Learning Objectives

- To present basic definitions and muscle physiology of power and strength sports;
- To explain substrate use in power and strength sports;
- To understand the complexity of nutritional support for training and competition in strength and power sports;
- To use existing recommendations in clinical sport nutrition for planning specific nutritional strategies in power and strength sports;
- To safely and effectively use performance-enhancing substances on the basis of current sport nutrition guidelines.

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Key Messages

- The metabolic response to exercise is dictated by energy demand and duration of physical activity and substantially influences the ability to produce muscle power;
- Training for strength, power or speed causes specific changes in the immediate (ATP, PC) and short-term (glycolytic) energy system, as well as increases in the muscle buffering capacity improving strength and/or sprinting performance;
- The intake of energy and macronutrients must be personalized according to athletes’ training periodization and individual responses to specific training stimuli and characteristics;
- Ensuring strategic energy and nutrient availability at critical training points is important for optimal training, regeneration and competitive performance but is also essential for immune system protection and injury prevention, and a prevention of over-reaching and over training;
- The benefit of using approved performance enhancing substances should be individually checked and adjusted to the specific athlete’s needs.
1. Introduction

Scientific findings about the underlying mechanisms of various physiological phenomena induced by exercise, including the recovery process, are the basis for nutritional strategies adjusted to the specific demands of every athlete. The strategically adjusted consumption of key nutrients, depending on the specific needs of an individual, aims to enhance athletic performance and regeneration, thus allowing an athlete to reach his or her full genetic potential and benefit from physical activities which alternate in duration and intensity (1).

An appropriate strategy for nutritional support in power and strength sports is developed as a combination of general recommendations from the field of clinical sports nutrition for energy intake, amounts and composition of nutrients and fluid intake, and recommendations specific for the type of sport and for different phases in the training process. The dietary intake of food has immediate as well as long-term effects on the athlete’s well-being, health, and performance. The diet directly affects the key elements of athletic performance, and should be prescribed in accordance with other factors that could potentially influence food composition, such as social and cultural influences and the personality of the athlete.

2. Basic Considerations for Power and Strength Sports

The term exercise is defined as any activity involving force and power generation by coordinated activation of the appropriate skeletal muscles (2). Power is defined as the amount of work performed per unit of time (2). It reflects the ability to exert maximum muscular contraction instantly or in an explosive burst of movements. The two components of power are strength and speed (e.g. jumping or a sprint start). From the energetic, and also nutritional, point of view, it is important to understand that power is the rate at which work can be performed or the rate of the transformation of metabolic potential energy to work and/or heat.

Strength is defined as the ability to carry out work against the highest resistance. Muscle strength represents the maximal force generated by muscle contracting against a load (e.g. holding or restraining an object or person) (3). A typical example of muscle strength is the force and velocity of the motion with which the weightlifter acts on the barbell.

The assessment and quantification of these physical abilities is described by the use of International System of Measurements (SI) for force (Newton); energy, work and heat (Joules), torque (Newton-meters) and power (Watts).

Power in sport can be determined for a single body movement, a series of movements, or a large number of repetitive movements. It can be determined instantaneously at any point in a movement, or averaged for any portion of a movement or bout of exercise (3). In complex human motions, the maximum output of mechanical power is reached with approximately 50% of maximum force and velocity of a given athlete (4).

Optimal power output demands effective muscle coordination and mechanical efficiency of limb movement, meaning that optimal sports performance requires the consideration of both mechanical (e.g. best gear ratio in cycling) and biomechanical factors (e.g. step length in running, stroke length in swimming). The best choice of gear ratio, step or stroke length etc. is the one that allows muscles to contract with optimum speed and optimum force, which results in maximum mechanical muscle power. In complex motor tasks, the resulting power is influenced not only by the qualities of individual muscles and tendons, but also by muscle coordination, the relationship between muscles and external forces, and by activity of the nervous system (5).
2.1. Definition of Power and Strength Sports

Intense exercise events in which high power output is required for success are considered as power sports. Typical power sports are medium-distance running, track cycling, Olympic rowing, canoeing/kayaking, and swimming (6).

The term strength sports covers the type of activities where maximal force of torque can be developed by muscles performing a particular joint movement (7). Muscles may contract maximally during isometric, concentric, eccentric actions or stretch-shortening cycles. The ability to generate explosive muscle power and strength is important for sports such as weightlifting, sprinting, throwing events and bodybuilding (8).

Training methods to increase maximal muscle force (strength) and power are developed employing resistance exercise programs. These programs make use of very high opposing force (routinely termed resistance), the training includes lifting weights or otherwise increasing the resistance against which is worked. Power and strength athletes incorporate resistance exercise programs in their yearly training plan. Resistance training is frequently included in the training of endurance athletes too (9). It was shown that the focus on more explosive type of lifting (Olympic lifting) results in better power and strength gain in comparison with more traditional strength-based lifting mainly because of inducing neural adaptation (10, 11).

The focus of this module is to present nutritional recommendations for athletes involved in events lasting up to 10 minutes. However, elements of strength and power sports are included also in games and fighting sports (e.g. tennis, boxing) where specific cyclic movements are interrupted with acyclic movements such as jumps, throws and hits.

2.2. Structural Basis for Muscle Training and Muscle Fibre Metabolism

The metabolic response to exercise is dictated by energy demand and duration of physical activity and it substantially influences the ability to produce muscle power. Training for strength, power or speed causes specific changes in the immediate (adenosine triphosphate - ATP, creatine phosphate - CP) and short-term (glycolytic) energy system, as well as increases in muscle buffering capacity, which is shown by improvements in performance (12, 13). The amount of CP can be increased with ingestion of creatine (14). Glycolytic rate can be significantly increased with high intensity or interval type of training. Increased acid buffering capacity is shown in a muscle cell and on a systemic level. Buffering capacity can be augmented with sports supplements (sodium bicarbonate, β-alanine) (15).

Several months of resistance training causes hypertrophy of muscle fibres and increases muscle cross sectional area, thus increasing maximum power output (16).

The pattern of fibre metabolism and recruitment is reflected in the metabolic response (13, 17). This also reflects individual characteristics (genetics, training status). At low intensity effort, most of the glycogen used is in type 1 slow twitch fibres. At high intensities, type 2 fibres account for most of the glycogen used, even though type 1 fibres are active. Type 2b/x fibres have a high glycolytic and oxidative capacity and ensure the necessary amount of ATP during activity of up to 1 min. Intense activation of these metabolic systems also releases a large amount of lactate, which is then accumulated by sportsmen during high-intensity effort. The longer such intensive effort is maintained, the lower the relative maximal uses of oxygen and the larger the fraction of energy contributed by the decomposition of substrates for oxidative phosphorylation. When the intensity of effort is lowered, type 1 fibres contribution to metabolic energy support increases.

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2.3. Summary

In complex human motions, maximum output of mechanical power is reached with approximately 50% of maximum force and velocity for a given athlete. The time frame for typical power sports is up to 10 minutes and is represented with sports activities such as middle-distance running, track cycling, rowing, canoeing/kayaking, and swimming. The term strength sports covers the type of activities where maximal force or torque can be developed by muscles performing particular joint movements. Because of the number of variables or conditions involved, the strength of a muscle or muscle group is defined as the maximal force generated at a specified or determined velocity. Training plans to increase maximal force production (strength) and maximal power of the muscle are developed through resistance exercise programs. Training for strength, power, or speed causes specific changes in the immediate (ATP, PC) and short-term (glycolytic) energy systems, and increases the muscle buffering capacity, resulting in improvements in strength or sprinting performance.

3. Nutritional Support

The nutritional support for power and strength athletes is a complex issue and aims:

- to provide metabolic fuels (nutrients) that will generate energy in the right quantity and at the right time for specific sport training;
- to provide energy for competition;
- to support recovery from training and competition;
- to promote training adaptations, including muscle hypertrophy;
- to help maintain well-being and health (6, 8, 18, 19).

The energy and nutritional needs of an athlete are determined by the metabolic characteristics of the individual and the metabolic requirement of the training load (duration, intensity and type of physical activity or sport). For the nutritional evaluation of an athlete the nutritional recommendations for energy and nutrient intake, as well as for fluid replacement are established, taking into account specific requirements of the physical activity or sport are established. Specific nutritional recommendations were discussed in several recently published papers (6, 8, 20-25).

The total nutritional intake – daily, weekly etc. – as well as the nutritional intake during physical effort must be adapted to energy needs, which correspond to the metabolic response of sport-specific training. Table 1 presents sport-specific energy consumption and its profile for the aerobic and anaerobic energy system contributions during a high-speed treadmill exercise that simulated 200-, 400-, 800-, and 1500-m track running events. Spencer and Gastin investigated the estimated contribution of muscle cell energy systems and found that the relative contribution of the aerobic energy system during track running events is considerable and greater than was traditionally thought (26). The comparative values for energy provision in other power sports are also shown in Table 1.
Resistance training requires a high rate of energy generation and is basically an anaerobic exercise. The contribution of energy systems (phosphagen, glycolytic) depends on the relative power output, the work-to-rest ratio, and the muscle blood flow (27). Fatigue during resistance exercise has a multifactorial genesis. Metabolic fatigue during the earlier part of the workout is partially due to phosphagen depletion and mild intramuscular acidosis, and is followed by systemic acidosis and impaired energy production from glycogenolysis (28). Neuromuscular dysfunction is an important additional cause of fatigue (29).

### 3.1 Periodization of Nutritional Support

For optimal performance in power and strength sports, training is necessary to improve and develop metabolic energy pathways for substrates: creatine, glucose and fats in different proportions. Improving the buffer capacity of the muscle cell also contributes to more successful training and development of a greater capacity. Therefore, a training plan in power sports involves different training modalities, which enable the development of these metabolic paths. In practice, it is important to keep in mind that the proportions of various energy sources depend primarily on the duration and intensity of physical activity, and to appropriately adapt nutritional strategies to the different types of training that are included in the training plan. To use the general recommendations for sports nutrition it is thus necessary to understand the basic concepts of training planning.

For their training plan, sportsmen should take into account the concept of training periodization. Training periodization is defined as a collection of workouts with a specific purpose, where training sessions are arranged so as to induce maximal adaptations in all metabolic systems that are required for the specific sport. An annual training plan or macro-cycle, is planned to peak at the important competition of the year. In general there are four phases in the macro-cycle: general preparation, specific preparation, competitive period, and transition. Macro-cycles are composed of micro-cycles, which typically last a week. Each micro-cycle is planned based on its position in the overall macro-cycle. A micro-cycle is also defined as a number of training sessions built around a given combination of acute programme variables, which include progression as well as alternating effort (heavy vs. light days). The length of a micro-cycle should correspond to the number of workouts in the week (30, 31).

### Table 1

Energy sources in power sports (adapted from 6).

<table>
<thead>
<tr>
<th>Event time range ((-))</th>
<th>Event example</th>
<th>Approx.% VO2max</th>
<th>% of energy contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Phosphagen breakdown</td>
<td>Anaerobic glycolysis</td>
</tr>
<tr>
<td>0.5 to 1 min</td>
<td>400 m running, cycling time trial (500 m-1km) 100 m swimming disciplines</td>
<td>~150</td>
<td>~ 10</td>
</tr>
<tr>
<td>1.5 to 2 min</td>
<td>800 m running; 200 m swimming disciplines 500 m canoe/kayak disciplines</td>
<td>113-130</td>
<td>~ 5</td>
</tr>
<tr>
<td>3 to 5 min</td>
<td>1500 m running; cycling pursuit; 400 m swimming disciplines; 1000 m canoe/kayak disciplines</td>
<td>103-115</td>
<td>~ 2</td>
</tr>
<tr>
<td>5-8 min</td>
<td>3000 m running; 800 m swimming disciplines; 2000m rowing</td>
<td>98-102</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

Reference:

27. [Reference](#)
28. [Reference](#)
29. [Reference](#)
On average, power athletes undertake 9-14 training sessions per week (6). The duration of workouts is between about 30 minutes and 3 hours (6). The training typically includes resistance and plyometric/neuromuscular training several times per week. The workout stimuli, and consequently the metabolic demands of each training cycle, differ depending on the intensity and amount of training, so that the sportsman needs a periodized and personalized nutritional support. In Table 2, a schematic overview of training and nutritional periodization during an annual training cycle is presented.

### Table 2

**Nutritional periodization during the annual training cycle (adapted from 6)**

<table>
<thead>
<tr>
<th>Training phase</th>
<th>General preparation</th>
<th>Specific preparation</th>
<th>Taper / Competition</th>
<th>Transition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Training/competition goal</strong></td>
<td>High training volume (~5-12 h/week)</td>
<td>Moderate training volume (~4-10+ h/week)</td>
<td>Low training volume (~3-10+ h/week)</td>
<td>Very low training volume</td>
</tr>
<tr>
<td>Aerobic energy system development</td>
<td>Lower training intensity</td>
<td>Anaerobic system development Race specific pace Training competitions</td>
<td>Race specific intensities Neuromuscular power</td>
<td>Very low intensity</td>
</tr>
<tr>
<td>Mixed training modalities</td>
<td>Specialized training/ altitude camps</td>
<td>Competitions</td>
<td>Recovery training to prevent over-reaching</td>
<td></td>
</tr>
</tbody>
</table>

| Resistance training periodization | High-volume, high-force, low velocity training | More explosive, lower force, low repetition training | Competitions |

<table>
<thead>
<tr>
<th>Nutritional goals</th>
<th>High energy intake to support training ~ 50-70 kcal/kg/d</th>
<th>Nutrition to support high intensity training ~ 42-64 kcal/kg/d</th>
<th>Nutrition to support high intensity racing ~ 40-60 kcal/kg/d</th>
<th>Nutrition for active individuals ~ 28-42 kcal/kg/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery after training</td>
<td>Specific support/recovery for key training sessions</td>
<td>Support recovery after races</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To reach optimal body composition</td>
<td>Preparing specific nutritional strategy for competition period</td>
<td>Avoiding weight gain with lower training volume</td>
<td>Minor weight gain</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Daily target (g/kg BW/d)</th>
<th>CHO**</th>
<th>PRO***</th>
<th>fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>~ 6-12 (4-7)*</td>
<td>~ 1.5-1.7</td>
<td>~ 1.5-2</td>
<td>~ 0.8-1.2</td>
</tr>
<tr>
<td>~ 6-10 (4-7)*</td>
<td>~ 1.5-1.7</td>
<td>~ 1-1.5</td>
<td>~ 1-1.2</td>
</tr>
</tbody>
</table>

*Carbohydrate intakes for strength athletes  
** CHO, carbohydrate  
***PRO, protein

### 3.2. Energy and Nutrient Intake Recommendations for Strength and Power Sports

Strength and power athletes form an extremely diverse group. In general, the energy intake for strength athletes and a majority of power athletes is not a concern as many of them strive to gain or maintain higher than normal lean body mass. However, this group of athletes also includes those who restrict their energy intake in an attempt to maintain their weight within a specific competition weight class (Olympic weight lifting, judo), and those who compete in sports with an aesthetic or image element (gymnastics, bodybuilding). As the optimal balance between body composition and body mass is in many sports an important parameter for 

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success, the appropriate nutritional strategies during the preparation period should be adapted to the goal of optimal body composition of the individual sportsman.

The starting point for a nutritional strategy for power sports is the general nutritional recommendations for the energy and nutritional intake of endurance athletes (see Section 3) (32, 33). However, basic knowledge of the metabolic demands of different types of physical activities is necessary for planning a nutritional strategy for power and strength athletes. In this way the recommendations can be adapted to the type of exercise, its duration and intensity, environmental conditions and specific characteristics (Table 2, Table 3) (6, 8). It seems that taller and more muscular individuals have lower total energy consumption and lower energy consumption at rest (34). A personalized approach is here even more important: when the energy intake is estimated correctly, given the body composition, this intake is lower than what is recommended for strength athletes (8, 23). When estimating the energy intake, it is therefore important to prioritize the timing of energy intake in relation to a training session, rather than simply to comply with the general nutritional guidelines. With a suitable nutritional strategy, it is necessary to ensure appropriate energy intake that will allow the sportsman to carry out the planned amount and intensity of training (35).

It has been shown in power and strength sports that female athletes have a substantially lower energy intake than males (35). Female intake is ~ 40 kcal/kg BW, while male intake is 55 kcal/kg BW. The reason for this substantial difference in energy volume may be due to the differences in the amount and intensity of training between males and females and/or greater under-reporting by females. The energy intake in females, but also in males, should be monitored carefully because of a high risk of hormonal disturbances resulting from a too low energy intake (33). An additional important reason for monitoring energy intake is the maintenance of a competitive body weight and enhancement of power-to-weight ratio. This is achieved with skeletal muscle hypertrophy and/or by maintaining low body fat levels, which can be physiologically and psychologically very demanding. It also increases the risk of developing eating disorders.

For monitoring body weight it is useful to follow body composition during different nutritional strategies and not only to perform regular weight measurements.

During the transitional period the maintenance of optimal body weight is less important, and due to less or no training the energy intake is reduced towards nutritional recommendations for the general public.

### 3.2.1. Carbohydrate Intake

Research data show that sufficient intake of carbohydrates is necessary for optimal sports performance in strength and power sports. In high-intensity effort, which lasts few seconds to 10 minutes, anaerobic and oxidative metabolism of carbohydrates provides the majority of ATP.

High intensity exercise considerably depletes glycogen stores. Thirty seconds of maximal running decreases muscle glycogen by 25 %, and experimental data about glycogen depletion in single resistance training show a reduction of glycogen stores by as much as 24-40% (27, 28, 36). The greatest reductions in glycogen stores are observed with higher repetitions-moderate load resistance training and affects mainly type 2 fibres. This type of training is used mainly to reach muscle hypertrophy. Resistance training is a frequent component of overall training programmes and has a considerable impact on glycogen storage in working muscles. Glycogen resynthesis after resistance training can also be impaired by skeletal muscle damage,
which accompanies resistance training. Low glycogen availability has also been shown to mediate muscle protein breakdown and in this way to diminish the efficiency of resistance training (37). It has been reported that nitrogen losses were more than doubled following a bout of exercise in a glycogen-depleted versus a glycogen-loaded state (38). Low glycogen stores result in reduced high-intensity performance in several experimental protocols (39).

On the other hand, sufficient glycogen stores improve exercise capacity during high-intensity exercise, although this effect is less consistent (8, 40).

**Daily carbohydrate intake**

Nutritional surveys about daily intake of carbohydrates in power and strength group of athletes have shown highly variable numbers in the range of 3-7 g/kg BW/day (8). A personalized approach is proposed, which includes periodization of training and volume, as well as intensity and type of training in each training cycle (Table 2). In the general preparation period the requirements for carbohydrates are higher in the absolute value because of the high training volume. During this period, athletes may need 6-12 g/kg BW/day. During the specific general preparation and the competition phases, the intensity of training is high, and because an important part of the workout is resistance training, the recommended carbohydrate intake is 6-10 g/kg BW/day. This amount is difficult to consume when normal food is eaten because it is equivalent to ~ 0,5-2 kg of spaghetti, and gastrointestinal intolerance is frequently present during prolonged and/or intensive training sessions, so that athletes do not fell like eating. (22). Furthermore, it seems that more than the absolute amount of carbohydrate intake, it is important to strictly follow the carbohydrate replenishment strategies. For these reasons, it is frequently recommended for elite athletes to consume concentrated carbohydrate drinks or supplements. Ensuring strategic carbohydrate availability at critical training points is not important only for optimal training performance, but is also a key to the strategies for immune system protection, injury prevention, and as preventive measures against overtraining. It is a common problem that many strength and power athletes follow a protein centred diet with a too low daily carbohydrate intake. Protein intake of more than 20% of the daily energy intake may displace carbohydrate intake and have harmful effect on performance and health. A low carbohydrate and high protein diet results in metabolic acidosis, which ensues within 24 h and persists for at least 4 days (18). This appears to be the result of an increase in the circulating concentrations of strong organic acids, particularly free fatty acids and 3-hydroxybutyrate, together with an increase in the total plasma protein concentration. It has been proposed that this acidosis, rather than the decrease in the muscle glycogen content, is responsible for the reduced exercise capacity during high-intensity exercise.

Another frequent problem is that the nutritional intake in female athletes is considerably lower than in male athletes and is on the lower limit of the recommended carbohydrate intake. It has been shown in several studies that female athletes follow a diet with 3-15% of carbohydrates. Such a low carbohydrate intake does not allow for the optimal replenishment of glycogen reserves. This results, for example, in a shorter time until exhaustion at a given activity, and it threatens the health of female athletes.

**Carbohydrate intake during exercise**

Many power sports have characteristic forms of training to develop the agility and technical ability of the specific sport. The intake of carbohydrates during this form of exercise does not only ensure enough substrate for the generation of energy for muscular work, but it also...
supports the neuromuscular metabolic processes and prevents cognitive exhaustion (41). However, at high intensity exercise, gastrointestinal tract function is often compromised. Gastric or intestinal intolerance prevents effective intake of nutrients and fluids. In this case, a nutritional strategy with carbohydrate mouth washing, without carbohydrate consumption, could be a potential nutritional strategy for improving performance in a high intensity sport. In an experiment on multiple 5 seconds cycle sprints with a 6% glucose mouth rinse, improvement in peak and mean power output in the first of the five sprints was reported. But in the final (5th) sprint, performance was significantly lowered in the glucose rinse condition compared to placebo (42). The performance drop was offset by caffeine ingestion. At the present state of knowledge we cannot yet the recommendation to follow this strategy.

**Carbohydrate intake after exercise**

Considering the evidence, and the substantial reliance of power and strength athletes on carbohydrate metabolism as fuel, maintaining a high intramuscular glycogen content at the onset of training seems beneficial for the desired resistance training outcomes. The IOC, ISSN, and ACSM all recommend post-exercise carbohydrate intake in the range of 1.0-1.5 g/kg BW to increase recovery from the exercise (21-24). The common recommendation is that carbohydrates should be ingested within 30 minutes after exercise in order to achieve higher glycogen levels. This timing is important for athletes who have a high training volume, who exercise with a higher intensity more than once a day, or who perform resistance exercises by the same muscle group again on the same day. Carbohydrates should be ingested within 30 minutes after exercise and then again every two hours for 4-6 hours. If an athlete rests for 1-2 days between the exercise sessions or events, specific nutrient-timing strategies are not as important, provided that daily carbohydrate requirements are met according to the level of activity. However, in case of limited time between exercise sessions, e.g. training more than once per day or events that comprise multiple-stage races, nutrient timing and recovery are of critical importance.

The addition of protein intake to the carbohydrate intake close to the time of exercise may increase muscle protein synthesis, fat-free mass and muscle strength, and may prevent muscle damage compared to the effects of carbohydrate intake alone (see Section 3.2.2.).

### 3.2.2. Protein Intake

**Daily protein intake**

Athletes’ daily needs for protein intake probably depend primarily on the quantity and quality of training and not so much on the specific sport. Elite athletes, who effectuate a large amount and intensity of training, generally cover their protein needs with a daily protein intake in the range of 1.6 -1.7 g/ kg BW/day, which corresponds with the IOC guidelines (200). Judging by the research performed, a higher protein intake is not sensible, as it does not contribute to increased protein synthesis or to better recovery after training (43). A protein intake larger than 1.7 g/kg BW/day increases the catabolism of amino acids without an additional hypertrophic effect. The superfluous proteins are broken down to lose their nitrogen, but the carbon may be used for other purposes: glucose formation, fatty acids synthesis or oxidation. For the metabolic effect, the type of proteins consumed, the time of consumption relative to the time of training, and the metabolic state prior to training (fasted or fed) are all more important than the absolute amount of protein intake of a sportsman (42).

There is also evidence that the daily protein requirements of experienced resistance-trained athletes are reduced because an intensive period of resistance training reduces the protein
turnover and improves net protein retention (44). Burd et al. reported that an acute bout of resistance training in untrained subjects stimulates both mitochondrial and myofibrillar protein synthesis, whereas in trained subjects, protein synthesis becomes more preferential over the myofibrillar component (45). This suggests that the more trained power and strength athletes may be paying closer attention to protein timing and type in order to optimize the rates of muscular adaptation.

In young subjects, about 20-25 g of proteins maximally stimulates protein synthesis, and there is evidence that wider distribution of daily protein may lower protein breakdown. Instead of focusing on total daily protein intake, power and strength athletes should consume 20 g of protein per meal several times during the day, preferably in close proximity to exercise (46, 47). However, more than 5-6 meals containing protein per day have no further anabolic value because muscle protein synthesis becomes refractory to persistent aminoacidaemia (48).

Smaller athletes can ingest the recommended daily amount of protein in a normal diet, e.g., 3-11 servings of chicken or fish contain 75-300 g protein. For larger athletes, as well as for smaller ones trying to follow the recommendations and consuming proteins immediately after exercise, the use of protein supplements (mainly powdered forms) provides good options. The proteins of choice are rapidly digested proteins of high quality (whey proteins, which contain 8-10 g of essential amino acids per 20 g), which cause the greatest increase in protein synthesis (49). High quality proteins contain essential branched-chain amino acid leucine, which is thought to play a central role in mediating mRNA translation for muscle protein synthesis. Leucine is also a key amino acid for the stimulation of muscle protein synthesis via the cell TOR system (53, 50-52,53).

Protein intake before and during strength and power training

It seems that there are not enough data available to support general guidelines for protein intake before and during strength and power training. The ISSN recommends that, depending on the individual’s exercise duration and fitness level, proteins should be included with carbohydrates in the pre-event meal before resistance exercises, or when a desired change in body composition is required (21). This can be achieved by including 0.15-0.25 g/kg BW of protein with the recommended 1-2 g/kg BW carbohydrates in the pre-event meal 3-4 hours before training or competition.

The IOC states that although there has been some evidence that supports the intake of protein before exercise, the follow-up studies have failed to unequivocally support this practice (20, 54-57).

Protein intake after exercise

Regarding acute protein dosage following resistance exercise it seems that 20-25g of proteins maximally stimulates protein synthesis. This dosage is recommended also by IOC (20, 43, 58). However, the absolute amount of protein and the precise timing of protein intake are still difficult to establish. Larger and older athletes probably need more protein, up to 40g (43, 59).

Classical recommendations for protein consumption (at least 25 g) as soon as possible after resistance training to promote a twofold increase in protein synthesis following the exercise, which is counterbalanced by the accelerated rate of proteolysis, was discussed in a paper by Aragon and Schoenfeld (40, 58, 53). They proposed that this recommendation is valid when training is initiated more than ~3–4 hours after the preceding meal, or minor pre-exercise nutritional interventions can be undertaken if a significant delay in the post-exercise meal is anticipated (40). Despite the fact that a clear benefit from consuming the proteins as soon as
possible after exercise, as opposed to delaying consumption, has been demonstrated in a study by Levenhagen et al., good evidence based support for this practice is still lacking (40,46).

It’s not entirely clear that the combined ingestion of carbohydrate and protein further stimulate muscle protein synthesis (60, 61). However, with the co-ingestion of carbohydrates and proteins the athlete can maximize training adaptation and restore muscle glycogen. Relative to body mass, the recommended amount of protein is 0.4 g/kg combined with a 0,8 g/kg carbohydrates (62).

**Protein intake in ageing athletes**

Ageing muscle responds less well after the intake of amino acids. This phenomenon has been named “anabolic resistance.” In elderly people, more protein is required to reach maximal rates of muscle protein synthesis, compared to young individuals. This means that the muscles of ageing athletes appear to be resistant to normal anabolic stimulation with amino acids and resistance exercise (63, 64). There is evidence that this may be associated with decreased intramuscular expression and/or activation (phosphorylation) of amino acid sensing/signalling proteins, induced by low grade inflammation present in most elderly people due to comorbidity or the aging process itself (65). Low grade inflammation activates immune responses and the synthesis of acute phase proteins taking place predominantly in the splanchnic region (liver, spleen, immune cells in the intestinal tract etc). This causes a greater uptake and utilization of the protein ingested in the splanchnic region than in a younger healthier age group and diminishes the availability of amino acids for peripheral organs (muscle, skin, bone etc). This may explain the lower fractional synthesis rate (FSR) of muscle protein after protein ingestion, and therefore also questions the validity of the term “anabolic resistance” to dietary protein in the elderly (66, 67, 68).

These findings explain why older subjects require higher quantities of protein (up to 40 g after resistance exercise) to acutely stimulate equivalent muscle protein synthesis above rest and optimize the training adaptation (63, 68). Yang et al. found that elderly subjects displayed greater increases in muscle protein synthesis when consuming a post exercise dose of 40 g whey protein compared to 20 g (69). After the resistance exercise a light meal of 20-40 g of proteins should be consumed, containing at least 2-2,5g of leucine.

Timing the protein intake around resistance exercise may be beneficial for stimulation of muscle protein synthesis in elderly athletes. So, a meal with 20-25g of high quality proteins should be eaten 3-4 hours before exercise, and a light meal of 20 -40 g of proteins, containing 2 -2.5 g of leucine, should be consumed afterwards;

Thus, when considering protein feeding strategies that will acutely increase muscle protein synthesis in the elderly, a protein source with high leucine content and rapid digestion kinetics (e.g. a high-leucine sources such as dairy proteins) in order to promote a transient leucinemia ‘spike’, would be an effective option.

However, reservations should be made regarding the significance of FSR’s measured shortly after exercise and after ingesting a protein/ amino acid bolus (69). Only synthesis is measured after a few hours and it is uncertain what happens simultaneously with protein degradation and what happens in the long term. It may for instance be possible that a protein/aminio acid bolus increases peak muscle FSR shortly after exercise, but that a protein/carbohydrate meal will lead to a more tapered release of amino acids to the circulation, diminish gluconeogenesis and exert a superior net anabolic response than a single protein bolus.
Protein intake and caloric deficit

According to Phillips and van Loon, strength and power athletes who, for any reason (aesthetic, competition in weight categories, and optimal competitive body composition with low body mass in running and similar), attempt to reduce the body fat or make weight with caloric restrictions for should increase their protein intake in hypocaloric condition to 1.8 – 2.7 g/ kg BW/day (71). The IOC recommendation for optimizing body composition in favour of losing fat and gaining muscle mass is by decreasing daily carbohydrate intake (3-4 g/kg BW/day) and increasing daily protein intake to the same level as was suggested by Phillips and Van Loon (1.8-2.7 g/kg BW/day) (20).

On theoretical grounds increasing protein intake and diminishing carbohydrate intake is promoting gluconeogenesis and ureagenesis from amino acids. This slightly increases total energy expenditure. Alternative approach would be to have normal intake of protein (recommended for sportsmen not wanting to lose fat mass), add normal amounts of carbohydrates but to diminish fat intake.

In a recent metaanalysis, it has been proposed that the protein needs for energy-restricted resistance-trained athletes are about 2.3-3.1 g/kg of fat free mass (72). In case of a more severe energy deficit or a higher level of leanness, protein intake should be upgraded. Finally, in an evidence-based recommendation for natural body building contest preparation from 2014, the authors recommended the same regime of protein intake: 2.3-3.1 g/kg of fat free mass per day in three to six meals per day, with a meal containing 0.4-0.5 g of protein prior to and after to resistance training (25).

3.2.3. Fat Intake

A modest nutritional intake of fats is necessary throughout all training phases because it ensures the absorption of fat-soluble vitamins, substrates for the synthesis of hormones, and the maintenance of integrity of cellular membranes and myelin neural sheaths.

Fat in the form of intramuscular triglycerides is a good source of energy during exertion for longer training sessions with moderate intensity of up to 85% VO2. For power sports athletes, this form of training is an important part of the general preparation phase, and in this case endogenous fat is an important source of fuel. For >2 hours endurance training, the quantity of fats that should satisfy the needs for replacement of depleted reserves of intramuscular triglycerides is estimated at 2 g/kg BW/day (73).

Therefore the nutritional recommendation for fat intake during this phase of training is 1, 5-2 g/kg BW/day (19). A higher fat intake may compromise muscle glycogen recovery and tissue repair because of a lower daily carbohydrate and/or protein intake. This can be a practical issue for strength and power athletes as the reported fat intake in this group of athletes is generally higher than that recommended for healthy nutrition (8). Fat intake is often derived from sources which are rich in saturated fats. This is probably connected with the emphasis on animal foods as a good protein source. This nutritional practice can also partly explain the lower dietary intake of carbohydrates. It is probable that the iso-energetic replacement of fat with carbohydrate would have a favourable effect on performance and long term health.

On the other hand, athletes who are gaining weight frequently cut fat sources from their diet. The IOC recommendation is that athletes should not follow a diet with less than 15-20% of total energy derived from fats (20).
3.2.4. Water

The dehydration effect in strength and power sports is not well documented. Experimental data show that the ability to perform resistance exercise and total peak cycling power are reduced with dehydration by about 3% of body mass (74,75). Kraft with co-workers studied the influence of dehydration on muscular strength and endurance, and on single and repeated anaerobic sprint bouts. They concluded that the critical level of water deficit affecting anaerobic performance (approximately 3-4%, depending on the mode of exercise) is larger than the deficit impairing endurance performance (approximately 2%) (76). From a performance and health point of view, as with all athletes, strength and power athletes are advised to begin the resistance and sprint training sessions in a well hydrated state, and then drink sufficiently to limit body mass loss to 2-3%.

3.3. Summary of Nutritional Strategies to Optimize Recovery

In Table 3, nutritional strategies to optimize recovery in different training situations are summarized (19). The total intake of energy and nutrients is important, but it is probably even more important that the intake of metabolic energetic and nutritional substrates is adjusted to the individual’s needs, depending on the amount of training. Thus, an elite sportsman must have the support of an appropriately adjusted nutritional strategy, which assures:

- the recovery of muscular energy reserves, primarily in the form of glycogen, and with endurance training, in the form of intramuscular triglycerides;
- protein intake for optimal protein synthesis;
- sufficient intake of fluids for rehydration.

Currently we know that carbohydrates and proteins should be ingested in close temporal proximity to the exercise bout in order to support recovery and the anabolic response to training.
Table 3
Recommendations for recovery nutrition in different training situations (adapted from 19).

<table>
<thead>
<tr>
<th>Exercise characteristics</th>
<th>Long aerobic/ endurance training</th>
<th>Intensive short duration or prolonged resistance training</th>
<th>Technical drills/short duration resistance training</th>
<th>Situations of short recovery (&lt;4h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary metabolism</td>
<td>Prolonged aerobic exercise (&gt;1h)</td>
<td>High intensity exercise (20-40min)</td>
<td>Low volume of explosive movements</td>
<td>Multiple races or training sessions on the same day</td>
</tr>
<tr>
<td></td>
<td>Oxidative metabolism (fat, CHO)</td>
<td>Non-oxidative glycolytic (CHO)</td>
<td>Glycolytic and phosphagen (PCr+CHO)</td>
<td></td>
</tr>
<tr>
<td>Training objective</td>
<td>Enhance oxidative enzymes, fat metabolism, endurance</td>
<td>Enhance: glycolytic enzymes, buffering capacity, lactate tolerance, muscle power</td>
<td>Submaximal and maximal muscular strength, technique and economy development</td>
<td>Specific to training and racing demands</td>
</tr>
<tr>
<td></td>
<td>Energy replacement (fat, CHO)</td>
<td>Energy replacement (CHO)</td>
<td>Energy needs are low</td>
<td>Some energy replacement (CHO)</td>
</tr>
<tr>
<td>Specific recovery needs</td>
<td>Carbohydrate intake of primary importance for glycogen re-synthesisProtein for muscle recovery and re-modelling</td>
<td>Carbohydrate intake of primary importance for glycogen re-synthesis Protein for muscle recovery and re-modelling</td>
<td>Lower carbohydrate needs (some glycogen re-synthesis) Protein for muscle recovery and re-modelling</td>
<td>Carbohydrate intake of primary importance for glycogen re-synthesis Focus on foods that are GI tolerable for subsequent exercise (minimize Fat, PRO intake)</td>
</tr>
<tr>
<td>Macronutrients recommendations (within 2 hours) (g/kg BW)</td>
<td>CHO* ~ 1.2-1.5 PRO** ~ 0.3 fat ~ 0.2- 0.3</td>
<td>CHO ~ 1.2-1.5 PRO ~ 0.3 fat minimal requirements</td>
<td>CHO ~ 0.5-1.0 PRO ~ 0.3 fat minimal requirements</td>
<td>CHO ~ 1.2-1.5 PRO minimal requirements fat minimal requirements</td>
</tr>
</tbody>
</table>

* CHO, carbohydrate  
**PRO, protein

3.4. Summary

In this section basic considerations about nutritional support in power and strength sports are discussed, with emphasis on energy and protein intake. Nutritional strategies should be periodized and personalized according to training needs and individual characteristics. An overview of recovery strategies is presented. Consensus documents and papers in References are recommended for further reading.

4. Ergogenic Supplements for Power Sports

The use of performance enhancing substances in strength and power sports is widespread and has a long history. These substances are often used indiscriminately and can have negative health consequences. Such indiscriminate use is promoted by the industry, and the majority of products on the market fail to reach expected goals (77). Competitive sportsmen also face a
high risk of positive doping substance tests since nutritional supplements may be contaminated with these substances.

A fundamental task of sports nutrition consultants is therefore to construct solid nutritional support for an optimally effective training plan and for a successful competitive strategy. Such a nutritional plan should include nutritional supplements on the basis of scientifically proven benefit in the specific situation of the individual sportsman. As with basic nutritional support, the use of nutritional supplements requires a personalized approach.

In an ISSN recommendation (2010) regarding the use of dietary supplements based on the basis of available scientific literature, the following substances are recognized as “apparently effective and generally safe” in strength and power sports: caffeine, creatine monohydrate, β-alanine and sodium bicarbonate (22).

Other supplements in this class are water and energy supplements in the form of carbohydrate drinks and snacks. For performance effects of proper carbohydrate supplementation and hydration see Sections 3.2.1 and 3.2.4.

4.1. Caffeine

Caffeine ingestion may improve strength, power and resistance exercise performance (78, 79). The optimal effective dosage is not clear, an ergogenic effect was reported with buccal administration of only 100mg caffeine (chewing gum) (80). This represents a very low dose of caffeine, equivalent to the dose in an average cup of coffee. The ergogenic effect of lower caffeine doses, up to ~3mg/kg BW, is probably connected with stimulation of the central nervous system. This effect is more pronounced in well trained athletes who are not regular caffeine consumers. Moderate to high caffeine doses (5g/kg BW and up) may increase the intestinal absorption of carbohydrates during exercise and may stimulate the resynthesis of muscle glycogen. This has the potential to speed up the recovery process in elite athletes (79). A dosage of up to 10mg/kg BM is unlikely to increase performance benefits because of the side effects, such as headaches, tremor, tachycardia, anxiety, nervousness, insomnia, increased urination, and gastrointestinal discomfort.

4.2. Creatine Monohydrate

Creatine monohydrate is probably the most effective nutritional supplement for strength and power sport athletes (14, 22). Data from numerous studies have indicated that the use of creatine increases the high intensity exercise capacity, particularly when there are repeated bouts of intensive exercise. Ingestion of creatine supports an increase in muscle mass, which may result from an improved ability to perform high intensity exercise and thus train harder. A more intensive workout can promote a greater training adaptation and muscle hypertrophy (14, 81, 82).

Creatine monohydrate appears to be the most useful form of creatine supplementation and the addition of carbohydrates and proteins to the creatine supplement can increase muscle retention of creatine (22).

Different protocols for creatine ingestion/loading are recommended. Already in 1986, Hultman and coworkers showed that the ingestion of creatine monohydrate for 6 days increases skeletal muscle creatine content by about 20% (83). According to the current guidelines, the fastest method to increase muscle creatinine appears to be to consume 0.3 g/kg BM/day of creatine monohydrate for at least 3 days (usually 20 g for 5 days), followed by 3-5 g thereafter to maintain elevated stores (22). Ingesting a smaller amount of creatine, 2-3 g/day, will increase...
the muscular creatine concentration in 3-4 weeks. The performance effect of this method is not well supported by scientific data.

4.3. β-alanine

β-alanine is a non-essential amino acid. In a dipeptide form with histidine it forms carnosine. Carnosine is a potent intramuscular buffer, found at high concentrations in the cytoplasm of skeletal muscles, particularly in type 2 fibres (15). Its nitrogen containing imidazole ring can buffer H+ ions with a pKa of 6.83 and it slows the decline in pH during intensive exercise. Carnosine buffering represents about 7% of intracellular buffering capacity. Supplementation with β-alanine in doses of 3-6 g for about 4-8 weeks can increase the amount of muscle carnosine by up to 40-50% of its normal level (84). This may double the carnosine buffering capacity in the muscle cell and is the basis for positive anaerobic performance during intense exercise lasting 1-6 min (high intensity track and field, swimming, rowing, etc.).

4.4. Sodium Bicarbonate

Ingestion of sodium bicarbonate can increase plasma bicarbonate and may slow the development of acidosis related to fatigue during high intensity exercise (6). Bicarbonate loading (e.g., 0.3 g/kg BW, or 20 g taken 1-3 h prior to exercise, or 5 g take twice per day for 5 days) can be an effective way to augment the blood buffering capacity in events lasting 1-6 minutes or repeated sprints (85). Supplementation with sodium bicarbonate is not suitable for everybody as experience shows that about 50% of athletes develop gastrointestinal discomfort, which has a negative influence on performance.

Given many inconsistencies in the literature regarding the effect of sodium bicarbonate on performance and the dosing regimen, as well as the high incidence (50%) of gastrointestinal upset, the athlete should experiment during training or in low key competition to find the optimal ergogenic response for the individual athlete.

4.5. β-hydroxy-β-methylbutyrate

According to the ISSN exercise & sport nutritional recommendations from 2010, β-hydroxy-β-methylbutyrate (HMB), a derivat of leucine, may be another potentially effective metabolic substrate coming from proteins for muscle building (22). Supplementing the diet with 1.5 to 3 g/day of HMB during resistance training has been reported to increase muscle mass and strength among previously untrained subjects (86-90).

In the elderly people, a similar muscle anabolic response to dietary HMB ingestion was reported as in young adults (91).

4.6. Summary

The use of performance enhancing substances in strength and power sports must be effected via sensible supplementation, and the oversight of a proper nutritional support in a specific training or competitive situation. It should be limited to the approved substances and individually adjusted.
5. References


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