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REVIEW ARTICLE

What is the optimal composition of an athlete's diet?

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Abstract

Designing the most suitable diet for an athlete requires an intimate knowledge of the relevant scientific literature, the training and competition demands of the sport, the individual athlete's preferences and social situation. The scientific literature contains an abundance of information on nutritional demands of athletes undertaking endurance or strength training programmes, but much less information is available on sprint/power sports, team, racquet, weight-making, aesthetic (diving, gymnastics), and skill-based events. Furthermore, most research has been undertaken on adult males, with the assumption that females and adolescent athletes follow the same patterns of fuel usage and requirements. Consequently, assessing the optimal composition of an athlete's diet relies at best on an informed interpretation of the scientific data, plus individually collected observations. The aims of this article are to provide an overview of the current evidence on macronutrient requirements for day-to-day training for a range of different athletes, provide some recommendations regarding formulating an athlete's diet, and highlight areas where more research is required.

Keywords: *Carbohydrate, fat, protein*

Introduction

Designing the most suitable diet for an athlete requires an intimate knowledge of the relevant scientific literature, the nature of the training and competition demands of the athlete, and the athlete him or herself. Over the past 20 years, we have developed a greater understanding of the macronutrient demands of exercise of various intensities and durations. We have also developed a greater understanding of the biochemical and physiological factors that occur with exercise training, and with varying conditions (heat, cool, pre-exercise diet), which subsequently alter the macronutrient demands for a given exercise task. However, our understanding of the issues central to the specialized discipline of sports nutrition is far from complete. This has at times created confusion about the most appropriate advice for athletes to maximize their exercise capacity while concurrently promoting the greatest physiological adaptations to training and protecting their immune function and health. To complicate things, many athletes need to alter their body composition at the same time, either gaining lean body mass or losing body fat or mass. Athletes and coaches often lack the ability to discriminate between the scientific evidence regarding exercise training demands from information directed towards the general, non-exercising, population. The skill of a sports nutrition specialist lies in his or her ability to interpret the scientific evidence and design the most appropriate diet for athletes to achieve all of their requirements simultaneously, and to alter their diet over time according to changes in those goals/requirements.

The aim of this article is to provide an overview on the current scientific evidence on macronutrient requirements for various types of exercise with the focus on day-to-day training requirements of athletes, and to consider how these requirements may vary under different exercise conditions. The intention is not to provide an exhaustive review of the literature, as this has been undertaken elsewhere (e.g. IOC Consensus Conference on Sports Nutrition, 2003), but to provide a practical interpretation of this body of literature and, when appropriate, highlight deficiencies in the current literature.

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Daily energy requirements

The fundamental difference in dietary intake between an athlete and non-athlete is that athletes must consume adequate energy to meet the demands of intense training and competition (Tarnopolsky & Gibala, 2005). Determining daily energy requirements for an athlete to match the demands of training, while simultaneously maintaining/achieving body weight and body composition targets, is a primary consideration for sports nutrition professionals when consulting an athlete.

How to establish daily energy needs?

The basic premise behind suggesting a fuelling mix for an athlete is underpinned by our understanding of what amount of energy intake is required to keep pace with their daily energy expenditure. Energy expenditure is difficult to measure in free living athletes outside of a laboratory, particularly as many athletes will be attempting to lose or gain weight at the same time as training to achieve maximum adaptations to their event. Therefore, it is important to have a mechanism of estimating an athlete's expected energy expenditure *per se*, and then be able to take into consideration the additional goals of body composition changes, before advising the athlete on what to eat for maximum training benefit.

The components of energy expenditure are essentially grouped in three categories:

- basal metabolic rate, which is largely related to a person's active tissue mass, and accounts for 60–80% of daily energy expenditure;
- thermic effect of feeding, which is essentially the metabolic cost of the body dealing with the consumption of food; and
- the energy expended in normal daily and exercise activities.

This latter component is highly variable between people and between days, and includes *all* activity from home-life, to work and exercise, as well as adjustments for climactic changes (heat, cold).

Although some variables can be accurately measured in laboratory conditions, or using isotope techniques, the practitioner is essentially limited to using prediction equations and some educated refinement to come up with a figure for energy expenditure. The Harris-Benedict equation is one such predictor of resting metabolic rate, although it is recognized to under-predict true values in an active population (Frankfield, Roth-Yousey, & Compher, 2005; Manore & Thompson, 2006). From this figure, estimated energy intake requirements are derived by multiplying first by a daily activity factor (sedentary activity) of 1.4 to account for most daily activities (Manore & Thompson, 2006) plus adding in a value for exercise energy expenditure. This is estimated once a training diary has been collected and training session type, intensity, and duration have been averaged and multiplied by a body mass and sport and exercise-specific expenditure figure (McArdle, Katch, & Katch, 1991, p. 804). Finally, after weight change goals are factored into this value, an approximate energy intake target can be determined. Refinement of this energy intake target will occur following assessment of the athlete's progress towards his or her goals following implementation of a meal plan.

Daily patterns of energy intake of athletes

Decisions how to distribute an athlete's food intake throughout the day will be influenced by: total energy requirements; the number of training sessions scheduled throughout the day; how practical/necessary it is to consume energy before or during training; the physiological and performance objectives of an exercise session; appetite; and post-training nutrition requirements. For instance, understanding the types of movement involved within a session, the intensity of exercise to be undertaken, and the athlete's experience/risk of gastrointestinal distress during exercise will influence the timing, type, and volume of food consumed before, during, and after exercise.

In general, studies indicate that athletes tend to eat several times a day, most commonly on 5–9 occasions (Burke *et al.*, 2003; Lindeman, 1990). Burke *et al.* (2003) found a positive relationship between energy intake ($\text{kJ} \cdot \text{kg}^{-1}$) and the number of eating occasions each day for male and female athletes. This pattern of grazing can be useful in assisting athletes to meet the additional energy requirements associated with daily training. Studies typically report that foods and fluids consumed as snacks outside of main meals contribute significantly to overall daily energy intake (~23–35%) (Burke *et al.*, 2003; Butterworth, Nieman, Underwood, & Linsted, 1994; Saris, van Erp-Baart, Brouns, Westerterp, & ten Hoor, 1989).

It would appear that athletes need to be organized, well supported, and educated about the benefits of nutrition, as the time available for eating (Nogueria & Da Costa, 2004) and the suppression of appetite after exhaustive exercise (King, Burley, & Blundell, 1994) may limit the athlete's ability or desire to consume adequate energy to meet daily fuel requirements. Furthermore, Blundell and King (1999) suggest that "there is no strong biological imperative to match energy intake to activity-induced energy expenditure". Complicating things further, many athletes are faced with the added challenge of organizing their food and fluid intake around training, work, sponsor commitments, study, and family responsibilities (Lindeman, 1990).

Although daily exercise/activity patterns vary for athletes in response to daily training loads, a common practice among sports nutrition professionals is to develop a food and fluid intake plan based on an *average* daily energy expenditure for an athlete, rather than design specific strategies for each daily variation in training load. Although athletes may fail to meet estimated energy requirements on heavy training days when using this model, light training days or rest days offer athletes a time to "catch up" on energy they have been unable to consume on high exercise/activity days.

An alternative approach is to develop a daily meal plan that can be easily manipulated by the athlete to compensate for daily changes in training load. Additional energy (namely in the form of carbohydrate) can be included before, during or after training to support daily exercise performance and recovery between exercise sessions. Saris and colleagues (1989) found that male cyclists contesting the Tour de France modified their daily carbohydrate and energy intakes to reflect daily energy expenditure when supported by a professional team. Despite a mean predicted energy expenditure of 25.4 MJ daily, athletes consumed sufficient energy to maintain body weight and body composition over the 22-day event. Cyclists in this study consumed 94 g of carbohydrate each hour while racing, which accounted for almost half (49%) of their total daily energy intake. By comparison, Burke *et al.* (2003) found that male team and endurance athletes reported consuming only ~3–5% of their total energy intake during training. It is likely that the striking disparity between these two studies reflects the organized support offered to elite cyclists by their professional team and the emphasis on maintaining "best" performance from one day to the next throughout the course of the event.

Failure to compensate for a large energy deficit within a few days of when it was incurred may result in excessive fatigue and reduced training potential, as can a cumulative energy deficit over time (e.g. over 2–3 weeks of heavy training). On the other hand, short-term energy (or specifically carbohydrate) deficits may enhance training adaptations, and therefore planned compensation either on the day or on a rest day scheduled soon after may not be warranted (see Baar and McGee, 2008, in this issue).

Psychological and sociological issues surrounding daily food and fluid intake are also important issues to consider when advising athletes. Some athletes may fail to adequately compensate on "rest days" or during weeks of lighter training, or implement pre-, during or post-exercise nutrition strategies on a daily basis for fear of gaining weight and/or body fat. Female athletes, involved in weight category sports or "body mass important" sports, and athletes competing in aesthetic sports are particularly prone to reporting inadequate dietary energy intakes (Loucks, 2004). Through specific education regarding the manipulation of pre-, during and post-exercise fuel, and recovery day/week eating, the practitioner can help an athlete adjust the variations in day-to-day energy expenditure more effectively to maximize training adaptations while minimizing the accumulation of substantial energy deficits. This can be undertaken while maintaining a relatively consistent base to the overall dietary prescription (e.g. main meals), reducing the requirement of detailed weekly or monthly meal plans.

Finally, athletes are faced with the added challenge of eating socially among family members, friends, team-mates, and work colleagues (for non-professional athletes). As clinical as sports nutrition guidelines may appear, athletes do not eat solely to support exercise performance and promote recovery between exercise sessions. Athletes must strike a balance to ensure they optimize their intake to support training and competition performances, while maintaining a flexible approach and attitude towards food to engage in social activities away from sport.

Guidelines for carbohydrate intake for athletes

Over many years, it has been repeatedly observed that carbohydrate, from blood glucose and muscle glycogen stores, is an important fuel for exercising muscle, particularly at higher exercise intensities (Coyle, 1995; O'Brien, Viguie, Mazzeo, & Brooks, 1993). A useful summary of such effects, both in relation to intensity of exercise and prolonged (2 h) exercise, is presented by Romijn *et al.* (1993). As the intensity of exercise increases, both energy expenditure and the contribution of carbohydrate to work production increase. In contrast, over prolonged exercise, the contribution of carbohydrate tends to fall, perhaps in relation to decreasing fuel stores (Romijn *et al.*, 1993). In essence, carbohydrate is an essential fuel for most athletes; however, because our ability to store this commodity is limited (Coyle, 1995), daily consumption is required to maintain adequate levels. It has also been shown that at any given exercise intensity, exposure to heat increases carbohydrate utilization in unacclimated individuals (Jeukendrup, 2003).

Carbohydrate intake guidelines in the everyday training diet

Experts have recently refined dietary prescription regarding daily carbohydrate intakes to encourage athletes to achieve a carbohydrate intake to meet the fuel requirements of training and to optimize restoration of muscle glycogen stores between training sessions (Burke, Kiens, & Ivy, 2004). It is now widely acknowledged that general recommendations for daily carbohydrate intake should be expressed as grams of carbohydrate per kilogram of the athlete's body mass, rather than a percentage of total dietary energy (Burke, Cox, Cummings, & Desbrow, 2001). Suggested carbohydrate intake guidelines for athletes based on daily exercise patterns and expressed relative to an athlete's body weight have recently been developed (see Table I). Interpretation of these guidelines into individual dietary prescription should consider the athlete's overall daily energy requirements, specific training volume and intensity, and requirements for growth and development (for children and adolescent athletes). Without an inherent knowledge of a sport, these guidelines can be easily misinterpreted. For example, it is common for a gymnast to train for 6–7 h per day, over two training sessions. If you consider the duration of the training sessions alone, their carbohydrate requirements would be $10\text{–}12+\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$. However, when the absolute amount of "activity" is calculated within these hours, the estimated amount of energy expended in that time period is quite small and suggested to be approximately $0.066\text{ kcal}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$ (McArdle *et al.*, 1991). The net result of true exercise energy expenditure in the sessions for an average 50-kg gymnast adds only 1200 kcal (5000 kJ) to their daily energy requirements. However, if the athlete consumed the amount based on training time alone ($10\text{–}12\text{ g carbohydrate}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ as suggested above), this would far exceed the energy expenditure of exercise, and thus the need to "know your sport". Although we have no definitive assessment of carbohydrate usage during gymnastics training, it is likely that daily requirements are within $5\text{–}6\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$.

Table I. Guidelines for carbohydrate intakes in everyday training

Activity	Carbohydrate intake
Immediate recovery after exercise (0–4 h)	$1.0\text{–}1.2\text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$
Daily recovery: moderate-duration/low-intensity training	$5\text{–}7\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$
Daily recovery: moderate to heavy endurance training	$7\text{–}12\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$
Daily recovery: extreme exercise programme ($4\text{–}6+\text{ h}\cdot\text{day}^{-1}$)	$10\text{–}12+\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$

Source: Burke *et al.* (2004).

As an alternate example, a 110-kg rugby union prop who trains twice a day in both strength- and field-based sessions incorporating high-intensity bouts of exercise would theoretically have carbohydrate requirements of $7\text{–}12\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$. If we consider first the intake represented by the 7 g level and multiply by the player's large body mass (110 kg), the result is a theoretical requirement of >770 g of carbohydrate per day. It is unlikely athletes would tolerate this amount given their daily training schedule. In practice, these athletes typically manage to consume $5\text{–}6\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$, which in absolute terms for a 110 kg player is 550–660 g of carbohydrate.

Little is mentioned in carbohydrate intake guidelines of the needs of strength or resistance training athletes, and only a few studies have assessed carbohydrate requirements. It has been shown that resistance exercise relies primarily on anaerobic energy sources – phosphocreatine and glycogen (Essen-Gustavsson & Tesch, 1990; McArdle *et al.*, 1991; Robergs *et al.*, 1991) – but also on some intramyocellular lipids (Essen-Gustavsson & Tesch, 1990). Reductions in muscle glycogen stores over a 30- to 45-min resistance training session have been shown to be similar in magnitude to a 60-min bout of endurance exercise at 70% maximum oxygen uptake ($\dot{V}O_{2\max}$) or 2–3 h of prolonged, lower-intensity endurance exercise (Essen-Gustavsson & Tesch, 1990; Koopman *et al.*, 2006; Robergs *et al.*, 1991). Therefore, likely carbohydrate requirements for athletes undertaking resistance exercise are $6\text{–}7\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$.

Effect of chronic carbohydrate intake on daily training performance and training studies

Despite the focus on carbohydrate in education messages to athletes and coaches, few studies have directly investigated the benefits of consuming a higher carbohydrate diet on daily training performance and mood-state throughout a period of endurance training (Achten *et al.*, 2004; Costill *et al.*, 1988; Kirwan *et al.*, 1988; Lamb, Rinehardt, Bartels, Sherman, & Snook, 1990; Sherman, Doyle, Lamb, & Strauss, 1993; Simonsen *et al.*, 1991; Vogt *et al.* 2003). Although some researchers have shown a better performance outcome for the high carbohydrate trial or training group (Achten *et al.*, 2004; Kirwan *et al.*, 1988; Simonsen *et al.*, 1991), this finding has not been universal (Lamb *et al.*, 1990; Sherman *et al.*, 1993; Vogt *et al.*, 2003).

One possible explanation for this lack of consensus from chronic training studies investigating varying carbohydrate intakes is that athletes adapt to lower muscle glycogen stores resulting from lower carbohydrate intakes, such that it does not impair training or competition performance (Sherman &

Wimer, 1991). Several methodological differences between studies, and the difficulties associated in detecting small differences in performance that are likely to be important in real-life sport and everyday training, are further explanations for this disparity in research findings. The calibre of the athlete, the duration of the study (5–35 days), and the mode of exercise (swimming, running, cycling, rowing) have varied across previous studies. The shorter time frame employed in many of the chronic training studies (5–10 days) may provide insufficient time for differences in training to translate into metabolic adaptations or performance changes. Differences in the dietary methodology implemented further complicate interpretation of previous study findings, with, for example, the daily amount of carbohydrate provided to participants varying between studies in the moderate and high carbohydrate treatment groups. This inconsistency has resulted in an overlap between what was considered high and moderate intakes of carbohydrate in existing studies.

One important methodological issue overlooked when feeding individuals higher carbohydrate diets is the effect of consuming the additional carbohydrate during the scheduled daily exercise sessions. Studies have either failed to mention when the additional carbohydrate was consumed throughout the day (Costill *et al.*, 1988) or have had participants consume the additional carbohydrate outside of scheduled exercise times (Achten *et al.*, 2004; Kirwan *et al.*, 1988; Lamb *et al.*, 1990; Sherman *et al.*, 1993; Simonsen *et al.*, 1991). Exercise performance trials, which doubled as training sessions scheduled throughout the dietary intervention periods, were performed under conditions of low carbohydrate availability (overnight fast, consuming water only during the exercise) in the high carbohydrate group or treatment in some previous studies (Achten *et al.*, 2004; Kirwan *et al.*, 1988). Failure to incorporate the additional carbohydrate during daily exercise bouts may mask the full potential of consuming the additional amount, given the acknowledged acute benefits of consuming carbohydrate before and during exercise in prolonging continuous exercise capacity and performance.

Some previous studies have manipulated daily energy intake to ensure body weight maintenance throughout the dietary treatment period. However, other studies have routinely set daily carbohydrate intakes in the moderate and high carbohydrate groups/treatments independent of daily training volume. For example, despite daily fluctuations in training load over the 11-day dietary intervention period, Achten *et al.* (2004) set daily carbohydrate intakes of 5 $g \cdot kg^{-1} \cdot day^{-1}$ and 8 $g \cdot kg^{-1} \cdot day^{-1}$ for the moderate and high carbohydrate treatments, respectively.

Carbohydrate intake guidelines for recovery between training sessions

The guidelines for carbohydrate intake in the recovery period, as outlined in Table I, assume that the athlete is training at least once a day, and undertaking a form of exercise that impacts substantially upon muscle glycogen stores. It is well documented that muscle glycogen resynthesis is faster in the first 2 h after exercise compared with a longer delay (Friedman, Neufer, & Dohm, 1991), and for athletes training again within 12 h this provides the advantage to refuelling muscles in preparation for the next training bout. This muscle glycogen resynthesis is specific to the muscle groups in which glycogen stores have been depleted by the exercise bout. Thus if the subsequent exercise bout involves different muscle groups (for example, swimming vs. running in a triathlete, or upper vs. lower body muscles in resistance training), the need for rapid muscle glycogen replenishment is less important.

Recent research has questioned whether active muscle glycogen restoration is potentially dampening the biochemical adaptations to exercise training (see Baar & McGee, 2008, in this issue). Training in a glycogen-depleted state increases the rates of transcription and translation of key mitochondrial and fat transport/energetic enzymes (Volek, Kraemer, Bush, Incledon, & Boetes,1997), giving rise to suggestions that training in a higher fat/lower carbohydrate environment may provide benefits in terms of training adaptations. Although studies investigating performance differences when training on a high fat diet have generally shown no benefits to exercise performance compared with training on a high carbohydrate diet (and potentially some negative impact: Burke *et al.*, 2004), a more acute glycogen deficit (e.g. for 2–3 training sessions a week) is a relatively untested notion. Whether this needs to be deliberately manipulated or is currently already undertaken inevitably by athletes in heavy training phases is open for debate. Any attempt to manipulate muscle glycogen stores to maximize training adaptations must account for practical issues, such as the need to undertake quality training sessions at specific times in a training programme (especially in an environment such as a team sport, where pressure for selection for the next game can be an issue). Furthermore, there is evidence to suggest that maintaining an adequate carbohydrate intake (8.5 vs. 5.4 $g \cdot kg^{-1} \cdot day^{-1}$) helps maintain running speed and reduce symptoms of stress during heavy phases of training (Achten *et al.*, 2004), indicating that the timing of trialling of some training sessions in a glycogen-depleted state needs to be carefully selected.

Summary

In summary, including adequate carbohydrate for training requirements remains a priority when designing an optimal diet for an athlete. The choice of carbohydrate sources should be such that they combine other nutrient requirements as well – such as those that are useful sources of protein, antioxidants, and micronutrients. Where carbohydrate requirements are high (e.g. $8+\ g \cdot kg^{-1} \cdot day^{-1}$), the inclusion of more refined carbohydrate sources is also beneficial so as not to dampen the appetite excessively, allowing attainment of total energy requirements. It is important to take advantage of faster muscle glycogen replenishment rates in the 1–2 h after a training session, especially when undertaking a phase of very heavy training. However, there may be times during other training phases (e.g. base preparation) when allowing this to lapse is more appropriate for encouraging optimal training adaptations.

Protein requirements to support daily training requirements

There has been much debate about the optimal protein intake for athletes. The general consensus now appears to be within the range of $1.2–1.7\ g \cdot kg^{-1} \cdot day^{-1}$, regardless of type of exercise (resistance vs. endurance) (Tarnopolsky, 2000; Tipton & Wolfe, 2004). Dietary intake surveys of athletes frequently report that protein requirements are more than adequately met (Burke *et al.*, 2003; Tarnopolsky, 2006). However, some athletes have become over-zealous with their focus on consuming protein, and reduce carbohydrate intake in an attempt to reduce their body fat (personal observation). Although there are no convincing arguments regarding the danger of excessive protein intakes, it is known that excess protein cannot be stored and that it is simply oxidized (Tipton & Wolfe, 2004). Protein intakes higher than recommended may well be consumed as part of a balanced, high-energy diet, and we currently have no evidence to suggest that this should be discouraged. However, if higher protein intakes result in an insufficient carbohydrate intake, increasing the likelihood of a negative impact on training capability when training loads are high, then this aspect of the athlete's diet must be addressed. The role of dietary protein in recovery after exercise and optimizing muscle hypertrophy is discussed elsewhere in this issue (Tarnopolsky, 2008; Tipton, 2008).

Dietary fat intake to support daily training requirements

Fat is an abundant source of fuel stored in the human body, and can be utilized by exercising muscle, with maximal rates of fat oxidation occurring at exercise of ~60% $\dot{V}O_{2max}$ (Romijn *et al.*, 1993). Dietary fat is also a source of essential fatty acids and fat soluble vitamins (Burke, 1996; McArdle, Katch, & Katch, 1999). The recommended levels of dietary fat intake for athletes are around 20–25% of total energy intake (Burke, 1996), primarily based on prioritizing carbohydrate and protein within total energy requirements. Athletes, however, are frequently reported to consume more than this (Burke *et al.*, 2003). Lower dietary fat intakes are correlated with reduced resting serum testosterone concentrations in males (Hamalainen, Adlercreutz, Puska, & Pietinen, 1984; Reed, Cheng, Simmonds, Richmond, & James, 1987; Volek *et al.*, 1997) and females (Goldin *et al.*, 1994; Ingram, Bennett, Willcox, & de Klerk, 1987), as well as with serum oestrogen concentrations in females (Bagga *et al.*, 1995; Ingram *et al.*, 1987). Yet it is recognized that athletes may restrict dietary fat, either for cultural reasons (Onywera, Kiplamai, Boit, & Pitsiladis, 2004) or in an attempt to maintain low body fat, especially in such sports as endurance running (Horvath, Eagan, Leddy, & Pendergast, 2000; Loucks, 2007) and aesthetic sports (Jonnalagadda, Bernadot, & Nelson, 1998). By doing so, they generally also consume a low total energy intake (Loucks, 2007), which as outlined by Loucks (2004) can result in menstrual dysfunction and its associated disorders in females, growth hormone resistance, an exacerbation of lower testosterone concentrations (Loucks, 2004), plus have a negative influence on immune function (Venkatraman, Leddy, & Pendergast, 2000). The dietary fat requirements of athletes have received little attention in the scientific literature.

Recent investigations have highlighted the potential role of intramuscular triglyceride (IMTG) stores as a source of fuel for exercising muscle. Early indications are that this fuel depot, both within and between muscle fibres, could contribute up to 50% of total fatty acid fuel (Stellingwerff *et al.*, 2007). Intramuscular triglyceride contributes to exercise fuels in resistance training (Essen-Gustavsson & Tesch, 1990; Koopman *et al.*, 2006) as well as endurance exercise (Stellingwerff *et al.*, 2007; van Loon *et al.*, 2003), with female athletes having higher stores (Roepstorff, Vistisen, & Kiens, 2005). It is now known that dietary fat intake influences IMTG concentrations. Coyle and colleagues found that a

2% fat diet for 7 days reduced total fat oxidation during 1 h exercise at 67% $\dot{V}O_{2max}$ by 27% due to the reduction in IMTG stores alone compared with a 22% fat diet (Coyle, Jeukendrup, Oseto, Hodgkinson, & Zderic, 2001). In contrast, increasing dietary fat intake from 22% to 60% total energy intake for 2 days increased IMTG concentrations by 36%, which was then responsible for a 72% increase in fat oxidation during 1 h exercise at 50% $\dot{V}O_{2peak}$ (Zderic, Davidson, Schenk, Byerley, & Coyle, 2004). It is thus important for exercising individuals, especially females, to ensure dietary fat intake is no lower than 20–25% total energy intake in order to promote higher fat oxidation, and conserve muscle glycogen, during exercise bouts. Indeed, once carbohydrate and protein requirements are adequately met, there is no reason why the remainder of total energy intake cannot be derived from fat to ensure adequate IMTG stores. Some athletes may therefore require active encouragement not to over-restrict dietary fat intake.

Differences between the sexes in macronutrient requirements for training

The majority of scientific studies on macronutrient requirements of athletes have been undertaken on males, partly due to the complexity of controlling for menstrual cycle variations. It can therefore be assumed that guidelines pertaining to macronutrient requirements during exercise have been based on male data, generally without reference to possible variations for female athletes.

The limited research available indicates that females utilize more fat, and less carbohydrate, as a fuel at the same relative exercise intensity as males (Carter, Rennie, & Tarnopolsky, 2001), and have higher intramuscular triglyceride stores than males (Roepstorff *et al.*, 2005; Tarnopolsky *et al.*, 2007). Endocrine hormone levels are suggested to be the main reason for this (Braun & Horton, 2001). Dietary surveys indicate that females are less likely than males to meet their recommended carbohydrate requirements (Burke *et al.*, 2001), and although arguments have been put forward that this shows they require less carbohydrate than males, the counter-argument is that their failure to achieve absolute energy and carbohydrate requirements, most likely due to attempts to control body fat/mass (Burke *et al.*, 2001), may prevent optimal training progression. In strength-training female athletes, the case has been argued that the intake of "very high" carbohydrate (e.g. 8–9 $g \cdot kg^{-1} \cdot day^{-1}$) should be reduced to prioritize protein and fat intakes for optimal training adaptations (Volek, Forsythe, & Kraemer, 2006) compared with men, although no specific recommendations were made. Only one study has shown a reduced glycogen utilization during resistance exercise in women compared with men (Bell & Jacobs, 1989). It would appear that female-specific nutritional recommendations are warranted, although further research is required.

Conclusions

Many variables require assimilation when formulating the optimal diet for an athlete. The diet must be specific to the type, intensity, frequency, and duration of the training undertaken, and be specific to each individual athlete's food preferences and social situation. Achieving daily carbohydrate and protein requirements to support training and health should always be a high priority, without excessive reduction of dietary fat. An athlete's daily food and fluid intake will vary across a training season, according to the priorities of optimizing training adaptations (including changes in lean muscle mass or body fat) and sustaining a high training load. More research is required in many areas of sports nutrition to assist in understanding the specific macronutrient requirements for individual sports. Further research should also be directed at females to better understand potential differences that may assist between the sexes. And lastly, the interaction of nutrient availability on daily exercise performance and the favoured metabolic adaptations that occur within muscle in response to daily training warrants further investigation.

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