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SYSTEMATIC REVIEW

Dietary Intake of Competitive Bodybuilders

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Abstract
Background Competitive bodybuilders are well known for extreme physique traits and extremes in diet and training manipulation to optimize lean mass and achieve a low body fat. Although many of the dietary dogmas in bodybuilding lack scientific scrutiny, a number, including timing and dosing of high biological value proteins across the day, have more recently been confirmed as effective by empirical research studies. A more comprehensive understanding of the dietary intakes of bodybuilders has the potential to uncover other dietary approaches, deserving of scientific investigation, with application to the wider sporting, and potential health contexts, where manipulation of physique traits is desired.
Objective Our objective was to conduct a systematic review of dietary intake practices of competitive bodybuilders, evaluate the quality and currency of the existing literature, and identify research gaps to inform future studies.
Methods A systematic search of electronic databases was conducted from the earliest record until March 2014. The search combined permutations of the terms 'bodybuilding', 'dietary intake', and 'dietary supplement'. Included studies needed to report quantitative data (energy and macronutrients at a minimum) on habitual dietary intake of competitive bodybuilders.
Results The 18 manuscripts meeting eligibility criteria reported on 385 participants ($n = 62$ women). Most studies were published in the 1980–1990s, with three published in the past 5 years. Study methodological quality was evaluated as poor. Energy intake ranged from 10 to 24 MJ/day for men and from 4 to 14 MJ/day for women. Protein intake ranged from 1.9 to 4.3 g/kg for men and from 0.8 to 2.8 g/kg for women. Intake of carbohydrate and fat was <6 g/kg/day and below 30 % of energy, respectively. Carbohydrate intakes were below, and protein (in men) intakes were higher than, the current recommendations for strength athletes, with no consideration for exploration of macronutrient quality or distribution over the day. Energy intakes varied over different phases of preparation, typically being highest in the non-competition (>6 months from competition) or immediate post-competition period and lowest during competition preparation (≤6 months from competition) or competition week. The most commonly reported dietary supplements were protein powders/liquids and amino acids. The studies failed to provide details on rationale for different dietary intakes. The contribution of diet supplements was also often not reported. When supplements were reported, intakes of some micronutrients were excessive (~1000 % of US Recommended Dietary Allowance) and above the tolerable upper limit.
Conclusion This review demonstrates that literature describing the dietary intake practices of competitive bodybuilders is dated and often of poor quality. Intake reporting required better specificity and details of the rationale underpinning the use. The review suggests that high-quality contemporary research is needed in this area, with the potential to uncover dietary strategies worthy of scientific exploration.

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Key Points

Much of the existing research on the dietary intake of bodybuilders is dated and of limited quality.

A number of dietary strategies long used by bodybuilders, particularly the timing and dosing of protein around training have been 'ahead of the science'.

Contemporary research on the dietary strategies used by bodybuilders has the potential to uncover dietary approaches worthy of future research.

1 Introduction

Competitive bodybuilders are dedicated to rigorous diet and training practices with the aim of achieving an extremely muscular, symmetrical, and well-proportioned physique [1–3]. The use of dietary supplements is ubiquitous and, in a subset of bodybuilders, drugs designed to enhance the accumulation of lean mass, reduce body fat, or improve appearance are also a factor in 'sculpting' a more perfect physique [4–6]. Historical evidence supports the notion that the ideal body desired by competitive bodybuilders has evolved substantially over time from something previously considered widely socially desirable to the extreme manifestations that exist in order to win competitions such as Mr. Olympia (considered the pinnacle of bodybuilding) today [7]. For example, one of the heaviest Mr. Olympia winners, Ronnie Coleman (weighing in at 133 kg in 2009), was some 50 kg heavier than Frank Zane, who won Mr. Olympia on three consecutive occasions during the 1970s, Such huge gains in muscle mass across the decades are likely a consequence of several factors, including more evidence-based diet and training support, but also likely as a consequence of anabolic agent abuse [7–14]. Low body fat is also a hallmark of bodybuilding, with levels reported to be below 5 % for competition in men [2, 8] and 10 % for women [1]. The combination of both high muscle mass and low body fat enables modern bodybuilders to display a 'shredded', 'vascular', and what has been likened to a superhero or 'Incredible Hulk'-type appearance [9, 10]. Although bodybuilding has evolved over the years, a commitment to strict dietary intake remains [1, 7].

1.1 Evolution of Competitive Bodybuilding

Information on diet, supplementation, and drug use in bodybuilding has historically been passed on by successful competitors and bodybuilding magazines but increasingly now via the internet [15, 16]. Although many dietary dogmas lack scientific scrutiny, several have more recently been evaluated by empirical research, with practices such as consumption of protein around the time of training [17], use of high biological value protein supplements, and frequent dosing of protein ingestion over the day gaining scientific support [13]. In fact, athletes and coaches often emulate the diet and training strategies used by bodybuilders to enhance their own physique or athletic performance [18]. Only in more recent years have scientists taken greater interest in examining the potential efficacy of some of these diet strategies, a number of which are now being applied to both athletes and clinical populations seeking to increase lean muscle mass and reduce body fat [17, 19, 20].

In the late 1970s, bodybuilding widened its scope to incorporate a drug-free natural bodybuilding competition [21]. This change was prompted by concerns about the negative health effects of drug use in bodybuilding [21]. The physiques of competitors had reached such an extreme that they were no longer aesthetically pleasing to a wider audience, resulting in a downturn in popularity with participants and spectators [7, 11]. Other less extreme bodybuilding categories have since been introduced (e.g., figure/physique, sports/fitness, and swimsuit/bikini). For example, in 2013, the Mr. Olympia contest introduced a physique category for men, one that aims to attract competitors with less extreme physiques. Greater participation by women in newer bodybuilding categories is evident [22]. In fact, it should be acknowledged that resistance training and non-competitive bodybuilding is prevalent across a wide spectrum of the population for the purpose of improving strength, athletic performance, injury rehabilitation, weight management, and health promotion as well as physical appearance [23].

1.2 Purpose of this Systematic Review

Many of the dietary approaches used in bodybuilding have been developed and refined by bodybuilders themselves well before efficacy was confirmed by scientific research [13]. A more comprehensive understanding of the dietary intakes of bodybuilders has the potential to identify effective and unique dietary approaches deserving of additional research to assist in the development of lean mass and reducing body fat. As lean mass gains and fat loss is commonly desired by athletes and the general community, there is wider interest in the potential benefit of such strategies. Evidence also exists that a number of the dietary strategies used by bodybuilders, including multiple or heavy supplement use, may be detrimental to health and that these are increasingly filtering through to the general community [24–26].

The primary aim of this study was to systematically review the dietary intake practices of competitive bodybuilders. A secondary aim was to evaluate the quality and currency of the existing literature and identify research gaps to inform future studies. Bodybuilding in this review was limited to resistance training with the specific goal of improving muscularity (size and tone) purely for the aesthetic benefit to physique assessed at amateur and professional bodybuilding competitions.

2 Methods

2.1 Design

A systematic search of electronic databases, including Allied Complementary Medicine (via OvidSP), Cumulative Index to Nursing, and Allied Health Literature (via EBSCO), MEDLINE (via OvidSP), SPORTDiscus (via EBSCO), and Web of Science, was performed from earliest record until March 2014. The search strategy combined the terms 'body building', 'body-building', 'bodybuilding', 'body builder', 'body-builder', and 'body builder' with diet, diet intake, diet supplement, and dietary supplement. Due to the large volume of magazine and lay articles (see Fig. 1), the search was limited to peer-reviewed journal manuscripts. Following the search, a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) informed systematic review process was completed [27].

2.2 Selection of Studies

To be included, studies needed to explicitly describe dietary energy and macronutrient consumption with or without micronutrient and dietary supplement intake in male and/or female bodybuilders. Participants had to be engaged in training specifically for amateur or professional bodybuilding competitions across any category (e.g., natural body building, sport fitness model, etc.). Dietary intakes needed to be described quantitatively (e.g., kcal/kJ, g, μg) rather than qualitatively (e.g., menus, food group servings, etc.). Studies of any phase of training or competition preparation were eligible for inclusion. These phases were divided into four distinct periods: non-competition (NC: $>$ 6 months from competition), competition preparation (CP: $\leq$ 6 months from competition), competition (C: week of competition), and post-competition (P: immediate days after competition). When the phase of data collection was not specified (NS), this was also noted.

Although all study designs (e.g., randomized controlled trials, cohort, and observational) were potentially eligible for inclusion, only baseline data describing habitual intake was used for intervention studies. As the study aim was to describe free-living intakes of male and female bodybuilders, studies that only provided a description of an experimentally manipulated dietary intake (due to the study imposing a diet or supplement prescription) were excluded, as were studies of participants training to improve physique but not specifically to be competitive in bodybuilding or studies that provided only the mean of intakes for men and women combined (as this does not provide realistic information on the habitual intake consumed for either sex).

In longitudinal studies where dietary intake may have been described across the different competition phases outlined above, data from each phase described were extracted. Where multiple time points were described in a particular phase, the data closest to the mean were calculated (if two time points), or the median (if three or more time points) for that phase were used. When studies described dietary intake with and without the contribution of dietary supplements, both data sets were extracted, but the data set with supplements incorporated was used in summary weighted means as this was considered to more accurately describe total intake of nutrients. Diet intake from food without supplements was included when it was not possible to add on the intake derived from supplements (i.e., they were described qualitatively not quantitatively). When supplement intake was quantified and provided separately to the intake from food, the intake from supplements was added to the intake from food to calculate the total nutrient intake. Drug use was noted when reported. Studies in which participants were preparing to compete in competition where drug testing was conducted were assumed to not use prohibited substances unless otherwise reported. Studies that only examined supplements without reporting dietary intake from food, or case studies with only one participant, were excluded.

Anthropometric (height, mass) and body composition data (percent fat) was extracted for each phase described in the manuscript. When multiple time points were provided within a particular phase, the highest and lowest body mass and percent fat was extracted to reflect the range and change in these parameters across the different phases of training and competition. The method used to measure body composition was also extracted.

After eliminating duplicates, the search results were screened by one reviewer (HO) against the eligibility criteria. Those references that were not eliminated by title or abstract were retrieved and independently reviewed for inclusion by two reviewers (JS, HO). Abstracts, thesis dissertations, and reviews were excluded. Reference lists of all retrieved papers were manually hand searched for additional potentially relevant manuscripts. Papers from all languages were included; however, these were excluded if a translation could not be made. Where a journal article

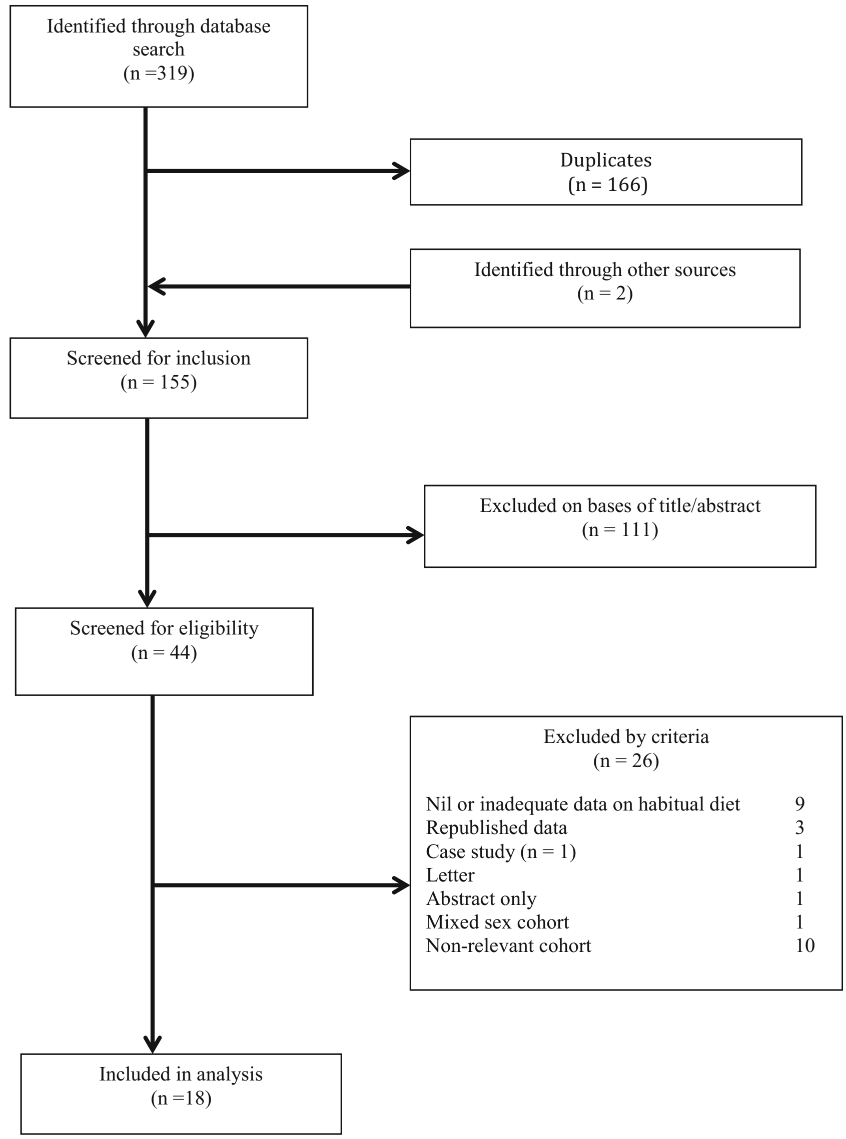

Fig. 1 Search strategy and results

contained insufficient information, attempts were made to contact authors to obtain missing details.

2.3 Data Extraction, Conversions, and Statistics

Data extracted from studies included participant characteristics such as age, sex, years of training, competition caliber, weight, height, and body composition. Dietary intake from food, with or without supplements, notably energy, macronutrient, micronutrient, type and number of supplements used, and method of dietary assessment used (e.g., food diary, questionnaire, 24-h recall) were also extracted. Anthropometric parameters reported in imperial (e.g., pounds) and dietary energy reported in kilocalories were converted to kg and kJ (1 kg = 2.2 pounds; 1 kcal = 4.2 kJ), respectively. Body mass index (BMI) was calculated [$(\text{weight/height})^2$] from the mean height (m) and body mass (kg). When required, Atwater factors were used to calculate grams of a nutrient into percent of energy (protein 17 kJ/g or 4 kcal/g; fat 37 kJ/g or 9 kcal/g; carbohydrate 16 kJ/g or 4 cal/g; alcohol 29 kJ/g or 7 cal/g) [28]. Extracted data were presented as mean and standard deviation (SD) when SD was reported. When standard error was used, SD was calculated and used in the data tables. Weighted means were calculated for age, anthropometric variables, energy, and macronutrient intakes.

Macronutrient intake was compared with existing recommendations specific to nutrition for athletic performance [29]. Adequacy of micronutrient intakes as a percent of the Recommended Dietary Allowance (RDA) set by the country in which the study was conducted was extracted when reported. When not reported, adequacy was assessed against the current US RDA [30], as the majority of papers (11/18) were from the USA, and mean intakes for each nutrient were used. The US tolerable upper intake levels were also used [30] to assess intakes that may have reached or exceeded these recommendations. As some studies analysed the dietary contribution of food separately from supplements (while in other studies supplements were incorporated into this calculation), the methodology of how the food/supplement intake was calculated was extracted. All data were independently extracted twice (JS, LM, HO), with disagreements resolved by discussion with a third researcher (GS, JG) if required.

2.4 Assessment of Methodological Quality

The quality of 17 (of the 18) studies meeting inclusion criteria were independently assessed by two researchers (JG and LM) using a modified assessment scale devised by Downs and Black [31]. One study, by Cho et al. [15], could not be rated for quality since an adequate English language translation of all text was not possible. Using the scale, 13 of the 27 criteria that logically applied (items 4, 8, 9, 12–15, 17, 21, 23–27 were excluded) to the identified studies were used. Two additional items addressing nutrition methodology from a nutrition-specific quality criteria checklist were incorporated [32]. The two items added were "Were nutrition measures appropriate to question and outcomes of concern?" and "Were the observations and measurements based on standard, valid, and reliable data collection instruments/tests/procedures?" When each paper was reviewed, each reviewer checked for internal (intra-rater) consistency across categories before scores were amalgamated. Disagreements were resolved by discussion with a third researcher for consensus (HO).

3 Results

3.1 Identification and Selection of Studies

The original search netted 319 potential articles. After the removal of duplicates ($n = 166$), a further 111 were removed after screening using title and abstract. The full text of the remaining 44 articles, along with an additional two identified by hand searching, were retrieved. Of these, 28 were excluded due to not meeting the eligibility criteria, resulting in 18 eligible manuscripts. A summary of the systematic PRISMA process is shown in Fig. 1. One paper [33] was excluded after attempts to contact the authors in an effort to obtain more specific information about participant characteristics and dietary details failed.

3.2 Demographic Characteristics, Competition Phase/Calibre and Drug Use

Participant demographic characteristics are outlined in Tables 1 and 2 for the male and female participants, respectively. The 18 studies described a total of 385 participants (323 men and 62 women). The majority of papers were published in the 1980 and 1990s; four papers were published in 2000, 2007, 2010, and 2011. The weighted mean age of the men was 26.9 ± 4.7 years (range 21.5–30) and of the women was 28.6 ± 4.2 years (range 18–30). Of the 18 studies, ten described men only, three described women only, and five contained male and female cohorts. Most ($n = 11$) studies were conducted in the USA, while two were from Korea, one was from South Africa, and the remaining four were from Europe (Tables 1, 2). The males had trained for a mean of 6.1 years (range 2–9.5) and the females for 3.5 years (range 1.7–7.5). Use of anabolic agents was reported by the participants in five of the 18 studies, with no use reported in seven studies (or implied via the competition being a drug-tested event), leaving the drug-taking status within the remaining six studies unknown.

The competition caliber of the participants was not always described, but only six of the 18 studies reported recruiting participants competing at the national level and only one study reported inclusion of participants at the international level. None of the studies reported whether participants were competing in newer bodybuilding competition categories (e.g., figure, model, swimsuit, etc.) and only two papers [6, 15] reported details of the weight class for which the competitors were preparing.

The competition phase of data collection varied across studies, with the non-competition phase described in five, competition preparation in four, and competition week in eight studies (Tables 1, 2). Six papers described more than one competition phase. A total of seven studies failed to identify the phase of the training/competition cycle. Only one study (in women only) reported on the post-competition period.

3.3 Anthropometric and Body Composition Characteristics

The weighted mean height of the men and women was 175.7 ± 6.4 cm (range 169.9–180) and 163.3 ± 5.8 cm (range 160–172), respectively (Tables 1, 2). The weighted mean body mass, fat-free mass, and percent fat of the men was 83.7 ± 9.1 kg (range 77.6–94.9), 77.8 ± 7.6 kg (range 67.7–83.1), and 12.1 ± 2.5 % (range 4.7–17), respectively. In women, these parameters were 54.2 ± 5.1 kg (range 52.3–60), 48.8 ± 4.3 kg (range 47.4–51.8), and 9.3 ± 2.1 % (range 8.4–11.1), respectively. In studies that measured body

Table 1 Male participant characteristics

References	n	Age, years	Country	Training, years (caliber)	Comp phase	Height, cm	Weight, kg	BMI, kg/m^2	FFM, kg	Fat, %
Baldo-Enzi et al. [38]$^{D(Y\&N)}$	14 $_{D(Y)}$	26.6 ± 5.3	Italy	3.9	NS	172.3 ± 6.1	82.4 ± 8.5	27.7 ± 2.1	72.2 ± 6.5	13.8 ± 3.1^{B}
	17 $_{D(N)}$	24.9 ± 3.8	Italy	3.9	NS	175.7 ± 5.7	77.6 ± 8.3	25.1 ± 1.9	68.4 ± 7.1	16.1 ± 2.0^{B}
Bazzare et al. [8]$^{D(T)}$	13	30.0 ± 4.0	USA	11.9 (N)	C	171.0 ± 7.0	80.0 ± 12.0	27.7	76.1	4.9 ± 1.6$^{SF(7)}$
Cho et al. [15]$^{D(NS)}$	34	27.0 ± 2.1	Korea	4.9 (N)	NS	173.5 ± 5.0	82.3 ± 9.1	27.3 ± 2.5	NR	8.3 ± 0.6$^{SF(5)}$
Faber and Benade [37]$^{D(NS)}$	76	27.4 ± 6.5	S. Africa	7.2	NC	177.4 ± 6.6	81.9 ± 9.0	25.9 ± 1.2	NR	15.4 ± 2.9^{W}
Giada [34]$^{D(N)}$	20	25.0 ± 4.0		3.5	NS	175.0 ± 6.0	76.8 ± 8.6	24.9 ± 19	67.7 ± 7.3	12.8 ± 2.0^{B}
Heyward et al. [1]$^{D(NS)}$	9	27.8 ± 5.7	USA	3.6 (Ci, R, S, N)	CP, C	177.1 ± 3.7	CP: 91.5 ± 9.2	CP: 29.1	CP: 82.7	CP: 9.7 ± 3.1
							C: 86.1 ± 9.5	C: 27.8	C:81.1 ± 10.4	C: 5.9 ± 3.2^{HW}
Keith et al. [4]$^{D(Y)}$	19	26.0 ± 6.0	USA	7.2 (R, S)	NC	177.1 ± 8.0	93.0 ± 12.5	29.8 ± 2.5	NR	NR
Kim et al. [80]$^{D(N)}$	8	21.5 ± 2.6	Korea	2.0 (N)	NC	175.5 ± 6.0	94.9 ± 12.9	30.7 ± 2.6	74.4 ± 8.7	17.0 ± 4.4^{B}
Kleiner et al. [5]$^{D(Y\&N)}$	18$^{D(Y)}$	29.5 ± 6.5	USA	9.5 ± 5.6	NC	176.8 ± 7.9	87.2 ± 9.6	28.1	NR	13.1 ± 2.8^{HW}
	17$^{D(N)}$	25.6 ± 4.8	USA	6.6 ± 3.7	NC	179.8 ± 7.9	88.5 ± 11.2	27.7	NR	13.9 ± 4.2^{HW}
Kleiner et al. [6]$^{D(Y)}$	19	28.0 ± 4.0	USA	8.2 (N)	C	169.9 ± 7.5	80.1 ± 11.7	27.6	75.3	6.0 ± 1.8$^{SF(7)}$
Linseisen et al. [35]$^{D(Y)}$	13	24.6 ± 4.2	Germany	4.5	NC	180.0 ± 6.5	89.5 ± 8.4	27.4 ± 1.9	75.5 ± 5.3	15.4 ± 3.9$^{SF(4)}$
Maestu et al. [36]$^{D(N)}$	7	28.3 ± 10.3	Estonia	N, I	C	175.3 ± 5.4	82.3 ± 9.3	26.7 ± 2.8	72.9 ± 8.4	9.6 ± 2.3^{DXA}
Newton et al. [2]$^{D(NS)}$	6	26.5	USA	7 (S, N)	CP, C	173.6	CP: 91.0 ± 4.4	CP: 30.2	CP: 82.7 ± 3.6	CP: 9.2 ± 1.2
							C: 83.7 ± 2.0	C: 27.8	C: 80.3 ± 1.2	C: 4.1 ± 1.3^{HW}
Poortmans and Dellalieux [81]$^{D(N)}$	20	29 ± 1	Belgium	UK	NS	NR	86.4 ± 1.7	NR	NR	NR
Sandoval et al. [3]$^{D(NS)}$	5	25.0 ± 3.3	USA	3.6 (Ci, R, S)	C	176.7 ± 3.6	82.2 ± 9.7	26.3 ± 9.2	81.1 ± 10.4	7.2 ± 1.6^{HW}
Vega and Jackson [40]$^{D(NS)}$	8	28.5 ± 5.5	USA	6.3	NS	175.0 ± 6.0	84.6 ± 11.6	27.6	NA	NR
Weighted mean (range)		26.9 ± 4.7 (21.5–30.0)		6.1 (2.0–9.5)		175.7 ± 6.4 (169.9–180.0)	83.7 ± 9.1 (77.6–94.9)	27.9 ± 3.7 (24.9–30.7)	77.8 ± 7.6 (67.7–81.3)	12.1 ± 2.5 (4.1–17.0)

Data are presented as mean ± SD or mean (range) unless otherwise indicated

B bioelectrical impedance, *BMI* body mass index, *Ci* city, *C* competition, *comp phase* competition phase, *CP* competition preparation, *D(N)* participants did not consume drugs, *D(NS)* not specified whether participants used drugs, *D(T)* participants competed in competition where drug testing is performed, *DXA* dual-energy X-ray absorptiometry, *D(Y)* participants consumed drugs, *FFM* fat-free mass, *HW* hydrostatic weighing/underwater weighing, *I* international, *N* national, *NA* not available, *NC* non-competition, *NR* not reported, *NS* not specified, *R* regional, *S* state, *SD* standard deviation, *SF(n)* skin fold sites (n = number of sites), *UK* unknown, *W* weight only

Table 2 Female participant characteristics

References	*n*	Age, years	Country	Training, years (caliber)	Comp phase	Height, cm	Weight, kg	BMI, kg/m^2	FFM, kg	Fat, %
Bazzare et al. [8]$^{D(T)}$	17	29 ± 3	USA	7.5 (N)	C	160.0 ± 7.0	53.0 ± 6.0	20.7	48.3	9.1 ± 1.4$^{SF(7)}$
Heyward et al. [1]$^{D(NS)}$	12	28.7 ± 7.2	USA	2.2 (Ci, S, N)	CP, C	162.4 ± 7.0	CP: 58.3 ± 5.2	CP: 22.4	CP: 48.5 ± 5.7	CP: 16.8 ± 4.5
							C:52.3 ± 4.5	C: 19.8	C: 47.4 ± 4.9	C: 9.5 ± 3.3^{HW}
Kleiner et al. [6]$^{D(Y)}$	8	28.0 ± 4.0	USA	3.4 ± 1.4	C	165.6 ± 7.5	57.4 ± 9.2	20.8	51.8	9.8 ± 1.5$^{SF(7)}$
Lamar-Hildebrand et al. [41]$^{D(NS)}$	6	(18–30)	USA	R	CP, C	NR	C: 53.2 ± 4.9	NR	NR	NR
Newton et al. [2]$^{D(NS)}$	2	(25–37)	USA	4 (S)	CP, C	162.0	CP: 58.0 ± 0.2	22.3	CP: 49.4 ± 1.4	14.8 ± 2.2^{HW}
							C: 55.6 ± 3.2	21.2	C: 49.4 ± 3.0	11.1 ± 0.2
Sandoval et al. [3]$^{D(NS)}$	6	27.8 ± 4.1	USA	1.7 (Ci, R, S)	C	162.9 ± 4.1	52.5 ± 3.1	19.8	48.1 ± 3.3	8.4 ± 3.2$^{(HW)}$
Vega and Jackson [40]$^{D(NS)}$	5	29.8 ± 4.6	USA	3.2 ± 1.9	NS	172.0 ± 6.8	60.0 ± 3.7	20.0	NR	NR
Walberg-Rankin et al. [41]$^{D(N)}$	6	27.3 ± 5.1	USA	2.8 (R)	CP, C, P	165.0 ± 4.4	CP: 57.0 ± 2.5	21.1	NR	12.7 ± 1.7$^{SF(3)}$
							C: 54.3 ± 2.2	20.0		
							P:58.2 ± 2.7	21.5		
Weighted mean (range)		25.8 ± 4.2 (18–30)		3.5 (1.7–7.5)		163.3 ± 5.8 (160.0–172.0)	54.2 ± 5.1 (52.3–60.0)	NR	48.7 ± 4.23 (47.4–51.8)	9.3 ± 2.1 (8.4–11.1)

Data are presented as mean ± SD or range unless otherwise indicated

BMI body mass index, *C* competition, *Ci* city, *comp phase* competition phase, *CP* competition preparation, *D(N)* participants did not consume drugs, *D(NS)* not specified whether participants used drugs, *D(T)* participants competed in competition where drug testing is performed, *DXA* dual-energy X-ray absorptiometry, *D(Y)* participants consumed drugs, *FFM* fat-free mass, *HW* hydrostatic weighing/underwater weighing, *I* international, *N* national, *NC* non-competition, *NR* not reported, *NS* not specified, *P* post-competition, *R* regional, *S* state, *SD* standard deviation, *SF(n)* skin fold sites (*n* = number of sites), *UK* unknown, *W* weight only

Table 3 Dietary intake in men

References	n	Phase	Energy, kJ/day (kJ/kg)	Protein[a]	CHO	Fat	Alcohol[b]	Data collection method
Baldo-Enzi et al. [38][−S]	14	NS	11,327 ± 3112 (138)	253; (3.1) 31	333; (4.0) 47	66.1; 22	NR; CAL 0	FD(4)
	17	NS	13,759 ± 3355 (173)	159; (2.1) 20	439; (5.7) 51	106.4; 29	NR; CAL 0	FD (4)
Bazzare et al. [8][SNR]	13		11,004 ± 3372 (138)	247 ± 105; (3.1) 40	334 ± 194; (4.2) 49	33 ± 19; 11	NR; CAL 0	FD(3)
Cho et al. [15][SNR]	34	NS	10,851 ± 3672 (132)	157 ± 91; (1.9) 27	367 ± 133 (4.5) 64	50 ± 34; 9	NR; CAL 0	24 HR
Faber and Benade [37][+S, c, +S, d]	76	NS	15,455 (189)	188; (2.3) 21	337; (4.4) 35	168 ± 50; 40	11 ± 18; 4	FD(7)
Giada [34][−S]	20	NS	15,473 ± 4368 (202)	166; (2.2) 18	534; (7.0) 55	121; 29	13 ± 16; 2	FD(4)
Heyward et al. [1][+S, c]	9	CP	15,078 ± 4867 (165)	215 ± 59; (2.3) 25	457 ± 148; (5.0) 52	110 ± 71; 26	NR; CAL 0	
		C	9790 ± 1088 (114)	163 ± 59; (1.9) 28	365 ± 76; (4.2) 63	32 ± 18; 13	NR; CAL 0	
Kim et al. [80][+S, d]	8	NC	22,099 ± 5690 (233)	406 ± 101; (4.3) 30	470; (5.0) 34	215; 36	NR; CAL 0	FD(3) + S
Keith et al. [4][SNR]	14	NC	18,770 ± 5905 (202)	252 ± 109; (2.7) 23	544 ± 193; (5.8) 46	151 ± 9330	NR; CAL 0	FD(3)
Kleiner et al. [5][+S, d]	35	NS	24,104 ± 10,500 (276)	324 ± 163; (3.7) 23	637 ± 7; (7.2) 42	241 ± 109; 33	NR; CAL; 17; 2	EFD (3)
Kleiner et al. [6][−S]	19	C	8463 ± 4452 (106)	169.9 ± 94; (2.1) 34	243 ± 121; (3.0) 50	40 ± 51; 15	NR; CAL 0	FD(7)
Linseisen et al. [35][+S, d, S]	13	NC	17,165 ± 3007 (192)	219 ± 85; (2.5) 22	497 ± 138; (5.6) 49	118 ± 51; 26	6 ± 17; 1	
Maestu [36][SNR]	7	CP	14,646 ± 4250 (178)	205.8 ± 42.2; (2.5) 24	447.1 ± 183.6; (5.4) 49	90.1 ± 16; 22.8	NR; CAL; 23; 5	FR(3)
		C	13,587 ± 4015 (165)	195.7 ± 36.7; (2.4) 25	387.6 ± 84.8; (4.7) 46	93.2 ± 15.4; 25	NR; CAL; 21; 5	
Newton et al. [2][+S, d, −S]	6	CP	10,802 ± 2675 (124)	244 ± 62; (2.8) 38	363 ± 143; (4.1) 56	33 ± 10; 14	NR; CAL 0	FD(3)
		C	8572 ± 2461 (102)	168 ± 86;(2.0) 33	290 ± 73; (3.5) 57	19 ± 18; 8	NR; CAL; 6; 2	
Poortmans and Dellalieux [81][−S]	20	NS	16,413 ± 1130 (190)	169 ± 13; (2.0) 18	NR	NR	NR	FD(7)
Sandoval et al. [3][−S]	5	C	9857 ± 924 (120)	199 ± 65; (2.4) 34	305 ± 91 (3.7) 52	41 ± 19; 16	NR;CAL 0	FD(3)
Vega and Jackson [40][SNR]	8		16,107 ± 6250 (190)	262 ± 104; (3.1) 28	506 ± 281 (6.0) 50	89 ± 53; 20.4	NR;CAL; 9; 2	
Competition phase								
NC	66	NC	15,988 ± 4059 (184)	240.6; (2.8) 25	454; (5.3) 47	122.8; 28	–	
CP	22	CP	13,774 ± 4073 (158)	220; (2.5) 28	428; (4.9) 52	82.7; 22	–	
C	63	C	10,029 ± 3162 (123)	194.5 (2.4) 34	310 (3.8) 52	41; 14	–	
NS	193	NS	16,339 ± 5636 (196)	205.9 (2.5) 22	421.1 (5.0) 45	148.0; 30	–	

Data are presented as mean ± SD g/day (g/kg/day) % of energy intake unless otherwise indicated

ACSM American College of Sports Medicine, *C* competition, *CAL* calories, *CHO* carbohydrate, *CP* competition preparation, *EFD* estimated food diary, *FD(n)* food diary (number of days collected), *NC* non-competition, *NR* not reported, *NS* not specified, *SNR* supplements not reported, *−S* dietary supplements excluded from the analysis, *+S* dietary supplements included in analysis, *24HR* 24-h recall

[a] Recommended protein, CHO, and fat intake for athletic performance according to ACSM Position Stand: protein 1.2–1.7 g/kg/day (10–35 %), CHO 6–10 g/kg/day, fat (20–35 %)

[b] Australian public health recommendations for alcohol intake: no more than 10 g of ethanol per day for women and 20 g of ethanol per day for men, with 2 alcohol-free days

[c] Protein powder only

[d] All supplements (protein powder, vitamins and minerals)

composition in non-competition/competition preparation versus competition phases, body mass and fat was substantially less at competition in both men (~5–7 kg lighter and ~4–5 % lower body fat) and women (~3–6 kg lighter and ~5–7 % lower body fat). When body composition was assessed, studies used hydrodensitometry ($n = 4$), surface anthropometry ($n = 5$), bioelectrical impedance ($n = 3$), or dual energy X-ray absorptiometry ($n = 1$).

3.4 Dietary Intake in Men

3.4.1 Energy and Macronutrient Intake in Men

The intake of energy and macronutrients for the men are reported in Table 3, which also shows the phase (i.e., non-competition, competition, or non-specified) and whether intakes included the contribution of dietary supplements. Of the 16 studies that reported data in men, only six included dietary supplements in the nutritional analysis, with five of these including both powder/liquid and pill-form supplements (the remaining study analyzed only sports food supplements). Two of these six studies also provided nutritional analysis without supplements, enabling the contribution of dietary supplements to be assessed. Of the remaining ten studies in men, six failed to specify whether supplements were included in the analysis and four only provided an analysis of intake from foods consumed, omitting supplements. No studies in men reported on the post-competition period, and a large number of participants were from studies in which the phase of preparation was not specified ($n = 193$). The majority of participants were described in the non-competition ($n = 66$) or competition ($n = 63$) phase, with a smaller number described in the competition preparation phase ($n = 22$). Limited details were provided on the types of dietary approaches or rationale used by the participants in these phases, i.e., whether they were 'bulking', 'cutting', restricting fluids or sodium, etc.; rather, just the nutritional analysis was provided.

The energy intake in the men across the 16 studies ranged from 8572 kJ/day (102 kJ/kg/day) through to 24,104 kJ (276 kJ/kg/day) (Table 3). Energy intake varied across competition phases, with weighted means showing it was highest (excluding the non-specified phase data) in the non-competition phase (15,988 kJ/day; 184 kJ/kg/day) and lowest in the competition phase (10,029 kJ/day; 123 kJ/kg/day) (Table 3). The protein intake in men ranged from 157 g/day (1.9 g/kg/day) to 406 g/day (4.3 g/kg/day). The proportion of energy from protein ranged from 17.5 to 40 %. Weighted means showed that the absolute intake of protein was highest in the non-competition phase (220 g/day; 2.5 g/kg) and lowest in the competition phase (194.5 g/day; 2.4 g/kg/day) (Table 3).

Carbohydrate intake across the studies in men ranged from 243 g/day (3.0 g/kg/day) through to 637 g/day (7.2 g/kg/day). The proportion of energy from carbohydrate ranged from 34 to 64 %. Weighted means indicated the absolute intake of carbohydrate was highest in the non-competition phase (454 g/day; 5.3 g/kg/day) and lowest during the competition phase (310 g/day; 3.8 g/kg/day) (Table 3). The absolute intake of fat across the studies ranged from 19 g/day (8 % of energy) through to 241 g/day (33 % of energy). Weighted means indicated the highest absolute fat intake (aside from the mean of studies where phase of data collection was not specified) was during the non-competition phase (123 g/day; 28 %) and lowest during the competition phase at 41 g/day (14 % of energy) (Table 3).

Most studies failed to report a value for alcohol consumption, so this was calculated via difference from the sum of the proportions derived from protein, fat, and carbohydrate and found in most cases to be zero (Table 3). However, this calculation was problematic for some studies [1–3, 34], as the sum of the percent energy contribution from protein, fat, and carbohydrate exceeded 100 %, indicating the authors had made an error with the reported data (see quality ratings, Table 9). Half ($n = 8$) of the papers in men were found (five via calculation) to have an energy contribution from alcohol that ranged from 1 % [35] to 5 % of energy [36]. The absolute highest mean intake of alcohol in any study was 23 g/day [36].

3.4.2 Micronutrient Intake in Men

Vitamin intake was reported in nine of the 16 studies in men (Table 4). However, only five of these studies provided a comprehensive analysis of intake, which included the contribution of dietary supplements [1, 2, 5, 35, 37]. Two of these five papers were also analysed without supplements for comparison [2, 35]. The remainder ($n = 4$) failed to specify whether supplements were included in the nutrient analysis. A total of nine vitamins were reported on across the studies, including folate, retinol equivalents, and vitamins B_1, B_2, B_3, B_6, B_{12}, C, and E. Of these, only vitamins B_2 and B_3 had intakes below the RDA from at least one study. Most striking was the substantially high intakes of certain nutrients, and this occurred more often in the intakes where supplements were included in the nutritional analysis. Some nutrients were consumed at levels more than 1000 % above the RDA. Nutrients consumed above the upper limit (according to US recommendations) [30] were folate, vitamin B_6, and vitamin C. As intakes of vitamin A were reported as retinol equivalents, it was not possible to assess the upper limit (Table 4).

Mineral intake was reported in 12 of the 16 studies in men (Table 5). Of these, six studies calculated intake with

Table 4 Vitamin intakes in men

References	*n*	Phase	Folate, µg	Vit A, RE	Vit B_1	Vit B_2	Vit B_3	Vit B_6	Vit B_{12}	Vit C	Vit E
Bazzareet al. [8]	13	C^{SNR}	NR	NR	NR	NR	NR	NR	NR	272 ± 258 (453)	NR
Cho et al. [15]	34	NS^{SNR}	NA	1143 ± 1208 (181)	1 ± 1 (114)	2 ± 01 (86)	53 ± 41 (312)	NR	NR	181 ± 134 (273)	NR
Faber and Benade [37]	45	$NS^{+S, a}$	632 (158)	16,127 (323)	4 (329)	6 (375)	47 (261)	5 (223)	17 (563)	260 (433)	NR
	30	$NS^{+S, b}$	845 (211)	23,736 (475)	17 (1238)	16 (981)	92 (511)	17 (759)	68 (2250)	970 (1616)	NR
Heyward et al. [1]	7	$CP^{+S, a}$	NR	NR	3 ± 1 (171)	2 ± 1 (138)	58 ± 16 (323)	42 ± 18 (311)	NR	154 ± 94 (256)	17 ± 10 (165)
		$C^{+S, b}$	NR	NR	2.1 ± 0.8 (125)	3 ± 6 (242)	59 ± 24 (327)	41 ± 24 (30)	NR	171 ± 82 (285)	10 ± 3 (100)
Keith et al. [4]	14	NC^{SNR}	753 ± 477 (376)	15,386 ± 9167 (304)	4 ± 2 (173)	6 ± 3 (204)	73 ± 36 (245)	5 ± 3 (236)	12 ± 8 (603)	222 ± 237 (370)	15 ± 20 (100)
Kleiner et al. [5]	35	$NS^{+S, a}$	NR	17,709 ± 29,990 (1968)[c]	9 ± 14 (750)[c]	11 ± 15 (846)[c]	84 ± 50 (525)[c]	NR	NR	493 ± 326 (548)[c]	NR
Linseisenet al. [35]	13	$NC^{+S, b}$	732 ± 553 (488)	1 ± 1 (110)	12 ± 13 (553)	10 ± 9 (398)	46 ± 23 (258)	55 ± 155 (1263)	NR	321 ± 233 (428)	39 ± 34 (321)
		NC^{-S}	236 ± 88 (157)	1 ± 1 (58)	2 ± 1 (72)	3 ± 1 (129)	24 ± 12 (136)	3 ± 1 (66)	NR	140 ± 61 (187)	13 ± 5 (111)
Newton et al. [2]	6	$CP^{+S, b}$	(174)	(376)	(1353)	(1180)	(463)	(4782)	(7239)	(2483)	(213)
		CP^{-S}	(114)	(274)	(150)	(150)	(399)	(224)	(227)	(285)	(93)
	6	$C^{+S, b}$	(174)	(436)	(1329)	(1145)	(380)	(3829)	(7659)	(1880)	(369)
		C^{-S}	(96)	(352)	(106)	(90)	(251)	(157)	(248)	(308)	(129)
Sandoval et al. [3]	5	C^{SNR}	NR	NR	2 ± 1 (157)	2 ± 0 (133)	78 ± 32 (244)	5 ± 1 (211)	NR	137 ± 71 (229)	NR
Range %RDA			96–488	58–1968	72–1353	86–1180	136–525	66–1263	227–7659	187–2483	93–369

Data are presented as mean ± SD mg (%RDA) unless otherwise indicated

C competition, *CP* competitor preparation, *NC* non-competition, *NR* not reported, *NS* not specified, *RDA* recommended dietary allowance or intake of the country in which the study was conducted, *RE* retinol equivalents, *SD* standard deviation, *SNR* supplements not reported, −*S* dietary supplements excluded from the analysis, +*S* dietary supplements included in analysis, *Vit* vitamin, *%RDA* percent of the RDA/AI in the country from which data were collected

[a] Protein powder only

[b] All supplements (protein powder, vitamins, and minerals)

[c] Calculated as relevant age (from group mean) and sex percent RDA of the USA because %RDA from country of origin was not reported in the paper

Table 5 Mineral intakes in men

References	*n*	Phase	Calcium	Copper	Iron	Magnesium	Phosphorus	Potassium	Sodium[a]	Zinc
Bazzare et al. 1992 [8]	13	C^{SNR}	917 ± 953(98)[b]	2 ± 1 (233)[b]	24 ± 6(300)[b]	700 ± 318 (175)[b]	NR	NR	NR	14.3 ± 5.4(95)
Cho et al. [15]	34	NS^{SNR}	551 ± 302 (79)	NR	17 ± 7 (135)	NR	NR	NR	NR	NR
Faber and Benade [37]	45	NS$^{+S, c}$	2502 (313)	5 (180)	41 (410)	620 (177)	3404 (426)	5471	3306	30 (200)
	30	NS$^{+S, d}$	2718 (340)	5 (204)	52 (520)	670 (190)	3547 (443)	5685	3279	32.4 (216)
								NR	NR	
Heyward et al. [1]	7	CP$^{+S, c}$	2141 ± 1672 (267)	NR	29 ± 10 (286)	631 ± 204 (180)	NR	6222 ± 2481 (166)	3971 ± 2475 (132)	24 ± 12 (163)
		C$^{+S, d}$	416 ± 209 (52)	NR	19 ± 7 (188)	494 ± 146 (141)	NR	5163 ± 1276 (138)	1451 ± 842 (48)	12 ± 4 (81)
Keith et al. [4]	14	NC^{SNR}	2277 ± 1666 (259)	NR	37 ± 16 (343)	688 ± 376 (192)	3561 ± 1890 (412)	6950 ± 3533 (148)[b]	5511 ± 2003 (367)[b]	24.7 ± 13.0 (165)
Kim et al. [80]	8	NC$^{+S, d}$	2177 ± 1588 (218)[b]	NR	NR	NR	3269 ± 1023 (467)[b]	5952 ± 2136 (127)[b]	4905 ± 3168 (327)[b]	NR
Kleiner et al. [5]	35	NS$^{+S, d}$	2987 ± 1825 (299)[b]	NR	44 ± 31 (550)[b]	NR	4717 ± 2475 (674)[b]	NR	6693 ± 3175 (446)[b]	40 ± 31 (364)[b]
Kleiner et al. [6]	19	C^{-S}	605 ± 586 (75)	3 ± 2 (111)	16 ± 9 (156)	345 ± 214 (98)	NR	4420 ± 2769 (94)[b]	1442 ± 1300 (96)[b]	11 ± 6 (71)
Linseisen et al. [35]	13	NC$^{+S, d}$	2319 ± 896 (232)	NR	26 ± 8 (260)	744 ± 232 (213)	3189 ± 1000 (456)	5940 ± 1650 (126)[b]	3650 ± 980 (243)[b]	NR
		NC^{-S}	2082 ± 759 (208)	NR	22 ± 5 (220)	687 ± 237 (196)	3066 ± 915 (438)	5800 ± 1620 (123)[a]	3550 ± 1000 (237)[b]	NR
Newton et al. [2]	6	CP$^{+S, d}$	(213)	NR	(354)	(173)	(283)	(148)	NR	(362)
		CP^{-S}	(119)	NR	(246)	(165)	(278)	(148)	NR	(103)
	6	C$^{+S, d}$	(152)	NR	(332)	(166)	(178)	(106)	NR	(550)
		C^{-S}	(49)	NR	(187)	(117)	(170)	(106)	NR	(69)
Poortmans and Dellalieux [81]	20	NC^{-S}	1898 ± 307 (90)[b]	NR	NR	NR	NR	NR	NR	NR
Sandoval et al. [3]	5	C^{SNR}	433.0 ± 189.0 (54)	NR	18.8 ± 6.0 (188)	NR	NR	NR	NR	NR
Range %RDA/AI[e]			49–340	111–233	135–550	98–213	170–674	94–166	48–446	71–550

Data are presented as mean ± SD mg (%RDA) unless otherwise indicated

AI adequate intake, *C* competition, *CP* competition preparation, *NC* non-competition, *NR* not reported, *NS* not specified, *P* post-competition, *RDA* recommended dietary allowance, *SNR* supplements not reported, *−S* dietary supplements excluded from the analysis, *+S* dietary supplements included in analysis, *%RDA* percent of the RDA/AI in the country from which data were collected

[a] Sodium from food, does not include added salt

[b] Calculated as relevant age (from group mean) and sex percent RDA, of the USA because %RDA from country of origin was not reported in the paper

[c] Protein powder only

[d] All supplements (protein powder, vitamins, and minerals)

[e] When diet intake reported with and without supplements, range given with supplements

supplements included. The minerals reported by the studies included calcium, copper, iron, magnesium, phosphorus, potassium, sodium, and zinc. Of these nutrients, at least one study reported intake of calcium, magnesium, potassium, sodium, and zinc below the RDA (range 48–98 % RDA). Despite this, most of the intakes were well above the RDA (Table 5). Comparing the mineral intakes with the US recommendations for upper limit of intake showed that calcium and sodium (which did not include discretionary use) were above the upper limit in at least one study, and zinc was consumed around the upper limit in one study. No studies reported the vitamin or mineral intakes against the estimated average requirements (EAR). A number of studies only reported the percent of the RDA rather than quantifying the actual micronutrient intake.

3.4.3 *Dietary Supplements and Drugs in Men (Qualitative Data)*

Six of the 16 studies in men provided a qualitative description of the dietary supplements consumed, which included protein powders/liquid, amino acids, vitamins, minerals, and liver tablets. Five studies reported the use of anabolic steroids in men [4–6, 35, 38], with two of these studies dividing cohorts into participants using anabolic agents and participants who were not [5, 38]. Other drugs reported to be used by participants included diuretics and laxatives [6].

3.5 Dietary Intake in Women

3.5.1 *Energy and Macronutrient Intake in Women*

The intake of energy and macronutrients for the women are reported in Table 6, which also shows the phase when the data was collected and whether intakes included the contribution of dietary supplements. Only two of the eight studies in women provided an analysis that included dietary supplements and only one of these included both powder/liquid and pill-form supplements. Four studies failed to specify whether supplements were included in the analysis, and the remaining two only provided an analysis of intake from foods consumed, omitting supplements. Most of the participants were described in the competition phase ($n = 57$), followed by competition preparation ($n = 14$) and non-competition ($n = 12$), with a small number of participants ($n = 5$) for whom the phase of competition was not described. Again, as with the men, limited details were provided on the types of dietary approaches or rationale used by the participants in these phases, i.e., whether they were ‘bulking’, ‘cutting’ (see Sect. 4.3), restricting fluids or sodium etc.; instead, just the nutritional analysis was provided.

The energy intake in women ranged from 3742 kJ/day (66 kJ/kg/day) through to 13,595 kJ (246 kJ/kg/day) (Table 6). The intake varied across competition phases, with weighted means showing it was highest in the post-competition period (13,595 ± 244 kJ/day; 246 kJ/kg/day) and lowest in the competition preparation phase (5081 ± 1697 kJ/day; 91 kJ/kg/day) (Table 6). The protein intake in women ranged from 48 ± 16 g/day (0.8 g/kg/day) to 162 ± 93 g/day (2.8 g/kg/day). The proportion of energy from protein ranged from 10 to 39 % of energy. Weighted means showed that the absolute intake of protein was highest in the post-competition period (119 g/day; 2.2 g/kg) and lowest in the pre-competition period (90 g/day; 1.6 g/kg/day) (Table 6).

Carbohydrate intake across the studies in women ranged from 160 g/day (2.8 g/kg/day) through to 415 g/day (7.5 g/kg/day). The proportion of energy from carbohydrate ranged from 48 to 78 %. Weighted means indicated the absolute intake of carbohydrate was lowest during the competition preparation phase (176 g/day; 3.1 g/kg/day) and highest in the post-competition phase (415 g/day; 7.5 g/kg/day) (Table 6). The intake of fat across the studies of women ranged from 9 g/day (9 % of energy) through to 124 g/day (34.5 % of energy). Weighted means indicated the highest intake was during the post-competition period (124 g/day; 34.5 %) and lowest (as percent of energy)-during competition (24 g/day; 12.2 % of energy) (Table 6).

Most studies failed to report a value for alcohol consumption, so this was calculated via difference from the sum of the proportions derived from protein, fat, and carbohydrate and, in most cases, was found to be zero (Table 6). As with the data for men, this calculation was problematic for some studies [1–3, 39], as the sum of the percent energy contribution from protein, fat, and carbohydrate exceeded 100 %, indicating the authors had made an error in the reported data (see Table 6). Only two of the papers in women were found (via calculation) to have an energy contribution from alcohol, which was 3 % (non-specified competition period) [40] and 13 % (an analysis of competition week, which incorporated the day after competition) [41] (Table 6).

3.5.2 *Micronutrient Intake in Women*

Vitamin intake was reported in six of the eight studies in women (Table 7). Of these, only one study [2] provided analysis of total intake with the contribution of supplements included. Another paper [1] included the contribution of protein powders but not pill-form supplements. Two papers failed to specify whether dietary supplements were included in the analysis. Despite the lack of inclusion of micronutrients from supplements in a number of the studies, intakes were generally above the RDA for most of the

Table 6 Dietary intake in women

References	*n*	Phase	Energy, kJ/day (kJ/kg)	Protein	CHO	Fat	Alcohol	Data collection method
Bazzare et al. [8][SNR]	17	C	6707 ± 2579 (127)	143 ± 45 (2.7) 39	206 ± 120 (3.9) 48	22 ± 17 (12)	NR; CAL 0	FD3(NS) + NS
Heyward et al. [1][+S, C]	12	CP	6846 ± 2310 (117)	102 ± 30 (1.7) 26	208 ± 60 (3.6) 53	42 ± 30 (21)	NR; CAL 0	EFD3 +S (protein only)
		C	6102 ± 2738 (117)	77 ± 57 (1.5) 21	261 ± 112 (5) 72	15 ± 7 (10)	NR; CAL 0	EFD3 +S (protein only)
Lamar-Hildebrand et al. [41][SNR]	6	CP[d]	3742 ± 1138 (66)	48 ± 16 (0.8) 22	160 ± 61 (2.8) 71	9 ± 5 (9)	NR; CAL 0	FD3(NS) −S
		C[d]	9357 ± 5006 (176)	57 ± 25 (1.1) 10	359 ± 194 (6.7) 64	49 ± 48 (20)	NR; CAL 13	FD3(NS) −S
Newton et al. [2][+S, e, −S]	2	CP[d]	4989 ± 2822 (86)	92 ± 50 (1.6) 31	168 ± 95 (2.9) 57	23 ± 20 (17)	NR; CAL 0	EFD3 +S (micronutrients only)
		C	5359 ± 1041 (96)	108 ± 42 (1.9) 34	166 ± 145 (3.0) 52	20 ± 3 (14)	NR; CAL 0	EFD3 +S (micronutrients only)
Vega and Jackson [40][SNR]	5	NS[d]	10,588 ± 5309 (177)	158 ± 99 (2.6) 25	392 ± 173 (6.5) 59	37 ± 26 (13)	NR; CAL 3	24HR +NS
Kleiner et al. 1990 [5][SNR]	8	C	9492 ± 11,172 (165)	162 ± 93 (2.8) 37	332 ± 525 (5.8) 49	33 ± 41 (13)	NR; CAL 0	FD7 (NS) −S
Sandoval et al. [3][−S]	6	C[d]	6405 ± 2503 (122)	105 ± 59 (2) 26	242 ± 87 (4.6) 64	25 ± 12 (14)	NR; CAL 0	EFD (3) −S
Walberg-Rankin et al. [41][−S]	6	CP	6451 ± 1882 (117)	131.3 (2.4) 34	198.5 (3.6) 51	NA	NR	FD3 (NS) +NS
		C[d]	7723 ± 2717 (142)	76.3 (1.4) 17	360.0 (6.6) 78	13 (6)	NR; CAL 0	
		P	13,595 ± 5359 (246)	119.0 (2.2) 15	415 (7.5) 51	124 (35)	NR; CAL 0	
Competition phase								
ND	12	NC	6846 ± 2310 (117.4)	102 (1.7) 26	208 (3.6) 53	42; 21	0	
CP	14	CP	5081 ± 1697 (90.8)	90 (1.6) 28	176.5 (3.1) 60	18; 12	0	–
C	57	C	7278 ± 4027 (135.2)	110.5 (2.0) 28	270 (5.0) 59	24; 12	0	
Post-competition	6	P	13,595 ± 244 (246.3)	119 (2.2) 14	415 (7.5) 51	124; 35	0	
NS	5	NS	10,588 ± 5308 (176.5)	158 (2.6) 25	392 (6.5) 62	37; 13	0	

Data are presented as mean ± SD g/day (g/kg/day), % of energy intake[a] unless otherwise indicated

ACSM American College of Sports Medicine, *C* competition, *CAL* calories, *CHO* carbohydrate, *CP* competition preparation, *EFD* estimated food diary, *FD(n)* food diary (number of days collected), *NC* non-competition, *NR* not reported, *NS* not specified, *SNR* supplements not reported, *−S* dietary supplements excluded from the analysis, *+S* dietary supplements included in analysis, *24HR* 24-h recall

[a] Recommended protein, CHO, and fat intake for athletic performance according to ACSM Position Stand: protein 1.2–1.7 g/kg/day (10–35 %), CHO 6–10 g/kg/d, fat (20–35 %)

[b] Australian public health recommendations for alcohol intake no more than 10 g of ethanol per day for women and 20 g of ethanol per day for men, with 2 alcohol-free days

[c] Protein powder only

[d] Error in reported macronutrient intake totaling <99 % or >101 % of energy

[e] All supplements (protein powder, vitamins, and minerals)

nine vitamins reported (Table 7). Of these nine, only three vitamins—folate, vitamin B_6, and vitamin E—had studies reporting levels below the RDA. Folate tended to be the nutrient that had more studies reporting it to be below (and also further below) the RDA.

The one study including the most comprehensive analysis of supplements also provided data on the intake from food only and this demonstrated that, while intakes from food alone were close to the RDA for most nutrients, when supplements were included, the intakes for vitamin B_1, B_2, B_3, B_6, B_{12}, C, and E were far above the RDA, often in excess of 1000 %. Comparison with the current US recommendations for upper limit of intake demonstrated that this study reported ingestion rates well above the upper limit for vitamins B_3 and B_6 and close to the upper limit for vitamins C and E. As intakes of vitamin A were reported as retinol equivalents, it was not possible to assess the upper limit.

Mineral intake was reported in seven of the eight studies in women (Table 8). As for vitamins, only one study included a comprehensive analysis of dietary supplements [2], another included analysis with protein powders/liquid, not pill-form supplements [1], and the remainder either did not include supplements in the dietary intake analysis or failed to report whether or not they were included. Eight minerals were reported in the analysis: calcium, copper, iron, magnesium, phosphorus, potassium, sodium, and zinc. Sodium intake did not include discretionary use. In contrast to the vitamins, eight of the minerals had at least one study with an intake below the RDA (all except phosphorus). Intakes below the RDA ranged from 20 % for sodium through to 84 % for copper. As with vitamins, the study analyzing dietary intake with and without supplements showed intakes were substantially higher and more likely to meet the RDA when supplements were included, but this study did report an intake of potassium that was below the RDA (Table 8). Comparison of the mineral intakes with the US recommendations for upper limits of intake found that two nutrients—iron and sodium—were consumed above the upper limit in at least one study. For iron, this was only in the study that included dietary supplements in the analysis; for sodium, it was only in the post-competition period (Table 8). No studies reported the vitamin or mineral intakes against the EARs. A number of studies only reported the percent of the RDA rather than quantifying the actual micronutrient intake.

3.5.3 Dietary Supplements and Drugs in Women

Four of the eight studies in women provided a qualitative description of the dietary supplements consumed, which included protein powders/liquid, amino acids, vitamins, minerals, and L-carnitine [2, 6, 39, 41]. In the one study in which the women reported use of drugs, participants indicated that they used diuretics but none of the women reported using anabolic steroids [6]. The authors of this paper commented that a number (unquantified) of the participants failed to complete the items probing drug use in the survey used to obtain this information [6].

3.6 Evaluation of Methodological Quality

The mean quality rating score was 7.4 ± 1.7 of a possible 15 (Table 9). All studies scored 0 for describing confounders and having a representative sample. The lowest scores were for using appropriate nutrition methods (mean score 0.1 ± 0.3); for using standard, valid, and reliable nutrition instruments, tests, and procedures (mean score 0.2 ± 0.4); describing subject characteristics (mean score 0.2 ± 0.4); and compliance (mean score 0.2 ± 0.4). The best scores were for describing the main findings, estimating random variability, and not data dredging (all studies scored 1).

4 Discussion

This study provides a comprehensive and systematic summary of the literature on dietary intake in competitive bodybuilders. Overall, the body of literature is limited, especially in women. It is also dated (1980–1990), with only four studies published since 2000. There are few longitudinal studies tracking the changes in dietary intake across different phases of preparation. The majority of studies fail to provide detailed information on dietary supplementation and how this contributes to energy, macro, and micronutrient intake. Most studies fail to report on the rationale for supplement use and sources of information. In the few studies that included analysis of total dietary intake from food and supplements, it is clear that micronutrient intake is much higher than, with levels for some nutrients well above, the US tolerable upper limit. As expected, protein intakes were higher than recommendations [29] for the general adult population, and the intakes, particularly in men, were often higher than sports nutrition recommendations for strength athletes. The protein intakes in this study were also likely underestimated, as not all studies included dietary supplements in the nutrient analysis. No studies examined the timing of nutrient intake; however, one study, by Cho et al. [15] investigated the daily distribution of energy by mealtime (breakfast, lunch, dinner, and snacks) but not macronutrient distribution. Often the rationale for the dietary strategies used by participants was neither provided nor explored. The

Table 7 Vitamin intakes in women

References	n	Phase	Folate, μg	Vit A, RE	Vit B_1	Vit B_2 [a]	Vit B_3	Vit B_6	Vit B_{12}	Vit C	Vit E
Bazzare et al. [8]	11	C^{SNR}	NR	NR	NR	NR	NR	NR	NR	196 ± 168 (261)[b]	NR
Heywardet al. [1]	1	$CP^{+S, C}$	NR	NR	1 ± 1 (119)	2 ± 1 (125)	32 ± 11 (250)	2 ± 1.0 (118)	NR	133 ± 80 (221)	7.9 ± 4.0 (99)
	2	$C^{+S, C}$	NR	NR	3 ± 8 (310)	1 ± 1 (108)	30 ± 16 (230)	3 ± 2 (154)	NR	187 ± 109 (311)	5.5 ± 2.8 (68)
Lamar-Hildebrand et al. [41]	6	CP^{SNR}	(<66)	NR	NR	NR	NR	NR	(<66)	NA	(<66)
		C^{SNR}	(<66)	NR	NR	NR	NR	NR	(<66)	NA	(<66)
Newton et al. [2]	2	$CP^{+S, D}$	(334)	(441)	(13,026)	(1106)	(1328)	(10,733)	(2084)	(2023)	(1268)
		CP^{-S}	(34)	(241)	(100)	(103)	(184)	(84)	(118)	(106)	(56)
	2	$C^{+S, D}$	(355)	(430)	(13,036)	(13,026)	(1467)	(10,786)	(2056)	(1205)	(1267)
		C^{-S}	(47)	(190)	(92)	(100)	(311)	(106)	(344)	(140)	(55)
Sandoval et al. [3]	6	C^{-S}	NR	NR	2 ± 1 (164)	3 ± 2 (236)	42 ± 22 (190)	3 ± 2(146)	NR	166 ± 103 (277)	NR
Walberg-Rankin et al. [41]	6	CP^{-S}	225 ± 101 (75)[b]	4945 ± 3652 (706)[e]	1 ± 0 (100)[b]	2 ± 1 (173)[b]	61 ± 35 (437)[b]	3 ± 2(207)[b]	NR	100 ± 42 (133)[b]	NR
		C^{-S}	181 ± 96 (60)[b]	3247 ± 4480 (468)[e]	2 ± 2 (209)[b]	2 ± 1 (145)[b]	32 ± 13 (229)[b]	3 ± 1 (207)[b]	NR	151 ± 106 (201)[b]	NR
		P^{-S}	313 ± 129 (104)[b]	5500 ± 1449 (784)[e]	2 ± 1 (173)[b]	2 ± 1 (218)[b]	32 ± 10 (232)[b]	2 ± 1 (169)[b]	NR	111 ± 90 (149)[b]	NR
Range %RDA[f]			60–355	430–784	100–13,026	108–13,026	184–1328	<66–10,786	2056–2084	60–133	<66–1268

Data are presented as mean ± SD mg (%RDA) unless otherwise indicated

C competition, *CP* competition preparation, *NR* not reported, *P* post-competition, *RDA* recommended dietary allowance, *RE* retinol equivalent, *SD* standard deviation, *SNR* supplements not reported, +*S* dietary supplements included in analysis, −*S* dietary supplements excluded from the analysis, *vit* vitamin, *%RDA* percent of the RDA in the country from which data were collected

[a] Niacin, not niacin equivalents

[b] Calculated as relevant age (from group mean) and sex %RDA of the USA because %RDA from country of origin was not reported in the paper

[c] Protein powder only

[d] All supplements (protein powder, vitamins, and minerals)

[e] Given as retinol equivalents

[f] When diet intake reported with and without supplements, range given with supplements

Table 8 Mineral intakes in women

References	*n*	Phase	Calcium	Copper	Iron	Magnesium	Phosphorus	Potassium	Sodium[a]	Zinc
Bazzare et al. [8]	11	C^{SNR}	418 ± 198 (42)[b]	1 ± 1 (122)[b]	17 ± 10 (91.6)[b]	424 ± 158 (137)[b]	NR	NR	NR	9 ± 5 (114)[b]
Heyward et al. [1]	12	$NC^{+S,\ C}$	705 ± 390 (88)	NR	14 ± 4 (78)	304 ± 103 (101)	NR	3028 ± 1139 (81)	1920 ± 1204 (64)	9 ± 4 (62)
		$C^{+S,\ C}$	272 ± 140 (34)	NR	11 ± 5 (63)	280 ± 168 (93)	NR	3561 ± 1498 (95)	603 ± 458 (20)	8 ± 5 (50)
Kleiner et al. [6]	8	C^{-S}	293 ± 231 (36)	2 ± 1 (84)	24 ± 40 (160)	254 ± 107 (91)	NR	2931 ± 1392 (62)[b]	1874 ± 2585 (125)[b]	9 ± 5 (75)
Lamar-Hildebrand et al. [41]	6	CP^{SNR}	348 ± 213 (34.8)[b]	NR	12 ± 4 (66.7)[b]	NR	NR	NR	NR	(<66)
		C^{SNR}	709 ± 662 (<66)	NR	12 ± 6 (66.7)[b]	NR	NR	NR	NR	(<66)
Newton et al. [2]	2	$CP^{+S,\ D}$	(163)	NR	(347)	(250)	(140)	(70)	NR	(260)
		CP^{-S}	(45)	NR	(59)	(83)	(116)	(64)	NR	(57)
	2	$C^{+S,\ D}$	(169)	NR	(363)	(256)	(154)	(77)	NR	(250)
		C^{-S}	(49)	NR	(70)	(87)	(140)	(66)	NR	(57)
Sandoval et al. [3]	6	C^{-S}	478.0 ± 339.0 (60)	NR	14 ± 5 (76)	NR	NR	NR	NR	NR
Walberg-Rankin et al. [41]	6	CP^{-S}	473.7 ± 306.5 (47)[b]	1 ± 1 (133)[b]	14 ± 4 (76.1)[b]	251 ± 118 (81)[b]	NR	NR	1741 ± 884 (116)[b]	7 ± 3 (85)[b]
		C^{-S}	280.1 ± 121.0 (28)	2 ± 1 (200)[b]	18 ± 6 (101)[b]	298 ± 112 (96.2)[b]	NR	NR	1554 ± 1768 (104)[b]	5 ± 2 (66)[b]
		P^{-S}	1262.3 ± 572.8 (126)[b]	2 ± 1 (199)	19 ± 5 (108)[b]	306 ± 94 (99)[b]	NR	NR	4540 ± 1910 (303)[b]	12 ± 6 (154)[b]
Range RDA/AI %[e]			28–169	84–211	63–347	81–137	140–154	62–95	20–255	50–134

Data are presented as mean ± SD mg (%RDA) unless otherwise indicated

AI adequate intake, *C* competition, *CP* competition preparation, *NR* not reported, *P* post-competition, *RDA* recommended dietary allowance, *SD* standard deviation, *SNR* supplements not reported, −*S* dietary supplements excluded from the analysis, +*S* dietary supplements included in analysis, *%RDA* percent of the RDA/AI in the country from which data were collected

[a] Sodium from food, does not include added salt

[b] Calculated as relevant age (from group mean) and sex % RDA of the USA because %RDA from country of origin was not reported in the paper

[c] Protein powder only

[d] All supplements (protein powder, vitamins, and minerals)

[e] When diet intake reported with and without supplements, range given with supplements

Table 9 Methodological quality ratings

References	Hypothesis stated	Main outcomes described	Participants described	Confounders described	Main findings described	Variability estimates	Actual *p* value reported	Representative participants
Baldo-Enzi et al. [38]	1	1	0	0	1	1	0	0
Bazzarre et al. [8]	0	1	0	0	1	1	0	0
Faberand Benade [37]	1	1	0	0	1	1	1	0
Giada [34]	1	1	1	0	1	1	0	0
Heyward et al. [1]	1	1	0	0	1	1	1	0
Keith et al. [4]	1	1	0	0	1	1	1	0
Kim et al. [80]	1	1	1	0	1	1	1	0
Kleiner et al. [5]	1	1	1	0	1	1	1	0
Kleiner et al. [6]	1	1	0	0	1	1	0	0
Lamar-Hildebrand et al. [41]	1	0	0	0	1	1	0	0
Linseisen et al. [35]	1	1	0	0	1	1	0	0
Maestu et al. [36]	1	1	0	0	1	1	0	0
Newton et al. [2]	1	1	0	0	1	1	0	0
Poortmans and Dellalieux [81]	1	1	0	0	1	1	0	0
Sandoval et al. [3]	1	1	0	0	1	1	1	0
Vega and Jackson [40]	1	1	0	0	1	1	0	0
Walberg Rankin et al. [41]	1	1	0	0	1	1	0	0
Mean	0.9	0.9	0.2	0.0	1.0	1.0	0.4	0.0
SD	0.2	0.2	0.4	0.0	0.0	0.0	0.5	0.0
Median								
Range								

References	Data dredging	Statistical tests appropriate	Compliance	Non-nutrition measures valid/reliable	Nutrition measures appropriate[a]	Nutrition measures valid/reliable[a]	Same recruitment period	Total (of 15)
Baldo-Enzi et al. [38]	1	0	0	0	0	0	0	5
Bazzarre et al. [8]	1	1	0	0	0	0	1	6
Faberand Benade [37]	1	1	0	1	0	1	0	9
Giada [34]	1	1	0	0	0	0	0	7
Heyward et al. [1]	1	0	1	1	0	0	1	9
Keith et al. [4]	1	1	0	1	0	0	0	8
Kim et al. [80]	1	0	0	0	0	0	0	7
Kleiner et al. [5]	1	0	0	1	0	0	0	8
Kleiner et al. [6]	1	0	0	0	0	0	1	6

Table 9 continued

References	Data dredging	Statistical tests appropriate	Compliance	Non-nutrition measures valid/reliable	Nutrition measures appropriate[a]	Nutrition measures valid/reliable[a]	Same recruitment period	Total (of 15)
Lamar-Hildebrand et al. [41]	1	0	0	0	0	0	1	5
Linseisenet al. [35]	1	1	0	1	1	1	0	9
Maestu et al. [36]	1	1	0	1	0	0	0	7
Newton et al. [2]	1	1	0	1	0	0	1	8
Poortmans and Dellalieux [81]	1	1	1	1	1	0	0	9
Sandoval et al. [3]	1	1	1	1	0	1	1	11
Vega and Jackson [40]	1	1	0	0	0	0	1	7
Walberg Rankin et al. [41]	1	0	0	0	0	0	0	5
Mean	1.0	0.6	0.2	0.5	0.1	0.2	0.4	7.4
SD	0.0	0.5	0.4	0.5	0.3	0.4	0.5	1.7
Median								7
Range								5–11

SD standard deviation

[a] From the Australian Department of Health [23]

methodological quality of the studies was poor, and several were identified as reporting data with obvious analysis errors in the nutrient intakes [1–3, 34, 39]. This review highlights that contemporary, high-quality research on dietary intake in bodybuilders is needed.

4.1 Anthropometry, Body Composition, and use of Anabolic Agents

As expected, the participants included in the studies were lean with percent body fat below 11 % for women (8.4–11.1) and 17 % for men (4.1–17.0). The caliber of bodybuilders was not well described, and fewer studies report on national or internationally representative competitors. A number also failed to nominate the phase of preparation during which the data were collected. This is likely why the studies in women appear to have an upper range of body fat lower than that of the men. However, in studies reporting both competition preparation and competition phases, there was a clear and often substantial reduction in both body mass and fat of approximately 3–6 kg and 4–7 %, respectively (Tables 1, 2) that occurred in the preparation for competition. All four of the papers in women [1–3, 6] that quantified body fat percentage in the week of competition reported mean body fat percentages below the estimated minimum level of body fat (12 %) as per the American College of Sports Medicine guidelines [9, 29]. Two of the six male competition week papers reported a mean body fat percentage below the estimated minimum level of body fat compatible with long-term health outcomes (5 %) [10, 29]. Few of the studies reported the use of anabolic agents; however, in one of the two studies [8] reporting on participants who used versus those who did not use anabolic steroids, body mass was substantially higher in those bodybuilders using steroids.

The men, as expected, were substantially heavier than the women, with a weighted mean body mass of approximately 84 versus 54 kg for the women. These body masses are below what is typically seen in winners of Mr. and Ms. Olympia where men typically weigh in excess of 120 kg [9, 10] and women 60 kg [42]. As stated above, range of competition caliber (and inclusion of only one study with internationally competitive participants) likely explains the lower mass seen in the included studies. Most of the studies failed to report the weight category (if any) for which competitors were aiming; details on this would have been useful to provide context to the anthropometric data. It is also important to consider that the manuscripts are dated, and the mean body mass of competitors in professional competitions post the year 2000 is reported to be greater than in the 1980s and 1990s, when most of the included studies were published [10, 42].

4.2 Energy Intake

The absolute energy intake of the male bodybuilders (10–16 MJ/day; >13 MJ/day except for competition) was substantially higher than that reported in a study of male Australian Olympic athletes where mean absolute energy intake was around 13 MJ/day (166 kJ/kg/day) [43]. Compared with the energy intake of Australian Rugby League players, that of the bodybuilders was closer to the higher end, with a reported mean of 17 MJ/day [44]. In terms of kJ/kg/day, the intake of the bodybuilders was at least similar and typically higher across all phases except the competition phase, where it was substantially lower (123 kJ/kg/day) than that of the male Olympic athletes [43]. In the women bodybuilders, weighted mean absolute energy intake ranged from 5 to 10.5 MJ/day (91–176 kJ/kg/day). In the same study of Olympic athletes reported above [43], the female Olympians had an average absolute energy intake of 9 MJ/day (144 kJ/kg/day) [43], which was within a similar range to that of the female bodybuilders in this study. Lack of empirical data on energy requirements of resistance training makes it difficult to assess the energy needs of bodybuilders. Unfortunately, accurately quantifying the energy expenditure of a heavy resistance training session is challenging [45–48].

In the current study, energy intakes in the men were greater during the non-competition phase, where they would typically undertake 'bulking', and lowest in the competition phase, where the 'cutting' occurs (Table 3). In the women, lowest intakes were during the competition preparation phase (Table 4). Given the extreme changes in training practices across the training phases, dietary needs are of utmost importance when aiming to achieve a competitive physique [49]. Unfortunately, the level of detail in the papers in this review prohibits a comprehensive evaluation of the dietary strategies used across the different phases and how dietary supplements (and in some cases drugs) and training were incorporated to manipulate energy balance.

4.3 Macronutrient Intake

4.3.1 Protein Intake

The macronutrient intakes of the bodybuilders were generally what was expected, with a protein intake either similar to or higher than the recommendation of 1.2–1.7 g/kg/day for strength-training athletes [29]. The protein intakes in men did not fall below 2 g/kg/day and peaked at 4.3 g/kg/day. The intakes of the women were lower and often below 2 g/kg/day, with the highest intake being 2.8 g/kg/day. The weighted mean protein intakes tended to be higher than those reported in the abovementioned study of male and female Australian Olympic athletes (1.7 and 1.3 g/kg/day, respectively) [43].

Research has emerged, particularly over the past 10–15 years, that supports the benefit of a higher protein intake in athletes than is recommended for sedentary individuals [29]. Rather than an absolute need or requirement, protein intake in athletes could be considered within the context of supporting optimal development of muscle mass [50], clearly a desirable outcome for bodybuilders. Both acute [51] and longitudinal training studies [52, 53] support the benefit of the timing of protein intake around resistance training sessions, with the strongest support for ingestion of 20–25 g of high biological value protein (e.g., dairy, egg or lean meat) within 2 h post-training [54]. High biological value proteins that contain all of the essential amino acids have been shown to be superior [54], with strong support available for dairy proteins such as whey, with a high leucine content [55]. Up-regulation of muscle protein synthesis has been found to be particularly responsive to signaling driven predominantly by leucine [55]. Notably, none of the studies in the review focused on timing of protein intake.

Emerging evidence also supports the benefit of regular protein intake over the day [13]. A recent study investigating the effectiveness of different protein dosing regimens compared ingestion of 80 g of additional high biological value protein distributed as either two 40 g doses, four 20 g doses, or eight 10 g doses of protein (whey protein isolate) within the 12 h of recovery post-resistance training [13]. The study found the four 20 g doses were superior for stimulating protein synthesis, a dose (as outlined above) similar to that found effective for optimizing protein synthesis post-training [56]. Bodybuilders have also been reported to use higher protein intakes to promote proportionally greater gains in lean mass when in energy surplus, specifically during 'bulking' or predominantly mass gaining phases of training. A recent study by Bray et al. [57] and others supports this approach, at least in non-athletes, demonstrating that when sedentary participants were in a 40 % energy surplus, a higher protein diet (25 % of energy) was superior for gaining lean mass and minimizing fat gain [compared with a low (5 %) and normal (15 %) protein diet] [57]. Similarly, a systematic review by Weinheimer et al. [58] and others demonstrated superior retention of lean mass with a higher protein diet when in energy deficit (typically used by bodybuilders during the 'cutting' phase).

A number of studies in this review raised concerns regarding chronic higher protein intake and health, including increased calcium excretion and risk of bone reabsorption and detrimental effects on renal function. A recent review [59] on higher protein diets and bone health indicates a positive rather than a negative relationship with bone density [60]. Large volumes of resistance training in bodybuilders would also be strongly protective of bone mass [60]. Additionally, a recent review on high-protein diets and renal function fails to support a detrimental effect in healthy individuals without a history of renal disease [60]. Only one study included in this review measured renal function parameters and it found no adverse effects on renal function.

4.3.2 Carbohydrate Intake

The carbohydrate intake of the bodybuilders in this review was generally lower than the sports nutrition recommendations of 6–10 g/kg/day [29]. Only one study in men exceeded the 6 g of carbohydrate/kg/day, although several in women were above this level. Carbohydrate intakes tended to be higher in the non-competition phase, where bodybuilders typically aim to increase lean mass (‘bulking’) but are often less concerned with the accumulation of additional body fat [10, 42]. Carbohydrate intake tended to be lower in the competition phase for men (weighted mean 3.8 g/kg/day) but was higher for women (weighted mean 5 g/kg/day). Again, the small sample of women (especially in the phases other than competition) is likely not as representative as the men. However, the intake of carbohydrate was not dissimilar to the previously mentioned study on Australian Olympic athletes who were reported to consume 5.4 g or 4.9 g/kg/day in men and women, respectively [43].

One important issue with the reported intakes was the variability in measurement days, especially over the competition week. This is important for carbohydrate intake because evidence exists that some bodybuilders use carbohydrate loading during the competition week to promote a fuller muscle appearance [61]. It is also relevant that during the 1980s and 1990s, higher carbohydrate diets were more popular than from the early 2000s when lower carbohydrate diets such as Atkins became more popular in the wider community [62]. However, carbohydrate intakes were around 5 g/kg/day, at least in the two studies in men published since 2010, so not as low as recommended by Atkins [63] and the more recent Paleo diets [64]. Again, as not all studies included supplements, the intake of carbohydrates may also be underestimated.

Although direct empirical evidence is limited, at least one study [65] has demonstrated the importance of muscle glycogen for resistance training, showing three sets of bicep curls (8–10 repetitions per set) at 80 % of one repetition max reduced local muscle glycogen content by around 35 % [65]. Haff [66] reported a significant benefit of consuming a carbohydrate supplement versus a placebo during resistance training, with those taking the supplement better able to perform a greater number of sets and repetitions. Additionally, muscle glycogen depletion in conjunction with aerobic exercise has been found to compromise muscular strength performance [67]. Therefore, resistance training performance will be enhanced when diet or supplementation allows the maintenance of intramuscular glycogen stores.

4.3.3 Total Fat and Alcohol Intake

As expected, the total dietary fat intakes of the bodybuilders were low and generally well below 30 % of energy intake [29]. A number of studies reported on the higher saturated fat intake. Although individual saturated fatty acids do not always have a negative effect on plasma lipid levels [68, 69], some may still negatively impact blood lipids, vascular function, blood pressure, and inflammation and have other detrimental health effects [69]. Use of anabolic steroids also contributes to cardiovascular disease risk [5, 38]. Most of the papers failed to report on alcohol intake but by difference this was nil or negligible across the studies. High intakes of alcohol, specifically binge drinking, has been shown as detrimental to lean mass gain [70].

4.4 Micronutrient Intake

Micronutrient intake across the studies was often excessive, >1000 % of the RDA, and above the tolerable upper limit, especially when dietary supplements were included. Use of multiple supplements increases the risk of excessive nutrient consumption [25]. Unfortunately, the dietary methodology used across the studies to assess micronutrient intake was weak. However, the risk of inadequate intake would seem low.

4.5 Dietary Supplement Intake

Most of the supplements reported in the included papers were vitamins, minerals, protein powders/liquid, and amino acids. However, the majority of the papers were dated, and a wide range of newer supplements are now available. In a recent study, male competitive bodybuilders reported using a combination of approximately three types of supplements during the ‘bulking’ phase (the most popular being protein shakes, creatine, branched-chain amino acids, and glutamine) and a similar number of supplements during the ‘cutting’ phase, with the exception of a moderate proportion of respondents reportedly using ephedrine/caffeine-containing products [71]. Dietary supplements probably pose less of a threat to the health of a bodybuilder than do anabolic steroids [26, 43, 51, 72].

4.6 Methodological Quality

The quality of the literature in this review rated poorly. Confounding factors such as steroid use and training programs were typically not considered. Selection criteria (inclusion and exclusion) and representativeness of the participants was usually not adequately described. Only two of 17 studies employed nutrition methodology appropriate to the outcomes reported. Many studies described micronutrient intakes with 3-day food records, when most micronutrients require more than 7 days for accurate assessment (some more than a month) [73, 74]). Although collection of self-reported dietary data is notorious [75, 76] for under-reporting and evident in individuals with high energy expenditure (e.g., athletes) [77–79], monitoring and compliance was mostly not indicated. None of the studies utilized statistical techniques, a secondary measure of dietary intake, or measured energy expenditure or weight stability during recording to give an indication of internal validity, and most did not include a referenced statement of validity for the methodology employed.

Only seven studies specifically indicated that the expertise of qualified dietitians was utilized for dietary data collection or analysis (although two others listed investigators who were dietitians). Five studies did not indicate computer analysis of dietary data, and nutrient intake was presumably calculated by hand. Of five studies where errors and inconsistencies were noted in Tables 3 and 4, three collected information on foods or supplements that were added to the main database for analysis, one collected further information and most likely added this to the database for analysis (although not indicated), and one appeared to calculate nutrient intakes without the use of a computer. These factors may have contributed to errors in the dietary analysis.

4.7 Strengths, Limitations, and Future Directions

The strengths of this study include the systematic nature of the search and the rigorous nature of data extraction and quality assessment of the papers. The quality of the papers was a major limitation. Representation of women in studies was also inadequate. The majority of the papers failed to adequately incorporate the contribution made by dietary supplements. As dietary supplements are known to be used extensively by bodybuilders, not incorporating them into the dietary analysis, particularly those providing energy and macronutrients, seriously compromised the accuracy of the intakes. The phases of preparation could also only be generally defined. As preparation time frames vary from one bodybuilder to another, a better approach would be to capture different dietary strategies used, i.e., ‘cutting’, ‘bulking’, ‘carbohydrate loading’, so that the parameters of these practices can be more accurately defined. Collection of rationale with the dietary intakes would also be useful to better understand how and why bodybuilders take the dietary approaches they do. A wider variety of body composition assessment methods are also now available, so these, when used in combination, may provide a better description of participant physique.

Bodybuilding has evolved from a sport that was undertaken by relatively few individuals to now incorporate a range of newer categories with less extreme muscular development required to be competitive. Participation has expanded, particularly in women [22]. Little is known of the dietary strategies of these newer bodybuilder groups. The lack of rigor in many of the included studies clearly indicates that a comprehensive and contemporary description of the dietary practices of the traditional categories of bodybuilding is still needed.

Greater involvement of more individuals in bodybuilding and the wider use of resistance training to optimize health, athletic performance, and rehabilitation, and for the management of a range of diseases, brings the community in closer contact with bodybuilders. Clearly, bodybuilders have pioneered a number of highly effective dietary strategies for optimizing the development of lean mass and reducing body fat. Some of these strategies, particularly those revolving around the timing and dosing of high-quality proteins are translatable to elite athletes and the wider community. However, we also need to understand the translation of some of the riskier practices of bodybuilders, which include the use of drugs and multiple supplements (which may also contain prohibited substances), which filters out into the community, including to elite athletes and adolescents.

5 Conclusion

This review demonstrates a number of research gaps and weaknesses in the current literature. It highlights that bodybuilders have a strong commitment to dietary manipulation and that many of the strategies used have been ‘ahead of the science’. A deeper and rigorous approach to evaluating the dietary strategies of bodybuilders would inform future research that may benefit groups other than bodybuilders who aim to increase lean mass and reduce body fat. This review supports that high-quality contemporary research is needed in this area.

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