REVIEW ARTICLE

Behavior, Psychology and Sociology

The effect of a very low calorie diet on subjective depressive symptoms and anxiety: meta-analysis and systematic review

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Abstract

There are conflicting findings regarding the effect very low calorie diets (VLCDs) have on self-reported depressive symptoms and anxiety levels. Some studies have reported decreased subjective depressive symptoms and anxiety post-diet, whereas other studies have not. Further complicating matters, the protocol for VLCDs vary substantially across studies, which could account for the mixed findings. The primary goal of this meta-analysis and systematic review was to determine the effect VLCDs have on subjective depressive symptoms and anxiety pre- to post-diet. In addition, potential moderators (the presence/absence of behavioral therapy, duration of diet, inclusion/exclusion of low intensity exercise, and amount of weight lost) were examined to assess the effect of procedural deviations across VLCD studies on depressive symptoms and anxiety. A random-effects model was used for the meta-analysis and included nine studies with 16 independent samples. To further explain the results, study rigor was examined in the systematic review, which included 11 studies with 20 independent samples. Depressive symptoms significantly decreased pre- to post-diet when behavioral therapy was implemented during the diet, the duration of the diet was relatively long (8–16 weeks), low intensity exercise was included, and the dieters lost 14.1 kg or more post-diet. However, no difference in depressive symptoms were observed pre- to post-diet when behavioral therapy was not included, the diet was shorter (1–7 weeks), no exercise was implemented and dieters lost <14 kg of weight post-diet. There was no change in anxiety pre- to post-diet. Health care providers involved in supervising VLCDs should consider using a VLCD of at least 8 weeks that includes behavioral therapy and low intensity exercise in order to enhance the potential benefits of VLCDs on depressive symptoms. More research is required to examine the effect of VLCDs on anxiety.

A very low calorie diet (VLCD) is a dietary program that provides a total meal replacement plan and consists of a maximum consumption of 800 calories per day [1, 2]. Typically, a VLCD is recommended for individuals with obesity (e.g., a body mass index [BMI] of 30 kg/m²) [1] or with obesity-related complications (e.g., diabetes) [3]. The replacement meals of a VLCD contain high levels of protein and low amounts of carbohydrates to aid weight loss. VLCDs also include vitamins, minerals, electrolytes, and

fatty acid supplements to ensure all necessary nutrients are consumed daily [4]. The main purpose of a VLCD is to achieve rapid weight loss through strict caloric intake, while maintaining lean body mass [2, 4, 5]. Prior research has reported that VLCDs are effective in the treatment of obesity [2]. Additionally, VLCDs improve physical health in individuals with obesity by decreasing blood pressure by 8–13% in individuals with hypertension [3], improving glucose, lipid, and insulin levels in those with diabetes [3, 6] and reducing fat content and liver size due to weight loss [7].

Although VLCDs improve physical health, the effect the diet has on psychological well-being is less clear. To understand the effect VLCDs have on individuals with obesity, both physical and psychological health are essential factors to consider, as these two domains are fundamentally connected [8]. The overarching goal of the current work is to examine the effect of VLCDs on self-reported depressive symptoms and anxiety via a meta-analysis and systematic

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review of VLCD studies. In this work, the term depressive symptoms is defined as the self-reported ratings of current symptoms associated with depression (e.g., the total score on the Beck Depression Inventory [BDI]) [9]. Anxiety is defined as the self-reported rating of current symptoms of anxiety (e.g., the total score on the State-Trait Anxiety Inventory-State Version [STAI-S]) [10]. Depressive symptoms and anxiety were chosen as the psychological variables in the current work because depressive symptoms and anxiety are commonly associated with obesity [11–13] and thus typically assessed in VLCD studies, whereas measures of other psychological constructs (e.g., guilt) are not.

It is well established that obesity generates significant psychological burden [14, 15]. Prior research has shown that psychological outcomes such as depressive symptoms and anxiety improve after weight loss surgery [16] and after completing a weight loss program that is less extreme (e.g., permits more calories per day) than a VLCD [17, 18]. However, the literature is currently mixed about how VLCDs impact depressive symptoms and anxiety. Some research shows that subjective ratings of depressive symptoms and anxiety decrease after completing a VLCD [19–21] but other studies show no change in depressive symptoms and anxiety pre- to post-VLCD [22] or a trend ($p = 0.08$) toward increased depressive symptoms [23]. In order to understand the impact VLCDs have on depressive symptoms and anxiety, it is necessary to determine the possible reasons for the mixed findings.

One possibility to account for the mixed findings described above is the use of VLCD protocols that deviate from one another in the inclusion/exclusion of behavioral therapy, duration of the diet and presence/absence of low intensity exercise. Indeed, currently there is no consensus among VLCD researchers on these three parameters. The resulting variability among studies is understandable given the dearth of published guidelines for a standard VLCD protocol but renders it difficult to understand the effect of VLCDs on depressive symptoms and anxiety. Further complicating matters, the amount of weight lost in VLCD studies has also varied substantially (e.g., 5.8–27.10 kg) [23, 24] possibly as a function of duration (however, see ref. [2]), and the presence/absence of behavioral therapy, and/or low intensity exercise [22, 25]. The fact that different amounts of weight are lost is important because the more weight dieters lose during weight loss interventions (of all types), the more their psychological well-being tends to improve [26] (however, see ref. [27]). Thus, four major sources of variation across VLCDs were considered in the current work: whether behavioral therapy was included, the duration of the VLCD, whether low intensity exercise was prescribed, and the amount of weight lost.

VLCD programs commonly include multi-disciplinary supervision from an array of specialists (e.g., physicians, dieticians, and psychologists) [1, 2]. In some VLCD studies, the psychologists on the research team provide patients with behavior modification approaches such as behavioral therapy [20]. Core components of behavioral therapy include educating dieters about nutrition and eating habits such as amount of food consumed, training self-awareness and assertiveness, and suggesting coping techniques for long-term alteration of lifestyle in order for dieters to maintain weight loss [1, 28, 29]. Prior research has shown that incorporating behavioral therapy into a weight loss intervention benefits psychological well-being. For example, depressive symptoms significantly improved in obese women after completing a behavioral treatment program [30]. Some prior research also suggests that the presence of behavioral therapy increases the amount of weight lost [25]. Thus, it was predicted that VLCDs that included behavioral therapy would improve depressive symptoms and anxiety more than VLCDs without behavioral therapy.

With respect to VLCD duration, 12 weeks is the most common length of a VLCD [31], but there is substantial variability in the lengths of VLCDs. Indeed, VLCDs typically range from 8 to 16 weeks [5], but shorter diets have also been used (e.g., 4 weeks) [23]. Whether the length of a VLCD affects the extent to which depressive symptoms and anxiety change pre- to post-diet is unknown. Importantly, 12–14 weeks post-diet, a refeeding phase occurs, in which conventional foods are reintroduced to stabilize weight [2]. Refeeding in each study was not considered in the current work because depressive symptoms and anxiety were assessed before the refeeding period. A reason to suspect that longer length VLCDs might benefit depressive symptoms more than shorter VLCDs is that longer VLCDs might be expected to result in more weight loss, and hence improve depressive symptoms and anxiety via the greater weight loss [26]. In contrast, a meta-analysis showed that the duration of a VLCD and the amount weight lost are not related [2]. Consequently, there was no hypothesis about how the duration of a VLCD would affect the extent to which depressive symptoms and anxiety changed pre- to post-diet.

Additionally, the inclusion of low intensity exercise (e.g., walking) varies among the VLCD studies, such that some studies included low intensity exercise [19, 25] while other studies did not prescribe any form of exercise [22, 23]. Critically, research has shown that exercise can decrease depressive symptoms and anxiety [32]. As such, it was predicted that VLCDs that included low intensity exercise would improve depressive symptoms and anxiety more than VLCDs without low intensity exercise. That noted, it is unclear whether the inclusion of low intensity exercise is an essential factor for reducing these psychological outcomes within the VLCD programs.

As aforementioned, the average amount of weight lost by participants on VLCDs varies. Although greater weight loss after dieting tends to be associated with improved psychological well-being [26], these findings have not occurred in all VLCDs studies. Indeed, it has been reported that the more weight that the participants lost, the more the increase in their depressive symptoms [27]. Consequently, a prediction was not set forth about how the amount of weight lost would impact the extent to which depressive symptoms and anxiety change.

The primary objective of the current work was to examine whether subjective depressive symptoms and anxiety change pre- to post-VLCD using both a meta-analysis to examine the direction and magnitude of the effects, and a systematic review to further explain the results of the meta-analysis. Inclusion of behavioral therapy, diet duration, addition of low intensity exercise, and amount of weight lost were examined as potential moderators of the effect a VLCD has on depressive symptoms and anxiety.

Methods

Literature search and selection

Studies were selected from the literature that examined the effect of VLCDs on depressive symptoms and anxiety. Searches were conducted through three online databases: PsycINFO, MEDLINE, and Scopus, on November 10, 2017, and only included studies published prior to this date. The search terms included ("very low calorie diet" OR "very low energy diet" OR "VLCD" OR "calorie restriction") AND ("mood" OR "depression" OR "anxiety").

Inclusion and exclusion criteria

Eligibility criteria were established to screen for selected studies. The criteria for eligible studies included: (1) studies that contain a VLCD of 800 calories or less per day, (2) a minimum of two time point measurements of self-reported depressive symptoms and/or anxiety (pre- and post-VLCD), and (3) adults of all body weights with or without any psychological and/or medical conditions. Studies were excluded based on the following: (1) animal studies, (2) literature reviews, (3) studies that used VLCDs in conjunction with other interventions (e.g., pharmaceutical, surgery, or high intensity exercise [e.g., running]), (4) exclusive fasting diets of zero calories per day, and (5) studies in which measures of depressive symptoms and anxiety were not made via self-report.

A total of 396 studies were identified from the three databases. Duplicates were removed resulting in a total of 363 studies. Of these studies, 146 studies were excluded based on the study's abstract. Of the remaining 217 studies, full texts were retrieved and reviewed in their entirety. At this stage, 207 full text studies were excluded. One additional study was included after searching prominent authors' publication websites and manually searching the reference lists of the remaining 10 studies. In total, 11 studies were included in the analysis. Of these 11 studies, nine provided useable data while two required author contact; however, the authors did not respond. Thus, the meta-analysis of the current paper included nine studies and the systematic review included 11 studies (see Fig. 1). At each stage, two authors (N.E. and B.A.) assessed all studies independently. The initial inter-rater reliability was high (81%). All discrepancies were resolved through discussion. There were no disagreements and the final study selection had 100% inter-rater reliability.

Data extraction and coding

For all studies, descriptive study information and psychological outcome scores were extracted. Key potential moderating factors extracted were whether behavioral therapy was included (yes or no), duration of the VLCD was short (0–7 weeks) or long (8 weeks or more), low intensity exercise was included (yes or no), and amount of weight lost was low (0–14 kg) or high (14.1 kg or more). The cutoffs for the duration of the VLCD and amount of weight lost were determined a priori. Specifically, short and long diet durations were based on VLCDs typically ranging from 8 to 16 weeks [5]. We classified a duration as short if the diet was less than the commonly used 8 weeks (i.e., 0–7 weeks) and long if the diet was the more commonly used range (i.e., 8–16 weeks). Low and high weight loss was categorized using a 14.1 kg cutoff for two reasons: 14.1 kg was the average amount of weight lost in VLCD programs [25], and 14.1 kg is the approximate amount of weight that participants self-reported wishing to lose in a cross-sectional survey [33]. Thus, we classified weight loss as low (<14.1 kg) and high (14.1 kg and above).

Psychological outcome scores that were extracted included subjective measurements of depressive symptoms and/or anxiety. Other descriptive variables were also extracted including sample size, percentage of female participants, age of participants, population type (those that are healthy, have medical conditions, and/or psychological disorders), and BMI classification (i.e., healthy weight, overweight, or obese). However, there was little variability in the demographic variables. For example, all studies included adults (ages 20–56). Further, the majority of the studies (13 out of 20) included participants with obesity. The remaining seven samples included participants that were either of normal weight

Fig. 1 Flow diagram of study selection procedure
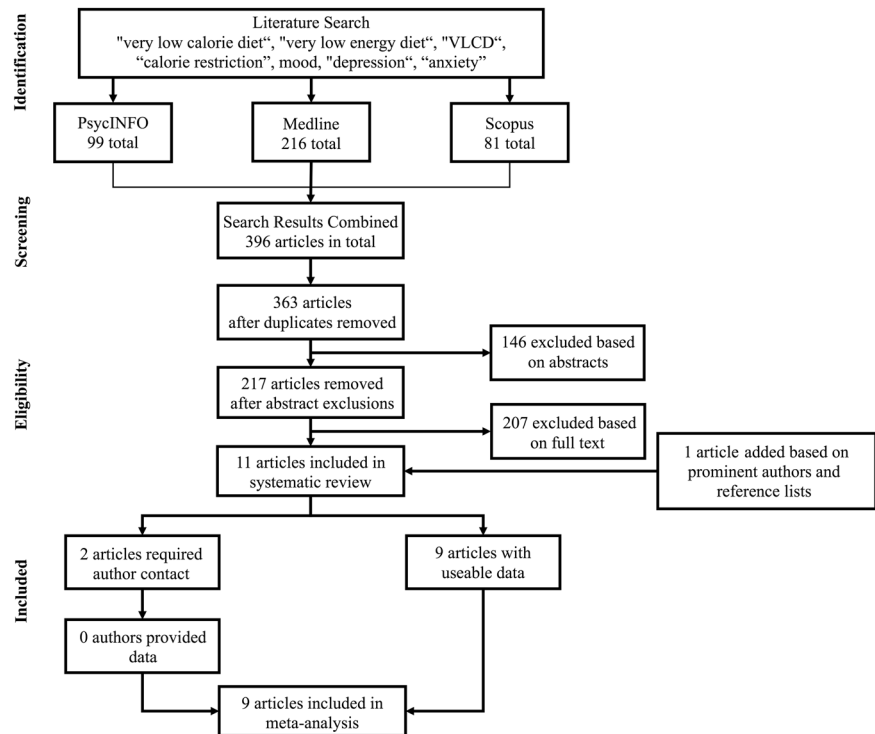
(k = 2), overweight (k = 1), or description of weight was not reported (k = 4). Consequently, these demographic variables were not considered in subsequent analyses due to low sample size.

Data analytic plan: meta-analysis

Comprehensive meta-analysis software (CMA) version 3.0 [34] was used to conduct the meta-analysis, with Hedges' g used to estimate the effect size (i.e., the mean difference divided by the pooled standard deviation) [34]. The following information was extracted from each of the studies: sample size, depressive symptoms, and anxiety scores before and after the VLCD (means and standard deviations), whether behavioral therapy was provided (yes/no), the duration of the VLCD (short/long), whether low intensity exercise was included (yes/no), and the amount of weight lost by dieters (low/high). In addition, correlations for pre- and post-depressive symptoms and anxiety were required. The correlation was used to account for between-subject variance in within-subject designs [34]. Although the correlations were requested from the authors, no responses were received. Similar to previous research [35], a conservative default value of 0.50 was used as the correlation coefficient. Last, Duval and Tweedie's (2000) trim-and-fill procedure was used to determine whether publication bias

occurred and the adjusted effect size estimates were imputed based on missing samples.

Data analytic plan: systematic review

The systematic review included all studies in the analysis. Statistical directional findings (e.g., a significant decrease in depressive symptoms pre- to post-VLCD) were extracted, and study rigor was determined and used as a proxy of the quality of research conducted for each study. In particular, study rigor is a rating attributed to each study that evaluates whether the methods used are reliable and valid [36]. To determine study rigor, the following information was extracted from the studies and organized into categories: (1) sample size, (2) sample selection (i.e., how many sources did the study use to recruit participants), (3) whether the study used validated psychological measures (e.g., Beck Depression Inventory), (4) whether a clear explanation of the VLCD protocol was included (e.g., duration of VLCD), and (5) whether statistical analyses were clearly described (e.g., the statistical test used and effect sizes were reported). Based on this information, we gave each category a numerical value. Each numerical value was tallied to determine study rigor for a rating of weak, moderate, or strong (see Appendix A for details) [37].

Results

Study characteristics

The meta-analysis included nine studies with 16 independent samples. In total, the nine studies included 354 participants. Eleven samples included scores of depressive symptoms and five samples included scores of anxiety. Six samples included behavioral therapy and 10 samples did not. Seven samples used short-term diets, nine samples used long-term diet. Five samples included low intensity exercise, while 10 did not and one sample did not provide this information. In regards to weight lost post-VLCD, dieters in eight samples lost a small amount of weight, and dieters in eight samples lost a large amount of weight (see Table 1).

The systematic review included all 11 studies with 20 independent samples. In total, the studies included 441 participants. Of the 20 samples, researchers examined depressive symptoms in 14 samples, and anxiety in 6 samples. There were 9 samples that included behavioral therapy and 11 samples did not. Seven samples used a short-term diet and 13 samples used a long-term diet. Nine samples included low intensity exercise while 10 samples did not and one sample did not specify this information. Dieters in 11 samples lost a small amount of weight and dieters in 9 samples lost a large amount of weight (see Table 1).

Meta-analysis: effects of VLCD on psychological outcomes

Depressive symptoms and anxiety scores were examined pre- to post-VLCD with four potential moderators: behavioral therapy (yes/no), duration (short/long), low intensity exercise (yes/no) and weight lost (low/high).

Depressive symptoms

A total of 11 samples were submitted to the random-effects model to determine the effect the VLCD has on depressive symptoms scores. Results indicated that depressive symptom scores statistically decreased from pre- to post-VLCD with a mean weighted effect size of $g = -0.728$ ($SE = 0.243$, 95% CI $= -1.204$ to -0.253; $z = -3.001$, $p = 0.003$). Overall, the effect sizes were heterogeneous, $Q(10) = 133.740$, $p < 0.001$, indicating variability of depressive symptoms scores amongst samples (see Fig. 2).

A significant effect of behavioral therapy on depressive symptoms was found, $Q(1) = 11.601$, $p = 0.001$. Samples that did receive behavioral therapy showed a significant decrease on depressive symptom scores from pre- to post-VLCD, with a mean weighted effect size of $g = -1.551$ ($SE = 0.414$, 95% CI $= -2.363$ to -0.739; $z = -3.743$, $p < 0.001$). However, samples that did not receive behavioral therapy showed no significant change in depressive symptoms pre- to post-VLCD ($p = 0.507$).

For VLCD duration, we first used the raw data as a continuous variable. Using the raw data, a meta-regression using a random-effects model with moment method was conducted to determine whether duration of the VLCD moderated the magnitude of effect sizes in depressive symptoms. The Q-statistic determined that at least some of the differences in duration significantly contributed to the effect size ($Q = 4.78$, $df = 1$, $p = 0.029$). Based on this finding, we categorized duration into two categories, as stated above (short/long). All subsequent analyses are based on this categorization. A significant effect of duration of the VLCD on depressive symptoms was also observed, $Q(1) = 11.331$, $p = 0.001$. Dieters that participated in long-term VLCDs showed significant changes on depressive symptoms scores pre- to post-VLCD, with a mean weighted effect size of $g = -1.163$ ($SE = 0.321$, 95% CI $= -1.792$ to -0.533; $z = -3.622$, $p < 0.001$). However, the samples that participated in short-term VLCDs showed no significant differences in depressive symptoms pre- to post-VLCD ($p = 0.908$).

A significant effect of low intensity exercise on depressive symptoms was found, $Q(1) = 7.510$, $p = 0.006$. Samples that did include exercise showed a significant decrease on depressive symptom scores from pre- to post-VLCD, with a mean weighted effect size of $g = -1.838$ ($SE = 0.630$, 95% CI $= -3.072$ to -0.604; $z = -2.919$, $p = 0.004$). However, samples that did not include exercise showed no significant change in depressive symptoms pre- to post-VLCD ($p = 0.507$).

Regarding weight loss, we first used the raw data as a continuous variable. Using the raw data, a meta-regression using a random-effects model with moment method was conducted to determine whether weight loss moderated the magnitude of effect sizes in depressive symptoms. The Q-statistic determined that differences in weight loss was trending on significance and could be contributing to the effect size ($Q = 3.49$, $df = 1$, $p = 0.061$). Based on this trending effect, we categorized weight loss into two categories, as stated above (low/high). All subsequent analyses are based on this categorization. A significant effect of weight loss on depressive symptoms occurred as well, $Q(1) = 13.179$, $p < 0.001$. Samples that lost a high amount of weight showed a significant difference in depressive symptoms pre- to post-VLCD, with a mean weighted effect of $g = -1.361$ ($SE = 0.356$, 95% CI $= -2.059$ to -0.663; $z = -3.882$, $p < 0.001$). However, the samples that lost a low amount of weight showed no significant differences in depressive symptoms scores pre- to post-VLCD ($p = 0.968$).

Table 1 Summary of study characteristics

Study	N	Age M(SD)/range	BMI M(SD)/range	Female (%)	Behavioral therapy	Duration of VLCD	Low intensity exercise	Weight loss (kg) Post-pre weight	Psychological outcome Pre-VLCD M (SD)	Post-VLCD M (SD)
*Buffenstein et al. [23]: moderate	9	20–36	26.1(2.8)	100%	No	Short (4 weeks)	No	Low −5.80	POMS-D 43.20 (7.00)	POMS-D 47.10 (11.00)
*Cheskin et al. [22]: weak	17	35.1(8.1)	19–25	47%	No	Short (6 days)	No	Low −0.73	SM-D 4.24 (5.61) SM-A 0.10 (0.49)	SM-D 4.25 (5.77) SM-A 0.22 (1.03)
de Zwaan et al. [20]: moderate	35	37.7(6.5)	35.7(4.2)	100%	No	Long (12 weeks)	Yes	High −14.60	↓ BDI**	
	36	40.9(7.7)	36.6(3.2)	100%	Yes	Long (12 weeks)	Yes	Low −13.20	↓ BDI**	
*Foster et al. [49]: strong	68	40.6(2.0)	37.6(1.1)	100%	Yes	Long (12 weeks)	Yes	High −17.77	BDI[a]** 8.30 (0.90)	BDI[a]** 3.40 (0.80)
*Kitto [24]: moderate	71	41.0(11.3)	40.2(6.4)	81%	Yes	Long (12 weeks)	–	High −27.10	BDI** 10.19 (6.81)	BDI** 5.19 (5.21)
*LaPorte [38]: strong	94	21+[c]	37.8(–)	70%	Yes	Long (10 weeks)	Yes	High −17.82	BDI** 4.45 (3.70) STAI-S 44.50 (10.20)	BDI** 2.28 (3.60) STAI-S 45.60 (12.30)
*Snel et al. [21]: moderate	14	56.0(2.0)	37.9(1.4)	57%	No	Long (16 weeks)	No	High −23.70	HADS-D** 5.00 (3.74) HADS-A** 5.00 (3.74)	HADS-D** 3.00 (3.74) HADS-A** 4.00 (3.74)
*Wadden et al. [19]: strong	28	36.8(8.9)	40.0(5.7)	100%	Yes	Long (16 weeks)	Yes	High −20.50	BDI** 13.20 (8.08)	BDI** 6.65 (9.97)
*Wadden et al. [25]: strong	15	44.3(8.7)	41.6(–)	85%[b]	No	Long (8 weeks)	No	Low −13.20	BDI 9.30 (12.40)	BDI 8.90 (13.20)
	19	44.3(8.6)	40.9(–)	–	Yes	Long (8 weeks)	Yes	High −15.30	BDI** 12.40 (10.50)	BDI** 4.20 (4.80)
*Wadden et al. [50]: weak	10	38.1(–)[b]	–	89%[b]	No	Short (4 weeks)	No	Low −7.30	BDI 9.10 (6.96) STAI-S** 45.9 (10.75)	BDI 6.10 (7.91) STAI-S** 38.4 (10.12)
	9	–	–	–	No	Short (4 weeks)	No	Low −8.70	BDI 7.60 (7.80) STAI-S** 46.6 (11.40)	BDI 8.4 (2.10) STAI-S** 43.6 (13.80)
Wadden et al. [51]: weak	16	37.5(6.6)	Obese[d]	100%	Yes	Long (8 weeks)	Yes	Low −11.60	↓ BDI** ↓ STAI-S**	

BMI body mass index, VLCD very low calorie diet, POMS-D profile of mood—Depression Scale, SM-D subject mood—depression, SM-A subject mood—anxiety, BDI Beck Depression Inventory, STAI-S State-Trait Anxiety Inventory—State only, HADS-D Hospital Anxiety and Depression Scale—depression scale, HADS-A Hospital Anxiety and Depression Scale—anxiety scale

↑ = increase from pre- to post-VLCD; ↓ = decrease from pre- to post-VLCD

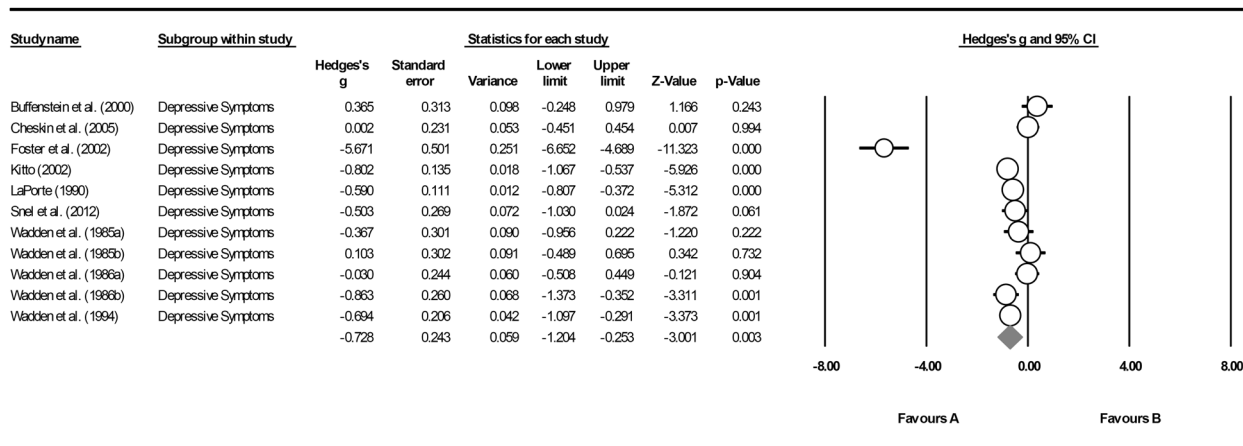| Studyname	Subgroup within study	Statistics for each study							Hedges's g and 95% CI
		Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	
Buffenstein et al. (2000)	Depressive Symptoms	0.365	0.313	0.098	-0.248	0.979	1.166	0.243	
Cheskin et al. (2005)	Depressive Symptoms	0.002	0.231	0.053	-0.451	0.454	0.007	0.994	
Foster et al. (2002)	Depressive Symptoms	-5.671	0.501	0.251	-6.652	-4.689	-11.323	0.000	
Kitto (2002)	Depressive Symptoms	-0.802	0.135	0.018	-1.067	-0.537	-5.926	0.000	
LaPorte (1990)	Depressive Symptoms	-0.590	0.111	0.012	-0.807	-0.372	-5.312	0.000	
Snel et al. (2012)	Depressive Symptoms	-0.503	0.269	0.072	-1.030	0.024	-1.872	0.061	
Wadden et al. (1985a)	Depressive Symptoms	-0.367	0.301	0.090	-0.956	0.222	-1.220	0.222	
Wadden et al. (1985b)	Depressive Symptoms	0.103	0.302	0.091	-0.489	0.695	0.342	0.732	
Wadden et al. (1986a)	Depressive Symptoms	-0.030	0.244	0.060	-0.508	0.449	-0.121	0.904	
Wadden et al. (1986b)	Depressive Symptoms	-0.863	0.260	0.068	-1.373	-0.352	-3.311	0.001	
Wadden et al. (1994)	Depressive Symptoms	-0.694	0.206	0.042	-1.097	-0.291	-3.373	0.001	
		-0.728	0.243	0.059	-1.204	-0.253	-3.001	0.003	

Fig. 2 Effect size statistics and forest plot of selected studies that measured depressive symptoms pre- to post-VLCD. The first author's name is used to identify each individual study. Studies with multiple independent samples are identified with letter sequencing

Anxiety

A total of five samples were submitted to the random-effects model to examine the effect of VLCD on anxiety scores. Results showed that anxiety scores did not statistically change pre- to post-VLCD with a mean weighted effect size of $g = -0.088$ ($p = 0.493$). Overall, the effect sizes were homogeneous, $Q(4) = 6.717$, $p = 0.152$, suggesting small variability of anxiety scores amongst samples. All potential moderators of anxiety had too low a sample size to examine whether moderators exist.

Risk of publication bias

Duval and Tweedie's (2000) trim-and-fill procedure was used to determine the potential presence of publication bias. Upon visual inspection of the funnel plot, the samples of the studies were evenly nested between both sides of the funnel plot. The point estimate of the overall effect sizes in the random-effects model for observed values was -0.559 (CI -0.920 to -0.196) to the adjusted value of -1.087 (CI -1.529 to -0.645). The classic Fail-safe N analysis revealed that 271 studies with non-significant findings would be required in order to nullify the current results. In other words, there would need to be 16.9 missing studies for every observed study for the effect to be nullified. Therefore, it is reasonable to assume that the samples selected for the current meta-analysis were not likely subject to any publication bias.

Systematic review: effects of VLCD on psychological outcomes

A total of 11 studies with 20 independent samples were included in the systematic review. There were 14 samples that measured depressive symptoms and six samples

measured anxiety. To assess the results, the statistical directional findings (whether positive, negative, or non-significant) were used for each outcome. For example, the results reported were classified as a decrease in depressive symptoms post-VLCD, as depressive symptoms scores significantly declined after the diet [19]. Additionally, data from the moderators, as well as the study rigor ratings, were used to compare the findings from the systematic review with the meta-analysis results.

Depressive symptoms

Nine of the 14 samples showed consistent findings with the meta-analysis results. Five of these samples reported significantly lower depressive symptoms pre- to post-VLCD when behavioral therapy was included, a long-term diet was used, low intensity exercise was prescribed (with one sample not reporting this information), and a high amount of weight was lost. The majority (4 out of 5) of these studies included samples that were rated as strong in rigor, suggesting these studies should be weighted more. The other four samples supported the meta-analytic results by reporting no differences in depressive symptoms pre- to post-VLCD when behavioral therapy was not included, a short-term diet was used, no exercise was prescribed and a low amount of weight was lost. These studies included samples that were mostly rated weak in rigor (3 out of 4) and had deviating moderators (e.g., not implementing behavioral therapy; see Table 2).

The remaining five samples showed inconsistent findings with the meta-analysis results with rigor varying from weak to strong. Three out of the five samples showed decreases in depressive symptoms with one deviating moderator. One sample found decreases in depressive symptoms with two deviating moderators. One sample showed non-significant changes in depressive symptoms with one deviating

Table 2 Systematic review results summary for depressive symptom scores from pre- to post-VLCD

Results	Author	Rigor	n	Behavioral therapy	Duration	Exercise	Weight loss	Depressive symptoms outcome
Consistent								
Adhered								
	Wadden et al. [19]	Strong	28	Yes	Long	Yes	High	Decreased
	Foster et al. [49]	Strong	68	Yes	Long	Yes	High	Decreased
	Kitto [24]	Moderate	71	Yes	Long	N/A	High	Decreased
	LaPorte [38]	Strong	94	Yes	Long	Yes	High	Decreased
	Wadden et al. [25]	Strong	19	Yes	Long	Yes	High	Decreased
Deviated								
	Cheskin et al. [22]	Weak	17	No	Short	No	Low	Non-significant
	Buffenstein et al. [23]	Moderate	9	No	Short	No	Low	Non-significant
	Wadden et al. [50]	Weak	10	No	Short	No	Low	Non-significant
	Wadden et al. [50]	Weak	9	No	Short	No	Low	Non-significant
Inconsistent								
	Snel et al. [21]	Moderate	14	**No**	Long	**No**	High	Decreased
	de Zwaan et al. [20]	Moderate	35	**No**	Long	Yes	High	Decreased
	de Zwaan et al. [20]	Moderate	36	Yes	Long	Yes	**Low**	Decreased
	Wadden et al. [25]	Strong	15	No	**Long**	No	Low	Non-significant
	Wadden et al. [51]	Weak	16	Yes	Long	Yes	**Low**	Decreased

Note: Consistent: consistent findings with the results of the meta-analysis; inconsistent: inconsistent findings with the results of the meta-analysis; adhered: moderators that adhered to the VLCD protocol; deviated: moderators that deviated from the VLCD protocol. Depressive symptoms outcome: pre- to post-VLCD. Bold factors indicate deviation from meta-analysis result

moderator (see Table 2). Based on these results, it is difficult to explain why these results deviated from the other studies. However, a VLCD administrator may be able to deviate from one moderator and still obtain a decrease in depressive symptoms. Taken together, there are minimal samples within the systematic review that deviated from the results of the meta-analysis.

Anxiety

Four of the six samples reported decreases in anxiety scores pre- to post-VLCD. However, three of these four samples were rated weak in study rigor while the remaining sample was rated moderate in rigor. Therefore, the findings on how VLCDs affect anxiety reported in these samples should be reviewed with caution. The remaining two samples (one rated as weak and one as strong in rigor) reported no significant differences in anxiety pre- to post-VLCD, consistent with the results of the meta-analysis. Considering the range of study rigor, it is recommended to review each study with caution.

Discussion

The primary goal of the current meta-analysis and systematic review was to investigate the effect VLCDs have on subjective depressive symptoms and anxiety pre- to post-

diet. Moderator analyses were also used to examine whether variations in the VLCD program (inclusion of behavioral therapy, duration of the VLCD, addition of low intensity exercise, and amount of weight lost) affect the extent to which depressive symptoms and anxiety change from baseline to completion of the program. Main findings revealed a significant decrease in depressive symptoms, and no change in anxiety, pre- to post-VLCD. In addition, presence of behavioral therapy, duration of the diet, inclusion of low intensity exercise and amount of weight lost significantly moderated the effect of the diet on depressive symptoms. No moderating effects were examined for anxiety pre- to post-VLCD due to low sample size.

Meta-analysis: interpretation of results

Depressive symptoms and weight loss

Prior research has shown that weight loss programs are associated with improvements in psychological outcomes [17, 18], with one empirical study showing that the more weight dieters lost during a weight loss intervention, the more their psychological well-being improved [26]. However, weight loss was not associated with improvements in depressive symptoms across all VLCD studies [27]. Our results showed that those who lost a high amount of weight (i.e., 14.1 kg or more) also showed reduced depressive symptoms. In addition, all of the studies that reported

decreased depressive symptoms after the diet included individuals with obesity, the primary candidates of a VLCD, to help improve obesity-related comorbidities [1]. With successful completion of a VLCD, individuals with obesity not only typically lose a substantial amount of weight, they also experience medical relief (e.g., reduced hypertension) [1]. Therefore, with successful adherence to and completion of a VLCD, individuals with obesity may have experienced both weight loss and medical improvements, resulting in decreased depressive symptoms post-diet.

Depressive symptoms, behavioral therapy, and weight loss

Consistent with our hypothesis, a moderating effect of behavioral therapy was observed such that the implementation of behavioral therapy during the VLCD was associated with a significant decrease in depressive symptoms. However, when behavioral therapy was not included in the VLCD program, depressive symptom scores did not change. This finding suggests that decreases in depressive symptoms could, in part, be attributed to the inclusion of behavioral therapy during a VLCD.

Behavioral therapy is often included in the VLCD program to educate dieters and manage dieting progress [2, 29]. Prior research has shown that incorporating behavioral therapy into a weight loss intervention can improve psychological well-being. For example, when women with obesity completed a behavioral treatment program, depressive symptoms significantly improved compared to baseline levels [30]. Consistent with this finding, the majority of samples (5 out of 6) included in the current paper that reported decreased depressive symptoms post-VLCD included behavioral therapy. Conversely, all the samples (5 out of 5) that reported non-significant changes in depressive symptoms pre- to post-VLCD did not include behavioral therapy. Accordingly, it may be that the support and management received from behavioral therapists during the VLCD moderated the observed decrease in depressive symptoms, rather than the VLCD improving depressive symptoms per se.

Additionally, studies without behavioral therapy also tended to result in a lower amount of weight loss post-diet, compared to studies that included behavioral therapy. Consequently, the lack of behavioral therapy in some studies may have prevented dieters from receiving the necessary help to progress through the dietary program and achieve their primary goal of substantial weight loss. Furthermore, adhering to a VLCD requires drastic caloric restriction, and changing one's lifestyle in this manner can be challenging. Without support from behavioral therapy, adjusting to a strict diet may be difficult, potentially resulting in the underachievement of a weight-related goal.

Taken together, these possibilities suggest that whether depressive symptoms improve may depend in part on the presence or absence of behavioral therapy.

Depressive symptoms, diet duration, and weight loss

The results of the current paper showed a moderating effect of the duration of the VLCD on depressive symptoms. Specifically, studies that found decreases in depressive symptoms post-VLCD used a longer VLCD. However, studies that indicated non-significant findings employed a shorter VLCD. Thus, the duration of the VLCD program may be an essential component in order to understand how the VLCD impacts depressive symptoms.

Of course, the duration of a weight loss program often influences the amount of weight lost post-diet, with longer weight loss programs typically resulting in more weight loss. That noted, a previous meta-analysis reported no relationship between the duration of the VLCD and the amount of weight lost in the study [2]. As shown in Table 1, VLCD programs with a shorter duration (< 8 weeks) [22, 23] resulted in weight loss ranging from 0.73 to 8.70 kg on average, while VLCD programs with longer durations (> 8 weeks) [24, 38] resulted in larger average weight losses, ranging from 13.60 to 27.10 kg.

Possibly, a short-term VLCD program may not provide the noticeable weight loss and physical health improvements an individual was hoping to achieve, resulting in no significant changes in depressive symptoms pre- to post-diet. Alternatively, in the longer VLCD programs, greater weight loss and noticeable changes in body and health, as well as the sense of achievement, may have contributed to decreased depressive symptoms post-diet. However, future research is encouraged to directly examine the relationship between VLCD duration, weight loss and depressive symptoms levels.

Depressive symptoms, low intensity exercise, and weight loss

In line with previous literature [32], the results showed a moderating effect of low intensity exercise. Particularly, VLCD studies that included low intensity exercise showed significant decreases in depressive symptoms. However, studies that did not include exercise showed no significant change in depressive symptoms.

Exercise has been shown to increase levels of endocannabinoids, a neurotransmitter associated with sense of well-being, and decrease cortisol (stress hormone), potentially reducing depressive symptoms [32]. Accordingly, VLCD programs that did not include exercise may not have elicited these benefits, possibly explaining why no change in depressive symptoms occurred. In light of this finding,

the inclusion of low intensity exercise into the VLCD program may be an important element for reducing depressive symptoms. Importantly, this paper excluded high intensity exercise which could further reduce depressive symptoms.

Of note, upon examining the effects sizes of each moderator (i.e., Hedges' g), we observed that the confidence intervals overlap, suggesting that the moderators have a similar effect on depressive symptoms. Therefore, no moderators predict a decrease in depressive symptoms over and above other moderators. This suggests that the effect the moderators have on reducing depressive symptoms may be driven by their combination.

Anxiety

No significant change in anxiety pre- to post-VLCD was detected and no potential moderating effects were examined due to the low number of studies assessing anxiety. Specifically, only six samples examined the impact of VLCDs on anxiety, while 14 samples were included in analyses examining the impact of VLCDs on depressive symptoms. This discrepancy in the number of samples available for analysis demonstrates the limited amount of research that has investigated the effect VLCDs have on dieters' anxiety. Importantly, since measures of depressive symptoms and measures of anxiety have been shown to correlate significantly with one another [39–41], it may be the case that VLCDs that decrease depressive symptoms also decrease anxiety. This possibility draws attention to the need for further high quality research that examines how a VLCD impacts dieters' anxiety levels.

Systematic review: interpretation of results

Overall, the systematic review supported the findings from the meta-analysis. Specifically, five samples found reduced depressive symptoms post-diet when behavioral therapy, long VLCD duration, low intensity exercise were included and a high amount of weight was lost, with these samples mostly (4 out of 5) being rated strong in rigor. Additionally, there were four samples that reported non-significant findings of depressive symptoms when behavioral therapy was not included, a short-term VLCD was used, no exercise was prescribed and a small amount of weight loss post-diet was reported, with the majority of these samples (3 out of 4) being weak in rigor. That is, the results of 9 out of 14 samples were consistent with our meta-analysis. In sum, the results of the systematic review support the meta-analysis findings.

Of note, there were samples in the systematic review that deviated from the results of the meta-analysis. For example, of the four samples that reported decreased depressive symptoms post-diet, one sample did not include behavioral therapy, one sample did not include behavioral therapy and exercise, and two samples reported low weight loss. These results suggest that perhaps one moderator can be neglected without losing the reduction in depressive symptoms post-VLCD (i.e., the VLCD program may be flexible). Importantly, one study [25] found that dieters who completed a long-term diet still had non-significant changes in depressive symptoms following the VLCD.

On another note, we further examined the various components of behavioral therapy. Specifically, seven samples in the systematic review used behavioral therapy. Of these, four samples had the programs target weight control only, two samples targeted the combination of weight control and stress management, and one sample did not specify the type of therapy implemented. Thus, the behavioral therapy included in the VLCD programs did not target the improvement of depression or anxiety across participants. Accordingly, behavioral therapy programs could incorporate additional psychological components within the curricula to reduce depressive symptoms and anxiety. Also, 6 out of 7 samples included low intensity exercise, 6 out of 7 samples included weekly behavioral therapy sessions, 4 out of 7 implemented approximately one hour therapy sessions, and 7 out of 7 included group-based therapy, with the remainder of these samples not reporting these details. Thus, the behavioral therapy that was implemented in these studies was similar across samples (see Appendix B for details).

Strengths, limitations, and future directions

This is the first meta-analysis and systematic review to examine the impact a VLCD has on depressive symptoms and anxiety as a primary focus. Understanding the psychological impact of a VLCD is important as it may elucidate why some studies reported decreased depressive symptoms on average after the VLCD, while others did not. Further, this paper highlights the importance of establishing guidelines about the protocol for a VLCD in order to obtain the primary goal of a VLCD (i.e., weight loss), while also reducing negative psychological outcomes such as depressive symptoms.

In light of these findings, there are some limitations that merit discussion. As aforementioned, the small number of studies that examined subjective anxiety pre- to post-VLCD precluded any moderator analysis. Additionally, the current paper only examined self-reported measures of depressive symptoms and anxiety, which may vary from ratings made by clinicians [42]. Lastly, an older measure of depressive symptoms [9] was used by some researchers in this work, rather than the more recent revision of the same measure [43]. The BDI-II is

arguably preferable as it better assesses the intensity of depressive symptoms and does not reflect a theoretical basis [44].

Based on the results presented, there are important future directions to consider. Although sex was not used as a moderator due to many studies including more females, whether sex differences contribute to the discrepancies in reported depressive symptoms and anxiety post-VLCD should be investigated. Sex differences are important to consider as the recommended daily calorie intake varies among men and women [45, 46]. Reducing one's caloric intake to 800 calories per day regardless of sex may have a larger impact on men than women since, on average, men require more calories in relation to women. This discrepancy in caloric intake may cause variations in psychological health. Another important future direction is whether VLCDs may trigger disordered eating (and the commonly associated depressive symptoms) [47] in a minority of participants [48]. If VLCDs benefit psychological well-being in many participants but cause additional psychological distress in others, then careful screening for eligibility into a VLCD needs to be devised [48]. Finally, explicit VLCD diet guidelines should be developed that explicitly state a minimum amount of weeks that is recommended to be on the VLCD and whether behavioral therapy should be included in order to obtain weight loss for individuals with obesity.

Conclusion

The results of this paper suggest that the impact VLCDs have on depressive symptoms may result, in part, from the variations in VLCD protocols. In particular, depressive symptoms may decrease pre- to post-VLCD if behavioral therapy is provided, a VLCD duration of 8 weeks or longer is used, low intensity exercise is prescribed, and a high amount of weight was lost. Modifications to this protocol may contribute to no significant changes in depressive symptoms pre- to post-VLCD. Results also showed that anxiety did not change pre- to post-VLCD, likely due to low statistical power. Taken together, findings from this paper highlight important factors for future research when examining how VLCDs affect depressive symptoms and anxiety. Researchers and health care providers should consider the impact of deviations in their VLCD protocols as these modifications may affect the potentially beneficial effects of this diet on psychological health.

Compliance with ethical standards

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