Intermittent Fasting Programs and Their Effects on Body Composition: Implications for Weight-Restricted Sports

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Abstract

Intermittent fasting (IF) encompasses a variety of specific programs that utilize short-term fasts in order to improve body composition and overall health through altered substrate utilization and hormonal changes. This review examines the effects of IF programs on body composition and discusses potential implications for athletes, particularly those competing in weight-restricted sports. IF can reduce body weight and body fat in non-athletes, but little is known regarding athletic populations. Mixed results regarding retention of fat-free mass have also been reported. A discussion of how information from the existing literature can be cautiously used for application in weight-restricted athletes is provided.

Key Words: intermittent fasting, body composition, combat sports, weight loss, time-restricted feeding

Introduction

Athletes and active individuals often seek to improve their body composition by increasing muscle mass with minimal fat gain or by decreasing body fat while maintaining existing muscle mass. A combination of exercise and nutritional interventions is typically recommended to pursue these goals (13). Within athletic populations, achieving a low body fat percentage is particularly important for those competing in weight-restricted or "body composition sensitive" sports such as mixed martial arts, boxing, wrestling, gymnastics, rock climbing, and figure skating. For combat athletes trying to lose weight, the most common dietary strategy is limiting daily caloric intake so that caloric consumption is less than the amount needed to maintain existing body weight (10,37). To achieve this goal of daily caloric restriction, several dietary strategies are commonly utilized by individuals in attempt to lose weight such as eating smaller and more frequent meals throughout the day, limiting carbohydrate consumption, limiting fat intake, and increasing protein intake. However, daily caloric restriction can be difficult to maintain over long periods of time. In weight-restricted combat sports such as boxing and mixed martial arts, it is not uncommon for athletes to lose relatively large amounts of body weight prior to competition (10). After competition, significant amounts of weight are often regained due to the difficulty of maintaining a particular dietary strategy. If this happens, combat athletes may attempt to rely on more rapid, and potentially life-threatening, weight loss strategies to prepare for subsequent competitions. This may involve losing large amounts of "water weight" in the days prior to their official "weigh-in" or competition, which can adversely affect performance and wellbeing (10). Thus, combat athletes in particular may benefit form a dietary strategy that could theoretically be maintained throughout the year and potentially minimize large perturbations in weight between competitions. This may mitigate the need to lose as much "water-weight" leading up to competition, thereby allowing a potentially less difficult and safer weight cut.

Intermittent fasting (IF) is one potential strategy of interest to weight-restricted athletes. IF utilizes regular short-term fasts with the goal of improving body composition and overall health. While IF is a broad term that encompasses a number of specific programs, most forms can be divided into the following categories: time-restricted feeding (TRF), alternate-day fasting (ADF), whole-day fasting (WDF), and Ramadan IF. It is important to note that many IF programs utilize modified fasting rather than true fasting. True fasting requires abstinence from all caloric intake, but modified fasting allows small amounts of caloric intake. Even during modified fasting, the total energy consumed is drastically lower than weight-maintenance energy needs. Modified fasting can be viewed as following a very-low calorie diet, but only on certain days or parts of days.

TRF (e.g. – Warrior Diet® (27) and LeanGains method (67)) typically consists of following the same eating pattern each day, with certain hours comprising the fasting period (12 – 20 hours) and the remaining hours comprising the feeding window. There is variability between programs in the placement of the fasting and feeding periods during the day, but it is most common to place the feeding period in the evening. ADF alternates between *ad libitum* feeding days (i.e. unrestricted eating) and pseudo-fasting days that allow one meal containing ~25% of daily calorie needs. WDF (e.g. – Eat Stop Eat (42)) consists of 1 to 2 days of fasting per week and *ad libitum* eating on the other days.

Ramadan IF is primarily a religious fast rather than a fasting regimen employed specifically to enhance body composition and health. The effects of Ramadan on body composition and athletic performance have been previously summarized (1,14,15,47) and will not be the focus of this review. It is important to note that both food and fluid intake are restricted during Ramadan. The potential impact of dehydration and altered sleep schedules during Ramadan make interpretation and application of these studies more difficult.

While the majority of the research to-date has not been conducted with an athletic population, the current body of evidence demonstrates potential benefits and concerns of intermittent fasting programs and sets the stage for future studies in athletes. The purpose of this review is to discuss the existing research in the realm of intermittent fasting, particularly effects on body weight and composition, and discuss its potential applicability as an alternative dietary strategy for athletes competing in weight-restricted sports.

Metabolic Changes of Fasting

During short-term fasting, a transition in substrate utilization occurs which decreases reliance on carbohydrate and increases reliance on fatty acids (49). While blood glucose levels decline, whole body lipolysis and fat oxidation increase throughout the first 24 hours of food deprivation (33,44,49). The time period between 18 and 24 hours of fasting has shown an ~50% decrease in glucose oxidation and ~50% increase in fat oxidation (33). It is thought that increased sympathetic nervous system activity, higher concentrations of growth hormone, and reduced insulin concentrations may contribute to this shift in substrate utilization (36,49).

One concern associated with fasting is that muscle will be catabolized to provide substrate for gluconeogenesis. It is known that humans adapt to prolonged starvation by conserving body protein (11,45), but increased proteolysis has been seen during short-term fasting studies (22,41,43,56). However, the majority of these studies compared measurements taken after an overnight fast to those taken 60+ hours later (22,41,43). Since the duration of fasts during popular IF protocols are much shorter than 60 hours (e.g. up to 24 hours), it is possible that muscle mass loss does not occur to the same extent during shorter fasts.

Early literature examining complete fasting reported that protein catabolism did not begin to increase until the 3rd day of fasting (5), and Soeters et al. (48) found that 2 weeks of ADF (alternating between 20 hours fasting and 28 hours feeding) did not alter whole-body protein metabolism in lean healthy men. While these metabolic changes are interesting, it should be noted that the effects of habitual short-term fasts may be different than brief periods of short-term fasting in individuals who typically follow a normal eating pattern. Studies that specifically examine intermittent fasting protocols and track changes in body composition are the best evidence regarding the effectiveness of these programs.

Alternate Day Fasting

ADF is one of the more commonly studied forms of IF. ADF consists of alternating between *ad libitum* feeding days and modified fasting days that typically allow one meal containing ~25% of daily calorie needs. This meal is usually consumed midday. Studies have consistently shown body weight reductions of ~3 – 8% (6,17,18,25,26,29,35,58–60) and decreases in fat mass of ~4 – 15% (6,17,18,25,26,35,57,58,60). The majority of studies have been reported these results in obese (6,17,18,26,29,35,58,59) and overweight subjects (18,25,59,60), however this has been demonstrated in normal weight subjects as well (25,60). Table 1 presents an overview of the methods and results of ADF studies. The majority of studies used both male and female subjects, but did not specifically examine or report sex differences.

Results regarding changes in fat-free mass have been mixed: no change was reported in several studies (35,58,60), while others reported a decrease (6,17,25,26), and some did not report fat-free mass changes (18,29,59). Varady (57) stated that it appears that a lower proportion of lean mass is lost during intermittent caloric restriction (~10% of weight loss as lean mass) compared to daily caloric restriction (~25% of weight loss as fat mass), but no ideas concerning the potential mechanisms behind this observation were provided. These percentages were based on comparing only three studies of IF to eleven studies of daily caloric restriction. There were also differences in body composition assessment (i.e. dual energy x-ray absorptiometry [DXA] versus bioelectrical impedance analysis [BIA]) and study design (e.g. level of caloric deficit) that should be considered. Without further research, it cannot be said whether IF leads to a lean mass-sparing effect.

Whole-Day Fasting

WDF typically consists of 1 or 2 days of complete or modified fasting each week. WDF studies (3,24,28,34,54,55,65) have reported reductions of ~3 – 9% in body weight, as well as decreased body fat mass. No change in lean mass was observed in three of the studies (24,34,55), but Teng et al. (54) reported a ~1% decrease after 12 weeks of WDF. Two studies did not report changes in lean mass (28,65). A limitation of these studies is that only one utilized DXA to evaluate changes in body composition (34), while the remainder utilized BIA. Table 2 presents an overview of the methods and results of WDF studies. Contrary to ADF, most WDF studies have examined solely male (28,54,55) or female (24,34) subjects, rather than a combination. However, based on the differences between experimental design and subjects used (i.e. normal weight and overweight males vs. obese females), it is not possible to determine sex differences in the responses to these programs at this time.

Time-Restricted Feeding

When Ramadan IF studies are excluded, there is very little research examining TRF programs. Stote et al. (50) conducted a study of TRF which utilized daily 20-hour fasts in male and female participants (age 45.0 ± 0.7, mean ± SEM). The study used a randomized crossover design with two 8-week periods of eating either one meal per day or three meals per day. These two phases were separated by an 11-week washout period, and all food was provided to the subjects throughout the study. During the one meal per day phase, participants consumed all their calories within a 4-hour window of time in the evening. After eating one meal per day, as compared to three meals per day, lower body weight (65.9 ± 3.2 kg vs. 67.3 ± 3.2 kg and fat mass (14.2 ± 1.0 kg vs. 16.3 ± 1.0 kg) were reported. Although both treatments were designed to be isocaloric, the subjects ate ~65 fewer calories during the one meal per day phase of the study due to "extreme fullness" and difficulty eating all the food in the allotted time window (50). It is possible that individuals would have eaten even less if they had been free to choose when to stop eating, and a lower level of energy intake could have led to even greater weight loss. The ability to adhere to this type of eating pattern is questionable, as indicated by higher ratings of hunger and desire to eat in the one meal per day group. The severity of these phenomena increased throughout the study, indicating that the subjects did not grow adequately accustomed to the eating pattern.

Stote et al. (50) also reported a trend ($p = 0.06$) for greater fat-free mass after consuming one meal per day (50.9 ± 0.4 kg) than after consuming three meals per day (49.4 ± 0.4 kg). It should be noted that body composition was assessed using BIA, which has been previously questioned in regards to fat-free mass measurements during fasting. Faintuch et al. (19) examined non-obese individuals undergoing a complete fast for 43 days (subjects only ingested water, vitamins, and electrolytes). During the later stages of fasting (between the 31st and 43rd day), BIA reported unrealistic increases in fat-free mass, and the authors stated that these findings must be rejected due to questionable plausibility. However, the fasting protocols employed by Stote et al. (50) and Faintuch (19) varied considerably. Subjects in the study by Stote et al. (50) did not undergo complete fasting for even one entire day, and the dietary changes made were not nearly as extreme as those in Faintuch et al.'s study (19). Taken together, these studies may demonstrate that BIA is not the optimal tool for measuring lean mass changes during such fasting protocols, and the trend for greater fat-free mass reported by Stote et al. (50) should be interpreted cautiously.

No exercise intervention was used in the study by Stote et al. (50), and no changes in physical activity were found throughout the course of the study. It should be noted that there was a 28.6% withdrawal rate from the study, indicating that some individuals may not be able to adhere to this pattern of eating. However, there is limited long term success of maintaining weight loss induced by a daily hypocaloric diet (7,64).

Intermittent Fasting and Exercise

To our knowledge, only one study has examined combining an IF protocol with an exercise program (6). The study examined four groups: ADF, ADF plus exercise, exercise alone, and control. Twelve weeks of supervised endurance exercise on stationary bikes and elliptical machines was implemented in the two exercising groups. Subjects exercised three times per week, beginning with 25 minutes at 60% of their age-predicted maximum heart rate (HRmax) and progressing to 40 minutes at 75% HRmax over the course of the study. It was not reported whether subjects exercised on modified fasting days or on *ad libitum* feeding days, as well as whether subjects exercised in a fasted or fed state.

The ADF plus exercise group lost more weight and fat mass than any other group. The ADF and exercise alone groups both lost weight and fat mass, but did not differ in the amount lost. There were no differences between groups for fat-free mass changes, although the ADF did exhibit a small decrease in fat-free mass. Lean mass was retained in the group that exercised and followed ADF, and the authors reported that the exercise program may have been responsible. A limitation of this study is that BIA was utilized to measure body composition.

Reducing Meal Frequency

Meal frequency is often a polarizing topic, and many fitness practitioners recommend a relatively high meal frequency. While the number of studies specifically examining different IF protocols is limited, investigations of meal frequency alterations can provide some additional information about effects of decreasing meal frequency.

In 1997, Bellisle et al. (4) critically examined the literature to assess whether there are benefits of increasing meal frequency in order to reduce body weight. They concluded that epidemiological evidence for these benefits is very weak. They also identified two major issues with observational studies of meal frequency and weight gain: *post hoc* changes in meal frequency after weight gain and misreporting of energy intake (4). The *post hoc* changes occur when individuals skip meals in order to maintain or lose weight after weight gain has already occurred (4,51), generating an artificial inverse relationship between meal frequency and body weight. Misreporting of energy intake is well documented, and data from NHANES I Epidemiological Follow-Up Study points to widespread underreporting of food intake, particularly by those who are overweight and reported low meal frequencies (4,30). In the NHANES data, reported energy intake shows an inverse relationship with BMI and skinfold thickness that appears to be inexplicable apart from underreporting of energy intake (4).

The conclusions reached by Bellisle et al.(4) were largely echoed in 2011 through an updated review on meal frequency by La Bounty et al.(9), who concluded that although some observational studies support an inverse relationship between body weight and meal frequency, the majority do not support this (in normal weight, overweight, and obese subjects). In addition to the mixed results and potential problems with observational studies, it was concluded that the vast majority of the experimental studies fail to find any consistent improvements in body weight or body composition through higher meal frequencies (8,9,12,20,21,23,50,62,66). It also appears that the thermic effect of feeding (TEF) is unchanged by alterations in meal frequency (4,9,32), although some studies have shown increases (39,52) or decreases (38) in response to lower meal frequencies. More importantly, the evidence indicates that there is no change in 24-hour energy expenditure after alterations in meal frequency ranging from 2 to 7 meals per day (16,23,53,61–63,66).

Recently, Schoenfeld et al. (46) conducted a meta-analysis evaluating experimental research of meal frequency as it relates to body composition. Although the initial results of the analysis seemed to favor increased meal frequency for improvements in body composition, a sensitivity analysis revealed that a single study was responsible for this result. The authors concluded that if any benefits to higher or lower meal frequencies exist, they are likely to be negligible in terms of practical significance and personal choice should largely dictate the selection of a meal frequency in order to enhance compliance.

It should be noted that the line between decreased meal frequency and intermittent fasting protocols is somewhat blurred. IF, by definition, is a systematic reduction in meal frequency. However, IF emphasizes extending periods of fasting or modified fasting, which is not necessarily the case when meal frequency is otherwise reduced. For example, a diet that reduces meal frequency may include meals at breakfast and dinner, which leads to a significantly shorter daytime fasting window (~ 6-10 h) than most of the intermittent fasting protocols employ. As discussed, this prolonged fasting window may have beneficial effects on lipolysis and lipid oxidation, which could potentially lead to improved fat loss.

Practical Applications

The lack of research specifically examining the effects of implementing intermittent fasting programs in athletes makes it difficult to provide concrete recommendations for the use of these programs in athletes. However, several points are worth considering. IF can be an effective means of reducing calorie intake, body weight, and body fat in non-athletes. IF programs can be designed to allow adequate nutrient consumption before and after physical activity (i.e. exercise does not have to be performed in a fasted state when an IF program is implemented). Some IF programs are as simple as abstaining from food after dinner and not eating again until breakfast or lunch the next day. These milder TRF programs lead to a period of fasting that is ~12 – 16 hours in duration.

Most forms of IF could be modified to fit an athlete's training schedule. In ADF and WDF, the modified fasting days consisting of very low energy intake could be employed less frequently or placed on rest days or days with lighter training activities. A TRF schedule could be developed that allows the athlete to eat at the most critical times (e.g. before and after training sessions and competition). Even utilizing a single day per week of modified fasting could help an athlete achieve a negative energy balance for the week while not disturbing the usual pattern of food intake on heavier training and competition days. Although there is scant evidence to demonstrate the ability to adhere to these types of dietary interventions long term, IF may provide an alternative strategy for athletes who are trying to lose weight or prevent weight gain.

IF protocols may be particularly applicable for athletes competing in weight-restricted sports such as mixed martial arts, boxing, and wrestling. These sports often require athletes to lose significant amounts of weight prior to competition. Following competition, it is not uncommon for these athletes to quickly regain the weight, creating a “yo-yo” pattern of weight loss and weight gain - a cycle that is relatively common in combat sports. IF protocols may provide the athletes in these sports an alternative method in which they could achieve weekly caloric deficits and weight loss, but also maintain adequate intake needed to provide energy for strenuous training days.

Currently, there is a paucity of literature on the effects of intermittent fasting protocols on exercise performance. Thus, it cannot be decisively concluded if these types of dietary strategies hinder or enhance exercise performance, if they affect performance at all. However, if this type of dietary strategy is employed in a conservative fashion as described here (i.e. fasting one select day of the week or on non-training days), it could theoretically play a very minor role in exercise performance due to the limited impact on most training days. However, more research and empirical data are needed to make more definitive conclusions in this area.

It should also be noted that there are data showing the importance of regularly consuming dietary protein in order to maintain lean muscle tissue, which is an item of concern for many athletes. Thus, this should be considered when employing longer duration fasts. Moore et al. (40) and Areta et al. (2) have reported that ingesting 20 grams of whey protein at regular intervals every ~3 hours may be superior in regards to net protein balance and protein synthesis when compared to consuming the same total amount of protein (~80 grams) in larger, less frequent or in smaller, more frequent doses. The benefit of eating protein in this quantity and frequency may be due to the "leucine threshold" that is needed to optimize protein synthesis above baseline levels. Thus, if an athlete employs an intermittent fasting protocol, he or she may choose to modify it and consume whey protein or another protein source at metered points throughout the fasting window, particularly if lean mass preservation is a major concern.

Future research specifically examining IF programs in athletes should be conducted, particularly in athletes competing in weight-restricted sports. The temporal relationship between nutrient intake and athletic activities should be considered, and any IF program implemented in athletic populations should take into consideration the specific requirements of the sport as well as individual variation and preferences.

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Table 1. Summary of Alternate Day Fasting (ADF) Studies

					Weight & Body Composition (kg or % change)		
Reference(s)	**Subjects[1,2]**	**Methodology**	**Duration**	**BCA**	**BW**	**BF**	**FFM**
Heilbronn et al. (2005) (25)	16 normal weight and overweight M (age 34 ± 3) and F (age 30 ± 1)	Subjects alternated between fasting days (no calorie intake) and ad libitum feasting days.	22 days	DXA	-2.1 ± 0.3 -2.5 ± 0.5%	-4 ± 1%	53.4 to 5
Johnson et al. (2007) (29)	10 obese inactive M and F with moderate asthma (age NR)	All subjects alternated between fasting days (320 kcal consumption for women and 380 kcal consumption for men via canned meal replacement shake) and ad libitum feeding days.	8 weeks	N/A	-8.5 ± 1.7 (-8.0 ± 1.4 %)[4]	NR	NR
Donahoo et al. (2009) (17) – abstract	17 healthy obese subjects (age NR)	Subjects randomized into CR and IF groups. Subjects in the IF group alternated between ad libitum feeding days and fasting days without food intake. Subjects in the CR group followed a 400 kcal/d deficit diet. Food was provided to subjects in both groups.	8 weeks	DXA	IF[6]: -6.9 ± 1.3 (-7.4 ± 1.4%) CR[6]: -4.7 ± 1.3 (-4.2 ± 1.0%)	IF[6]: -3.9 ± 0.7 CR[6]: -2.8 ± 0.6	IF[6]: -2.9 0.8 CR[6]: NC
Varady et al. (2009) (58)	16 obese M and F (age 46 ± 2)	All subjects alternated between fasting days (~25% of kcal needs as determined by Mifflin equation; consumed between 12 pm and 2 pm) and ad libitum feeding days.	8 weeks	BIA	-5.6 ± 1.0 -5.8 ± 1.1%	-5.4 ± 0.8 45 ± 2% to 42 ± 2%	NC
Varady et al. (2011) (59)	60 overweight and obese M and F (ages: ADF: 47 ± 2, CR: 47 ± 3, Exercise:46 ± 3, Control: 46 ± 3)	Randomized, controlled, parallel-arm trial. Four groups were utilized (ADF, CR, exercise (EX), and control). Subjects in ADF and CR groups alternated between fasting days (~25% of kcal needs as determined by Mifflin equation; consumed between 12 pm and 2 pm) and ad libitum feeding days. The exercise group participated in supervised exercise 3 times per week on stationary bikes and elliptical machines. The sessions progressed from 45 min at 60% HRmax to 60 min at 75% HRmax over the course of the study.	12 weeks	N/A	ADF: -5.2 ± 1.1% CR: -5.0 ± 1.4% EX: -5.1 ± 0.9% control: NC	NR	NR
Varady et al. (2013) (60)	30 normal weight and overweight M and F (ages: ADF: 47 ± 3, Control: 48 ± 2)	Randomized, controlled, parallel-arm trial. Two groups were utilized (ADF and control). Subjects in ADF group alternated between fasting days (~25% of kcal needs as determined by Mifflin equation; consumed between 12 pm and 2 pm) and ad libitum feeding days.	12 weeks	DXA	-5.2 ± 0.9 (-6.5 ± 1.0%)	-3.6 ± 0.7	NC

Klempel et al. (2013) (35)	32 obese F (ages: ADF-HF: 42 ± 3, ADF-LF: 43 ± 2)	Subjects randomized into HF or LF groups. Subjects in both groups alternated between fasting days (~25% of kcal needs as determined by Mifflin equation; consumed between 12 pm and 2 pm) and ad libitum feeding days.	8 weeks	DXA	HF: -4.3 ± 1.0 (-4.8 ± 1.1%) LF: -3.7 ± 0.7 (-4.2 ± 0.8%)	HF: -5.4 ± 1.5 LF: -4.2 ± 0.6	NC
Bhutani et al. (2013) (6)	64 obese M and F (ages: Combo: 45 ± 5, ADF: 42 ± 2, E: 42 ± 2, Control: 49 ± 2)	Randomized, controlled, parallel-arm feeding trial. 4 groups were utilized (ADF + exercise [combo], ADF, exercise (E), and control). The combo and ADF groups alternated between fasting days (~25% of kcal needs as determined by Mifflin equation; consumed between 12 pm and 2 pm) and ad libitum feeding days.	12 weeks	BIA	Combo: -6 ± 4 ADF: -3 ± 1 E: -1 ± 0	Combo: -5 ± 1 ADF : -3 ± 1	ADF[7]: -1
Eshghinia et al. (2013) (18)	15 overweight and obese F (age 33 ± 6)[3]	All subjects consumed very low calorie diets (25-30% of energy needs) on the 3 weekly fasting days (Saturday, Monday, and Thursday) and consumed a diet of 1700 - 1800 kcal/d on feeding days.	6 weeks	BIA	84.3 ± 11.4 to 78.3 ± 10.2	45.8 ± 4.2% to 43.0 ± 4.0%	NR
Hoddy et al. (2014) (26)	74 obese M and F (age: ADF-L and ADF-D: 45 ± 3, ADF-SM: 46 ± 2)	Subjects in all groups alternated between fasting days (~25% of kcal needs as determined by Mifflin equation) and ad libitum feeding days. ADF-L consumed the fast-day meal midday, ADF-D consumed the fast-day meal in the evening, and ADF-SM divided the small meal between morning, midday, and evening.	8 weeks	DXA	ADF-L: - 3.5 ± 0.4 ADF-D: - 4.1 ± 0.5 ADF-SM: -4.0 ± 0.5	- ~3 kg in all groups[8]	- ~1 kg i all group

[1] Data reported as mean ± standard error of the mean unless otherwise noted.
[2] Weight categories based on World Health Organization classifications based on BMI (normal weight: 18.5-24.99, overweight: 25 - 29.99, obese: ≥ 30) and ages are reported in years
[3] Mean ± standard deviation
[4] Type of error reported was not specified
[5] Numerical value for SEM not provided
[6] No significant between-group changes
[7] No changes in other groups
[8] Exact values not reported

Abbreviations: ADF: alternate day fasting, BF: body fat, BIA: bioelectrical impedance, BW: body weight, CHD: coronary heart disease, CR: caloric restriction, CVD: cardiovascular disease, DBP: diastolic blood pressure, DXA: dual-energy x-ray absorptiometry, FFM: fat-free mass, HDL: high-density lipoprotein, HF: high-fat, HRmax: maximal heart rate, LDL: low-density lipoprotein, LF: low-fat, NC: no change, NR: not reported, SBP: systolic blood pressure, TC: total cholesterol, TG: triglycerides.

Table 2. Summary of Whole Day Fasting (WDF) Studies

					Weight & Body Composition (kg or %)		
Reference(s)	**Subjects[1,2]**	**Methodology**	**Duration**	**BCA**	**BW**	**BF**	**FFM**
Williams et al. (1998) (65)	47 obese M and F with Type II diabetes (ages for 3 groups were 54 ± 7, 51 ± 8, and 50 ± 9)	Subjects randomized to standard behavioral therapy (SBT) or one of two very-low calorie diet groups (VLCD-1, VLCD-5). Subjects in SBT consumed 1,500 to 1,800 kcal/d throughout the study. Subjects in VLCD-1 followed a VLCD (400 to 600 kcal/d) one day per week for 15 weeks. Subjects in VLCD-5 followed a VLCD for 5 consecutive days during weeks 2, 7, 12, and 17 of the study. On non-VLCD days, subjects consumed 1,500 - 1,800 kcal/d. During the first week and last 3 weeks of the 20 week study, all subjects consumed a diet of 1,500 to 1,800 kcal/d.	20 weeks	N/A	SBT: -5.4 ± 5.9 VLCD-1: -9.6 ± 5.7 VLCD-5: -10.4 ± 5.4	NR	NR
Harvie et al. (2011) (24)	107 overweight and obese premenopausal F (age 40 ± 4 for both groups)	Subjects randomly assigned to intermittent energy restriction (IER: 25% energy restriction via 2 consecutive VLCD days per week) or continuous energy restriction (CER: daily 25% energy restriction). CER group consumed a Mediterranean-type diet (30% fat, 45% low glycemic load carbohydrate, 25% protein). IER consumed ~650 kcal on VLCD days.	6 months	BIA	IER[3,4]: -6.4 (7.9 - 4.8) CER[4]: -5.6 (6.9 - 4.4)	IER[3,4]: 40.5% (39.0-42.0) to 37.3% (35.2-39.3) CER[4]: 40.5% (38.7-42.3) to 38.0% (35.8-40.3)	IER[3,4]: 47.[illegible] (46.3- 49.0 to 46.4 (44.9-47.9) CER[4]: 49.1 (47.7-50.5) to 48.3 (46.7-49.9)
Teng et al. (2011) (54)	25 normal weight/overweight M (ages for 2 groups were control: 58 ± 6, intervention: 59 ± 3)	Subjects randomized into intervention (FCR) and control groups. Daily caloric intake in the FCR group reduced calorie intake by 300 - 500 kcal/d and fasted for 2 nonconsecutive days per week. The control group maintained their regular eating pattern.	12 weeks	BIA	FCR[5]: -3.14% (71.6 ± 6.0 to 69.3 ± 6.0) CON: +1.1% (72.9 ± 8.5 kg to 73.7 ± 8.4)	FCR[5]: -6.35% (26.4 ± 3.9 to 25.3 ± 3.8) CON: +2.7% (25.0 ± 2.9 to 25.5 ± 2.9)	FCR[5]: -0.9% CON: +0.4%

Klempel et al. (2012) (34)	54 obese F (ages were IFCR-L: 47 ± 2, IFCR-H: 48 ± 2)[6]	Subjects randomized into primarily liquid (IFCR-L) or primarily food-based (IFCR-F) groups. The groups were isocaloric and utilized a 30% energy restriction. Both groups consumed calorie restricted diet for 6 days each week and fasted for 24 hours (~120 kcal intake from juice powder).	10 weeks	DXA	IFCR-L[6,7]: -3.9 ± 1.4 (-4.1 ± 1.5%) IFCR-F[6]: -2.5 ± 0.6 (-2.6 ± 0.4%)	IFCR-L[6]: -2.8 ± 1.2 IFCR-F[6]: -1.9 ± 0.7	NC
Hussin et al. (2013) (28)	32 normal weight and overweight M (ages were FCR: 60 ± 7, control: 60 ± 6)	Subjects randomized into intervention (FCR) and control groups. Daily caloric intake in the FCR group reduced calorie intake by 300 - 500 kcal/d and fasted for 2 nonconsecutive days per week. The control group maintained their regular eating pattern.	12 weeks	BIA	FCR: -3.8% (74.2 ± 7.8 kg to 71.4 ± 7.2 kg) CON: -0.9%	FCR: -5.7% (26.4 ± 2.4% to 24.9 ± 2.5%) CON: +1.1%	NR
Teng et al. (2013) (55)	56 normal weight and overweight M (ages - control: 59 ± 6, intervention: 60 ± 5)	Subjects randomized into intervention (FCR) and control groups. Daily caloric intake in the FCR group reduced calorie intake by 300 to 500 kcal/d and subjects fasted for 2 nonconsecutive days per week. The control group maintained their regular eating pattern.	12 weeks	BIA	73.1 ± 7.1 to 70.6 ± 6.7	26.4 ± 3.1% to 25.1 ± 3.1%	NC

[1] All data reported as mean ± standard deviation unless otherwise noted
[2] Ages reported in years
[3] No between-group differences
[4] Data reported as mean (95% confidence intervals)
[5] Group x time effect
[6] Mean ± SEM
[7] Larger change observed in IFCR-L group

Abbreviations: BF: body fat, BW: body weight, CON: control, DBP: diastolic blood pressure, FCR: fasting calorie restriction, FFM: fat-free mass, HDL: high-density lipoprotein, IER: intermittent energy restriction, LDL: low-density lipoprotein, NC: no change, NR: not reported, PPM: pre-portioned meals, SBP: systolic blood pressure, SBT: standard behavioral therapy, SSM: self-selected meals, TC: total cholesterol, TG: triglycerides, VLCD: very-low calorie diet, vs: versus