001	-
Thomsen et al. 2014[25]	-0.05	(-0.47, 0.37)	0.79	98.7	<0.001	-
Sperm total motility – Obesity (or obesity I) *vs* normal weight						
Overall	0.32	(-0.52, 1.16)	0.41	98.6	<0.001	-
Aggerholm et al. 2008[22]	0.19	(-0.68, 1.06)	0.63	97.8	<0.001	-
Belloc et al. 2014[2]	0.36	(-0.56, 1.28)	0.39	98.6	<0.001	-
Chavarro et al. 2010[8]	0.28	(-0.64, 1.20)	0.50	98.7	<0.001	-
Dupont et al. 2013[24]	0.55	(-0.16, 1.26)	0.09	98.4	<0.001	-
Ehala-Aleksejev et al. 2015[9]	0.23	(-0.66, 1.13)	0.57	98.6	<0.001	-
Keskin et al. 2017[14]	0.34	(-0.58, 1.26)	0.42	98.7	<0.001	-

Ma et al. 2019[3]	0.35	(-0.57, 1.28)	0.40	98.7	<0.001	-
Martini et al. 2010[16]	0.37	(-0.55, 1.28)	0.38	98.7	<0.001	-
Oliveira et al. 2018[17]	0.39	(-0.53, 1.30)	0.35	98.6	<0.001	-
Qin et al. 2007[4]	0.07	(-0.61, 0.75)	0.82	98.3	<0.001	-
Rybar et al. 2011[19]	0.35	(-0.57, 1.26)	0.41	98.7	<0.001	-
Shayeb et al. 2011[5]	0.31	(-0.61, 1.24)	0.46	98.7	<0.001	-
Thomsen et al. 2014[25]	0.35	(-0.57, 1.27)	0.41	98.7	<0.001	-
Sperm progressive motility – Overweight *vs* normal weight						
Overall	-0.26	(-0.57, 0.05)	0.06	93.6	<0.001	-
Andersen et al. 2016[23]	-0.25	(-0.58, 0.08)	0.09	94.1	<0.001	-
Bandel et al. 2015[1]	-0.31	(-0.65, 0.03)	0.04	94.2	<0.001	Influential study, ES becomes significant
Belloc et al. 2014[2]	-0.35	(-0.72, 0.02)	0.04	94.3	<0.001	Influential study, ES becomes significant
Fariello et al. 2012[11]	-0.24	(-0.58, 0.10)	0.11	93.8	<0.001	-
Hammiche et al. 2012[12]	-0.24	(-0.58, 0.10)	0.12	93.5	<0.001	-
Keskin et al. 2017[14]	-0.30	(-0.64, 0.04)	0.045	94.2	<0.001	Influential study, ES becomes significant
Ma et al. 2019[3]	-0.35	(-0.71, 0.02)	0.03	93.0	<0.001	Influential study, ES becomes significant
Oliveira et al. 2018[17]	-0.28	(-0.64, 0.07)	0.07	94.1	<0.001	-
Taha et al. 2016[28]	-0.15	(-0.34, 0.04)	0.07	89.3	<0.001	-
Vignera et al. 2012[20]	-0.22	(-0.53, 0.09)	0.11	93.5	<0.001	-
Wang et al. 2017[6]	-0.27	(-0.63, 0.08)	0.08	93.6	<0.001	-
Sperm progressive motility – Obesity (or obesity I) *vs* normal weight						
Overall	-0.33	(-0.71, 0.04)	0.051	91.0	<0.001	-
Andersen et al. 2016[23]	-0.32	(-0.73, 0.08)	0.08	91.8	<0.001	-
Bandel et al. 2015[1]	-0.39	(-0.77, -0.01)	0.02	89.4	<0.001	Influential study, ES becomes significant
Belloc et al. 2014[2]	-0.38	(-0.80, 0.05)	0.051	91.8	<0.001	-
Fariello et al. 2012[11]	-0.30	(-0.71, 0.10)	0.10	91.4	<0.001	-
Ferigolo et al. 2019[21]	-0.32	(-0.73, 0.08)	0.08	91.8	<0.001	-
Hammiche et al. 2012[12]	-0.36	(-0.77, 0.04)	0.047	91.7	<0.001	Influential study, ES becomes significant
Keskin et al. 2017[14]	-0.37	(-0.77, 0.04)	0.046	91.7	<0.001	Influential study, ES becomes significant

Ma et al. 2019[3]	-0.38	(-0.80, 0.04)	0.04	91.3	<0.001	Influential study, ES becomes significant
Oliveira et al. 2018[17]	-0.32	(-0.74, 0.10)	0.09	90.4	<0.001	-
Taha et al. 2016[28]	-0.19	(-0.40, 0.01)	0.04	84.5	<0.001	Influential study, ES becomes significant
Vignera et al. 2012[20]	-0.30	(-0.71, 0.10)	0.10	91.4	<0.001	-
Wang et al. 2017[6]	-0.36	(-0.78, 0.06)	0.06	91.8	<0.001	-
Sperm normal morphology – Overweight *vs* normal weight						
Overall	0.04	(-0.58, 0.67)	0.89	98.9	<0.001	-
Andersen et al. 2016[23]	0.08	(-0.58, 0.73)	0.81	98.9	<0.001	-
Belloc et al. 2014[2]	0.05	(-0.62, 0.71)	0.88	98.9	<0.001	-
Chavarro et al. 2010[8]	0.05	(-0.62, 0.71)	0.88	98.9	<0.001	-
Dupont et al. 2013[24]	0.14	(-0.48, 0.77)	0.63	98.8	<0.001	-
Ehala-Aleksejev et al. 2015[9]	0.01	(-0.65, 0.67)	0.98	98.9	<0.001	-
Eisenberg et al. 2014[10]	0.10	(-0.55, 0.75)	0.75	98.9	<0.001	-
Fariello et al. 2012[11]	0.05	(-0.61, 0.72)	0.86	98.9	<0.001	-
Jensen et al. 2004[13]	0.05	(-0.61, 0.71)	0.87	98.9	<0.001	-
Keskin et al. 2017[14]	0.04	(-0.62, 0.71)	0.89	98.9	<0.001	-
Luque et al. 2017[15]	0.05	(-0.62, 0.71)	0.88	98.9	<0.001	-
Martini et al. 2010[16]	0.05	(-0.62, 0.71)	0.88	98.9	<0.001	-
Oliveira et al. 2018[17]	0.05	(-0.61, 0.72)	0.86	98.9	<0.001	-
Qin et al. 2007[4]	-0.19	(-0.45, 0.07)	0.13	93.7	<0.001	-
Ramírez et al. 2020[18]	0.04	(-0.62, 0.71)	0.89	98.9	<0.001	-
Rybar et al. 2011[19]	0.05	(-0.62, 0.71)	0.88	98.9	<0.001	-
Taha et al. 2016[28]	0.11	(-0.53, 0.75)	0.71	98.9	<0.001	-
Vignera et al. 2012[20]	0.05	(-0.61, 0.71)	0.86	98.9	<0.001	-
Wang et al. 2017[6]	0.04	(-0.62, 0.71)	0.89	98.9	<0.001	-
Sperm normal morphology – Obesity (or obesity I) *vs* normal weight						
Overall	-0.04	(-0.66, 0.58)	0.89	96.0	<0.001	-
Andersen et al. 2016[23]	0.01	(-0.64, 0.66)	0.97	96.2	<0.001	-
Belloc et al. 2014[2]	-0.03	(-0.71, 0.64)	0.91	96.3	<0.001	-

Chavarro et al. 2010[8]	-0.04	(-0.71, 0.63)	0.89	96.3	<0.001	-
Dupont et al. 2013[24]	0.01	(-0.65, 0.66)	0.98	96.2	<0.001	-
Ehala-Aleksejev et al. 2015[9]	-0.05	(-0.72, 0.62)	0.87	96.3	<0.001	-
Eisenberg et al. 2014[10]	-0.02	(-0.69, 0.65)	0.95	96.3	<0.001	-
Fariello et al. 2012[11]	-0.04	(-0.70, 0.63)	0.90	96.3	<0.001	-
Ferigolo et al. 2019[21]	0.00	(-0.66, 0.65)	0.99	96.3	<0.001	-
Keskin et al. 2017[14]	-0.04	(-0.71, 0.63)	0.91	96.3	<0.001	-
Martini et al. 2010[16]	-0.05	(-0.72, 0.62)	0.88	96.3	<0.001	-
Oliveira et al. 2018[17]	-0.01	(-0.68, 0.66)	0.97	96.0	<0.001	-
Qin et al. 2007[4]	-0.27	(-0.52, -0.02)	0.02	89.0	<0.001	Influential study, ES becomes significant
Rybar et al. 2011[19]	-0.05	(-0.71, 0.62)	0.88	96.3	<0.001	-
Taha et al. 2016[28]	0.04	(-0.59, 0.68)	0.88	96.0	<0.001	-
Vignera et al. 2012[20]	0.00	(-0.67, 0.66)	0.99	96.2	<0.001	-
Wang et al. 2017[6]	-0.06	(-0.73, 0.61)	0.84	95.9	<0.001	-

[a.] Summary effect size recalculated after the systematical removal of one study at a time. We considered an influential study as the one whose exclusion changed the significance, direction or magnitude (by >10%) of the pooled estimate or changed the significance of the heterogeneity.

* p<0.05 considered significant for the pooled effect estimates.

** P-heterogeneity <0.10 is considered significant

Abbreviations: CI, confidence interval; ES, effect size; I^2, Heterogeneity.

REFERENCES

1. Bandel I, Bungum M, Richtoff J, et al. No association between body mass index and sperm DNA integrity. *Hum Reprod*. 2015;30(7):1704-1713. doi:10.1093/humrep/dev111
2. Belloc S, Cohen-Bacrie M, Amar E, et al. High body mass index has a deleterious effect on semen parameters except morphology: Results from a large cohort study. *Fertil Steril*. 2014;102(5):1268-1273. doi:10.1016/j.fertnstert.2014.07.1212
3. Ma J, Wu L, Zhou Y, et al. Association between BMI and semen quality: An observational study of 3966 sperm donors. *Hum Reprod*. 2019;34(1):155-162. doi:10.1093/humrep/dey328
4. Qin DD, Yuan W, Zhou WJ, Cui YQ, Wu JQ, Gao ES. Do reproductive hormones explain the association between body mass index and semen quality? *Asian J Androl*. 2007;9(6):827-834. doi:10.1111/j.1745-7262.2007.00268.x
5. Shayeb AG, Harrild K, Mathers E, Bhattacharya S. An exploration of the association between male body mass index and semen quality. *Reprod Biomed Online*. 2011;23(6):717-723. doi:10.1016/j.rbmo.2011.07.018
6. Wang E-Y, Huang Y, Du Q-Y, Yao G-D, Sun Y-P. Body mass index effects sperm quality: a retrospective study in Northern China. *Asian J Androl*. 2017;19(2):234. doi:10.4103/1008-682x.169996
7. Alshahrani S, Ahmed AF, Gabr AH, Abalhassan M, Ahmad G. The impact of body mass index on semen parameters in infertile men. *Andrologia*. 2016;48(10):1125-1129. doi:10.1111/and.12549
8. Chavarro JE, Toth TL, Wright DL, Meeker JD, Hauser R. Body mass index in relation to semen quality, sperm DNA integrity, and serum reproductive hormone levels among men attending an infertility clinic. *Fertil Steril*. 2010;93(7):2222-2231. doi:10.1016/j.fertnstert.2009.01.100

9. Ehala-Aleksejev K, Punab M. The different surrogate measures of adiposity in relation to semen quality and serum reproductive hormone levels among Estonian fertile men. *Andrology*. 2015;3(2):225-234. doi:10.1111/andr.12002

10. Eisenberg ML, Kim S, Chen Z, Sundaram R, Schisterman EF, Buck Louis GM. The relationship between male BMI and waist circumference on semen quality: Data from the LIFE study. *Hum Reprod*. 2014;29(2):193-200. doi:10.1093/humrep/det428

11. Fariello RM, Pariz JR, Spaine DM, Cedenho AP, Bertolla RP, Fraietta R. Association between obesity and alteration of sperm DNA integrity and mitochondrial activity. *BJU Int*. 2012;110(6):863-867. doi:10.1111/j.1464-410X.2011.10813.x

12. Hammiche F, Laven JSE, Twigt JM, Boellaard WPA, Steegers EAP, Steegers-Theunissen RP. Body mass index and central adiposity are associated with sperm quality in men of subfertile couples. *Hum Reprod*. 2012;27(8):2365-2372. doi:10.1093/humrep/des177

13. Jensen TK, Andersson AM, Jørgensen N, et al. Body mass index in relation to semen quality and reproductive hormones among 1,558 Danish men. *Fertil Steril*. 2004;82(4):863-870. doi:10.1016/j.fertnstert.2004.03.056

14. Keskin MZ, Budak S, Aksoy EE, et al. Investigation of the effect of body mass index (BMI) on semen parameters and male reproductive system hormones. *Arch Ital di Urol e Androl*. 2017;89(3):219-221. doi:10.4081/aiua.2017.3.219

15. Luque EM, Tissera A, Gaggino MP, et al. Body mass index and human sperm quality: Neither one extreme nor the other. *Reprod Fertil Dev*. 2017;29(4):731-739. doi:10.1071/RD15351

16. Martini AC, Tissera A, Estofán D, et al. Overweight and seminal quality: A study of 794 patients. *Fertil Steril*. 2010;94(5):1739-1743. doi:10.1016/j.fertnstert.2009.11.017

17. Oliveira JBA, Petersen CG, Mauri AL, et al. Association between body mass index and sperm quality and sperm DNA integrity. A large

population study. *Andrologia*. 2018;50(3):1-10. doi:10.1111/and.12889

18. Ramírez N, Molina R, Tissera A, et al. Recategorisation of body mass index to achieve andrological predictive power: a study in more than 20,000 patients. *Reprod Fertil Dev*. 2020. doi:10.1071/RD19429

19. Rybar R, Kopecka V, Prinosilova P, Markova P, Rubes J. Male obesity and age in relationship to semen parameters and sperm chromatin integrity. *Andrologia*. 2011;43(4):286-291. doi:10.1111/j.1439-0272.2010.01057.x

20. Vignera S La, Condorelli RA, Vicari E, Calogero AE. Negative effect of increased body weight on sperm conventional and nonconventional flow cytometric sperm parameters. *J Androl*. 2012;33(1):53-58. doi:10.2164/jandrol.110.012120

21. Ferigolo PC, Ribeiro de Andrade MB, Camargo M, et al. Sperm functional aspects and enriched proteomic pathways of seminal plasma of adult men with obesity. *Andrology*. 2019;7(3):341-349. doi:10.1111/andr.12606

22. Aggerholm AS, Thulstrup AM, Toft G, Ramlau-Hansen CH, Bonde JP. Is overweight a risk factor for reduced semen quality and altered serum sex hormone profile? *Fertil Steril*. 2008;90(3):619-626. doi:10.1016/j.fertnstert.2007.07.1292

23. Andersen JM, Rønning PO, Herning H, Bekken SD, Haugen TB, Witczak O. Fatty acid composition of spermatozoa is associated with BMI and with semen quality. *Andrology*. 2016;4(5):857-865. doi:10.1111/andr.12227

24. Dupont C, Faure C, Sermondade N, et al. Obesity leads to higher risk of sperm DNA damage in infertile patients. *Asian J Androl*. 2013;15(5):622-625. doi:10.1038/aja.2013.65

25. Thomsen L, Humaidan P, Bungum L, Bungum M. The impact of male overweight on semen quality and outcome of assisted reproduction. *Asian J Androl*. 2014;16(5):787. doi:10.4103/1008-682x.133321

26. Hadjkacem Loukil L, Hadjkacem H, Bahloul A, Ayadi H. Relation between male obesity and male infertility in a Tunisian population. *Andrologia*. 2015;47(3):282-285. doi:10.1111/and.12257

27. Koloszár S, Fejes I, Závaczki Z, Daru J, Szöllosi J, Pál A. Effect of body weight on sperm concentration in normozoospermic males. *Arch Androl*. 2005;51(4):299-304. doi:10.1080/01485010590919701

28. Taha EA, Sayed SK, Gaber HD, et al. Does being overweight affect seminal variables in fertile men? *Reprod Biomed Online*. 2016;33(6):703-708. doi:10.1016/j.rbmo.2016.08.023

Supplemental Table 3. Characteristics of previous systematic reviews and meta-analysis on adiposity and seminogram parameters.

Author/ Year/ Journal	Included till year	No. of studies in the systematic review	No. of studies in the meta-analysis	Exposure comparison	Outcomes	Subgroup analysis	Quality evaluation of the studies included	Main conclusion	Main differences with our meta-analysis	Limitations
(MacDonald et al., 2009)[1] **Human Reproduction Update**	2009	31	5	Normal weight versus underweight, overweight and obesity	Semen volume, sperm count, concentration, motility and morphology	No	No	No evidence of an association between increased BMI and semen parameters was found.	OR instead of SE.	Old WHO BMI classification used. Data from most studies could not be aggregated for meta-analysis.
(Sermondade et al., 2013)[2] **Human Reproduction Update**	2012	44	21 + personal data	Normal weight versus underweight, overweight, obesity and morbid obesity	Sperm count	No	No	Overweight and obesity were associated with an increased prevalence of azoospermia or oligozoospermia. There was a J-shaped relationship between BMI categories and risk of oligozoospermia or azoospermia.	OR instead of SE.	Studied populations varied, with men recruited from both the general population and infertile couples.
(Campbell et al., 2015)[3] **Reproductive BioMedcine Online**	2015	30	13	Normal weight versus obesity	Semen volume, sperm concentration, total and progressive motility and	Clinical population and general population	Yes. JBI checklist for descriptive studies	Men with obesity had an increased percentage of sperm with abnormal morphology (in the clinical ART	Only obese population comparison.	Studied populations varied, with men recruited from both the general

					morphology			population) and less progressive motility indexes (in the general population). Clinically significant differences were not found for other conventional semen parameters.		population and clinical population
(Guo et al., 2017)[4] Oncotarget	2015	24 + personal data	24 + personal data	Normal weight versus underweight, overweight and obesity	Semen volume, sperm concentration, total and progressive motility	Ethnicity	No	SWM differences in sperm concentration did not differ significantly across BMI categories.	No sperm normal morphology analysis.	Methods poor explained. The use of different boundaries for normal, overweight and obese in Chinese studies was different from others, which may affect the final results.
(Guo et al., 2019)[5] Medicine	2017	13	13	Normal weight versus underweight	Semen volume, sperm concentration, total and progressive motility	Ethnicity	No	There was a relationship between low BMI and semen quality (total sperm count and semen volume), which suggesting low BMI may be a harmful factor of male infertility.	Only underweight population. No morphology analysis.	Yet lacking of the raw data may influence the accuracy of the results. No limitations paragraph.

Abbreviations: ART, assisted reproductive technologies; BMI, body mass index; ES, effect size; OR, odds ratio; SWM, standardized weighted mean.

REFERENCES

1. MacDonald AA, Herbison GP, Showell M, Farquhar CM. The impact of body mass index on semen parameters and reproductive hormones in human males: A systematic review with meta-analysis. *Hum Reprod Update*. 2009;16(3):293-311. doi:10.1093/humupd/dmp047

2. Sermondade N, Faure C, Fezeu L, et al. BMI in relation to sperm count: An updated systematic review and collaborative meta-analysis. *Hum Reprod Update*. 2013;19(3):221-231. doi:10.1093/humupd/dms050

3. Campbell JM, Lane M, Owens JA, Bakos HW. Paternal obesity negatively affects male fertility and assisted reproduction outcomes: A systematic review and meta-analysis. *Reprod Biomed Online*. 2015;31(5):593-604. doi:10.1016/j.rbmo.2015.07.012

4. Guo D, Wu W, Tang Q, et al. The impact of BMI on sperm parameters and the metabolite changes of seminal plasma concomitantly. *Oncotarget*. 2017;8(30):48619-48634. doi:10.18632/oncotarget.14950

5. Guo D, Xu M, Zhou Q, et al. Is low body mass index a risk factor for semen quality? A PRISMA-compliant meta-analysis. *Med (United States)*. 2019;98(32). doi:10.1097/MD.0000000000016677

Supplemental Appendix 1. Search strategy for the literature published between the earliest available online indexing year and June 2019 in MEDLINE-Pubmed and EMBASE databases.

1. MEDLINE-Pubmed

1.1. Search terms:

((((((((((("infertility, male"[MeSH Terms]) OR asthenozoospermia[Title/Abstract]) OR oligozoospermia[Title/Abstract]) OR oligoasthenozoospermia[Title/Abstract]) OR oligoasthenoteratozoospermia[Title/Abstract]) OR teratozoospermia[Title/Abstract]) OR spermatogenesis[Title/Abstract]) OR semen quality[Title/Abstract]) OR sperm DNA damage[Title/Abstract]) OR varicocele[Title/Abstract])) AND ((((((((("obesity"[MeSH Terms]) OR abdominal obesity[Title/Abstract]) OR metabolic syndorme[Title/Abstract]) OR overweight[Title/Abstract]) OR Body mass index[Title/Abstract]) OR BMI[Title/Abstract]) OR body weight[Title/Abstract]) OR Fat mass[Title/Abstract]) OR body fat[Title/Abstract])

1.2. Inclusion filters:

Classical Article, Clinical Study, Clinical Trial, Clinical Trial, Phase I, Clinical Trial, Phase II, Clinical Trial, Phase III, Clinical Trial, Phase IV, Comparative Study, Controlled Clinical Trial, Corrected and Republished Article, English Abstract, Journal Article, Multicenter Study, Observational Study, Randomized Controlled Trial, Humans, English, Male.

2. EMBASE

2.1. Search terms:

('male infertility' OR asthenozoospermia:ab,ti OR oligozoospermia:ab,ti OR oligoasthenozoospermia:ab,ti OR oligoasthenoteratozoospermia:ab,ti OR teratozoospermia:ab,ti OR spermatogenesis:ab,ti OR 'semen quality':ab,ti OR 'sperm dna damage':ab,ti OR varicocele:ab,ti) AND (obesity OR 'abdominal obesity':ab,ti OR 'metabolic syndorme':ab,ti OR overweight:ab,ti OR 'body mass index':ab,ti OR bmi:ab,ti OR 'body weight':ab,ti OR 'fat mass':ab,ti OR 'body fat':ab,ti)

2.2. Inclusion filters:

('case control study'/de OR 'clinical article'/de OR 'clinical study'/de OR 'clinical trial'/de OR 'cohort analysis'/de OR 'comparative study'/de OR 'control group'/de OR 'controlled clinical trial'/de OR 'controlled study'/de OR 'cross-sectional study'/de OR 'human'/de OR 'human cell'/de OR 'human experiment'/de OR 'human tissue'/de OR 'in vivo study'/de OR 'longitudinal study'/de OR 'major clinical study'/de OR 'multicenter study'/de OR 'normal human'/de OR 'observational study'/de OR 'prospective study'/de OR 'randomized controlled trial'/de OR 'randomized controlled trial (topic)'/de OR 'retrospective study'/de) AND [male]/lim AND ('article'/it OR 'article in press'/it OR 'chapter'/it OR 'conference abstract'/it OR 'conference paper'/it)

Semen volume_BMI_Underweight vs. Normal

Meta-analysis model	
Model	Random effects model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

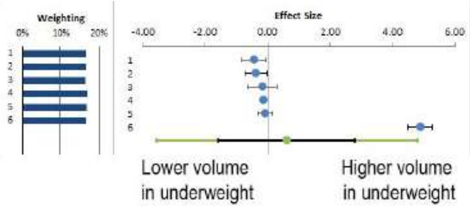
Combined Effect Size	
Effect Size	0.61
Standard error	0.85
CI Lower limit	-1.59
CI Upper limit	2.81
PI Lower limit	-3.58
PI Upper limit	4.80

Z-value	0.71
One-tailed p-value	0.238
Two-tailed p-value	0.476

Number of incl. studies	6

Heterogeneity	
Q	606.24
p_Q	0.000
I^2	99.18%
T^2	1.93
T	1.39

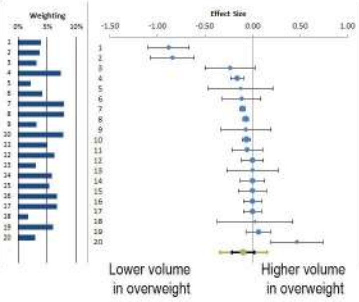
#	Study name	Sample size normal	Sample size underweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Bandel et al. 2015	905	27	-0.44	-0.82	-0.05	16.60%
2	Belloc et al. 2014	5799	27	-0.38	-0.72	-0.03	16.67%
3	Shayeb et al. 2011	839	18	-0.17	-0.63	0.30	16.44%
4	Ma et al. 2019	22762	1815	-0.14	-0.19	-0.09	16.92%
5	Wang et al. 2017	1398	68	-0.08	-0.33	0.16	16.79%
6	Qin et al. 2007	690	732	4.89	4.49	5.29	16.57%

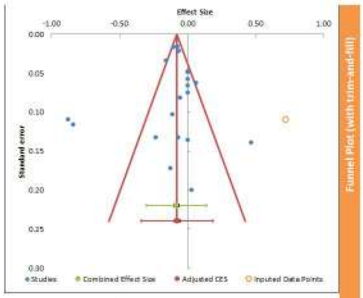


Semen volume_BMI_Overweight vs. Normal

Meta-analysis model	
Model	Random effects model
Confidence level	95%
Presentation	
Sort By	Effect Size
Order	Ascending
Combined Effect Size	
Effect Size	-0.10
Standard error	0.06
CI Lower limit	-0.21
CI Upper limit	0.02
PI Lower limit	-0.35
PI Upper limit	0.15
Z-value	-1.73
One-tailed p-value	0.041
Two-tailed p-value	0.083
Number of incl. studies	20
Heterogeneity	
Q	138.52
p_Q	0.000
I^2	86.28%
T^2	0.01
T	0.11

#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Hammiche et al. 2012	153	225	-0,88	-1,10	-0,66	3,86%
2	Chavarro et al. 2010	123	233	-0,84	-1,07	-0,61	3,64%
3	Eisenberg et al. 2014	83	191	-0,24	-0,50	0,02	3,13%
4	Luque et al. 2017	1339	2493	-0,16	-0,23	-0,09	7,27%
5	Rybar et al. 2011	74	63	-0,12	-0,46	0,22	2,20%
6	Keskin et al. 2017	165	222	-0,11	-0,31	0,09	4,11%
7	Ramirez et al. 2020	5894	10196	-0,11	-0,14	-0,07	7,83%
8	Ma et al. 2019	22762	5070	-0,07	-0,10	-0,04	7,85%
9	Fariello et al. 2012	82	187	-0,07	-0,33	0,19	3,11%
10	Belloc et al. 2014	5799	3607	-0,06	-0,11	-0,02	7,71%
11	Martini et al. 2010	251	388	-0,05	-0,21	0,10	5,05%
12	Bandel et al. 2015	905	456	0,00	-0,11	0,11	6,19%
13	Ehala-Aleksejev et al. 2015	127	95	0,00	-0,27	0,27	3,03%
14	Jensen et al. 2004	1042	299	0,00	-0,13	0,13	5,78%
15	Qin et al. 2007	690	241	0,00	-0,15	0,15	5,34%
16	Shayeb et al. 2011	839	909	0,00	-0,09	0,09	6,65%
17	Wang et al. 2017	1398	620	0,00	-0,09	0,09	6,63%
18	Vignera et al. 2012	50	50	0,03	-0,37	0,42	1,75%
19	Oliveira et al. 2018	370	856	0,06	-0,06	0,19	5,95%
20	Alshahrani et al. 2016	75	179	0,47	0,19	0,74	2,93%





Heterogeneity	Adjusted
Q	192.52
p_Q	0.000
I^2	89.61%
T^2	0.02
T	0.13

Combined effect size	Adjusted
Effect Size	-0.08
SE	0.01
CI Lower limit	-0.10
CI Upper limit	-0.06
PI Lower limit	-0.34
PI Upper limit	0.19

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	1

Semen volume_BMI_Obese (or obese I) vs. Normal

Meta-analysis model	
Model	Random effects model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

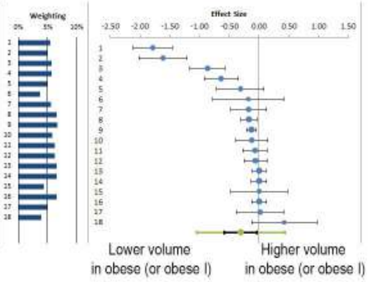
Combined Effect Size	
Effect Size	-0.31
Standard error	0.13
CI Lower limit	-0.58
CI Upper limit	-0.03
PI Lower limit	-1.05
PI Upper limit	0.43

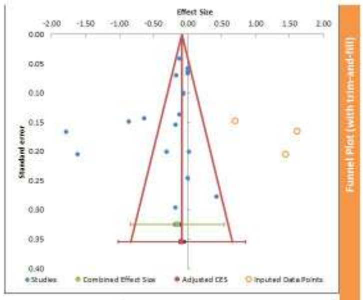
Z-value	-2.37
One-tailed p-value	0.009
Two-tailed p-value	0.018

Number of incl. studies	18

Heterogeneity	
Q	208.16
P_Q	0.000
I^2	91.83%
T^2	0.11
T	0.33

#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Hammiche et al. 2012	153	72	-1.79	-2.11	-1.46	5.40%
2	Ehala-Aleksejev et al. 2015	127	38	-1.61	-2.02	-1.21	4.87%
3	Eisenberg et al. 2014	83	122	-0.87	-1.16	-0.58	5.62%
4	Chavarro et al. 2010	123	87	-0.64	-0.92	-0.35	5.69%
5	Fariello et al. 2012	82	36	-0.31	-0.71	0.09	4.92%
6	Ferigolo et al. 2019	20	27	-0.18	-0.78	0.41	3.73%
7	Keskin et al. 2017	165	56	-0.18	-0.48	0.13	5.54%
8	Shayeb et al. 2011	839	269	-0.17	-0.31	-0.03	6.49%
9	Belloc et al. 2014	5799	634	-0.13	-0.21	-0.04	6.68%
10	Alshahrani et al. 2016	75	185	-0.12	-0.39	0.15	5.77%
11	Martini et al. 2010	251	155	-0.07	-0.27	0.13	6.19%
12	Bandel et al. 2015	905	115	-0.06	-0.26	0.13	6.22%
13	Ma et al. 2019	22762	302	0.00	-0.11	0.11	6.59%
14	Oliveira et al. 2018	370	598	0.00	-0.13	0.13	6.53%
15	Qin et al. 2007	690	17	0.00	-0.48	0.48	4.34%
16	Wang et al. 2017	1398	298	0.00	-0.13	0.13	6.54%
17	Vignera et al. 2012	50	50	0.02	-0.38	0.42	4.94%
18	Rybar et al. 2011	74	16	0.42	-0.13	0.98	3.94%





Heterogeneity	Adjusted
Q	405.13
P_Q	0.000
I^2	95.06%
T^2	0.20
T	0.45

Combined effect size	Adjusted
Effect Size	-0.08
SE	0.02
CI Lower limit	-0.13
CI Upper limit	-0.04
PI Lower limit	-1.02
PI Upper limit	0.85

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	3

Semen volume_BMI_Obese II (or more) vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

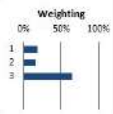
Combined Effect Size	
Effect Size	-0.72
Standard error	0.08
CI Lower limit	-1.07
CI Upper limit	-0.36
PI Lower limit	-5.02
PI Upper limit	3.59

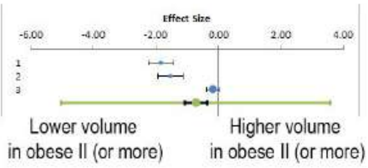
Z-value	-8.71
One-tailed p-value	0.000
Two-tailed p-value	0.000

Number of incl. studies	3

Heterogeneity	
Q	77.76
p_Q	0.000
I^2	97.43%
T^2	0.99
T	1.00

#	Study name	Sample size normal	Sample size obese II (or more)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Eisenberg et al. 2014	83	72	-1.84	-2.21	-1.46	18.36%
2	Chavarro et al. 2010	123	40	-1.54	-1.93	-1.14	16.81%
3	Belloc et al. 2014	5799	97	-0.19	-0.39	0.01	64.83%





Semen volume_BMI_Obese III vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

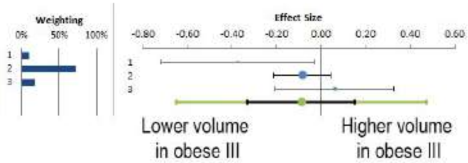
Combined Effect Size	
Effect Size	-0.09
Standard error	0.06
CI Lower limit	-0.33
CI Upper limit	0.15
PI Lower limit	-0.65
PI Upper limit	0.47

Z-value	-1.58
One-tailed p-value	0.057
Two-tailed p-value	0.114

Number of incl. studies	3

Heterogeneity	
Q	3.93
p_Q	0.140
I^2	49.14%
T^2	0.01
T	0.12

#	Study name	Sample size normal	Sample size obese III	Effect size	CI Lower limit	CI Upper limit	Weight
1	Belloc et al. 2014	5799	33	-0,38	-0,72	-0,03	10,19%
2	Ramirez et al. 2020	5894	244	-0,08	-0,21	0,05	72,83%
3	Luque et al. 2017	1339	57	0,06	-0,20	0,33	16,99%



Sperm count_BMI_Underweight vs. Normal

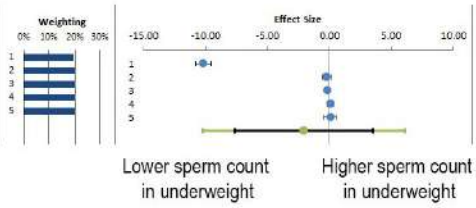
Meta-analysis model	
Model	Random effects model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

Combined Effect Size	
Effect Size	-2.07
Standard error	2.02
CI Lower limit	-7.68
CI Upper limit	3.55
PI Lower limit	-10.23
PI Upper limit	6.09
Z-value	-1.02
One-tailed p-value	0.153
Two-tailed p-value	0.307
Number of incl. studies	5

Heterogeneity	
Q	1043.18
p_Q	0.000
I^2	99.62%
T^2	4.55
T	2.13

#	Study name	Sample size normal	Sample size underweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Qin et al. 2007	690	42	-10.21	-10.82	-9.60	19.76%
2	Belloc et al. 2014	5799	27	-0.22	-0.60	0.15	20.02%
3	Ma et al. 2019	22762	1815	-0.18	-0.23	-0.13	20.18%
4	Wang et al. 2017	1398	68	0.08	-0.16	0.32	20.11%
5	Shayeb et al. 2011	839	18	0.08	-0.38	0.55	19.93%



Sperm count_BMI_Overweight vs. Normal

Meta-analysis model	
Model	Random effects model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

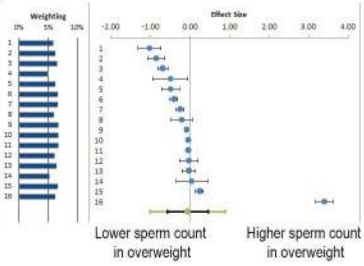
Combined Effect Size	
Effect Size	-0.05
Standard error	0.25
CI Lower limit	-0.57
CI Upper limit	0.47
PI Lower limit	-1.01
PI Upper limit	0.91

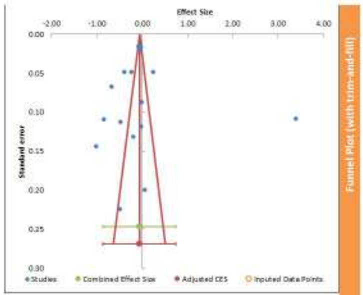
Z-value	-0.20
One-tailed p-value	0.420
Two-tailed p-value	0.840

Number of incl. studies	16

Heterogeneity	
Q	1322.47
P_Q	0.000
I^2	98.87%
T^2	0.14
T	0.38

#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Enala-Alekseiev et al. 2015	127	95	-1,02	-1,30	-0,73	5,89%
2	Hammiche et al. 2012	153	225	-0,85	-1,06	-0,63	6,22%
3	Jensen et al. 2004	1042	299	-0,68	-0,81	-0,55	6,54%
4	Andersen et al. 2016	40	42	-0,49	-0,93	-0,04	4,98%
5	Chavarro et al. 2010	123	233	-0,49	-0,71	-0,26	6,19%
6	Aggerholm et al. 2008	986	773	-0,40	-0,49	-0,30	6,64%
7	Wang et al. 2017	1398	620	-0,24	-0,34	-0,15	6,64%
8	Eisenberg et al. 2014	83	191	-0,20	-0,46	0,06	6,01%
9	Ma et al. 2019	22762	5070	-0,08	-0,11	-0,05	6,74%
10	Belloc et al. 2014	5799	3607	-0,05	-0,09	0,00	6,73%
11	Ramirez et al. 2020	5894	10196	-0,03	-0,07	0,00	6,73%
12	Dupont et al. 2013	151	137	-0,03	-0,26	0,21	6,15%
13	Thomsen et al. 2014	259	268	-0,02	-0,19	0,15	6,41%
14	Vignera et al. 2012	50	50	0,05	-0,35	0,45	5,26%
15	Shayeb et al. 2011	839	909	0,24	0,15	0,34	6,64%
16	Qin et al. 2007	690	241	3,40	3,18	3,61	6,23%





Heterogeneity	Adjusted
Q	1322.47
P_Q	0.000
I^2	98.87%
T^2	0.14
T	0.38

Combined effect size	Adjusted
Effect Size	-0.06
SE	0.01
CI Lower limit	-0.08
CI Upper limit	-0.04
PI Lower limit	-0.87
PI Upper limit	0.74

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	0

Sperm count_BMI_Obese (or obese I) vs. Normal

Meta-analysis model	
Model	Random effects model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

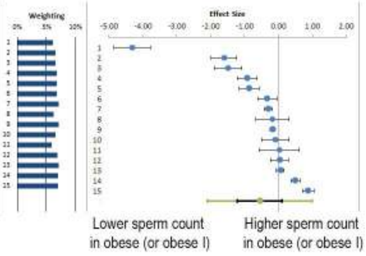
Combined Effect Size	
Effect Size	-0.55
Standard error	0.31
CI Lower limit	-1.21
CI Upper limit	0.11
PI Lower limit	-2.10
PI Upper limit	0.99

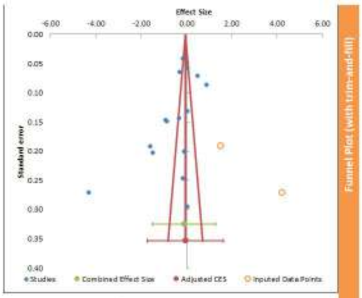
Z-value	-1.80
One-tailed p-value	0.036
Two-tailed p-value	0.072

Number of incl. studies	15

Heterogeneity	
Q	629.03
P_Q	0.000
I^2	97.77%
T^2	0.42
T	0.65

#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Qin et al. 2007	690	17	-4.32	-4.85	-3.78	6.06%
2	Dupont et al. 2013	123	87	-1.60	-1.98	-1.23	6.54%
3	Ehala-Aleksejev et al. 2015	127	38	-1.49	-1.89	-1.09	6.48%
4	Chavarro et al. 2010	123	87	-0.92	-1.21	-0.63	6.76%
5	Hammiche et al. 2012	153	72	-0.86	-1.15	-0.57	6.76%
6	Eisenberg et al. 2014	83	122	-0.34	-0.62	-0.05	6.78%
7	Wang et al. 2017	1398	298	-0.30	-0.43	-0.18	7.04%
8	Andersen et al. 2016	40	28	-0.18	-0.67	0.31	6.21%
9	Belloc et al. 2014	5799	634	-0.18	-0.26	-0.09	7.08%
10	Vignera et al. 2012	50	50	-0.10	-0.49	0.30	6.49%
11	Ferigolo et al. 2019	20	27	0.02	-0.57	0.62	5.90%
12	Thomsen et al. 2014	259	74	0.03	-0.23	0.29	6.83%
13	Ma et al. 2019	22762	1815	0.05	-0.07	0.16	7.05%
14	Shayeb et al. 2011	839	269	0.50	0.36	0.64	7.03%
15	Aggerholm et al. 2008	866	163	0.87	0.70	1.04	6.99%





Heterogeneity	Adjusted
Q	948.68
P_Q	0.000
I^2	98.31%
T^2	0.62
T	0.79

Combined effect size	Adjusted
Effect Size	-0.05
SE	0.02
CI Lower limit	-0.10
CI Upper limit	0.00
PI Lower limit	-1.72
PI Upper limit	1.62

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	2

Sperm count_BMI_Obese II (or more) vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

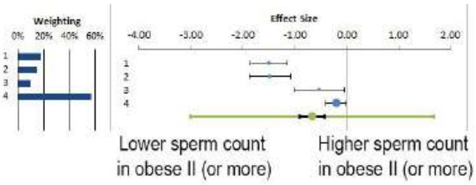
Combined Effect Size	
Effect Size	-0.66
Standard error	0.08
CI Lower limit	-0.91
CI Upper limit	-0.42
PI Lower limit	-3.01
PI Upper limit	1.68

Z-value	-8.57
One-tailed p-value	0.000
Two-tailed p-value	0.000

Number of incl. studies	4

Heterogeneity	
Q	58.05
p_Q	0.000
I^2	94.83%
T^2	0.54
T	0.73

#	Study name	Sample size normal	Sample size obese II (or more)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Eisenberg et al. 2014	83	72	-1.50	-1.86	-1.14	17.93%
2	Chavarro et al. 2010	123	40	-1.48	-1.88	-1.09	14.94%
3	Andersen et al. 2016	40	32	-0.53	-1.01	-0.05	10.24%
4	Belloc et al. 2014	5799	97	-0.21	-0.41	-0.01	56.89%



Sperm count_BMI_Obese III vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

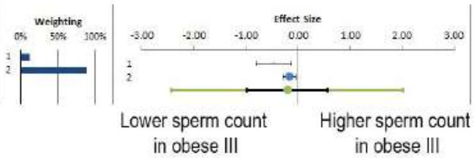
Combined Effect Size	
Effect Size	-0.20
Standard error	0.06
CI Lower limit	-0.98
CI Upper limit	0.57
PI Lower limit	-2.43
PI Upper limit	2.03

Z-value	-3.34
One-tailed p-value	0.000
Two-tailed p-value	0.001

Number of incl. studies	2

Heterogeneity	
Q	2.56
p_Q	0.110
I^2	60.90%
T^2	0.03
T	0.16

#	Study name	Sample size normal	Sample size obese III	Effect size	CI Lower limit	CI Upper limit	Weight
1	Belloc et al. 2014	5799	33	-0.47	-0.81	-0.12	12.27%
2	Ramírez et al. 2020	5894	244	-0.17	-0.30	-0.04	87.73%



Sperm concentration_BMI_Underweight vs. Normal

Meta-analysis model	
Model	Random effects model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

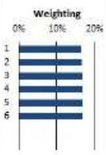
Combined Effect Size	
Effect Size	-2.29
Standard error	2.28
CI Lower limit	-8.14
CI Upper limit	3.56
PI Lower limit	-10.27
PI Upper limit	5.69

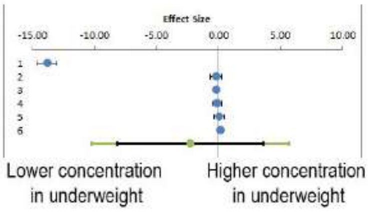
Z-value	-1.00
One-tailed p-value	0.157
Two-tailed p-value	0.315

Number of incl. studies	6

Heterogeneity	
Q	1205.28
p_Q	0.000
I^2	99.59%
T^2	4.45
T	2.11

#	Study name	Sample size normal	Sample size underweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Qin et al. 2007	690	42	-13.83	-14.60	-13.05	15.28%
2	Shayeb et al. 2011	839	18	-0.19	-0.66	0.28	16.64%
3	Ma et al. 2019	22762	1815	-0.14	-0.19	-0.09	16.85%
4	Belloc et al. 2014	40	32	-0.13	-0.50	0.25	16.71%
5	Bandel et al. 2015	905	27	0.06	-0.32	0.45	16.71%
6	Wang et al. 2017	1398	68	0.17	-0.07	0.42	16.80%





Sperm concentration_BMI_Overweight vs. Normal

Meta-analysis model	
Model	Random effects model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

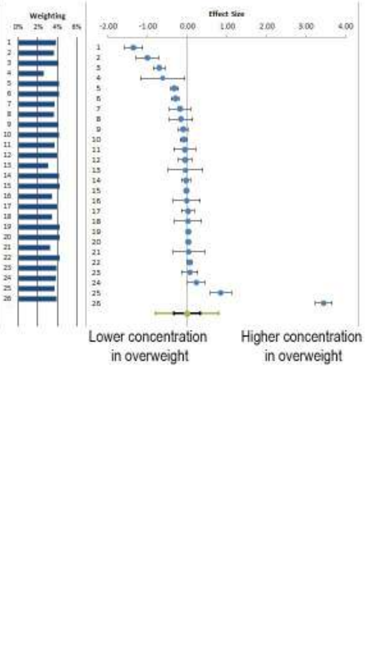
Combined Effect Size	
Effect Size	-0.01
Standard error	0.16
CI Lower limit	-0.34
CI Upper limit	0.32
PI Lower limit	-0.80
PI Upper limit	0.79

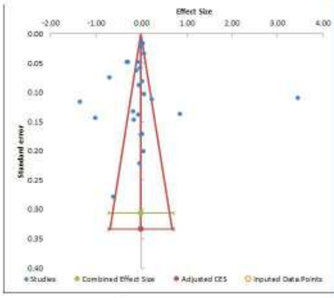
Z-value	-0.05
One-tailed p-value	0.481
Two-tailed p-value	0.962

Number of incl. studies	26

Heterogeneity	
Q	1419.18
P_Q	0.000
I^2	98.24%
T^2	0.12
T	0.35

#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Hammiche et al. 2012	153	225	-1,36	-1,59	-1,13	3,86%
2	Ehala-Aleksejev et al. 2015	127	95	-1,01	-1,29	-0,73	3,66%
3	Jensen et al. 2004	1042	299	-0,71	-0,86	-0,57	4,09%
4	Hadjkacem-Loukil et al. 2015	77	16	-0,62	-1,17	-0,06	2,62%
5	Wang et al. 2017	1398	620	-0,33	-0,42	-0,23	4,20%
6	Aggerholm et al. 2008	866	773	-0,30	-0,40	-0,21	4,20%
7	Fariello et al. 2012	82	187	-0,18	-0,45	0,08	3,74%
8	Koloszar et al. 2005	96	91	-0,16	-0,45	0,13	3,64%
9	Oliveira et al. 2018	370	856	-0,11	-0,23	0,01	4,15%
10	Shayeb et al. 2011	839	909	-0,09	-0,18	0,01	4,20%
11	Alshahrani et al. 2016	75	179	-0,06	-0,34	0,21	3,71%
12	Thomsen et al. 2014	259	268	-0,05	-0,22	0,12	4,03%
13	Andersen et al. 2016	40	42	-0,05	-0,49	0,39	3,06%
14	Bandel et al. 2015	905	456	-0,03	-0,14	0,08	4,17%
15	Belloc et al. 2014	5799	3607	-0,02	-0,06	0,02	4,26%
16	Rybar et al. 2011	74	63	-0,01	-0,35	0,33	3,45%
17	Martini et al. 2010	251	388	0,01	-0,14	0,17	4,06%
18	Taha et al. 2016	81	59	0,02	-0,32	0,36	3,46%
19	Ma et al. 2019	22762	5070	0,02	-0,01	0,05	4,27%
20	Ramirez et al. 2020	5894	10196	0,03	0,00	0,06	4,27%
21	Vignera et al. 2012	50	50	0,04	-0,36	0,43	3,23%
22	Luque et al. 2017	1339	2493	0,06	-0,01	0,12	4,24%
23	Keskin et al. 2017	165	222	0,06	-0,14	0,26	3,94%
24	Chavarro et al. 2010	123	235	0,22	0,00	0,44	3,88%
25	Eisenberg et al. 2014	83	191	0,84	0,57	1,11	3,72%
26	Qin et al. 2007	890	241	3,44	3,23	3,66	3,00%





Funnel Plot (with trim-and-fill)

Heterogeneity	Adjusted
Q	1419.18
P_Q	0.000
I^2	98.24%
T^2	0.12
T	0.35

Combined effect size	Adjusted
Effect Size	-0.01
SE	0.01
CI Lower limit	-0.03
CI Upper limit	0.01
PI Lower limit	-0.73
PI Upper limit	0.71

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	0

Sperm concentration_BMI_Obese (or obese I) vs. Normal

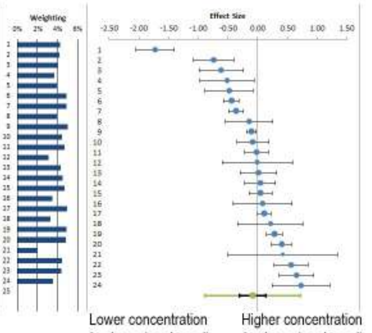
Meta-analysis model	
Model	Random effects model
Confidence level	95%

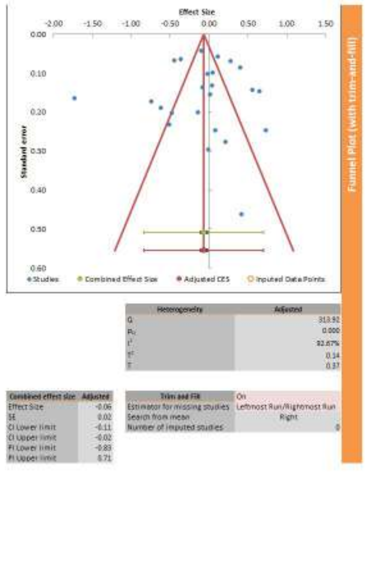
Presentation	
Sort By	Effect Size
Order	Ascending

Combined Effect Size	
Effect Size	-0.08
Standard error	0.11
CI Lower limit	-0.30
CI Upper limit	0.14
PI Lower limit	-0.88
PI Upper limit	0.72
Z-value	-0.76
One-tailed p-value	0.224
Two-tailed p-value	0.449
Number of incl. studies	24

Heterogeneity	
Q	313.92
P_Q	0.000
I^2	92.67%
T^2	0.14
T	0.37

#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Hammiche et al. 2012	153	72	-1.73	-2.05	-1.41	4.22%
2	Koloszar et al. 2005	96	58	-0.74	-1.08	-0.40	4.16%
3	Ehala-Aleksejev et al. 2015	127	38	-0.62	-0.99	-0.25	4.02%
4	Taha et al. 2016	81	25	-0.51	-0.97	-0.05	3.64%
5	Fariello et al. 2012	82	36	-0.48	-0.88	-0.08	3.89%
6	Oliveira et al. 2018	370	598	-0.44	-0.58	-0.31	4.89%
7	Wang et al. 2017	1398	298	-0.36	-0.49	-0.24	4.90%
8	Vignera et al. 2012	50	50	-0.15	-0.54	0.25	3.91%
9	Belloc et al. 2014	5799	634	-0.10	-0.19	-0.02	4.98%
10	Alshahrani et al. 2016	75	185	-0.08	-0.35	0.19	4.45%
11	Martini et al. 2010	251	156	-0.02	-0.22	0.18	4.69%
12	Ferigolo et al. 2019	20	27	-0.01	-0.60	0.59	3.10%
13	Keskin et al. 2017	165	56	0.01	-0.29	0.32	4.30%
14	Thomsen et al. 2014	259	74	0.04	-0.22	0.30	4.48%
15	Bandel et al. 2015	905	115	0.05	-0.15	0.24	4.71%
16	Andersen et al. 2016	40	28	0.08	-0.41	0.57	3.51%
17	Ma et al. 2019	22762	302	0.11	0.00	0.23	4.93%
18	Rybar et al. 2011	74	16	0.21	-0.33	0.76	3.25%
19	Shayeb et al. 2011	839	269	0.28	0.15	0.41	4.88%
20	Aggerholm et al. 2008	866	163	0.41	0.24	0.57	4.80%
21	Hadjkacem-Loukil et al. 2015	77	5	0.42	-0.50	1.34	1.98%
22	Chavarro et al. 2010	123	87	0.56	0.28	0.84	4.40%
23	Eisenberg et al. 2014	83	122	0.65	0.36	0.94	4.37%
24	Qin et al. 2007	370	598	0.73	0.25	1.21	3.51%





Heterogeneity	Adjusted
Q	313.92
P_Q	0.000
I^2	92.67%
T^2	0.14
T	0.37

Combined effect size	Adjusted
Effect Size	-0.06
SE	0.02
CI Lower limit	-0.11
CI Upper limit	-0.02
PI Lower limit	-0.83
PI Upper limit	0.71

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	0

Sperm concentration_BMI_Obese II (or more) vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

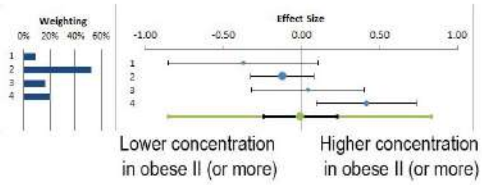
Combined Effect Size	
Effect Size	-0.01
Standard error	0.07
CI Lower limit	-0.24
CI Upper limit	0.23
PI Lower limit	-0.85
PI Upper limit	0.84

Z-value	-0.08
One-tailed p-value	0.468
Two-tailed p-value	0.935

Number of incl. studies	4

Heterogeneity	
Q	10.47
p_Q	0.015
I^2	71.34%
T^2	0.06
T	0.25

#	Study name	Sample size normal	Sample size obese II (or more)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Andersen et al. 2016	40	72	-0.37	-0.85	0.11	9.67%
2	Belloc et al. 2014	5799	97	-0.12	-0.32	0.08	52.76%
3	Chavarro et al. 2010	123	40	0.04	-0.32	0.40	16.70%
4	Eisenberg et al. 2014	83	72	0.42	0.10	0.74	20.87%



Sperm concentration_BMI_Obese III vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

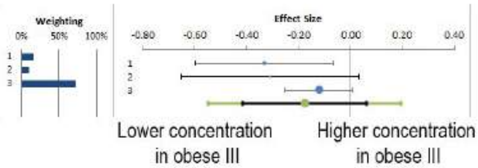
Combined Effect Size	
Effect Size	-0.18
Standard error	0.06
CI Lower limit	-0.42
CI Upper limit	0.06
PI Lower limit	-0.55
PI Upper limit	0.20

Z-value	-3.17
One-tailed p-value	0.001
Two-tailed p-value	0.002

Number of incl. studies	3

Heterogeneity	
Q	2.61
p_Q	0.272
I^2	23.23%
T^2	0.00
T	0.07

#	Study name	Sample size normal	Sample size obese III	Effect size	CI Lower limit	CI Upper limit	Weight
1	Luque et al. 2017	1339	57	-0,33	-0,60	-0,07	16,95%
2	Belloc et al. 2014	5799	33	-0,31	-0,65	0,03	10,19%
3	Ramirez et al. 2020	5894	244	-0,12	-0,25	0,01	72,86%



Sperm vitality_BMI_Overweight vs. Normal

Meta-analysis model	
Model	Random effects model
Confidence level	95%

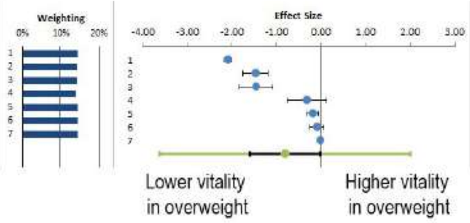
Presentation	
Sort By	Effect Size
Order	Ascending

Combined Effect Size	
Effect Size	-0.81
Standard error	0.32
CI Lower limit	-1.59
CI Upper limit	-0.03
PI Lower limit	-3.63
PI Upper limit	2.02

Z-value	-2.53
One-tailed p-value	0.006
Two-tailed p-value	0.012
Number of incl. studies	7

Heterogeneity	
Q	2077.46
p_Q	0.000
I^2	99.71%
T^2	1.23
T	1.11

#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Luque et al. 2017	1339	2493	-2,09	-2,17	-2,00	14,46%
2	Eisenberg et al. 2014	83	191	-1,48	-1,76	-1,19	14,24%
3	Taha et al. 2016	81	59	-1,46	-1,84	-1,08	14,06%
4	Andersen et al. 2016	40	42	-0,31	-0,75	0,13	13,92%
5	Oliveira et al. 2018	370	856	-0,20	-0,32	-0,07	14,44%
6	Martini et al. 2010	251	388	-0,09	-0,25	0,07	14,41%
7	Belloc et al. 2014	5799	3607	-0,02	-0,07	0,02	14,48%



Sperm vitality_BMI_Obese (or obese I) vs. Normal

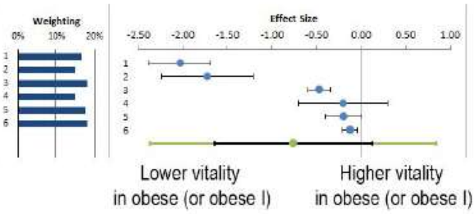
Meta-analysis model	
Model	Random effects model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

Combined Effect Size	
Effect Size	-0.76
Standard error	0.35
CI Lower limit	-1.65
CI Upper limit	0.13
PI Lower limit	-2.37
PI Upper limit	0.85
Z-value	-2.21
One-tailed p-value	0.014
Two-tailed p-value	0.027
Number of incl. studies	6

Heterogeneity	
Q	154.25
P_Q	0.000
I^2	96.76%
T^2	0.27
T	0.52

#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Eisenberg et al. 2014	83	122	-2.03	-2.38	-1.69	16.49%
2	Taha et al. 2016	81	25	-1.73	-2.24	-1.21	14.72%
3	Oliveira et al. 2018	370	598	-0.47	-0.60	-0.34	18.03%
4	Andersen et al. 2016	40	27	-0.20	-0.70	0.30	14.91%
5	Martini et al. 2010	251	155	-0.20	-0.40	0.01	17.65%
6	Belloc et al. 2014	5799	634	-0.13	-0.21	-0.04	18.21%



Sperm vitality_BMI_Obese II (or more) vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

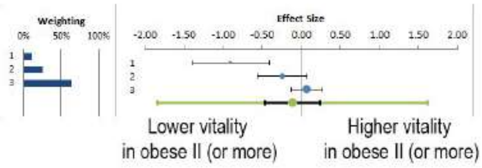
Combined Effect Size	
Effect Size	-0.11
Standard error	0.08
CI Lower limit	-0.46
CI Upper limit	0.24
PI Lower limit	-1.84
PI Upper limit	1.61

Z-value	-1.38
One-tailed p-value	0.083
Two-tailed p-value	0.167

Number of incl. studies	3

Heterogeneity	
Q	13.96
p_Q	0.001
I^2	85.67%
T^2	0.15
T	0.39

#	Study name	Sample size normal	Sample size obese II (or more)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Andersen et al. 2016	40	32	-0.90	-1.40	-0.41	10.76%
2	Eisenberg et al. 2014	83	72	-0.24	-0.56	0.08	25.57%
3	Belloc et al. 2014	5799	97	0.07	-0.13	0.27	63.67%



Sperm vitality_BMI_Obese III vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

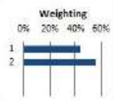
Combined Effect Size	
Effect Size	-3.16
Standard error	0.13
CI Lower limit	-4.82
CI Upper limit	-1.51
PI Lower limit	-72.77
PI Upper limit	66.44

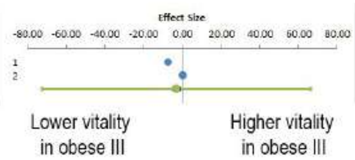
Z-value	-24.27
One-tailed p-value	0.000
Two-tailed p-value	0.000

Number of incl. studies	2

Heterogeneity	
Q	872.60
p_Q	0.000
I^2	99.89%
T^2	29.99
T	5.48

#	Study name	Sample size normal	Sample size obese III	Effect size	CI Lower limit	CI Upper limit	Weight
1	Luque et al. 2017	1339	57	-7,48	-7,86	-7,10	44,30%
2	Belloc et al. 2014	5799	33	0,27	-0,07	0,61	55,70%





Sperm total motility_BMI_Underweight vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

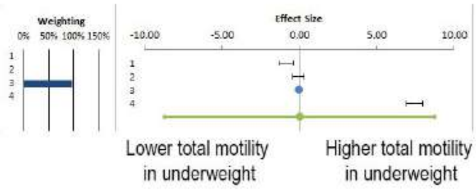
Combined Effect Size	
Effect Size	0.02
Standard error	0.02
CI Lower limit	-0.06
CI Upper limit	0.10
PI Lower limit	-8.74
PI Upper limit	8.78

Z-value	0.80
One-tailed p-value	0.212
Two-tailed p-value	0.423

Number of incl. studies	4

Heterogeneity	
Q	893.80
p_Q	0.000
I^2	99.66%
T^2	7.58
T	2.75

#	Study name	Sample size normal	Sample size underweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Shayeb et al. 2011	839	18	-0.85	-1.31	-0.38	1.01%
2	Belloc et al. 2014	5799	27	-0.08	-0.46	0.29	1.54%
3	Ma et al. 2019	22762	1815	-0.04	-0.09	0.01	96.54%
4	Qin et al. 2007	690	42	7.46	6.97	7.96	0.91%



Sperm total motility_BMI_Overweight vs. Normal

Meta-analysis model	
Model	Random effects model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

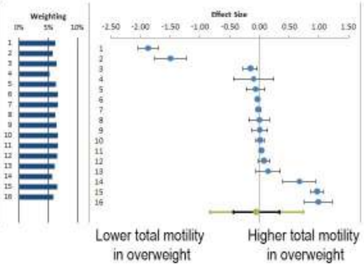
Combined Effect Size	
Effect Size	-0.05
Standard error	0.18
CI Lower limit	-0.43
CI Upper limit	0.34
PI Lower limit	-0.84
PI Upper limit	0.74

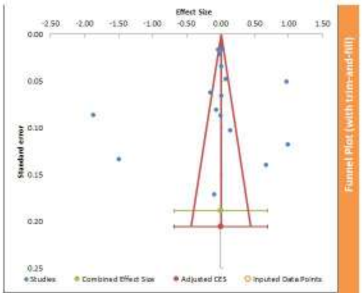
Z-value	-0.26
One-tailed p-value	0.397
Two-tailed p-value	0.794

Number of incl. studies	16

Heterogeneity	
Q	1071.97
P_Q	0.000
I^2	98.60%
T^2	0.10
T	0.32

#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Qin et al. 2007	690	241	-1,87	-2,04	-1,70	6,25%
2	Dupont et al. 2013	151	137	-1,50	-1,76	-1,23	5,72%
3	Oliveira et al. 2018	370	856	-0,15	-0,28	-0,03	6,46%
4	Rybar et al. 2011	74	63	-0,09	-0,43	0,24	5,22%
5	Martini et al. 2010	251	388	-0,06	-0,22	0,10	6,30%
6	Ramirez et al. 2020	5893	10189	-0,04	-0,07	0,00	6,68%
7	Belloc et al. 2014	5799	3607	-0,02	-0,06	0,02	6,67%
8	Thomsen et al. 2014	259	268	0,00	-0,17	0,17	6,24%
9	Jensen et al. 2004	1042	299	0,01	-0,12	0,14	6,43%
10	Luque et al. 2017	1339	2493	0,01	-0,05	0,08	6,62%
11	Ma et al. 2019	22762	5070	0,03	0,00	0,06	6,68%
12	Shayeb et al. 2011	839	909	0,08	-0,02	0,17	6,55%
13	Keskin et al. 2017	165	222	0,14	-0,06	0,35	6,08%
14	Ehala-Aleksejev et al. 2015	127	95	0,67	0,40	0,95	5,64%
15	Aggerholm et al. 2008	986	773	0,97	0,87	1,07	6,54%
16	Chavarro et al. 2010	123	233	0,99	0,76	1,22	5,91%





Heterogeneity	Adjusted
Q	1071.97
P_Q	0.000
I^2	98.60%
T^2	0.10
T	0.32

Combined effect size	Adjusted
Effect Size	0.01
SE	0.01
CI Lower limit	-0.01
CI Upper limit	0.03
PI Lower limit	-0.68
PI Upper limit	0.70

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Left
Number of imputed studies	0

Sperm total motility_BMI_Obese (or obese I) vs. Normal

Meta-analysis model	
Model	Random effects model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

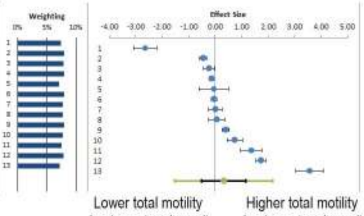
Combined Effect Size	
Effect Size	0.32
Standard error	0.39
CI Lower limit	-0.52
CI Upper limit	1.16
PI Lower limit	-1.54
PI Upper limit	2.18

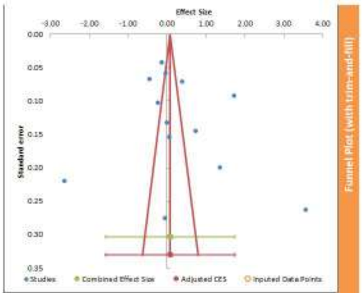
Z-value	0.83
One-tailed p-value	0.204
Two-tailed p-value	0.408

Number of incl. studies	13

Heterogeneity	
Q	834.25
P_Q	0.000
I^2	98.58%
T^2	0.58
T	0.76

#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Dupont et al. 2013	123	87	-2.65	-3.08	-2.22	7.40%
2	Oliveira et al. 2018	370	856	-0.44	-0.58	-0.31	7.95%
3	Martini et al. 2010	251	388	-0.24	-0.44	-0.04	7.87%
4	Belloc et al. 2014	5799	634	-0.13	-0.21	-0.05	7.99%
5	Rybar et al. 2011	74	16	-0.05	-0.60	0.50	7.09%
6	Ma et al. 2019	22762	302	-0.04	-0.15	0.07	7.97%
7	Thomsen et al. 2014	151	43	0.00	-0.26	0.26	7.78%
8	Keskin et al. 2017	259	74	0.05	-0.26	0.35	7.70%
9	Shayeb et al. 2011	165	56	0.39	0.25	0.53	7.95%
10	Chavarro et al. 2010	839	269	0.74	0.45	1.02	7.74%
11	Ehala-Aleksejev et al. 2015	127	38	1.37	0.97	1.76	7.50%
12	Aggerholm et al. 2008	986	163	1.73	1.54	1.91	7.90%
13	Qin et al. 2007	690	17	3.57	3.05	4.08	7.16%





Heterogeneity	Adjusted
Q	834.25
P_Q	0.000
I^2	98.56%
T^2	0.58
T	0.76

Combined effect size	Adjusted
Effect Size	0.08
SE	0.02
CI Lower limit	0.03
CI Upper limit	0.13
PI Lower limit	-1.58
PI Upper limit	1.74

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Left
Number of imputed studies	0

Sperm total motility_BMI_Obese II (or more) vs. Normal

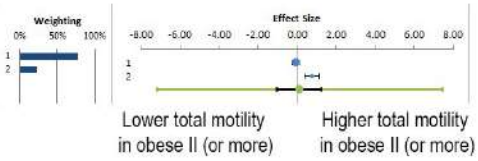
Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

Combined Effect Size	
Effect Size	0.12
Standard error	0.09
CI Lower limit	-1.02
CI Upper limit	1.26
PI Lower limit	-7.20
PI Upper limit	7.44
Z-value	1.34
One-tailed p-value	0.090
Two-tailed p-value	0.180
Number of incl. studies	2

Heterogeneity	
Q	15.26
P_Q	0.000
I^2	93.45%
T^2	0.32
T	0.57

#	Study name	Sample size normal	Sample size obese II (or more)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Belloc et al. 2014	5799	97	-0.07	-0.27	0.13	76.91%
2	Chavarro et al. 2010	123	40	0.76	0.39	1.13	23.09%



Sperm total motility_BMI_Obese III vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

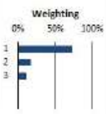
Combined Effect Size	
Effect Size	-0.37
Standard error	0.06
CI Lower limit	-0.61
CI Upper limit	-0.12
PI Lower limit	-0.85
PI Upper limit	0.12

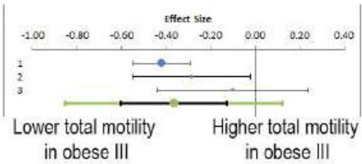
Z-value	-6.53
One-tailed p-value	0.000
Two-tailed p-value	0.000

Number of incl. studies	3

Heterogeneity	
Q	3.34
p_Q	0.188
I^2	40.16%
T^2	0.01
T	0.10

#	Study name	Sample size normal	Sample size obese III	Effect size	CI Lower limit	CI Upper limit	Weight
1	Ramirez et al. 2020	5893	243	-0,42	-0,55	-0,29	72,68%
2	Luque et al. 2017	1339	57	-0,29	-0,55	-0,02	17,06%
3	Belloc et al. 2014	5799	33	-0,10	-0,44	0,24	10,26%





Sperm progressive motility_BMI_Underweight vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

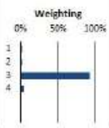
Combined Effect Size	
Effect Size	-0.03
Standard error	0.02
CI Lower limit	-0.11
CI Upper limit	0.04
PI Lower limit	-0.11
PI Upper limit	0.04

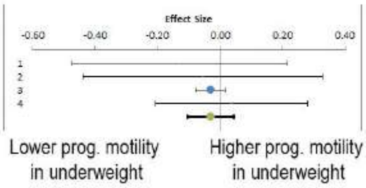
Z-value	-1.33
One-tailed p-value	0.092
Two-tailed p-value	0.183

Number of incl. studies	4

Heterogeneity	
Q	0.65
p_Q	0.889
I^2	0.00%
T^2	0.00
T	0.00

#	Study name	Sample size normal	Sample size underweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Belloc et al. 2014	5799	27	-0.13	-0.47	0.21	1.82%
2	Bandel et al. 2015	905	27	-0.06	-0.44	0.33	1.45%
3	Ma et al. 2019	22762	1815	-0.03	-0.08	0.02	93.13%
4	Wang et al. 2017	1398	68	0.04	-0.21	0.28	3.59%





Sperm progressive motility_BMI_Overweight vs. Normal

Meta-analysis model	
Model	Random effects model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

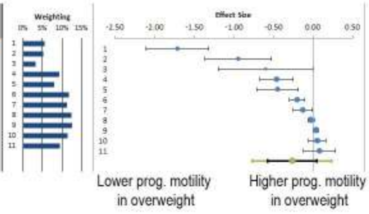
Combined Effect Size	
Effect Size	-0.26
Standard error	0.14
CI Lower limit	-0.57
CI Upper limit	0.05
PI Lower limit	-0.76
PI Upper limit	0.24

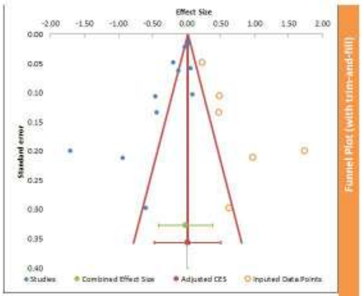
Z-value	-1.89
One-tailed p-value	0.030
Two-tailed p-value	0.059

Number of incl. studies	11

Heterogeneity	
Q	156.69
P_Q	0.000
I^2	93.62%
T^2	0.03
T	0.18

#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Taha et al. 2016	81	59	-1.71	-2.10	-1.31	5.53%
2	Vignera et al. 2012	50	50	-0.94	-1.36	-0.52	5.19%
3	Andersen et al. 2016	21	27	-0.60	-1.20	0.00	3.28%
4	Hammiche et al. 2012	153	225	-0.46	-0.67	-0.25	9.26%
5	Fariello et al. 2012	82	187	-0.45	-0.71	-0.18	8.00%
6	Wang et al. 2017	1398	620	-0.20	-0.30	-0.11	11.73%
7	Oliveira et al. 2018	370	856	-0.13	-0.25	0.00	11.22%
8	Belloc et al. 2014	5799	3607	-0.02	-0.07	0.02	12.44%
9	Ma et al. 2019	22762	5070	0.04	0.01	0.07	12.52%
10	Bandel et al. 2015	905	456	0.05	-0.06	0.17	11.41%
11	Keskin et al. 2017	165	222	0.08	-0.12	0.28	9.42%





Heterogeneity	Adjusted
Q	315.07
P_Q	0.000
I^2	94.92%
T^2	0.05
T	0.23

Combined effect size	Adjusted
Effect Size	0.02
SE	0.01
CI Lower limit	-0.01
CI Upper limit	0.04
PI Lower limit	-0.48
PI Upper limit	0.51

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	6

Sperm progressive motility_BMI_Obese (or obese I) vs. Normal

Meta-analysis model	
Model	Random effects model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

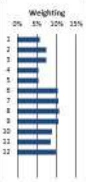
Combined Effect Size	
Effect Size	-0.33
Standard error	0.17
CI Lower limit	-0.70
CI Upper limit	0.04
PI Lower limit	-1.08
PI Upper limit	0.42

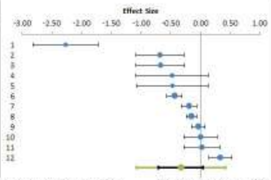
Z-value	-1.95
One-tailed p-value	0.026
Two-tailed p-value	0.051

Number of incl. studies	12

Heterogeneity	
Q	122.23
P_Q	0.000
I^2	91.00%
T^2	0.09
T	0.30

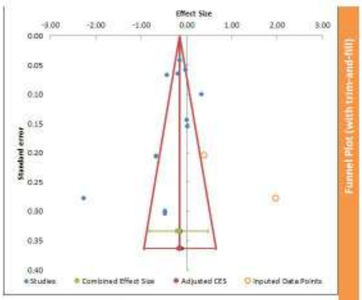
#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Tana et al. 2016	81	25	-2.27	-2.82	-1.72	5.77%
2	Fariello et al. 2012	82	36	-0.68	-1.08	-0.27	7.34%
3	Vignera et al. 2012	50	50	-0.67	-1.08	-0.26	7.32%
4	Andersen et al. 2016	21	24	-0.48	-1.09	0.13	5.29%
5	Ferigolo et al. 2019	20	27	-0.47	-1.08	0.13	5.36%
6	Oliveira et al. 2018	370	598	-0.44	-0.57	-0.31	10.34%
7	Wang et al. 2017	1398	298	-0.19	-0.32	-0.07	10.38%
8	Belloc et al. 2014	5799	634	-0.15	-0.23	-0.07	10.65%
9	Ma et al. 2019	22762	302	-0.03	-0.14	0.08	10.46%
10	Hammiche et al. 2012	153	72	0.00	-0.28	0.28	8.80%
11	Keskin et al. 2017	165	56	0.02	-0.28	0.33	8.53%
12	Bandel et al. 2015	905	115	0.33	0.14	0.53	9.76%





Lower prog. motility in obese (or obese I)

Higher prog. motility in obese (or obese I)



Heterogeneity	Adjusted
Q	188.52
P_Q	0.000
I^2	93.10%
T^2	0.13
T	0.36

Combined effect size	Adjusted
Effect Size	-0.15
SE	0.02
CI Lower limit	-0.20
CI Upper limit	-0.09
PI Lower limit	-0.94
PI Upper limit	0.64

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	2

Sperm progressive motility_BMI_Obese II (or more) vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

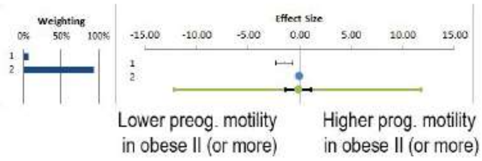
Combined Effect Size	
Effect Size	-0.16
Standard error	0.10
CI Lower limit	-1.42
CI Upper limit	1.10
PI Lower limit	-12.12
PI Upper limit	11.80

Z-value	-1.65
One-tailed p-value	0.049
Two-tailed p-value	0.098

Number of incl. studies	2

Heterogeneity	
Q	11.43
p_Q	0.001
I^2	91.25%
T^2	0.88
T	0.94

#	Study name	Sample size normal	Sample size obese II (or more)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Andersen et al. 2016	21	13	-1.46	-2.27	-0.66	6.24%
2	Belloc et al. 2014	5799	97	-0.08	-0.28	0.12	93.76%



Sperm normal morphology_BMI_Underweight vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

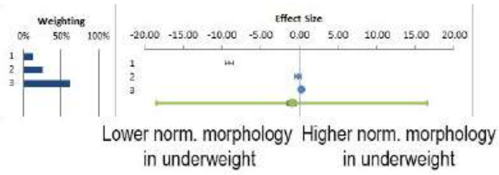
Combined Effect Size	
Effect Size	-0.98
Standard error	0.10
CI Lower limit	-1.40
CI Upper limit	-0.56
PI Lower limit	-18.47
PI Upper limit	16.52

Z-value	-9.96
One-tailed p-value	0.000
Two-tailed p-value	0.000

Number of incl. studies	3

Heterogeneity	
Q	913.28
p_Q	0.000
I^2	99.78%
T^2	16.53
T	4.07

#	Study name	Sample size normal	Sample size underweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Qin et al. 2007	690	42	-9.06	-9.62	-8.50	11.82%
2	Belloc et al. 2014	5799	27	-0.18	-0.56	0.20	25.87%
3	Wang et al. 2017	1398	68	0.22	-0.02	0.47	62.31%



Sperm normal morphology_BMI_Overweight vs. Normal

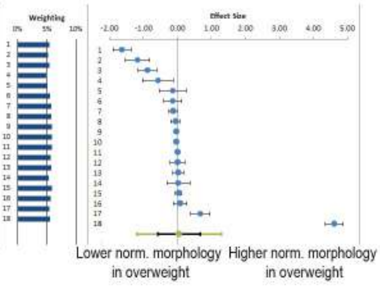
Meta-analysis model	
Model	Random effects model
Confidence level	95%

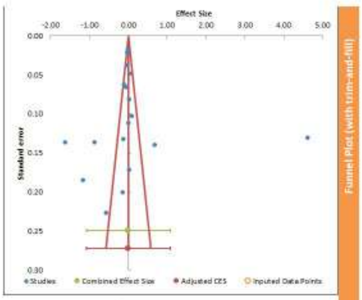
Presentation	
Sort By	Effect Size
Order	Ascending

Combined Effect Size	
Effect Size	0.04
Standard error	0.29
CI Lower limit	-0.58
CI Upper limit	0.67
PI Lower limit	-1.20
PI Upper limit	1.29
Z-value	0.15
One-tailed p-value	0.440
Two-tailed p-value	0.880
Number of incl. studies	18

Heterogeneity	
Q	1511.88
P_Q	0.000
I^2	98.88%
T^2	0.26
T	0.51

#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Dupont et al. 2013	151	137	-1,63	-1,90	-1,36	5,49%
2	Taha et al. 2016	81	59	-1,17	-1,54	-0,81	5,20%
3	Eisenberg et al. 2014	83	191	-0,88	-1,15	-0,61	5,49%
4	Andersen et al. 2016	40	41	-0,57	-1,02	-0,12	4,91%
5	Vignera et al. 2012	50	50	-0,14	-0,54	0,26	5,10%
6	Fariello et al. 2012	82	187	-0,14	-0,40	0,13	5,51%
7	Oliveira et al. 2018	370	856	-0,12	-0,24	0,00	5,80%
8	Jensen et al. 2004	1042	299	-0,06	-0,19	0,07	5,79%
9	Luque et al. 2017	1115	2029	-0,03	-0,11	0,04	5,85%
10	Belloc et al. 2014	5799	3607	-0,03	-0,07	0,02	5,87%
11	Ramirez et al. 2020	5201	8992	-0,01	-0,04	0,03	5,88%
12	Chavarro et al. 2010	123	233	0,00	-0,22	0,22	5,61%
13	Martini et al. 2010	251	388	0,02	-0,14	0,18	5,74%
14	Rybar et al. 2011	74	63	0,03	-0,31	0,37	5,29%
15	Wang et al. 2017	1398	620	0,03	-0,06	0,13	5,83%
16	Keskin et al. 2017	165	222	0,08	-0,12	0,28	5,65%
17	Ehala-Aleksejev et al. 2015	127	95	0,67	0,40	0,95	5,47%
18	Qin et al. 2007	690	241	4,61	4,35	4,87	5,52%





Heterogeneity	Adjusted
Q	1511.88
P_Q	0.000
I^2	98.88%
T^2	0.26
T	0.51

Combined effect size	Adjusted
Effect Size	0.00
SE	0.01
CI Lower limit	-0.02
CI Upper limit	0.02
PI Lower limit	-1.08
PI Upper limit	1.08

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	0

Sperm normal morphology_BMI_Obese (or obese I) vs. Normal

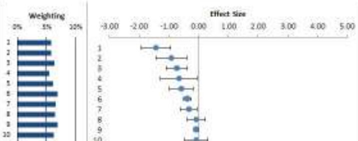
Meta-analysis model	
Model	Random effects model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

Combined Effect Size	
Effect Size	-0.04
Standard error	0.29
CI Lower limit	-0.66
CI Upper limit	0.58
PI Lower limit	-1.39
PI Upper limit	1.31
Z-value	-0.14
One-tailed p-value	0.445
Two-tailed p-value	0.890
Number of incl. studies	16

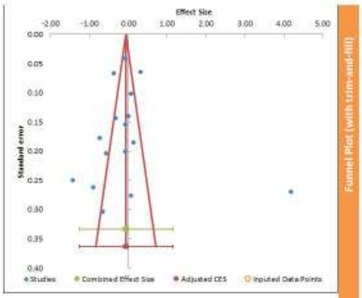
Heterogeneity	
Q	378.15
P_Q	0.000
I^2	96.03%
T^2	0.32
T	0.56

#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Taha et al. 2016	81	25	-1.43	-1.93	-0.94	5.81%
2	Andersen et al. 2016	40	27	-0.91	-1.43	-0.39	5.72%
3	Dupont et al. 2013	151	43	-0.73	-1.08	-0.38	6.33%
4	Ferigolo et al. 2019	20	27	-0.66	-1.27	-0.05	5.39%
5	Vignera et al. 2012	50	50	-0.58	-0.98	-0.17	6.14%
6	Oliveira et al. 2018	370	598	-0.38	-0.51	-0.25	6.85%
7	Eisenberg et al. 2014	83	122	-0.33	-0.61	-0.04	6.53%
8	Keskin et al. 2017	165	56	-0.08	-0.38	0.23	6.46%
9	Belloc et al. 2014	5799	634	-0.08	-0.16	0.01	6.91%
10	Fariello et al. 2012	82	36	-0.07	-0.47	0.32	6.17%
11	Chavarro et al. 2010	123	87	0.00	-0.28	0.28	6.55%
12	Martini et al. 2010	251	155	0.06	-0.14	0.26	6.73%
13	Rybar et al. 2011	74	16	0.07	-0.47	0.62	5.61%
14	Ehala-Aleksejev et al. 2015	127	38	0.13	-0.23	0.50	6.27%
15	Wang et al. 2017	1398	298	0.31	0.18	0.43	6.86%
16	Qin et al. 2007	690	17	4.20	3.67	4.73	5.66%



Lower norm. morphology in obese (or obese I)

Higher norm. morphology in obese (or obese I)



Heterogeneity	Adjusted
Q	378.15
P_Q	0.000
I^2	96.03%
T^2	0.32
T	0.56

Combined effect size	Adjusted
Effect Size	-0.06
SE	0.03
CI Lower limit	-0.12
CI Upper limit	0.00
PI Lower limit	-1.26
PI Upper limit	1.14

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	0

Sperm normal morphology_BMI_Obese II (or more) vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

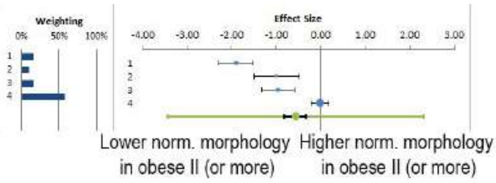
Combined Effect Size	
Effect Size	-0.57
Standard error	0.08
CI Lower limit	-0.82
CI Upper limit	-0.32
PI Lower limit	-3.44
PI Upper limit	2.31

Z-value	-7.30
One-tailed p-value	0.000
Two-tailed p-value	0.000

Number of incl. studies	4

Heterogeneity	
Q	83.78
p_Q	0.000
I^2	96.42%
T^2	0.81
T	0.90

#	Study name	Sample size normal	Sample size obese II (or more)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Eisenberg et al. 2014	83	72	-1.90	-2.29	-1.52	16.04%
2	Andersen et al. 2016	40	31	-0.99	-1.50	-0.49	9.41%
3	Chavarro et al. 2010	123	40	-0.96	-1.34	-0.59	16.82%
4	Belloc et al. 2014	5799	97	-0.01	-0.21	0.19	57.74%



Sperm normal morphology_BMI_Obese III vs. Normal

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

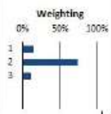
Combined Effect Size	
Effect Size	-0.31
Standard error	0.06
CI Lower limit	-0.56
CI Upper limit	-0.05
PI Lower limit	-1.06
PI Upper limit	0.45

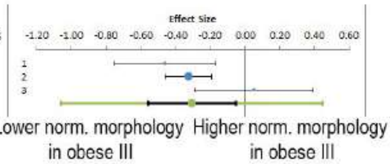
Z-value	-5.20
One-tailed p-value	0.000
Two-tailed p-value	0.000

Number of incl. studies	3

Heterogeneity	
Q	5.37
p_Q	0.068
I^2	62.73%
T^2	0.03
T	0.16

#	Study name	Sample size normal	Sample size obese III	Effect size	CI Lower limit	CI Upper limit	Weight
1	Luque et al. 2017	1115	47	-0,46	-0,76	-0,17	15,48%
2	Ramírez et al. 2020	5201	222	-0,33	-0,46	-0,19	73,22%
3	Belloc et al. 2014	5799	33	0,05	-0,29	0,39	11,30%





Semen volume_BMI_Underweight vs. Normal_Sensitivity analysis (fixed model)

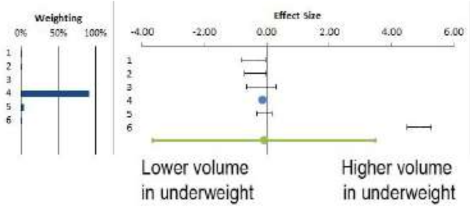
Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

Combined Effect Size	
Effect Size	-0.08
Standard error	0.02
CI Lower limit	-0.14
CI Upper limit	-0.02
PI Lower limit	-3.65
PI Upper limit	3.48
Z-value	-3.57
One-tailed p-value	0.000
Two-tailed p-value	0.000
Number of incl. studies	6

Heterogeneity	
Q	606.24
p_Q	0.000
I^2	99.18%
T^2	1.93
T	1.39

#	Study name	Sample size normal	Sample size underweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Bandel et al. 2015	905	27	-0.44	-0.82	-0.05	1.42%
2	Belloc et al. 2014	5799	27	-0.38	-0.72	-0.03	1.78%
3	Shayeb et al. 2011	839	18	-0.17	-0.63	0.30	0.95%
4	Ma et al. 2019	22762	1815	-0.14	-0.19	-0.09	91.04%
5	Wang et al. 2017	1398	68	-0.08	-0.33	0.16	3.51%
6	Qin et al. 2007	690	732	4.89	4.49	5.29	1.30%



Semen volume_BMI_Overweight vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

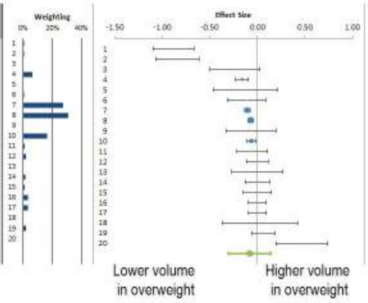
Combined Effect Size	
Effect Size	-0.08
Standard error	0.01
CI Lower limit	-0.10
CI Upper limit	-0.06
PI Lower limit	-0.30
PI Upper limit	0.14

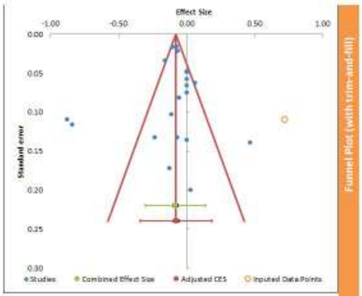
Z-value	-9.55
One-tailed p-value	0.000
Two-tailed p-value	0.000

Number of incl. studies	20

Heterogeneity	
Q	138.52
P_Q	0.000
I^2	86.28%
T^2	0.01
T	0.11

#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Hammiche et al. 2012	153	225	-0,88	-1,10	-0,66	0,62%
2	Chavarro et al. 2010	129	233	-0,84	-1,07	-0,61	0,55%
3	Eisenberg et al. 2014	83	191	-0,24	-0,50	0,02	0,43%
4	Luque et al. 2017	1339	2493	-0,16	-0,23	-0,09	6,45%
5	Rybar et al. 2011	74	63	-0,12	-0,46	0,22	0,25%
6	Keskin et al. 2017	165	222	-0,11	-0,31	0,09	0,70%
7	Ramirez et al. 2020	5894	10196	-0,11	-0,14	-0,07	27,55%
8	Ma et al. 2019	22762	5070	-0,07	-0,10	-0,04	30,84%
9	Fariello et al. 2012	82	187	-0,07	-0,33	0,19	0,42%
10	Belloc et al. 2014	5799	3607	-0,06	-0,11	-0,02	16,48%
11	Martini et al. 2010	251	388	-0,05	-0,21	0,10	1,13%
12	Bandel et al. 2015	905	456	0,00	-0,11	0,11	2,25%
13	Ehala-Aleksejev et al. 2015	127	95	0,00	-0,27	0,27	0,40%
14	Jensen et al. 2004	1042	299	0,00	-0,13	0,13	1,72%
15	Qin et al. 2007	690	241	0,00	-0,15	0,15	1,32%
16	Shayeb et al. 2011	839	909	0,00	-0,09	0,09	3,23%
17	Wang et al. 2017	1398	620	0,00	-0,09	0,09	3,18%
18	Vignera et al. 2012	50	50	0,03	-0,37	0,42	0,19%
19	Oliveira et al. 2018	370	856	0,06	-0,06	0,19	1,92%
20	Alshahrani et al. 2016	75	179	0,47	0,19	0,74	0,38%





Heterogeneity	Adjusted
Q	192.52
P_Q	0.000
I^2	88.61%
T^2	0.02
T	0.13

Combined effect size	Adjusted
Effect Size	-0.08
SE	0.01
CI Lower limit	-0.10
CI Upper limit	-0.06
PI Lower limit	-0.34
PI Upper limit	0.19

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Righmost Run
Search from mean	Right
Number of imputed studies	1

Semen volume_BMI_Obese (or obese I) vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

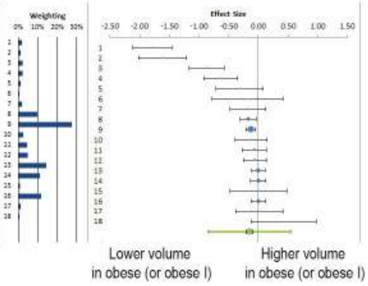
Combined Effect Size	
Effect Size	-0.15
Standard error	0.02
CI Lower limit	-0.19
CI Upper limit	-0.10
PI Lower limit	-0.84
PI Upper limit	0.54

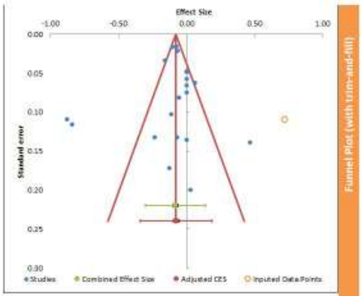
Z-value	-6.78
One-tailed p-value	0.000
Two-tailed p-value	0.000

Number of incl. studies	18

Heterogeneity	
Q	208.16
p_Q	0.000
I^2	91.83%
T^2	0.11
T	0.33

#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Hammiche et al. 2012	153	72	-1.79	-2.11	-1.46	1.74%
2	Ehala-Aleksejev et al. 2015	127	38	-1.61	-2.02	-1.21	1.14%
3	Eisenberg et al. 2014	83	122	-0.87	-1.16	-0.58	2.17%
4	Chavarro et al. 2010	123	87	-0.64	-0.92	-0.35	2.33%
5	Fariello et al. 2012	82	36	-0.31	-0.71	0.09	1.19%
6	Ferigolo et al. 2019	20	27	-0.18	-0.78	0.41	0.55%
7	Keskin et al. 2017	165	56	-0.18	-0.48	0.13	2.00%
8	Shayeb et al. 2011	839	269	-0.17	-0.31	-0.03	9.73%
9	Belloc et al. 2014	5799	634	-0.13	-0.21	-0.04	27.44%
10	Alshahrani et al. 2016	75	185	-0.12	-0.39	0.15	2.55%
11	Martini et al. 2010	251	155	-0.07	-0.27	0.13	4.59%
12	Bandel et al. 2015	905	115	-0.06	-0.26	0.13	4.89%
13	Ma et al. 2019	22762	302	0.00	-0.11	0.11	14.30%
14	Oliveira et al. 2018	370	598	0.00	-0.13	0.13	10.98%
15	Qin et al. 2007	690	17	0.00	-0.48	0.48	0.80%
16	Wang et al. 2017	1398	298	0.00	-0.13	0.13	11.78%
17	Vignera et al. 2012	50	50	0.02	-0.38	0.42	1.20%
18	Rybar et al. 2011	74	16	0.42	-0.13	0.98	0.62%





Heterogeneity	Adjusted
Q	192.52
p_Q	0.000
I^2	88.61%
T^2	0.02
T	0.13

Combined effect size	Adjusted
Effect Size	-0.08
SE	0.01
CI Lower limit	-0.10
CI Upper limit	-0.06
PI Lower limit	-0.34
PI Upper limit	0.19

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	1

Sperm count_BMI_Underweight vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

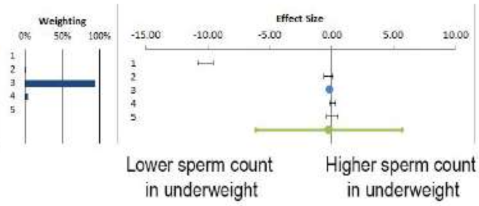
Combined Effect Size	
Effect Size	-0.23
Standard error	0.02
CI Lower limit	-0.29
CI Upper limit	-0.16
PI Lower limit	-6.15
PI Upper limit	5.70

Z-value	-9.56
One-tailed p-value	0.000
Two-tailed p-value	0.000

Number of incl. studies	5

Heterogeneity	
Q	1043.18
p_Q	0.000
I^2	99.62%
T^2	4.55
T	2.13

#	Study name	Sample size normal	Sample size underweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Qin et al. 2007	690	42	-10.21	-10.82	-9.60	0.57%
2	Belloc et al. 2014	5799	27	-0.22	-0.60	0.15	1.49%
3	Ma et al. 2019	22762	1815	-0.18	-0.23	-0.13	93.35%
4	Wang et al. 2017	1398	68	0.08	-0.16	0.32	3.60%
5	Shayeb et al. 2011	839	18	0.08	-0.38	0.55	0.98%



Sperm count_BMI_Overweight vs. Normal_Sensitivity analysis (fixed model)

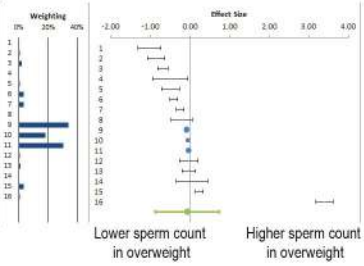
Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

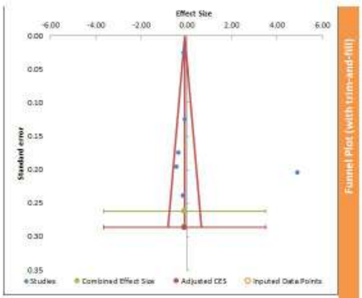
Presentation	
Sort By	Effect Size
Order	Ascending

Combined Effect Size	
Effect Size	-0.06
Standard error	0.01
CI Lower limit	-0.08
CI Upper limit	-0.04
PI Lower limit	-0.87
PI Upper limit	0.74
Z-value	-7.03
One-tailed p-value	0.000
Two-tailed p-value	0.000
Number of incl. studies	16

Heterogeneity	
Q	1322.47
P_Q	0.000
I^2	98.87%
T^2	0.14
T	0.38

#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Enala-Aleksejev et al. 2015	127	95	-1,02	-1,30	-0,73	0,39%
2	Hammiche et al. 2012	153	225	-0,85	-1,06	-0,63	0,69%
3	Jensen et al. 2004	1042	299	-0,68	-0,81	-0,55	1,83%
4	Andersen et al. 2016	40	42	-0,49	-0,93	-0,04	0,16%
5	Chavarro et al. 2010	123	233	-0,49	-0,71	-0,26	0,64%
6	Aggerholm et al. 2008	986	773	-0,40	-0,49	-0,30	3,48%
7	Wang et al. 2017	1398	620	-0,24	-0,34	-0,15	3,49%
8	Eisenberg et al. 2014	83	191	-0,20	-0,46	0,06	0,47%
9	Ma et al. 2019	22762	5070	-0,08	-0,11	-0,05	34,08%
10	Belloc et al. 2014	5799	3607	-0,05	-0,09	0,00	18,22%
11	Ramirez et al. 2020	5894	10196	-0,03	-0,07	0,00	30,44%
12	Dupont et al. 2013	151	137	-0,03	-0,26	0,21	0,59%
13	Thomsen et al. 2014	259	268	-0,02	-0,19	0,15	1,08%
14	Vignera et al. 2012	50	50	0,05	-0,35	0,45	0,20%
15	Shayeb et al. 2011	839	909	0,24	0,15	0,34	3,54%
16	Qin et al. 2007	690	241	3,40	3,18	3,61	0,69%





Heterogeneity	Adjusted
Q	606.24
P_Q	0.000
I^2	98.18%
T^2	1.93
T	1.39

Combined effect size	Adjusted
Effect Size	-0.08
SE	0.02
CI Lower limit	-0.14
CI Upper limit	-0.02
PI Lower limit	-3.65
PI Upper limit	3.48

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	0

Sperm count_BMI_Obese (or obese I) vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

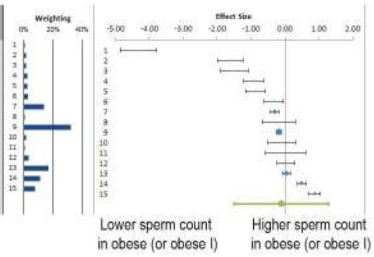
Combined Effect Size	
Effect Size	-0.10
Standard error	0.02
CI Lower limit	-0.16
CI Upper limit	-0.05
PI Lower limit	-1.50
PI Upper limit	1.29

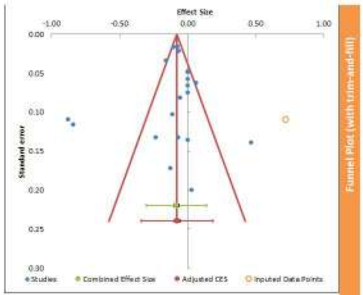
Z-value	-4.40
One-tailed p-value	0.000
Two-tailed p-value	0.000

Number of incl. studies	15

Heterogeneity	
Q	629.03
p_Q	0.000
I^2	87.77%
T^2	0.42
T	0.65

#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Qin et al. 2007	690	17	-4.32	-4.85	-3.78	0.77%
2	Dupont et al. 2013	123	87	-1.60	-1.98	-1.23	1.55%
3	Ehala-Aleksejev et al. 2015	127	38	-1.49	-1.89	-1.09	1.39%
4	Chavarro et al. 2010	123	87	-0.92	-1.21	-0.63	2.62%
5	Hammiche et al. 2012	153	72	-0.86	-1.15	-0.57	2.57%
6	Eisenberg et al. 2014	83	122	-0.34	-0.62	-0.05	2.77%
7	Wang et al. 2017	1398	298	-0.30	-0.43	-0.18	13.87%
8	Andersen et al. 2016	40	28	-0.18	-0.67	0.31	0.93%
9	Belloc et al. 2014	5799	634	-0.18	-0.26	-0.09	32.35%
10	Vignera et al. 2012	50	50	-0.10	-0.49	0.30	1.42%
11	Ferigolo et al. 2019	20	27	0.02	-0.57	0.62	0.65%
12	Thomsen et al. 2014	259	74	0.03	-0.23	0.29	3.27%
13	Ma et al. 2019	22762	1815	0.05	-0.07	0.16	16.94%
14	Shayeb et al. 2011	839	269	0.50	0.36	0.64	11.30%
15	Aggerholm et al. 2008	986	163	0.87	0.70	1.04	7.59%





Heterogeneity	Adjusted
Q	192.52
p_Q	0.000
I^2	88.61%
T^2	0.02
T	0.13

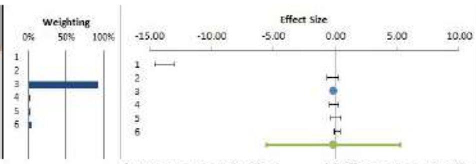
Combined effect size	Adjusted
Effect Size	-0.08
SE	0.01
CI Lower limit	-0.10
CI Upper limit	-0.06
PI Lower limit	-0.34
PI Upper limit	0.19

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	1

Sperm concentration_BMI_Underweight vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%
Presentation	
Sort By	Effect Size
Order	Ascending
Combined Effect Size	
Effect Size	-0.17
Standard error	0.02
CI Lower limit	-0.23
CI Upper limit	-0.11
PI Lower limit	-5.60
PI Upper limit	5.25
Z-value	-7.44
One-tailed p-value	0.000
Two-tailed p-value	0.000
Number of incl. studies	6
Heterogeneity	
Q	1205.28
p_Q	0.000
I^2	99.59%
T^2	4.45
T	2.11

#	Study name	Sample size normal	Sample size underweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Qin et al. 2007	690	42	-13.83	-14.60	-13.05	0.35%
2	Shayeb et al. 2011	839	18	-0.19	-0.66	0.28	0.97%
3	Ma et al. 2019	22762	1815	-0.14	-0.19	-0.09	92.21%
4	Belloc et al. 2014	40	32	-0.13	-0.50	0.25	1.48%
5	Bandel et al. 2015	905	17	0.06	-0.32	0.45	1.44%
6	Wang et al. 2017	1398	68	0.17	-0.07	0.42	3.56%



Lower concentration in underweight

Higher concentration in underweight

Sperm concentration_BMI_Overweight vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

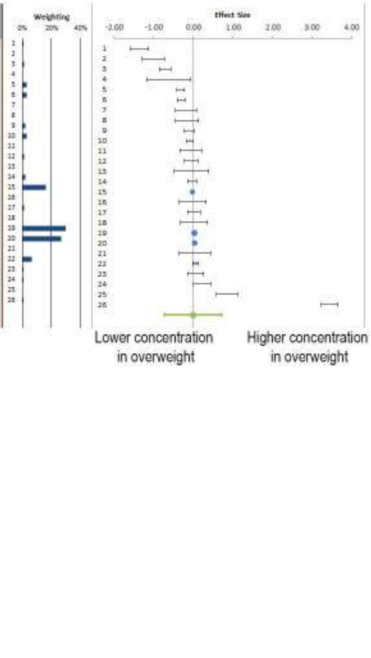
Combined Effect Size	
Effect Size	-0.01
Standard error	0.01
CI Lower limit	-0.03
CI Upper limit	0.01
PI Lower limit	-0.73
PI Upper limit	0.71

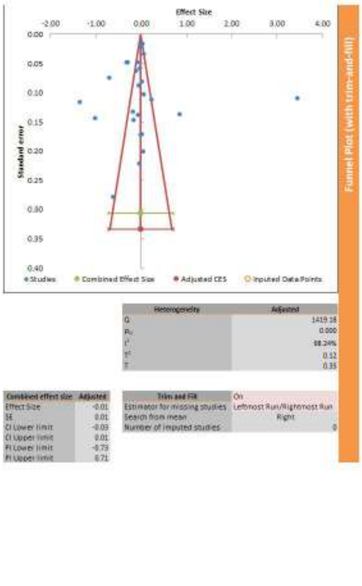
Z-value	-0.96
One-tailed p-value	0.170
Two-tailed p-value	0.339

Number of incl. studies	26

Heterogeneity	
Q	1419.18
P_Q	0.000
I^2	98.24%
T^2	0.12
T	0.35

#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Hammiche et al. 2012	153	225	-1,36	-1,59	-1,13	0,53%
2	Ehala-Aleksejev et al. 2015	127	95	-1,01	-1,29	-0,73	0,34%
3	Jensen et al. 2004	1042	299	-0,71	-0,86	-0,57	1,29%
4	Hadjkacem-Loukil et al. 2015	77	16	-0,62	-1,17	-0,06	0,09%
5	Wang et al. 2017	1398	620	-0,33	-0,42	-0,23	3,03%
6	Aggerholm et al. 2008	986	773	-0,30	-0,40	-0,21	3,06%
7	Fariello et al. 2012	82	187	-0,18	-0,45	0,08	0,41%
8	Koloszar et al. 2005	96	91	-0,16	-0,45	0,13	0,33%
9	Oliveira et al. 2018	370	856	-0,11	-0,23	0,01	1,84%
10	Shayeb et al. 2011	839	909	-0,09	-0,18	0,01	3,11%
11	Alshahrani et al. 2016	75	179	-0,06	-0,34	0,21	0,38%
12	Thomsen et al. 2014	259	268	-0,05	-0,22	0,12	0,94%
13	Andersen et al. 2016	40	42	-0,05	-0,49	0,39	0,15%
14	Bandel et al. 2015	905	456	-0,03	-0,14	0,08	2,17%
15	Belloc et al. 2014	5799	3607	-0,02	-0,06	0,02	15,88%
16	Rybar et al. 2011	74	63	-0,01	-0,35	0,33	0,24%
17	Martini et al. 2010	251	388	0,01	-0,14	0,17	1,09%
18	Taha et al. 2016	81	59	0,02	-0,32	0,36	0,24%
19	Ma et al. 2019	22762	5070	0,02	-0,01	0,05	29,71%
20	Ramirez et al. 2020	5894	10196	0,03	0,00	0,06	26,54%
21	Vignera et al. 2012	50	50	0,04	-0,36	0,43	0,18%
22	Luque et al. 2017	1339	2493	0,06	-0,01	0,12	6,21%
23	Keskin et al. 2017	165	222	0,06	-0,14	0,26	0,68%
24	Chavarro et al. 2010	323	235	0,22	0,00	0,44	0,57%
25	Eisenberg et al. 2014	83	191	0,84	0,57	1,11	0,38%
26	Qin et al. 2007	890	241	3,44	3,23	3,66	0,60%





Heterogeneity	Adjusted
Q	1419.18
P_Q	0.000
I^2	98.24%
T^2	0.12
T	0.35

Combined effect size	Adjusted
Effect Size	-0.01
SE	0.01
CI Lower limit	-0.03
CI Upper limit	0.01
PI Lower limit	-0.73
PI Upper limit	0.71

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	0

Sperm concentration_BMI_Obese (or obese I) vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

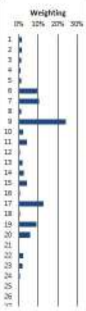
Combined Effect Size	
Effect Size	-0.06
Standard error	0.02
CI Lower limit	-0.11
CI Upper limit	-0.02
PI Lower limit	-0.83
PI Upper limit	0.71

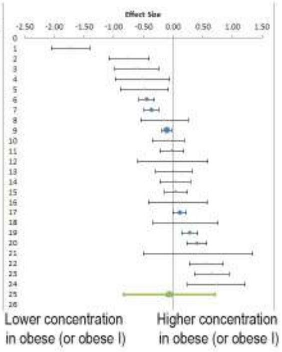
Z-value	-3.09
One-tailed p-value	0.001
Two-tailed p-value	0.002

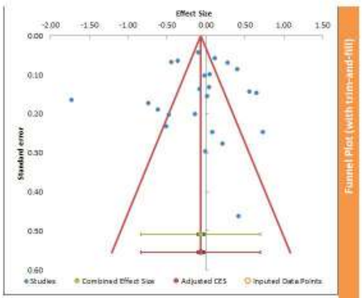
Number of incl. studies	24

Heterogeneity	
Q	313.92
P_Q	0.000
I^2	92.67%
T^2	0.14
T	0.37

#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Hammiche et al. 2012	153	72	-1.73	-2.05	-1.41	1.56%
2	Kolostar et al. 2005	96	58	-0.74	-1.08	-0.40	1.43%
3	Enala-Aleksejev et al. 2015	127	38	-0.62	-0.99	-0.25	1.19%
4	Taha et al. 2016	81	25	-0.51	-0.97	-0.05	0.79%
5	Fariello et al. 2012	82	36	-0.48	-0.88	-0.08	1.09%
6	Oliveira et al. 2018	370	598	-0.44	-0.58	-0.31	9.43%
7	Wang et al. 2017	1398	298	-0.36	-0.49	-0.24	10.28%
8	Vignera et al. 2012	50	50	-0.15	-0.54	0.25	1.05%
9	Belloc et al. 2014	5799	634	-0.10	-0.19	-0.02	24.16%
10	Alshahrani et al. 2016	75	185	-0.08	-0.35	0.19	2.25%
11	Martini et al. 2010	251	155	-0.02	-0.22	0.18	4.04%
12	Ferigolo et al. 2019	20	27	-0.01	-0.60	0.59	0.49%
13	Keskin et al. 2017	165	56	0.01	-0.29	0.32	1.76%
14	Thomsen et al. 2014	259	74	0.04	-0.22	0.30	2.43%
15	Bandel et al. 2015	905	115	0.05	-0.15	0.24	4.31%
16	Andersen et al. 2016	40	28	0.08	-0.41	0.57	0.69%
17	Ma et al. 2019	22762	302	0.11	0.00	0.23	12.59%
18	Rybar et al. 2011	74	16	0.21	-0.33	0.76	0.55%
19	Shayeb et al. 2011	839	269	0.28	0.15	0.41	9.16%
20	Aggerholm et al. 2008	986	163	0.41	0.24	0.57	5.84%
21	Hadjkacem-Loukil et al. 2015	77	5	0.42	-0.50	1.34	0.20%
22	Chavarro et al. 2010	123	87	0.56	0.28	0.84	2.07%
23	Eisenberg et al. 2014	83	122	0.65	0.36	0.94	1.98%
24	Qin et al. 2007	370	598	0.73	0.25	1.21	0.70%
25							
26							







Heterogeneity	Adjusted
Q	313.92
P_Q	0.000
I^2	92.67%
T^2	0.14
T	0.37

Combined effect size	Adjusted
Effect Size	-0.06
SE	0.02
CI Lower limit	-0.11
CI Upper limit	-0.02
PI Lower limit	-0.83
PI Upper limit	0.71

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	0

Sperm vitality_BMI_Overweight vs. Normal_Sensitivity analysis (fixed model)

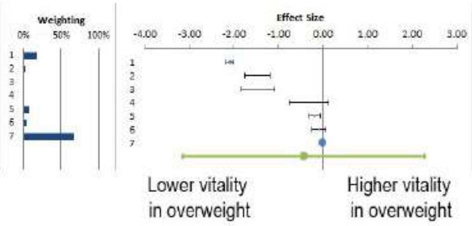
Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

Combined Effect Size	
Effect Size	-0.44
Standard error	0.02
CI Lower limit	-0.48
CI Upper limit	-0.39
PI Lower limit	-3.15
PI Upper limit	2.27
Z-value	-25.18
One-tailed p-value	0.000
Two-tailed p-value	0.000
Number of incl. studies	7

Heterogeneity	
Q	2077.46
p_Q	0.000
I^2	99.71%
T^2	1.23
T	1.11

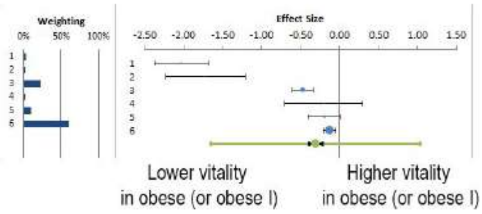
#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Luque et al. 2017	1339	2493	-2,09	-2,17	-1,00	17,61%
2	Eisenberg et al. 2014	83	191	-1,48	-1,76	-1,19	1,42%
3	Taha et al. 2016	81	59	-1,46	-1,84	-1,08	0,82%
4	Andersen et al. 2016	40	42	-0,31	-0,75	0,13	0,61%
5	Oliveira et al. 2018	370	856	-0,20	-0,32	-0,07	7,78%
6	Martini et al. 2010	251	388	-0,09	-0,25	0,07	4,60%
7	Belloc et al. 2014	5799	3607	-0,02	-0,07	0,02	67,16%



Sperm vitality_BMI_Obese (or obese I) vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%
Presentation	
Sort By	Effect Size
Order	Ascending
Combined Effect Size	
Effect Size	-0.31
Standard error	0.03
CI Lower limit	-0.39
CI Upper limit	-0.22
PI Lower limit	-1.65
PI Upper limit	1.04
Z-value	-9.44
One-tailed p-value	0.000
Two-tailed p-value	0.000
Number of incl. studies	6
Heterogeneity	
Q	154.25
p_Q	0.000
I^2	96.76%
T^2	0.27
T	0.52

#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Eisenberg et al. 2014	83	122	-2.03	-2.38	-1.69	3.45%
2	Taha et al. 2016	81	25	-1.73	-2.24	-1.21	1.57%
3	Oliveira et al. 2018	370	598	-0.47	-0.60	-0.34	23.34%
4	Andersen et al. 2016	40	27	-0.20	-0.70	0.30	1.68%
5	Martini et al. 2010	251	155	-0.20	-0.40	0.01	9.99%
6	Belloc et al. 2014	5799	634	-0.13	-0.21	-0.04	59.97%



Sperm total motility_BMI_Overweight vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

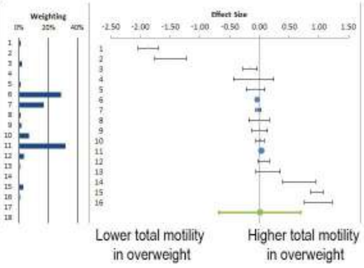
Combined Effect Size	
Effect Size	0.01
Standard error	0.01
CI Lower limit	-0.01
CI Upper limit	0.03
PI Lower limit	-0.68
PI Upper limit	0.70

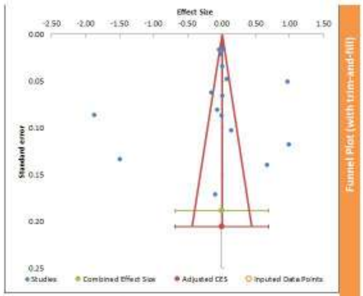
Z-value	0.96
One-tailed p-value	0.168
Two-tailed p-value	0.336

Number of incl. studies	16

Heterogeneity	
Q	1071.97
P_Q	0.000
I^2	98.60%
T^2	0.10
T	0.32

#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Qin et al. 2007	690	241	-1,87	-2,04	-1,70	1,03%
2	Dupont et al. 2013	151	137	-1,50	-1,76	-1,23	0,43%
3	Oliveira et al. 2018	370	856	-0,15	-0,28	-0,03	1,98%
4	Rybar et al. 2011	74	63	-0,09	-0,43	0,24	0,26%
5	Martini et al. 2010	251	388	-0,06	-0,22	0,10	1,17%
6	Ramirez et al. 2020	5893	10189	-0,04	-0,07	0,00	28,57%
7	Belloc et al. 2014	5799	3607	-0,02	-0,06	0,02	17,10%
8	Thomsen et al. 2014	259	268	0,00	-0,17	0,17	1,01%
9	Jensen et al. 2004	1042	299	0,01	-0,12	0,14	1,79%
10	Luque et al. 2017	1339	2493	0,01	-0,05	0,08	6,69%
11	Ma et al. 2019	22762	5070	0,03	0,00	0,06	31,98%
12	Shayeb et al. 2011	839	909	0,08	-0,02	0,17	3,35%
13	Keskin et al. 2017	165	222	0,14	-0,06	0,35	0,73%
14	Eraia-Alekssejev et al. 2015	127	95	0,67	0,40	0,95	0,40%
15	Aggerholm et al. 2008	986	773	0,97	0,87	1,07	2,98%
16	Chavarro et al. 2010	123	233	0,99	0,76	1,22	0,56%





Heterogeneity	Adjusted
Q	1071.97
P_Q	0.000
I^2	98.60%
T^2	0.10
T	0.32

Combined effect size	Adjusted
Effect Size	0.01
SE	0.01
CI Lower limit	-0.01
CI Upper limit	0.03
PI Lower limit	-0.68
PI Upper limit	0.70

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Left
Number of imputed studies	0

Sperm total motility_BMI_Obese (or obese I) vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

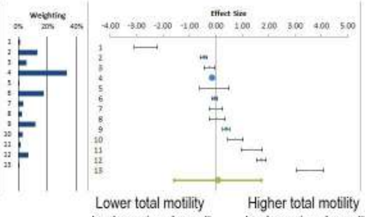
Combined Effect Size	
Effect Size	0.08
Standard error	0.02
CI Lower limit	0.03
CI Upper limit	0.13
PI Lower limit	-1.58
PI Upper limit	1.74

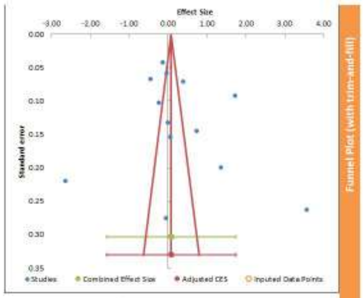
Z-value	3.37
One-tailed p-value	0.000
Two-tailed p-value	0.001

Number of incl. studies	13

Heterogeneity	
Q	834.25
P_Q	0.000
I^2	98.56%
T^2	0.58
T	0.76

#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Dupont et al. 2013	123	87	-2.65	-3.08	-2.22	1.20%
2	Oliveira et al. 2018	370	856	-0.44	-0.58	-0.31	12.92%
3	Martini et al. 2010	251	388	-0.24	-0.44	-0.04	5.51%
4	Belloc et al. 2014	5799	634	-0.13	-0.21	-0.05	33.11%
5	Rybar et al. 2011	74	16	-0.05	-0.60	0.50	0.76%
6	Ma et al. 2019	22762	302	-0.04	-0.15	0.07	17.25%
7	Thomsen et al. 2014	151	43	0.00	-0.26	0.26	3.33%
8	Keskin et al. 2017	259	74	0.05	-0.26	0.35	2.42%
9	Shayeb et al. 2011	165	56	0.39	0.25	0.53	11.60%
10	Chavarro et al. 2010	839	269	0.74	0.45	1.02	2.76%
11	Ehala-Aleksejev et al. 2015	127	38	1.37	0.97	1.76	1.45%
12	Aggerholm et al. 2008	986	163	1.73	1.54	1.91	6.85%
13	Qin et al. 2007	690	17	3.57	3.05	4.08	0.83%





Heterogeneity	Adjusted
Q	834.25
P_Q	0.000
I^2	98.56%
T^2	0.58
T	0.76

Combined effect size	Adjusted
Effect Size	0.08
SE	0.02
CI Lower limit	0.03
CI Upper limit	0.13
PI Lower limit	-1.58
PI Upper limit	1.74

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Left
Number of imputed studies	0

Sperm progressive motility_BMI_Overweight vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

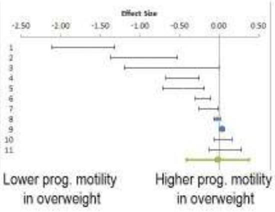
Combined Effect Size	
Effect Size	-0.01
Standard error	0.01
CI Lower limit	-0.04
CI Upper limit	0.01
PI Lower limit	-0.41
PI Upper limit	0.38

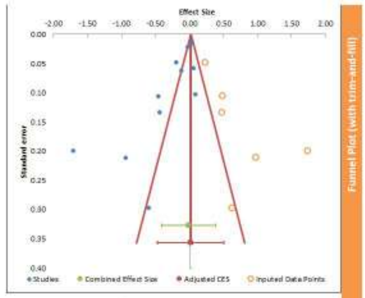
Z-value	-1.23
One-tailed p-value	0.109
Two-tailed p-value	0.218

Number of incl. studies	11

Heterogeneity	
Q	156.69
P_Q	0.000
I^2	93.62%
T^2	0.03
T	0.18

#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Taha et al. 2016	81	59	-1.71	-2.10	-1.31	0.33%
2	Vignera et al. 2012	50	50	-0.94	-1.36	-0.52	0.29%
3	Andersen et al. 2016	21	27	-0.60	-1.20	0.00	0.15%
4	Hammiche et al. 2012	153	225	-0.46	-0.67	-0.25	1.16%
5	Fariello et al. 2012	82	187	-0.45	-0.71	-0.18	0.73%
6	Wang et al. 2017	1398	620	-0.20	-0.30	-0.11	5.56%
7	Oliveira et al. 2018	370	856	-0.13	-0.25	0.00	3.36%
8	Belloc et al. 2014	5799	3607	-0.02	-0.07	0.02	29.00%
9	Ma et al. 2019	22762	5070	0.04	0.01	0.07	54.24%
10	Bandel et al. 2015	905	456	0.05	-0.06	0.17	3.96%
11	Keskin et al. 2017	165	222	0.08	-0.12	0.28	1.23%





Heterogeneity	Adjusted
Q	315.07
P_Q	0.000
I^2	94.92%
T^2	0.05
T	0.23

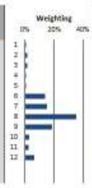
Combined effect size	Adjusted
Effect Size	0.02
SE	0.01
CI Lower limit	-0.01
CI Upper limit	0.04
PI Lower limit	-0.48
PI Upper limit	0.51

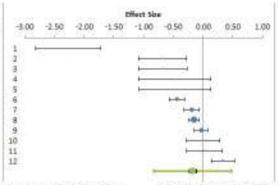
Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	6

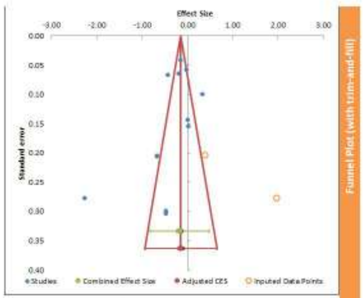
Sperm progressive motility_BMI_Obese (or obese I) vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%
Presentation	
Sort By	Effect Size
Order	Ascending
Combined Effect Size	
Effect Size	-0.17
Standard error	0.02
CI Lower limit	-0.23
CI Upper limit	-0.12
PI Lower limit	-0.82
PI Upper limit	0.48
Z-value	-6.88
One-tailed p-value	0.000
Two-tailed p-value	0.000
Number of incl. studies	12
Heterogeneity	
Q	122.23
P_Q	0.000
I^2	91.00%
T^2	0.09
T	0.30

#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Taha et al. 2016	81	25	-2.27	-2.82	-1.72	0.81%
2	Fariello et al. 2012	82	36	-0.68	-1.08	-0.27	1.48%
3	Vignera et al. 2012	50	50	-0.67	-1.08	-0.26	1.47%
4	Andersen et al. 2016	21	24	-0.48	-1.09	0.13	0.68%
5	Ferigolo et al. 2019	20	27	-0.47	-1.08	0.13	0.69%
6	Oliveira et al. 2018	370	598	-0.44	-0.57	-0.31	13.87%
7	Wang et al. 2017	1398	298	-0.19	-0.32	-0.07	15.20%
8	Belloc et al. 2014	5799	634	-0.15	-0.23	-0.07	35.36%
9	Ma et al. 2019	22762	302	-0.03	-0.14	0.08	18.52%
10	Hammiche et al. 2012	153	72	0.00	-0.28	0.28	3.04%
11	Keskin et al. 2017	165	56	0.02	-0.28	0.33	2.59%
12	Bandel et al. 2015	905	115	0.33	0.14	0.53	6.30%







Heterogeneity	Adjusted
Q	188.52
P_Q	0.000
I^2	93.10%
T^2	0.13
T	0.36

Combined effect size	Adjusted
Effect Size	-0.15
SE	0.02
CI Lower limit	-0.20
CI Upper limit	-0.09
PI Lower limit	-0.94
PI Upper limit	0.64

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	2

Sperm normal morphology_BMI_Overweight vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

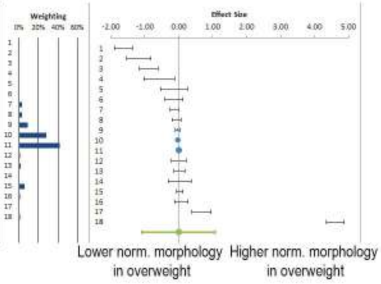
Combined Effect Size	
Effect Size	0.00
Standard error	0.01
CI Lower limit	-0.02
CI Upper limit	0.02
PI Lower limit	-1.08
PI Upper limit	1.08

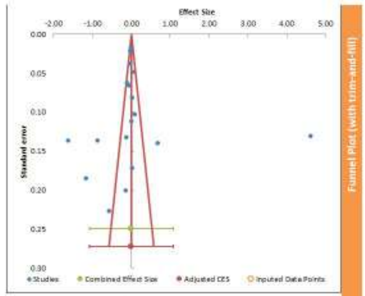
Z-value	-0.05
One-tailed p-value	0.481
Two-tailed p-value	0.961

Number of incl. studies	18

Heterogeneity	
Q	1511.88
P_Q	0.000
I^2	98.88%
T^2	0.26
T	0.51

#	Study name	Sample size normal	Sample size overweight	Effect size	CI Lower limit	CI Upper limit	Weight
1	Dupont et al. 2013	151	137	-1,63	-1,90	-1,36	0,68%
2	Taha et al. 2016	81	59	-1,17	-1,54	-0,81	0,37%
3	Eisenberg et al. 2014	83	191	-0,88	-1,15	-0,61	0,68%
4	Andersen et al. 2016	40	41	-0,57	-1,02	-0,12	0,25%
5	Vignera et al. 2012	50	50	-0,14	-0,54	0,26	0,32%
6	Fariello et al. 2012	82	187	-0,14	-0,40	0,13	0,72%
7	Oliveira et al. 2018	370	856	-0,12	-0,24	0,00	3,27%
8	Jensen et al. 2004	1042	299	-0,06	-0,19	0,07	2,95%
9	Luque et al. 2017	1115	2029	-0,03	-0,11	0,04	9,13%
10	Belloc et al. 2014	5799	3607	-0,03	-0,07	0,02	28,25%
11	Ramirez et al. 2020	5201	8992	-0,01	-0,04	0,03	41,94%
12	Chavarro et al. 2010	123	239	0,00	-0,22	0,22	1,02%
13	Martini et al. 2010	251	388	0,02	-0,14	0,18	1,94%
14	Rybar et al. 2011	74	63	0,03	-0,31	0,37	0,43%
15	Wang et al. 2017	1398	620	0,03	-0,06	0,13	5,44%
16	Keskin et al. 2017	165	222	0,08	-0,12	0,28	1,20%
17	Ehala-Aleksejev et al. 2015	127	95	0,67	0,40	0,95	0,65%
18	Qin et al. 2007	690	241	4,61	4,35	4,87	0,75%





Heterogeneity	Adjusted
Q	1511.88
P_Q	0.000
I^2	98.88%
T^2	0.26
T	0.51

Combined effect size	Adjusted
Effect Size	0.00
SE	0.01
CI Lower limit	-0.02
CI Upper limit	0.02
PI Lower limit	-1.08
PI Upper limit	1.08

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	0

Sperm normal morphology_BMI_Obese (or obese I) vs. Normal_Sensitivity analysis (fixed model)

Meta-analysis model	
Model	Fixed effect model
Confidence level	95%

Presentation	
Sort By	Effect Size
Order	Ascending

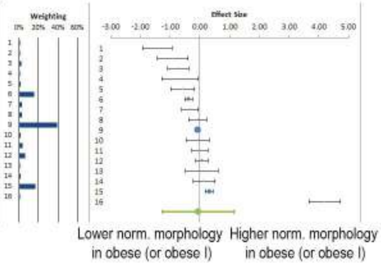
Combined Effect Size	
Effect Size	-0.06
Standard error	0.03
CI Lower limit	-0.12
CI Upper limit	0.00
PI Lower limit	-1.26
PI Upper limit	1.14

Z-value	-2.29
One-tailed p-value	0.011
Two-tailed p-value	0.022

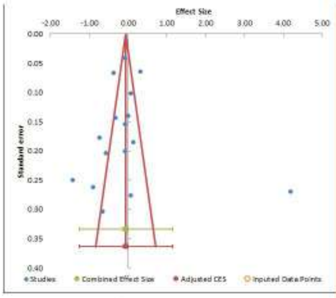
Number of incl. studies	16

Heterogeneity	
Q	378.15
p_Q	0.000
I^2	96.03%
T^2	0.32
T	0.56

#	Study name	Sample size normal	Sample size obese (or obese I)	Effect size	CI Lower limit	CI Upper limit	Weight
1	Taha et al. 2016	81	25	-1.43	-1.93	-0.94	1.10%
2	Andersen et al. 2016	40	27	-0.91	-1.43	-0.39	1.00%
3	Dupont et al. 2013	151	43	-0.73	-1.08	-0.38	2.19%
4	Ferigolo et al. 2019	20	27	-0.66	-1.27	-0.05	0.75%
5	Vignera et al. 2012	50	50	-0.58	-0.98	-0.17	1.65%
6	Oliveira et al. 2018	370	598	-0.38	-0.51	-0.25	15.43%
7	Eisenberg et al. 2014	83	122	-0.33	-0.61	-0.04	3.35%
8	Keskin et al. 2017	165	56	-0.08	-0.38	0.23	2.87%
9	Belloc et al. 2014	5799	634	-0.08	-0.16	0.01	39.28%
10	Fariello et al. 2012	82	36	-0.07	-0.47	0.32	1.72%
11	Chavarro et al. 2010	123	87	0.00	-0.28	0.28	3.50%
12	Martini et al. 2010	251	155	0.06	-0.14	0.26	6.57%
13	Rybar et al. 2011	74	16	0.07	-0.47	0.62	0.90%
14	Ehala-Aleksejev et al. 2015	127	38	0.13	-0.23	0.50	2.01%
15	Wang et al. 2017	1398	298	0.31	0.18	0.43	16.75%
16	Qin et al. 2007	690	17	4.20	3.67	4.73	0.94%



Funnel Plot (with trim-and-fill)



Heterogeneity	Adjusted
Q	378.15
p_Q	0.000
I^2	96.03%
T^2	0.32
T	0.56

Combined effect size	Adjusted
Effect Size	-0.06
SE	0.03
CI Lower limit	-0.12
CI Upper limit	0.00
PI Lower limit	-1.26
PI Upper limit	1.14

Trim and Fill	On
Estimator for missing studies	Leftmost Run/Rightmost Run
Search from mean	Right
Number of imputed studies	0