Title: Weight Gain Recommendations for Athletes and Military Personnel: A Critical Review of the Evidence

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Key Words: intentional weight gain; calorie surplus; energy surplus; hypercaloric; muscle hypertrophy, resistance exercise; carbohydrate supplementation; protein supplementation; liquid meal; energy density; meal frequency

Words: 5009 words

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Abstract

Purpose of Review Sports nutrition guidelines typically state that athletes desiring weight gain follow a regimen that includes increasing energy intake by ~400-500 kcal/day with an emphasis on adequate protein and carbohydrate and judicious inclusion of energy dense foods, along with rigorous resistance training. This regimen is thought to promote weekly gains of 0.23-0.45 kg, mostly as lean body mass (LBM). This paper reviews the evidence supporting these intentional weight gain regimens in athletes.
Recent Findings Although some research has been conducted in the past five years supporting these recommendations, research on intentional weight gain is lacking**.**
Summary Currently available data suggests that weekly weight gain of 0.45 kg, primarily as LBM, may be difficult for some athletes to achieve. Available evidence, however, suggests that commonly recommended strategies to promote calorie surplus, including consuming larger portions, incorporating energy dense foods, and *prioritizing* liquid over solid foods, may prove helpful.

Introduction

Many athletes and military personnel desire weight gain primarily as lean body mass (LBM) to improve performance and effectiveness in sport and military endeavors. While extensive research has been conducted concerning the energy restriction required to reduce body fat mass (FM), little is understood about the energy and macronutrients needed to promote healthy gains in total body mass (TBM), particularly as LBM. Despite this, sports nutrition texts and other sources (Table 1) typically state that athletes increase energy intake by 400 to 500 [1-4] to upwards of 700 to 1000 kcal/day [3, 5] in combination with rigorous resistance exercise training (RET). Adequate protein (1.2- 2.0 g/kg), adequate carbohydrate [1-3, 6, 7] and judicious inclusion of healthy fat-containing, energy dense foods (e.g., nuts, seeds, peanut butter, dried fruit, fruit juice avocado, etc.) are often emphasized as part of the guidelines [1-3, 7]. This regimen targets weekly gains of ~0.23 to 0.45 kg (1 pound).

The purpose of this review is to summarize and evaluate research supporting healthy weight gain in athletes. The term "healthy weight gain" is coined to encompass slow, intentional weight gain predominantly as LBM, with minimal increases in FM. This is different than optimization of protein intake, without hypercaloric, feeding to maximize muscle protein synthesis, which has been extensively studied and reviewed [8, 9]. The current paper focuses on research addressing intentional weight gain through combined hypercaloric nutrition and RET regimens, and also reviews what is known about the population attempting weight gain and practices employed, energy and macronutrients needed to support LBM gains, RET recommendations, and hormonal milieu associated with weight gain. Although emphasis is placed on the past five years of published studies, weight gain trials in athletes are extremely limited. Thus, all identified trials are included in this review. The paper also serves to highlight gaps in knowledge related to healthy weight gain with an overall goal of encouraging research to help better design evidence-based healthy weight gain regimens. * and also reviews research on populations and practices employed by individuals attempting weight gain, macronutrient and specific dietary recommendations, RET recommendations for hypertrophy and the hormonal milieu associated with weight gain

Methods

A literature search was conducted using the PubMed database and search terms "intentional weight gain" "weight gain", "energy surplus" "hypercaloric" "muscle hypertrophy" "resistance training/exercise", "satiety", "liquid meal", "energy density" and "weight gain practices" with focus on the years 2016-2021. Additional studies were obtained by reviewing references cited in sports nutrition texts and identified key sources Studies were excluded if they did not address the combined effects of energy surplus and RET.

Weight Gain Attempts and Practices

With increased prevalence of overweight and obesity, emphasis on understanding healthy weight gain in both the general population and among athletes and military personnel has been largely ignored. However, a survey conducted by Minnick and colleagues of close to 977,000 Canadian adults, aged 17-32 years, found that 23% of men and 6% of women reported attempting to gain weight in the past 12 months [10]. In athletes [11] and military personnel [12], desire to gain weight was a top reason reported for supplement use. Attempts to gain weight included eating more overall and eating more protein [10]. Exercising and weightlifting were also consistently reported by both sexes as a mechanism to promote weight gain. Minnick et al [10] also found that participants of all ages reported a desire to gain weight but that men were more likely than women to engage in intentional weight gain attempts. Similar to Minnick et al [10], a 2001 study from O'Dea et al [13] found that 25.9% of 397 male high school students (13 to 18 years) reported attempting weight gain within the past 12 months. Reported methods used included: increasing caloric intake while reducing exercise, eating higher fat, fried, and "junk" foods, eating more food in general while participating in sports and weightlifting, eating more "healthful" foods with the addition of exercise, and consuming more protein. Exercise was used as a weight gain method in 28.2% of participants. The common reasons for desired weight gain included increased physical strength, greater fitness and improved body image, sports performance, self-protection, appearance and/or self-esteem.

In more recent studies, Woodruff et al[14] surveyed 1068 Canadian male and female 7th grade students (ages 10 to 12 years), and found that 9% reported eating more in attempts to gain weight. A 24-hour diet recall and various food-related behavior questions assessed practices used to attempt weight gain. Reported total energy and fat intakes were higher in those desiring weight gain compared to those maintaining weight, but sugar and caffeine were not. Weight gainers also reported consuming more grain and meat servings. Many also resorted to dietary supplement use, including protein powders and creatine. Bukhari and colleagues [12] surveyed 240 male and 49 female active duty soldiers from three U.S. military installations; focus-group interviews followed the survey. Survey results showed that 11% of soldiers were trying to gain weight with 66% reporting use of protein or amino acid supplements. Of those, 57% engaged in weekly strength training. Follow-up focus groups data found that physical appearance or physique, including desire for increased muscle mass, were of the most frequent reasons for dietary supplement use. Other reasons included self-esteem, greater fitness and/or improved body image, sports performance or self-protection.

While sources of information on weight gain were not reported in all studies[10, 14], O'Dea et al[13] reported that high school boys received weight gaining advice from parents, friends, coaches, teachers, health professionals, advertisements, and magazines. Bukhari et al [12] reported that Army personnel received information from fitness forums, blogs, magazines, 'others', and trial and error.

Summary. Research demonstrates that intentional weight gain is desired by a small number of men as well as women of all ages. Those desiring weight gain may resort to unhealthy weight gain mechanisms highlighting the necessity of developing readily available information to promote effective gain LBM without compromising health.

Weight Gain Interventions in Athletes

Although methods of weight gain in athletes were heavily discussed in mid-to late-1990's [1, 6], few studies have been conducted over the past 20 years (Table 2). In the earliest and most controlled study, Bartels and colleagues [15] found that the addition of 500 extra kcal per day during 9-weeks of RET resulted in approximately 0.4 kg increase in LBM per week with no corresponding increase in FM. Another semi-controlled study by Kreider et al [16] examined whether supplementing the diet with one of two commercially-available weight gain powders for 28-days influenced LBM accretion compared to a maltodextrin placebo. Carbohydrate ingestion alone promoted a non-significant increase in LBM of 0.670 kg without noticeable increases in FM, while ingestion of one commercial supplement produced identical increases in LBM (0.665 kg) but also small but significant increases in FM. The other supplement, that also contained creatine, promoted an increase of 0.707 kg predominantly as LBM. Unfortunately, the supplements and control were not isocaloric which makes interpretation of results difficult.

In similarly designed studies, Rozenek [17] and Spillane[18] evaluated the effect of carbohydrate or carbohydrate-protein supplements on weight gain in men who partook in prescribed RET. Rozenek [17] randomly assigned 73 untrained men to a high-carbohydrate, a high-protein plus carbohydrate or a no-supplement control group. Supplements were mixed into 720-ml of 2% milk, which provided ~2010 extra kcal per day. While all groups had increases in muscular strength, both TBM and LBM gains were higher in the two supplement groups versus the control group, but no differences were found between supplement interventions. Spillane and Willoughby [18], in contrast, studied 21 men with prior RET experience. The nutrition intervention was either a high-carbohydrate or high-carbohydrate plus protein powder mixed with water that provided ~1248 kcal per day. After the eight-week intervention, increases in TBM and LBM were observed in both supplement groups, with no significant differences between groups.

Three more recent studies evaluated weight gain in Olympic-sport athletes during their regular training regimens. Garthe et al [11] examined the effect of nutritional counseling, designed to create a 500 kcal/day surplus, compared to *ad libitum* dietary intake on TBM changes during ten to twelve weeks of focused strength training in 21 elite Norwegian athletes (that included four women). Individually prescribed hypercaloric meal plans and counseling resulted in successful short- and long-term gains in both TBM and LBM. Two studies in male Japanese collegiate light-weight wrestlers, who were provided all meals and ~1000 [19] or ~1400 kcal [20] of surplus energy daily [20] for 8 [20] to 12 weeks [19] during their regular training observed significant increases in both TBM and LBM, that were independent of meal and snack consumption frequency [20]. While athletes in the former study participated in RET four days per week, such specifics were not mentioned in the latter studies.

Summary: Surprisingly few clinical trials have been conducted which have evaluated combined hypercaloric feeding and RET protocols, with only X conducted in past five years. These studies show that such protocols do promote weight gain mostly as LBM, but that weight gain of to either validate typical textbook guidelines for weight gain (Table 1) or help establish more targeted guidelines

Energy Surplus and Weight Gain Requirements

To promote gains in body mass mostly as muscle tissue, sports nutrition texts suggest consumption of 400 to 500 kcal/day above the typical diet or above that required for weight maintenance [1-4, 7](Table 1). The estimated daily surplus was established from the estimated energy required to support gain of one unit of muscle mass, i.e., one pound (454 g) or one kilogram, and the desired reasonable weekly weight gain [2, 5, 7]. As has been outlined by Williams [2] and Rawson [7], and colleagues, skeletal muscle is estimated to contain approximately 700 to 800 kcal per pound (454 g) due to its high water content (~70% water, ~22% protein) [2]. This is in contrast to adipose tissue that is approximately 87% fat and 13% water, and contains a rounded 3500 kcal per pound. The energy cost of stimulating and synthesizing muscle growth is considered to be higher than the stored energy value. As outlined by Williams [2] and Rawson [7], estimates for the cost of tissue accretion from the National Academy of Sciences of 5 to 5.65 kcal/g of tissue have been used historically to estimate the energy surplus required to promote LBM gains. Using these values, ~2250 to 2543 kcal is required to promote one pound (0.45 kg) of LBM, assuming all excess calories directly support muscle synthesis [21]. From these estimates, 2300 to 3500 kcal per week or 330 to 500 kcal per day has been determined to be sufficient to support gains of 0.45 kg of LBM per week [2, 7]. *range (Table 1).

Slater and colleagues[22], however, recently reevaluated the stored energy content of muscle and provided slightly lower estimates of 543 to 565 kcals for 1 pound of skeletal muscle (370 from protein, 152-164 from intramyocellular fat and 32-50 from glycogen). They also point out that textbook estimates of lean tissue accretion have never been validated during hypercaloric feeding combined with RET, and that there is need to confirm the "sweet spot" for the energy surplus that facilitates optimal muscle relative to FM gains. The true cost of LBM accretion is expected to vary according to age, genetics, sex, age and prior training [22].

Using the aforementioned estimated 2300 to an upward 3500 kcal thought necessary to promote a gain of one pound of lean tissue, a rounded 350 to 500 kcal/day have been determined to sufficient to support slow gains of ½ to 1 pound per week, recommended by most sources (Table 1). **This rate of** slow and steady weight gain theoretically allow for promotion of muscle versus fat tissue gain as long as RET is part of the weight gain regimen. Most sources recommend weekly weight gains of 0.23 to 0.45 kg (1/2-1 pound) (Table 1), but weekly gains as high as 1 kg are also suggested [5]. Similar to the aforementioned discussion, however, these guidelines are backed by limited scientific evidence [22]. Classic overfeeding studies suggest that rate of TBM and FM gains are dependent of energy surplus [23, 24], but gains in LBM are thought to be dictated by the RET stimulus plus the sufficient (but not excessive) surplus energy to promote gains of both LBM and TBM. Thus in the case of LBM gain, both excess energy and RET are considered independent and necessary stimulus [6, 25].

Unfortunately, only one of the aforementioned published interventions (Table 2) included a true control group, which is necessary to evaluate the contribution of both components of the weight gain regimen. In this study, RET alone resulted in an average 1.4±1.7 kg gain in LBM over eight weeks that was less than the 3.4±2.5 and 2.9±3.4 kg gains experienced by the energy surplus groups [17], and the range ~2.4 to 3.5 kg gain collectively ovserved over eight- to nine-weeks in all intervention studies (Table 2). LBM gain in the controls was similar to that reported in a recent meta-which found that 13±8 weeks of RET increased fat-free mass (FFM) by 1.1±1.2 kg when 4±2 sets of 9±4 reps/set were performed 3±1 days per week[8]. In contrast, hypercaloric diets without RET in sedentary individuals promotes mostly FM gain with an estimated 33% [26] to 46%[27] as LBM. LBM gains in these situations, which do not incorporate RET, are dependent on genetics[26] and the protein content of the hypercaloric diets[24].

Few studies beyond 8 to 10 weeks have been conducted to help better understand the weight gain possible through hypercaloric and RET regimens alone. Anectdotal evidence reported in sports nutrition texts suggests that high-intensity training coupled with increased energy and protein intake can result in 9 kg gain over one-year in young male athletes [5-7], with 8.2 kg of that as muscle[6]. Smaller gains are said to occur in femal athletes (). Subsequent yearly gains are reported to be only ~1 to 3% of TBM [6]. Garthe et al [11] is the only study to evaluate longer-term gains with energy surplus and RET. In this study short-term gains of 0.7% of initial body weight were observed possible over 12 weeks in some but not all elite athletes, with an average 12-month gain of 1% observed. If average weekly rate of weight gain of previous studies (0.23 to 0.45 kg) were to continue beyond 8 week intervention, achievement 9 kg weight gain would be possible, although the data for Garthe suggests such gains are not experienced by Olympic sport athletes. This may be because of maximal weight gain is dependent on genetics, sexual maturity and training more so than sports nutrition weight gain regimen employed. For instance, Jones and colleagues [28], monitored body weight changes in senior rugby players for six years observed greater changes in LBM in younger verses older players. observed greater changes in TBM, LBM and physique occurred in younger professional rugby players compared to older players. Nowhere, however, could we find scientific evidence supporting the aforementioned maximal weight gain velocity recommended in common textbooks (Table 1). From the reviewed intervention studies, however, it appear that gains of 0.23 to 0.45 are reasonably accomplished (Table 2).

Summary: While a handful of previous studies have evaluated the importance of macronutrient composition on weight gain in athletes, there is currently no evidence suggesting that protein plus carbohydrate is more effective than carbohydrate alone when surplus energy is combined with RET. No studies have evaluated possible benefit or determent of dietary fat.

Macronutrient Recommendations

Additionally, it is not yet established whether the macronutrient content of the energy surplus diet is important for the effectiveness or composition of weight gain. While protein provides the necessary amino acids for muscle protein synthesis and is considered less lipogenic when consumed in surplus[22, 29], carbohydrate is often emphasized because it supports recovery of muscle glycogen stores following intense training [3, 6, 22], stimulates insulin secretion and spares protein so it can be utilized for muscle hypertrophy and repair [1, 5-7]. Concurrent carbohydrate and protein ingestion may also stimulate insulin-mediated amino acid uptake [2].

Three [15, 17, 18] of the seven aforementioned intervention studies (Table 2) evaluated whether carbohydrate plus protein in various amounts and combinations is more effective at promoting weight or LBM gains than carbohydrate alone during hypercaloric feeding and RET. Overall, no differences were observed when the hypercaloric diet provided 45 versus 65% carbohydrate [15] or the surplus contained carbohydrate plus protein compared to carbohydrate alone over the 8-9 week intervention periods [17, 18]. Additionally, pure maltodextrin, used as a control in the study of Kreider et al [16] was as effective as one of the carbohydrate-protein weight gain supplements evaluated. Spillane and Willoughby [18] suggested that lack of differences between macronutrient effectiveness is due the "muscle full" effect, whereby muscles become saturated with amino acids so additional intake does not induce further benefit. Others have referred to this phenomenon as a saturable effect[8]. As shown in Table 2, the assigned protein and carbohydrate intake in previously published studies provided protein (1.2-2.0 g/ kg) and carbohydrate (3-7 g/kg minimum) in at least the minimum range recommended in textbooks [30]. In support of a saturable effect for protein, a recent meta-regression analysis found that the protein intake associated with maximal gains in FFM was 1.6 g per kg in the normal caloric state. Exceeding this intake had no added benefit on RET-induced gains in FFM[8]. In all of these studies, however, timing of protein and/or carbohydrate was not evaluated despite common recommendation that athletes attempting weight gain contain ***

Summary: While a handful of previous studies have evaluated the importance of macronutrient composition on weight gain in athletes, there is currently no evidence suggesting that protein plus carbohydrate is more effective than carbohydrate alone when surplus energy is combined with RET. No studies have evaluated possible benefit of timing of nutrient intake or the addition of dietary fat.

Specific Dietary Recommendations

To meet the excess energy needed to promote weight gain, many sources recommend consuming larger portions at meals, increasing meal (and snack) frequency, incorporating energy dense and high-fat foods, and supplementing with energy-dense liquids such as fruit juice, smoothies, and commercially-available supplements (Table 1). While these recommendations seem reasonable, there is limited data to support their effectiveness, particularly among athletes. Concern over an athletes ability to increase food volume without promoting early satiety [22] or causing gastrointestinal distress [1, 20] have been previously [1] and recently [22] expressed, particularly when training occurs in close proximity to eating [1] or when a large volume of the same food is consumed [31]. Thus, increasing eating frequency to 5 to 9 meals/snacks per day is commonly recommended [1, 3, 7]. In a recent cross-over study, Taguchi et al [20] addressed the potential benefit of meal frequency on appetite and body mass gain. In this study, 10 Japanese collegiate rowers were provided identical hypercaloric diets as three or six meals per day for 8-weeks each. While the weight gain regimen resulted in increased TBM and LBM gains (Table 2), partitioning intake over six versus three meals did not alter appetite or weight gain efficiency.

Although not specifically in athletes, current and past studies from the laboratories of Rolls [32, 33] and Mattes [34] provide support for several of the aforementioned strategies that include consuming larger portions, incorporating energy dense and higher-fat foods (with more kcal per volume), and prioritizing liquid over solid foods. In a recent study, Roe, Kling, and Rolls [33] offered 48 women lunch in a laboratory on four occasions where the portion sizes of three low-energy dense foods and three medium-energy dense foods were simultaneously varied. Participants consumed 34% more energy (215 kcal) when portions of all foods were doubled, but this response was more impactful for better-liked foods. On the flip side, reducing the energy density of the diet through selection of low-energy dense foods is well recognized to spontaneously decrease daily energy intake [32], even in athletics [35]. Low-energy dese foods are typically higher in water and fiber while high-energy-dense foods are lower in water and fiber and higher in fat. Whether judicious incorporation of high-energy dense foods would help create an energy surplus during RET is not known, but it is worth mention that classic studies have shown that covert manipulation of dietary fat leads to spontaneous increases in both energy intake and body weight gain among non-athletic subjects [36, 37]. In a study by Lissner et al [36], for example, young women consumed an average 15% more energy (362 kcal/day) when they ate *ad libitum* for two-weeks from buffet meals that offered high-fat (45-50%) menu items compared to equally-palatable low- (15-20%) or moderate-fat (30-35%) items, and also experienced spontaneous weight gain (average of 0.32 kg). Consumption of excess energy in beverage form may also facilitate energy surplus [22] because liquids induce a lower satiety-response than solids [34] and may be easier to consume if appetite is suppressed post-exercise [38]. In a pilot study, McCartney and colleagues [39] offered ten young, non-obese adults a breakfast consisting of cereal and milk, a nutritionally comparable fruit smoothie or a high-energy fruit smoothie weekly in a randomly assigned order. The cereal and fruit smoothie provided ~400±68 kcal, which was close to the participants usual breakfast, whereas the high-energy smoothie contained an additional 24 kcal per kg of maltodextrin that provided 173±19 kcal. While average 3-day energy intake was similar when participants ate the cereal or fruit smoothie, they consumed ~250 kcal more when offered the high-energy smoothie [39], suggesting that this practice may be an effective strategy to inadvertently create calorie surplus.

The potential appetite-suppressing effect of higher protein foods, or higher protein intakes in general, is also worth brief discussion due to the purported satiety promoting effects of dietary protein. Results of a recent meta-analysis of Kohanmoo and colleague [40], however, suggest that the appetite-suppressing effects of protein and the corresponding appetite-regulating hormones are more evident in acute-studies and not observed long-term. A laboratory-based study from Roll's group came to a similar conclusion. In this study, the protein content of lunch or dinner entrées were covertly manipulated to contain from 10 to 30% of energy from protein; no differences on hunger, fullness, or subsequent daily *ad libitum* energy intake were observed [41]. Related to post-exercise protein intake, a recent study provided interesting evidence that the temperature of a protein-containing liquid supplement has the potential to influence appetite through alterations in gastric motility [42]. In this study, 12 men were found to consume 15% more calories in a post-exercise *ad libitum* meal when a 21-g protein-containing beverage was consumed hot (60˚C) rather than cold (2˚C) immediately following exercise.

Summary: Several commonly recommended strategies to promote calorie surplus, including consuming larger portions, incorporating energy dense foods, and *prioritizing* liquid over solid foods, may prove helpful in promoting calorie surplus. Studies, however, are needed specifically during intentional weight gain in athletes.

Resistance Training to Promote Muscle Hypertrophy and Lean Body Mass Gain

The purpose of RET in the weight gain regimens of athletes desiring weight gain is to promote muscle hypertrophy and theoretically ensure weight gain as LBM and not FM. In contrast, overfeeding in nonathletes without RET is known to result in gains of mostly FM [29]. Hypertrophic gain has long been considered best accomplished by multiple sets of higher reps (i.e., 8-10 reps/set), which is opposed to gains in strength/power that are better accomplished by multiple sets of fewer reps (1-5 reps) of near maximum loads (80-100%)[2, 43]. This is well known as the "repetition continuum". Few sports nutrition texts, however, include specific RET advice as part of the weight gain regimen. Only the textbooks of Williams and Colleagues and Fink and Mikesky [4] review hypertrophic guidelines which include recommendation to perform multiple sets of 8 to 12 reps of the major muscle groups, two to three times per week [2, 4, 7] in agreement with repetition continuum. Williams also adds that completion of a total of 30-60 reps per session are important for maximizing hypertrophic grains (*). In general, the RET protocols employed in previous intervention studies (Table 2), or at least those that included sufficient details, have met these guidelines [11, 15, 17, 18]. For instance, Rozenek [17] and Spillane[18] incorporated three-to-four sets within the hypertrophy range (~8 reps) whereas Bartels[15] and Garthe[11] employed protocols that focused on both strength and hypertrophy within the same session [15] or periodized over the 8- to 12-week intervention [11]. The only shortfall of previous interventions may be in having participants complete 30 to 60 repetitions per session [2].

Research published in the past five years, however, has scrutinized the necessity of the classic aforementioned hypertrophic loading recommendations [43], and also evaluated elements of RET program design that might be involved in maximizing muscle hypertrophy. In a systematic review and meta-analysis, Schoenfeld and colleagues[43] reviewed emerging evidence comparing the strength and hypertrophy responses the strength and hypertrophy responses across the "repetition continuum". While the authors confirmed that maximal strength benefits are obtained from use of heavy loads, muscle hypertrophy was observed to be equally achieved across a spectrum of loading ranges (assuming that maximal effort is put forth). A collection of publications evaluated whether hypertrophic gain could be increased through specific changes to the RET protocol. Overall these studies provided no compelling evidence for a hypertrophic advantage of higher frequency training (i.e., 6 vs. 1 to 2 or 3 days per week) [44-46]; changes in inter-set rest intervals [47]; slow versus fast velocity training [48] or concentric- versus eccentric-only training over traditional concentric-eccentric RET [49] as long as volume and intensity were equated. Some evidence, however, was in support for performing RET sets to failure [50], and for longer inter-set rest intervals [47], particularly for experienced lifters [51]. Additionally, a recently released position stand from the International Universities Strength and Conditioning Association [51] and a recent meta-analysis [52] reaffirmed that training volume is the most important variable for dictating muscle hypertrophy and that high volume may be better achieved through a variety of exercises rather than by high sets of the same exercise. Interestingly, training across a spectrum of repetitions as was employed by Bartels[15] and Garthe[11].

Summary: Collectively current studies suggest that training across a spectrum of repetitions maximize hypertrophic adaptations[53]. However, training volume is the most important variable for dictating muscle hypertrophic response.

Anabolic Hormone Profile

Anabolic hormone milieu is suggested to play a role in muscle hypertrophy and healthy weight gain[25]. The general theory is that elevations in circulating hormone concentrations in response to either RET [54] and/or surplus energy bind to specific hormone receptors and upregulate intramyocellular anabolic pathways involved in hypertrophic responses [54]. Few studies, however, have examined changes in hormone concentrations with weight gain regimens in athletes [15, 18]. Bartels et al[15] originally predicted that insulin, insulin-like growth factor (IGF), and growth hormone (GH) would increase with a hypercaloric diet and RET program due to their role in protein synthesis. In their study, fasting serum insulin concentration remained unchanged throughout the nine-weeks on both the moderate- and high-carbohydrate hypercaloric diets, whereas serum IGF concentration increased by ~35%. Fasting GH concentration did not increase as predicted blood sample timing may have missed GH increases later in the day that went undetected [15]. Spillane and Willoughby [18] measured some of these same hormones and found no increases in IGF, GH, or human growth factor after eight-weeks of ~1200 kcal surplus plus RET. Results vary somewhat from the 21-day overfeeding study of Forbes et al [27] in mostly sedentary women who found that both insulin and IGF concentrations increased by 21% and 48%; Forbes, however, did not assess GH concentration and neither Bartels et al[15] nor Spillane and Willoughby [18] measured serum testosterone which trends positively with increases in muscle mass [27].

Given the limited studie, it is currently not possible to speculate whether the hormone meiuli is important in TBM or LBM gains in athletes undergoing intentional weight gain. Extensive research has evaluated the role of anabolic hormones with RET in isocaloric state and concluded that RET-induced hormonal elevation has at best only minor effects on muscle hypertrophy [54]. A meta-analysis of Roberts et al [55] specific to the significance of testosterone also does not support that testosterone is a significant player in muscle hypertrophy due to inconsistent findings and the justification that women do not have post-exercise fluctuations in testosterone, as men do, yet experience similar hypertrophy [55]. Overall, these conflicting findings suggest the need for further research regarding how the aforementioned and other hormones change with weight gain regimens and whether hormonal profile influences gains as LBM.

Summary: There are conflicting findings regarding how hormone concentrations may change with or play a role in healthy weight gain. Research is needed to help establish the connection between hormone prifiles and the efficacy of body weight and lean body mass gains during hypercaloric-RET training regimens in athletes.

Resistance to Weight Gain and Metabolic Adaptation

The difficulty of weight gain has been well recognized in the sports nutrition literature, with some source suggesting that gaining weight as LBM for athletes is as difficult as losing weight for obese, sedentary individuals[1]. Indeed, results of the intervention trails (Table 2) observed smaller changes in TBM than predicted by the energy surplus provided. This suggests both the possibility of an underestimation of the energy surplus required to induce LBM gains (as discussed above) or the presence of counter-regulatory responses (such as decreased appetite or adaptive thermogenesis) that act to dampen weight gain in the presence of energy surplus. Possible thermogenic responses include increased resting or diet induced thermogenesis [22], increased spontaneous physical activity ("fidgeting" [3] or decreased metabolic efficiency. Suppressed appetite and inadvertent reduction of typical food intake may have accounted for smaller than predicted gains in the studies of Kreider et al [16], Rozenek et al [17]and Spillane and Willoughby [18], that had participants incorporate liquid supplements on top of their normal diet [16-18], but less likely a concern in the better-controlled studies of Bartels et al [15]Nagasawa et al [56] and Taguchi et al[20] of that more-carefully monitored intake [15, 19, 20]. In the study of Bartels et al [15], for example, meals were consumed under supervision and regularly adjusted to provide sufficient energy to promote a 0.45 kg weekly gain in TBM. Despite this, average increase in TBM was only 0.4 kg per week. Unfortunately, only one of the previous studies measured appetite [20] and none evaluated adaptive thermogenesis.

Additionally, previous studies in sedentary individuals recognize the considerable variability in the amount and composition of weight gain in response to standardized overfeeding [21, 23, 26], that is infrequently mentioned in sports nutrition sources. Garthe et al[11] is the only study to report that a significant percentage (58%) of their athletes were unable to accomplish weight gain goals despite provision of meal plans with a standardized 500-kcal surplus. Interestingly, the investigators initially considered these athletes "non-compliers" but later labeled them as "non-responders" because they suspected the lower than predicted weight gain was due to thermogenic adaptation rather than non-compliance on the athletes' part. While obligatory increases in resting and diet-induced thermogenesis and total energy expenditure are expected with increased TBM and food intake [21, 57], it remains controversial whether thermogenesis is increased above obligatory costs in response to energy surplus[21].

Summary: No studies have explored the potential adaptive factors that act to counter weight gain in athletes following hypercaloric feeding and RED regimens. Such research would help better understand the variability and efficacy of such regimens in athletes.

Conclusion

Recent research suggests that a significant number of men as well as women desire weight gain. Despite this, intentional weight gain is largely ignored in the sports nutrition arena. Surprisingly little research has been conducted to validate typical text book recommendations suggested in the 1990's to increase daily energy intake by 400 to 500 kcal to promote weekly gain of 0.23 to 0.45 kg primarily as LBM. Few intervention trials incorporating hypercaloric feeding combined with RET have been conducted, with only two published in the last 5 years. Most of these studies were not tightly controlled, lacked a control group, provided energy surplus through commercially-available liquid supplements and were conducted almost exclusively in men; several, however, did provided prescribed meal plans. One of these studies found that carbohydrate and protein composition of the energy surplus did not influence efficiency of weight gain as previously suggested. Other studies provided evidence that commonly recommended weight gain strategies (consuming larger portions, incorporating energy dense foods, and prioritizing liquid over solid foods), may prove helpful in creating calorie surplus. Concerning weight gain guidelines, a recent review highlights that neither the cost of muscle tissue accretion used to estimate the 400-500 kcal surplus nor the suggested maximal weekly rate of LBM gain (0.23-0.45 kg) has been validated during intentional weight gain efforts in athletes performing RET. Collectively, recent studies (or lack thereof) support the need for further research, particularly in women and in relation to weight gain resistance due to appetite reduction and/or increased thermogenesis. Better understanding of endocrine factors that may optimize healthy weight gain is also needed.

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