

Nutrition in Combat Sports

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INTRODUCTION

Combat sports refer to a group of individual sports that are very relevant to the world sportive scenario. Altogether, the Olympic disciplines of combat sports (i.e., judo, wrestling, taekwon-do and boxing) account for almost 25% of the total medals disputed in the Olympic games. In addition, professional boxing and mixed martial arts (MMA) are two non-Olympic sports that gather millions of spectators from all over the world and constitute a billion dollar industry [1].

Each specific combat sport has a unique combination of rules that confers singular characteristics to each one (e.g., grappling-based techniques or striking-based techniques; scoring system; number of rounds; recovery time between rounds; time duration of each round). Despite those differences, studies have shown that most combat sports can be characterized as high-intensity, intermittent sports [2–6] and consequential adaptations have been consistently found in these athletes [7,8]. Nonetheless, it seems that grappling combat sports rely more on the anaerobic lactic metabolism [4,9] whilst the striking combat sports are more dependent on the alactic anaerobic metabolism [2], although in both types of combat sports the actions used to score are often maintained by the anaerobic alactic metabolism. For all combat disciplines, however, aerobic metabolism is predominant during low-intensity efforts and recovery periods, as it is responsible for ATP and PCr resynthesis. Another important characteristic of all combat sports is the long duration of a competitive event. While a

professional MMA fight may last up to five 5-minute rounds or a professional boxing fight may last twelve 3-minute rounds, Olympic judo, wrestling and taekwondo athletes may perform up to seven matches in the same day.

A common characteristic of all combat sports is that competitions are disputed in weight divisions. Although the weight classes promote more even matches in terms of body size, strength, speed and agility, most athletes tend to reduce significant amounts of body weight in short periods of time in order to qualify for a lighter weight division [10–12]. By doing so, athletes believe they will gain competitive advantage as they will compete against lighter, smaller and weaker opponents. Indeed, rapid weight loss practices are harmful to health and have great potential to impair performance [13], hence, successful management of body weight and body composition is crucial for any nutritional program for combat athletes.

Based on the characteristics of combat sports (i.e., high-intensity, intermittent and long-duration events) the major factors causing fatigue can be identified. In light of results from both *in vitro* and *in vivo* studies, it is possible to affirm that fatigue is caused, among other factors, by muscle acidosis [14,15], increased extracellular K⁺ concentration [16], depletion of phosphocreatine [17] and depletion of muscle glycogen [18]. Dehydration and consequential thermal and electrolyte imbalance are also important factors related to fatigue in combat sports [19–21]. Knowledge of the causes of fatigue during both training and competition situations is essential for designing nutritional

strategies aiming to delay performance decrements and maximize training adaptations as well as competitive performance. In this chapter, the aspects of sports nutrition relevant to combat sports will be discussed, including micro- and macronutrients, hydration, supplements and weight management.

ROLE OF NUTRIENTS

The human body obtains nutrients from the digestion and absorption of food, and they are needed for virtually all bodily functions. While the macronutrients (i.e., carbohydrates, fats and proteins) provide energy, the micronutrients (i.e., vitamins and minerals) are essential for a number of specific metabolic functions. A healthy and balanced diet must supply all nutrients to fulfil the requirements for energy and the other elements that support metabolism, including water. The individual need for each nutrient varies depending on age, gender, presence of medical conditions and level of physical activity [22]. In comparison with non-athletes, athletes generally have greater needs in terms of macronutrients and, in some specific cases, micronutrients. The success in supplying these extra needs is a key factor for any nutritional plan to support intensive training regimens and maximize competitive performance. This will be discussed in the present section and, whenever applicable, the concepts will be extended to the specificities of combat sports.

Macronutrients

Carbohydrates

The most important role played by carbohydrates (CHO) is energy supply for cell functions. CHO act as energy substrates and can be either oxidized via aerobic metabolism (i.e., glycolytic pathway coupled with Krebs cycle and respiratory chain) or converted into lactate via anaerobic metabolism (i.e., anaerobic glycolysis). In both cases, energy is transferred and ATP is synthesized. Whereas the aerobic metabolism is more efficient (i.e., more ATP is synthesized) and the energy transferred is less readily available (i.e., the rate of ATP synthesis is lower), the anaerobic metabolism produces lower amounts of ATP per glucose molecule, but at very high rates, which is crucial for high-intensity exercises. In the context of sports nutrition, the energetic role of carbohydrates is even more evident because they will provide energy for muscle contraction and for sustaining the exercise.

Muscle glycogen content has been classically related to the ability to sustain exercise [23]. Although glycogen depletion has been consistently related as a major cause

of fatigue in endurance exercise [24], data from both human [25] and animal [18] studies suggest that glycogen depletion also occurs in high-intensity exercises. That means that glycogen availability plays, at least, a permissive role in high-intensity performance [26] and may even be a limiting factor in competitive performance in many combat sports, especially when multiple bouts are performed.

Studies have shown that the acute ingestion of high-glycemic-index CHO is beneficial for performance in high-intensity intermittent exercises [27]. The ingestion of ~40 g of dextrose (e.g., 600 mL of a 6.5% dextrose beverage) immediately before a long-term high-intensity intermittent exercise accompanied by the ingestion of 200 mL of a 6.5% dextrose beverage at every 15 minutes has proven effective in enhancing exercise tolerance [27]. Other studies have also shown similar ergogenic effects of CHO ingestion before and during high-intensity exercises in a broad variety of exercise models [28].

According to some authors, approximately 40–60 g of high-glycemic index CHO should be consumed every hour during a continuous exercise [29]. Similar quantities are very likely to be beneficial to combat athletes during their training routines or during competitive events. Other recommendations state that athletes engaged in high-intensity sports, such as combat sports, should consume 10–12 g/kg/day of CHO [26]. The timing of CHO intake has to be individually adjusted, taking into account food preferences, training schedule and other activities performed by each athlete. A well planned diet should comprise the intake of appropriate amounts of CHO well suited with the training times. This will allow the athlete to perform better in the training sessions, which will improve training quality and maximize training adaptations. The ingestion of CHO-rich meals containing 200–300 g of high-glycemic-index CHO 3–4 hours before the exercise is another effective strategy to improve performance [30]. Whether the CHO is consumed in liquid solutions (e.g., carbohydrates-electrolytes beverages or in the form of supplements) or in solid food is irrelevant for exercise performance, as both liquid and solid carbohydrates are equally beneficial to performance [28].

The ingestion of CHO increases the availability of exogenous glucose for the muscle cells, which diminishes the rate of muscle glycogen usage by active muscles, sparing muscle glycogen and delaying its depletion [31]. Such an effect likely explains the ergogenic effect of CHO ingested immediately and during exercise. In addition, the ability of CHO to increase glycemia and prevent the fall in blood glucose concentration may also play a role in delaying fatigue and, at least in part, explain the ergogenic effects of CHO [28,29].

Because muscle glycogen depletion is a major cause of fatigue [18,24] and exercise tolerance is directly related to pre-exercise muscle glycogen content [23], pre-competition nutritional strategies must ensure maximal glycogen accumulation before competitive events. A classical study by Bergstrom and colleagues in 1967 [23] was the first to describe a protocol capable of markedly increasing muscle glycogen content and improving exercise capacity, as compared with a regular mixed diet. The so-called supercompensation diet consists in a 3-day period of CHO deprivation combined with high-intensity/high-volume endurance exercise followed by a 3-day period of high-CHO intake. In the first 3-day period, muscle glycogen is severely depleted, which stimulates insulin action and glycogen accumulation [32] over the following 3-day period of high-CHO availability. Although effective, this glycogen supercompensation protocol is somewhat aggressive as it requires a relatively long period of CHO deprivation and exhaustive exercise sessions, which may result in low adherence by athletes. Some investigations have found similar results of increased muscle glycogen content after less extreme regimens. The study by Arnall et al. [33], for example, has shown that a single bout of exercise that depletes muscle glycogen, when followed by 3 days of an extremely high-CHO diet (i.e., 85% of the total calories from CHO), can successfully increase muscle glycogen levels above baseline values. Moreover, this elevated muscle glycogen content can be maintained for 5 days if the athlete keeps his/her exercise levels at a minimum and consumes a CHO-rich diet (i.e., ~60% of the total calories from CHO) [33]. Other studies have also shown that even simpler procedures can maximize muscle glycogen. Sherman et al. [34] have observed supercompensated muscle glycogen after a 3-day period of a high-CHO diet (i.e., 70% from total calories) following a glycogen-depleting protocol (i.e., 5 days of exercises and 3 days of diet containing 50% of CHO). Interestingly, high-intensity exercises, such as those usually performed in combat sports' training sessions, seem to elicit faster responses of glycogen accumulation during the recovery from exercise. In combination with a high-CHO diet, this may result in muscle glycogen above normal levels after several hours. In fact, data from Fairchild et al. [35] has confirmed that short bouts of high-intensity exercise and subsequent intake of a CHO-rich diet (~10 g/kg/day) is an effective stimulus for faster muscle glycogen supercompensation, which occurs in less than 24 hours [35].

After the exercise, CHO also play fundamental roles in the recovery process, especially in the restoration of the muscle glycogen depleted during the exercise [26]. Therefore, it is necessary to consume adequate amounts of CHO not only before and during, but also

after the exercise. In fact, studies have demonstrated that there is a close relationship between the amount of CHO consumed in the 24 hours after an exercise session and the amount of muscle glycogen replenished [26]. However, it seems to have a saturation point from which further increases in CHO intake do not result in further glycogen accrual. Interestingly, this saturation point matches quite well with the daily amount of carbohydrates recommended for athletes involved with high-intensity activities (i.e., 10–12 g/kg/day). Importantly, the highest rates of glycogen synthesis seem to occur at the early stages of post-exercise recovery (i.e., the first hours after the training session) [36,37], which means that the earlier an athlete consumes a CHO-rich meal after the exercise, the earlier he/she will be recovered and ready to perform at his/her best in the next training session. Furthermore, some evidence indicates that ingesting smaller amounts of CHO at every ~30 min is more effective in restoring muscle glycogen during the early phase of recovery than taking a high amount of CHO in a single bolus [26], probably due to a more sustained glucose and insulin availability. Thus, it is important for any athlete who is training at high intensities, as is the case of most combat athletes, to keep consuming high-CHO diets because they will provide not only the energy necessary for the training sessions, but they will also provide the substrates needed for restoring the glycogen depleted during the previous training sessions.

To summarize, combat sports athletes are recommended to consume CHO-rich diets containing 10–12 g/kg/day of CHO. The timing of the intake must ensure appropriate supply of energy for all training sessions throughout the day, which can be achieved by consuming a meal containing 200–300 g of CHO 3–4 h before any training session and smaller amounts immediately before and during the exercise (i.e., ~40 g before and 10–15 g every 15 min during the exercise). Although the form of CHO (liquid beverages/supplements or solid meals) has no influence on the ergogenic effects of CHO, the gastric discomfort related to the ingestion of solid meals immediately before or during strenuous exercise may hamper the use of solid meals at some specific times. Thus, the use of liquid beverages/supplements may help athletes to consume the recommended amounts of CHO at the most appropriate times. After a training session, the immediate intake of a CHO-rich meal will maximize glycogen restoration rates. Most important, the total amount consumed in the 24 hours following a training session will determine the amount of glycogen that will be restored, until a saturation point of 12 g/kg/day is reached. However, for short recovery periods between sessions (i.e., 8 hours or shorter), it is important to speed up glycogen recovery and consume large amounts of CHO straight

after the training and keep ingesting 20–30 g of CHO by snacking every 30 minutes. For the competition day, all these strategies can be summed with any other strategy that results in muscle glycogen supercompensation.

Proteins

Skeletal muscle is the major deposit of protein molecules (about 40% of body weight in young males [38]) and it is in a constant balance between anabolism and catabolism, known as “protein turnover”. Skeletal muscle protein turnover is the ratio between protein synthesis and protein breakdown rates [39]. Thus, protein balance could be: (a) neutral – protein synthesis and breakdown are equal, which results in muscle mass maintenance; (b) positive – protein synthesis is higher than breakdown, which results in muscle mass gain; or (c) negative – protein breakdown rate is greater than the rate of protein synthesis, which results in muscle mass loss.

In sports, it is well established that muscle mass loss can significantly change an athlete’s performance, strength and power capacity. In this context, it is important to avoid muscle mass losses, guaranteeing neutral or positive protein balance. This is of special importance for combat sports athletes, as competitive performance is strongly dependent on strength and power.

Negative protein balance and muscle loss occur under catabolic conditions such as malnutrition, fasting state, cancer, AIDS, sepsis, burns, disuse and aging [40]. Rapid weight loss, a commonly practiced strategy for weight adjustment in combat sports, is another condition that results in negative protein balance and muscle loss [41]. Conversely, positive protein balance leading to muscle hypertrophy could be increased by physical training, stimulating protein synthesis and controlling protein breakdown [42,43]. Likewise, protein and essential amino acids consumption via food intake have a direct influence on protein synthesis [44]. Both amino acids intake and physical training are independent factors that contribute to positive protein balance [45,46]. Therefore, gain of muscle mass (or muscle hypertrophy) is the result of the accumulation of successive periods of positive protein balance after exercise and protein consumption. Based on it, a combat sport athlete aiming to maximize his/her body composition and preserve muscle mass must be aware that resistance training and adequate protein consumption (i.e., proper amounts of high-quality protein ingested at the best times throughout a day) are key aspects for success.

In order to investigate the ideal amount of protein intake, Tarnopolsky and co-workers [44] conducted studies of strength-trained athletes and sedentary subjects taking three protein regimens: low protein (0.86 g protein/kg/day), moderate protein (1.40 g protein/kg/

day) or high protein (2.40 g protein/kg/day). According to the protein synthesis, strength athletes’ protein requirements were higher than those of sedentary subjects. For the sedentary population, low protein (0.86 g protein/kg/day) is sufficient to maintain protein balance. However, for strength athletes the low-protein diet did not provide adequate protein, suggesting that the moderate- and high-protein diets fit better with their needs. In addition to these results, it is interesting to observe that current dietary reference intakes (DRIs) recommend a low-protein diet (0.8 g protein/kg/day) for all individuals, with no recommendation for consumption of extra protein when combined with exercise [22]. Indeed, combat athletes’ daily requirements for proteins are very similar to those of strength athletes because training regimens are quite intense and also involve resistance/power training sessions. However, it is important to highlight that excessive intake of protein might result in decreased protein synthesis rate, as demonstrated by Bolster et al. [46a]. In this study, the ingestion of 3.6 g/kg/day of protein reduced protein synthesis when compared with 1.8 g/kg/day. Although this was done in endurance-trained athletes, this result supports the concept that excessively high protein diets do not provide any further benefit to athletes and, in fact, may even be detrimental.

Considering the specific amount of daily protein intake, it is suggested that the total amount should be divided in four or five single doses to be taken throughout the day, giving priority to the periods following exercise bouts [46a,46b]. The timing of protein intake is another important point to be considered for muscle hypertrophy. Several studies have shown that carbohydrate alone is not capable of increasing protein synthesis or diminishing protein breakdown after exercise. However, carbohydrates ingested together with protein before and/or after resistance exercise promote a better anabolic response and a positive protein balance [43,47]. Cribb and Hayes [48] demonstrated that protein (0.1 g protein/kg/day) combined with CHO ingested immediately before and/or after an exercise training was capable of significantly increasing cross-sectional area of the type II fibers, contractile protein content, strength and lean body mass, when compared with the same amount of protein and CHO taken 5 hours before or after the workout.

Additionally, the amount of protein intake just after an exercise bout seems to be relevant. A study using 0, 5, 10, 20, or 40 g of whole-egg protein after an intense bout of resistance exercise demonstrated that muscle protein synthesis exhibits a dose-dependent response to dietary protein until a plateau is reached at 20 g. Therefore, the maximal anabolic response after the exercise is achieved with 20 g of protein. Ingesting higher amounts of protein will not further improve the

anabolic response of the muscle but only increase amino acid oxidation, which indicates an excess of protein intake [49].

In respect of quality, milk, whey, casein and soy protein have proven effective in stimulating muscle protein synthesis when consumed after an exercise session [50–52]. However, not all high-quality protein influences the protein turnover to the same extent, as each protein elicits different physiological responses and possesses different digestibility and muscle retention [53]. Casein, for instance, coagulates and precipitates in stomach acid, which results in low rates of digestion and absorption [54]. Hence, casein promotes slower but more sustained rise in plasma amino acid. On the other hand, soy, milk and whey protein are considered “fast” proteins because they have rapid digestion, which leads to a large but transient rise in aminoacidemia (amount of amino acids in the blood). Evidence indicates that milk and whey protein are able to promote superior muscle mass accretion than casein and soy protein, but all four strategies are superior to carbohydrates alone [48,55]. These responses are probably related to the hyper-aminoacidemia provoked by milk and whey protein.

Considering the aforementioned, it is important to keep in mind that protein consumption plays a key role in maintaining muscle mass, although excessive ingestion will be not translated into more muscle mass. Protein intake should be adjusted per athlete’s body weight. For combat athletes, a range between 1.8 and 2.4 g/kg/day should be achieved. Also, daily protein must be ingested four to five times throughout a day. Straight after exercise bouts, the doses should be of approximately 20 g of high-quality protein. Larger quantities of protein can be ingested in meals if this is necessary to achieve the recommended daily amounts. Protein quality and digestibility should be considered. That means that, after the training sessions, milk or whey proteins are preferable as they result in rapidly increased aminoacidemia. On the other hand, evidence suggests that consuming casein before bedtime may attenuate muscle catabolism during overnight sleep because of its slower absorption rates [56].

Micronutrients

Micronutrients (i.e., vitamins and minerals) are so named because the daily intake requirements for these nutrients are low. As they cannot be endogenously produced in sufficient amounts, adequate intake through diet is of great importance. Micronutrients do not provide energy and, therefore, they do not play any role in fattening or weight-gaining processes.

Vitamins exert a large number of different functions in the human body, such as acting as coenzymes in several metabolic reactions, hormonal function, calcium metabolism, antioxidant, coagulation, and structure of tissues, among others. Unlike vitamins, minerals are inorganic compounds. Minerals are also essential to several metabolic pathways, cell signaling, synthesis and maintenance of tissues.

In theory, athletes involved with high-volume intensive training regimens could have increased requirements for daily vitamins and minerals intake. This would be due to increased rates of synthesis, maintenance and repair of muscle tissue, as well as to losses of some micronutrients in sweat. In addition, exercise stimulates metabolic pathways in which micronutrients are involved and can produce biochemical adaptations in muscle tissue that would increase the requirements of vitamins and minerals [57].

However, studies have shown that a balanced diet that adequately supplies the needs for energy will also adequately supply the needs for micronutrients, which is true for both non-athletic and athletic populations [57,58]. Hence, athletes in general do not benefit from supplementation with vitamins and minerals, unless some specific micronutrient deficiency is present. In these cases, it is important to make all necessary changes in the diet in order to ensure that all micronutrients will be eaten in adequate amounts. Also, in the event of micronutrient deficiency, supplementation with vitamins or minerals may be indicated until that specific deficiency is circumvented [59]. The countermeasures for vitamin or mineral deficiency are especially important for athletes because physical performance is impaired by micronutrient deficiency [60,61].

It is worthy to note that some specific athletic groups are at increased risk of vitamins and minerals deficiency, such as those who constantly restrict food intake, exclude specific groups of foods from the diet, or constantly cycle their body weight. This is quite common in some sports, especially in combat sports because of the weight classes issue. Thus, many combat sports athletes are at high risk for inadequate intake of vitamins and minerals. This is of greater concern for women during menstrual periods as they may lose a significant amount of micronutrients, especially iron, in the menses, which may result in anemia and negatively affect performance [62,63]. Besides iron, calcium and zinc deficiency are also relatively common among athletes, especially among female athletes and vegetarians. Calcium deficiency can decrease bone mineral density, making the bone structures more fragile and susceptible to fractures. In these cases, there may be an indication for supplementation [57]. Another group at risk for micronutrient deficiency is

vegetarian athletes, to whom special attention in this regard must be given.

Finally, it is important to emphasize that maintaining healthy eating habits, such as preventing severe food restriction and refraining from the exclusion of particular groups of foods, is the most appropriate way to avoid micronutrients-related problems. Supplementation would be necessary only to overcome any eventual deficiency caused by unbalanced diets.

ROLE OF HYDRATION

Combat sports' training routines are often prolonged and intensive. Frequently, training rooms are not adequately ventilated or cooled and, in many combat sports, athletes use thick and heavy clothes, such as the traditional martial arts' "Gi". Altogether, these conditions lead to elevated sweating rates, which may cause loss of large amounts of body fluids throughout a prolonged session [64]. If an athlete fails to properly replace fluid and electrolytes, dehydration and electrolyte unbalance will probably occur and physical performance is most likely to be hampered.

Thirst is the main mechanism that drives voluntary fluid intake during exercise. However, voluntary rehydration usually does not fully replace sweat loss, and the consequence is a phenomenon known as voluntary dehydration [65]. It is well established that hypohydration has relevant health consequences, such as hyperthermia, impaired cardiovascular [66] and cognitive functions [67,68], among other deleterious effects. Compelling evidence also indicates that hypohydration is detrimental to exercise performance [69–71] and that high-intensity exercise capacity may be reduced even when hypohydration levels are as low as 2% of body weight [20]. Although maximal strength and short-term sprint capacity seem to be minimally or not affected by hypohydration [72,73], prolonged repeated sprint ability is negatively affected by moderate and high levels of dehydration [73], which means that almost all combat sports training and competitive situations are limited by dehydration. That is especially true if one takes into account that performance in combat sports is complex and multifactorial, being not limited only by physical capacities such as strength, power and endurance. In fact, performance in combat sports relies on a variety of physical (e.g., strength and anaerobic capacity), motor (e.g., specific skills), cognitive (e.g., ability to make fast decisions and to keep focused), and psychological (e.g., mood state and motivation) factors, so "field performance" may be more severely compromised by dehydration than is suggested by laboratory tests that assess only isolated physical attributes [73]. Therefore, nutritional

plans for training and competition days should never neglect fluid and electrolyte replacement.

During a combat, adequate rehydration strategies may not be feasible. Nonetheless, athletes should ensure that their pre-combat hydration status is normal, so that performance decrements due to fluid loss during the fight will not be extreme. In some combat sports in which multiple combats are performed in the same day, rehydration between combats is essential for replacing water and electrolytes lost in the previous match. In others, such as boxing and MMA, rehydration strategies between rounds may be important in preventing hypohydration-induced fatigue. Athletes are advised not to let thirst drive the amount of fluid replaced during exercise, as it usually does not compensate for the amount lost in sweat [73].

Although some guidelines recommend fixed amounts of fluid to be replaced during exercise, some authors argue that it is not possible to determine how much fluid every athlete must intake, since water and electrolyte losses are largely variable depending on environmental conditions (e.g., temperature and humidity) and individual characteristics (e.g., acclimatization and electrolyte content in sweat) [73].

According to the American College of Sports Medicine [74], water and electrolyte replacement strategies should aim to eliminate water losses greater than 2% of body weight. This general recommendation is useful regardless of environmental conditions and individual characteristics because it is automatically adjusted to the rate of water loss during all types of exercise. The same guideline also states that athletes should avoid excessive fluid ingestion capable of increasing body weight during exercise [74]. However, caution must be used when extrapolating this last recommendation to athletes who start the exercise in hypohydrated state [73]. As previously mentioned, it is fundamental to ensure that athletes start their training sessions or competitive events in euhydrated state.

Evidence indicates that beverage temperature and flavor influence the amount of fluid ingested during exercise. Thus, these characteristics may facilitate voluntary fluid replacement and contribute to performance [75]. In fact, it has been shown that cold beverages (i.e., with temperature below 22°C) are more palatable, resulting in increased voluntary consumption of fluid during exercise [75]. Cold beverages also seem to play a role in cooling the body and controlling the rise in body temperature [75]. Because beverages containing CHO plus electrolytes are more efficient in delaying fatigue than water alone [76] and because carbohydrates *per se* clearly have ergogenic effects, as previously discussed in this chapter, athletes are recommended to consume cold CHO plus electrolytes drinks during exercise as a strategy to replace fluid,

electrolytes and carbohydrates. Again, the volume to be replaced has to be individualized according to the amount of water lost in sweat, so that losses are less than 2% of body weight.

RAPID WEIGHT LOSS

Because most combat sports and martial arts competitions are divided into weight classes, the great majority of competitors undergo a number of aggressive methods to significantly reduce body weight in a short period of time. It is assumed that athletes believe that, by competing in a lighter weight class, they will get some competitive advantage against lighter, smaller and weaker opponents. In fact, several surveys have shown that rapid weight loss is probably the most remarkable common feature of all combat sports, as 60–90% of athletes from different countries have been engaged in rapid weight loss for the last 45 years at least – a tradition that does not seem to have changed over these years [11,12,77–88].

With regards to the methods commonly used to quickly reduce weight, athletes report restricting fluid and food intake in the week preceding the competition [12,81]. As competition approaches, athletes tend to restrict even more the intake of food and fluid. Hence, many athletes weigh-in without having had any meal or drink for 24 to 48 hours. This restricted pattern is usually combined with methods that induce water loss and leads to dehydration, such as: saunas, exercise in hot environments, exercise with winter clothing, plastic or rubberized suits, and spitting, among others [11,12,81,89,90]. Of greater concern, a considerable percentage of athletes uses more extreme and harmful methods, such as vomiting, using diet pills, laxatives and diuretics [12,81,90]. Athletes start reducing weight before competitions very young, many of them younger than 15 years of age [81]. A disturbing reported was of a 5-year-old wrestler who was encouraged to cut 10% of his body weight, which suggests that some athletes may be reducing weight at very early ages.

The negative impact of rapid weight loss and weight cycling on health is undisputed. Among other effects, it has been shown that rapid weight loss affects the cardiovascular system [91], suppresses the immune response [92–94], impairs hydroelectrolytic balance and thermal regulation [95], increases bone loss [96], and induces hormonal imbalance such as decreased serum testosterone and increased cortisol and GH levels [97,98]. Moreover, weight cycling may be associated with some eating disorders [90,99] and, during childhood and adolescence, it can lead athletes to a borderline undernourished state, putting growth and development at risk [100–102]. Once the competitive

career is finished, retired athletes who used to cycle their body weight have greater chance of becoming overweight or obese than do athletes who did not cycle weight [103], being subject to all health problems related to obesity.

In light of these negative effects for a range of health-related outcomes, it is reasonable to assume that athletes who are engaged in rapid weight loss procedures are at risk. Obviously, those athletes who cut more weight, in shorter periods of time, more times per season and through more aggressive and extreme methods are at higher risk. Not surprisingly, the deaths of a few wrestlers [104] and judo players [1] have been attributed to rapid weight loss and consequential severe hyperthermia, dehydration and electrolyte imbalance. Because of the widespread use of rapid weight loss strategies among athletes and due to its potential to harm athlete's health, the American National Collegiate Athletic Association (NCAA) has launched a program aiming to control the abusive weight management practices among collegiate wrestlers. Despite some criticisms, the minimum weight program has proven effective in improving weight loss management behaviors among collegiate wrestlers [87,105]. Interestingly, the same wrestlers who were moderate in managing their body weight for NCAA-regulated competitions presented much more aggressive behaviors in international-style wrestling competitions, which are not under the NCAA minimum weight regulations [78]. These data suggest that athletes will probably not voluntarily adhere to less harmful behaviors unless a set of rules compels them to do so. Therefore, institutional regulations are warranted for all weight-classed sports, like those undertaken by NCAA for collegiate wrestling and proposed for judo [13].

Rapid weight loss generally results in reduced fat mass as well reduced lean body mass [106]. It seems possible to maximize fat loss during weight reduction by supplementing with BCAA [107], which could be explained by the reduced muscle catabolism triggered by the anti-catabolic effect that leucine exerts on skeletal muscle under atrophic conditions [40,108].

Despite the reduction on lean body mass, it seems consensual that rapid weight loss has minimal detrimental effect on maximal strength, muscle power, aerobic and anaerobic capacities if athletes have at least 3 hours to rehydrate and recover after weight loss [106,109–111]. If athletes do not have a minimum of 3 hours to rehydrate and/or refeed after rapid weight loss, both aerobic and anaerobic performance will probably be impaired [71,112–114]. However, if the weight reduction is gradual rather than rapid and achieved by a high-CHO diet, performance is less likely to be reduced [112]. Thus, in any combat sport

where the period between weigh-in and competition varies from a few hours to a few days, the impact of weight loss can be largely minimized if the weight loss regimen is gradual, a high-CHO diet is adopted during weight loss period, and if the recovery period after weigh-in is used to fully replenish fluid, electrolytes and carbohydrates [97,106,115].

Although scientific evidence indicates that rapid weight loss, if followed by 3 h or longer “reload” period, has negligible effect on performance, it is important to emphasize that almost all studies have assessed performance after a ~5% of body weight reduction. Thus, there is currently no information available on the effects of larger weight reductions on physical capacity. In fact, studies have shown that a considerable percentage of athletes frequently reduces more than 5% of body weight; some of them reduce more than 10% of body weight [12,81]! It is quite possible that these athletes are competing below their physical, psychological and cognitive capacity as a consequence of the severe weight reduction.

Despite the lack of effect of acute weight loss on strength, a longitudinal study has demonstrated reduced strength after a wrestling season, during which athletes cycled their body weight [101], suggesting that weight loss has relevant long-term effects on muscle strength capacity. Besides physical capacities, competitive performance in combat sports is dependent on psychological aspects, such as mood state and cognitive function. Studies have shown that rapid weight loss negatively affects the profile of mood state and cognitive function, decreasing short-term memory, vigor, concentration and self-esteem as well as increasing confusion, rage, fatigue, depression and isolation [12,116,117]. According to Franchini et al. [1], lack of concentration can affect the ability to deal with distractions during high-level competitions; low self-esteem may result in difficulty in envisioning winning a match, especially against high-level opponents; confusion can impair the capacity to make decisions during the combat; and rage may result in lack of self-control. Although aggressiveness is relevant for combat sports, excessive rage may increase the possibility of illegal actions. Depression and isolation, in turn, can result in low adherence to training sessions. Obviously, all these changes can be detrimental for training and competitive performance [1].

In short, athletes are not recommended to cut weight before competitions. If strictly necessary, rapid weight loss should never exceed 5% of the body weight. Preferably, weight adjustments have to be done in a gradual fashion (i.e., no more than 1 kg per week) and include body fat reduction and muscle mass maximization, rather than acute dehydration. During the weight reduction period, a high-CHO diet

is highly recommended. After the weigh-in, a carbohydrate load (i.e., meal containing 200–300 g of CHO) is also recommended. Despite the slight impact on physical capacity, rapid weight loss has negative effects on several health parameters. In addition, competitive performance may be impaired, since other factors (e.g., mood profile and cognition) associated with competitive performance are impaired. Rapid weight loss should especially be avoided if the athlete will knowingly have less than 3 hours to refeed and rehydrate after the weigh-in.

SUPPLEMENTS FOR COMBAT ATHLETES

As previously discussed in this chapter, data from literature suggest that the major causes of fatigue in most combat sports are: (i) muscle acidosis; (ii) muscle glycogen depletion; (iii) muscle phosphocreatine depletion; (iv) increased extracellular K^+ concentration; (v) dehydration and hydroelectrolytic imbalance. Based on that, it is conceivable that some specific supplements may be especially beneficial for the combat sport athlete, as they could delay the onset of fatigue or allow the athlete to perform at higher exercise intensity, therefore maximizing performance in competitions or in training sessions. Because dehydration and strategies to maximize glycogen and to minimize glycogen depletion have already been comprehensively discussed in this chapter, this section will focus on supplements capable of acting on the other three major causes of fatigue listed above.

With regards to the decrease in intramuscular pH observed during high-intensity exercises, studies have shown that nutritional interventions able to increase extracellular buffering capacity (e.g., sodium bicarbonate or sodium citrate ingestion [118,119]) or intramuscular buffering capacity (e.g., increase in muscle carnosine content via beta-alanine supplementation [15,120]) possess ergogenic effects and therefore have great potential to benefit combat sport athletes. In fact, Artioli et al. [121] have demonstrated that the acute ingestion of 300 mg/kg of body mass of sodium bicarbonate 120 min prior to exercise significantly improves performance in judo-specific and judo-related tests. Other studies indicate that similar effects can be achieved if a chronic (i.e., ~500 mg/kg of body mass split in four or five smaller single doses) rather than acute ingestion protocol is used [122]. The chronic loading protocol seems to be preferable because it is less likely to cause gastrointestinal side effects and it promotes a more sustained and prolonged effect on anaerobic performance than does acute ingestion. Chronic ingestion of sodium bicarbonate can improve performance up to 2 days after the cessation of

ingestion [122] whereas acute ingestion will improve performance for no longer than 3–4 hours after ingestion.

While sodium bicarbonate and sodium citrate augment extracellular buffering capacity, beta-alanine supplementation was consistently shown to increase the concentration of carnosine in muscle cells [123]. Of note, carnosine is an intracellular cytoplasmic dipeptide, abundantly found in skeletal muscle, which exerts a relevant acid-base regulation function [124]. Carnosine is not taken up into the muscle cells, but it is synthesized inside muscle fibers from the amino acid histidine and beta-alanine [125]. The rate-limiting step for intramuscular carnosine synthesis is the availability of beta-alanine [124], an amino acid poorly found in diet. Therefore, supplementation with 1.6–6.4 g/day is the best way to significantly increase muscle carnosine content (doses are to be taken for 4 weeks or longer, and the expected increase in carnosine is >40%) [123]. Beta-alanine supplementation can elicit significant performance improvements in continuous and high-intensity intermittent exercises [15,126]. Clearly, the effects of beta-alanine supplementation are most likely to benefit combat sport athletes as well, as indicated by a study by Tobias and colleagues [127]. In this study, highly trained judo and jiu-jitsu athletes were randomly assigned to one of four groups: beta-alanine, sodium bicarbonate, beta-alanine plus sodium bicarbonate, and placebo. Athletes were assessed for intermittent anaerobic performance before and after supplementation. Interestingly, beta-alanine and sodium bicarbonate resulted in almost identical performance enhancements, indicating that one supplement is not superior to the other. Moreover, they appear to have additive effects, as the combination of both supplements yielded a twofold greater increase in performance in comparison with beta-alanine or sodium bicarbonate alone [127]. Hence, the use of beta-alanine at least 1 month before a major competition in addition to the use of sodium bicarbonate at least 5 days before the same competition will probably be highly beneficial for physical performance in most combat sports.

Muscle phosphorylcreatine (PCr) depletion during intensive exercise is another relevant factor causing fatigue. Increasing resting intramuscular PCr emerges, therefore, as an appealing way to delay PCr depletion and improve anaerobic performance. In fact, since 1992 studies with humans have consistently shown that creatine supplementation (~20 g for 5 days or longer) augments muscle PCr content at rest [128]. This increased muscle PCr is related to improved anaerobic performance, especially in high-intensity intermittent exercises [129], which highlights the potential ergogenic effects of creatine supplementation in combat sports. However, not every athlete will respond

positively to creatine supplementation since the increase in muscle PCr is dependent on the initial concentration of muscle PCr which, in turn, is dependent on dietary patterns [128]. More precisely, athletes who normally eat high amounts of creatine-rich foods (e.g., red meat and fish) present high muscle PCr concentration and do not respond to creatine supplementation, neither increasing muscle PCr content nor improving performance. On the other hand, athletes who don't eat creatine sources in their diets (e.g., vegetarians) present low muscle PCr concentration and respond quite well to supplementation.

In those athletes who respond to creatine supplementation, there is a notable retention of water in muscle, which is due to an osmotic effect of creatine and leads to increased total body water [130]. Although such effect is completely harmless, it results in a modest increase in body mass. Even though only modest, the increase in body mass may represent an enormous obstacle for most combat athletes, as they normally weigh more than their weight classes' limit [81,84]. If an athlete does not need to make weight, then creatine supplementation is probably an effective supplement. On the other hand, if an athlete is usually above his/her weight class, creatine supplementation will probably worsen the weight-cutting problem, and alternative supplementation strategies would be preferred. In these cases, creatine may be taken during training periods (e.g., preparation or competitive phases) in order to maximize training adaptations and ceased approximately 4 weeks before the weigh-in, as this is the average wash-out time for creatine in humans [131]. This procedure will ensure that muscle creatine and, consequently, total body water and body mass return to pre-supplementation levels before the weigh-in. Alternatively, if the athlete will compete in an event where the weigh-in occurs >48 hours prior to the matches, the use of creatine (20 g/day taken in four 5 g single doses) may help in performance, as the first 48 hours of supplementation are those with the highest increase in muscle PCr [128]. High doses of creatine ingested after the weigh-in may benefit performance even when the time between weigh-in and the first match is shorter (~15 h or longer) [132].

Caffeine supplementation seems to be another useful ergogenic aid in combat sports. Interestingly, acute ingestion of 6 mg/kg body mass of caffeine decreases extracellular potassium concentration [133], which is one of the underlying mechanisms that explains the ergogenic effects of caffeine on high-intensity performance. As a matter of fact, several studies have demonstrated the ergogenic potential of caffeine ingestion (3–6 mg/kg of body mass 1–3 h prior to exercise) on high-intensity intermittent performance [129]. Besides the local effects on skeletal muscle, caffeine also

increases plasma catecholamines concentration [134], which helps to explain its ergogenic properties.

In addition to beta-alanine, sodium bicarbonate or citrate, creatine and caffeine, a few other supplements may help to support combat athletes' training regimens. High-quality proteins and carbohydrates, for example, may be useful if an athlete is unable to ingest the recommended amounts, as previously discussed in this chapter. Similarly, vitamins or minerals may be valuable if a specific deficiency is detected, and electrolyte-carbohydrate beverages may help to prevent performance decrements during training and competition. Based on current literature, other supplements are less likely to benefit combat athletes, although new promising supplements may emerge in the near future. Nonetheless, the conscientious athlete will make his/her diet as healthy and complete as possible, leaving supplement to a minimum. Finally, an important caveat about the purity of some supplements found over the counters should be made: a considerable percentage of supplements may be contaminated with illegal substances [135]. Although such contamination is usually very small, it may be just enough to cause an athlete to fail anti-doping tests [136].

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