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Dairy and Sports Nutrition

INTRODUCTION

The term sports nutrition refers to the application of nutritional science to individuals engaged in physical activity. While it is tempting to consider only those participating in sport at the highest level (e.g. Olympic games), this field also encompasses individuals taking part in physical activity for a variety of reasons (enjoyment, weight management, GP referral etc). Clearly the nutritional requirements of an Olympic marathon runner will vary greatly to those of a recreational runner. To succeed in elite sport requires a complex phenotype influenced by a myriad of environmental and genetic factors: first and foremost genetic potential, coupled with effective training over a period of many years, the motivation/ desire to succeed, a resistance to

injury, and in some cases access to necessary technology/equipment. While many would argue that nutrition may only contribute a small fraction compared to the rest of these factors, adjusting what we eat and drink on a daily basis is arguably much easier to achieve than changing our genes. Certainly, correct nutritional practices are not going to turn a mediocre athlete into a world record holder, but similarly a top class athlete is not going to perform optimally without correct nutrition. This is particularly true when the margins between success and failure, first and second place for instance, are often so small in top level sport.

Performance may be improved by some forms of dietary manipulation, but the optimum diet will differ between sports, among individuals, and may also be influenced by environmental conditions. A tendency amongst many athletes is to look to supplements to fill gaps in dietary intake, but in most cases nutrients can be obtained, often at a fraction of the cost, through readily available foods. Elite athletes and teams have started to realise that a 'one size, fits all' approach to sports nutrition does not cover the needs of all individuals, and have adopted personalised diet and hydration strategies. In many cases, only general guidelines can be issued, even though coaches and athletes would like the prescription of a program of eating that will optimise performance.

Milk and other dairy products have been directly associated with sport, physical activity and a healthy lifestyle, with several high profile adverting campaigns and sponsorship of many athletic events throughout the 1970s and 80s. Milk consumption in the United Kingdom is more than 5.5 billion litres/year, primarily in the form of cow's milk although there is a growing contribution from goat and sheep. The aim of this review is to summarise several key issues in sports nutrition and highlight where appropriate the effectiveness of dairy products that would support its use by athletes and physically active individuals. Milk is the obvious focus, given the breath of studies looking at the application of milk to the sports performer, but where appropriate the use of other dairy products will be mentioned.

MILK CONSUMPTION AND NUTRIENT CONTENT

Milk is a nutrient dense food stuff, containing quantities of several major nutrient components of milk including, lactose, proteins, fats, minerals, vitamins and water. Lactose is the major carbohydrate present in the milk of most species. Lactose is a disaccharide composed of the monosaccharides glucose and galactose, joined in a B-1,4glycosidic linkage. It is essentially unique to milk, although it has been identified in the fruit of some plants. Lactose is broken down into glucose and galactose in the intestine by the enzyme lactase, with the galactose molecule then available to be converted into glucose in the liver. Other carbohydrates are found in milk, but in very small quantities; low concentrations of free glucose (about 0.1mM) and free galactose (about 0.2mM) are found in cow's milk and the milk of other species.

Milk fat is composed of a complex mixture of lipids, with the greatest contribution coming from triglycerides. Today dietary fat, in particular saturated fats, are considered to have a negative impact on health. This is reflected in the change in the typical fat content of milk; cows producing greater than 4% milk fat were considered important fifty years ago, whereas the average fat content of fluid milk consumed today is between 2% (semi-skimmed) and 0.1% (skimmed). The total protein component of milk is composed of numerous specific proteins. The primary group of milk proteins are the caseins, with 3-4 varieties of casein present in the milk of most species. All other proteins found in milk are grouped together under the term, whey proteins. Caseins are highly digestible in the intestine, and are an abundant source of amino acids in the human diet. Unlike casein, most whey proteins are relatively less digestible in the intestine. Other whey proteins are the immunoglobulins (antibodies; especially high in colostrum) and serum albumin (a serum protein). Whey proteins also include a long list of enzymes, hormones, growth factors, nutrient transporters, disease resistance factors, and others.

Calcium and phosphorous are the major minerals found in milk. Milk also contains relatively small amounts of most other minerals found in the body, such as zinc, magnesium, iron and copper. In addition, compared to other beverages on the market, milk contains relatively large quantities of the electrolytes sodium, chloride and potassium. Vitamins are essential organic compounds that are not synthesised by the body and are therefore required to be present in the diet. Milk contains varying quantities

of many of the vitamins found in the diet. The fat soluble vitamins, A, D, E, and K, are found primarily in the milk fat; milk also has limited amounts of vitamin K. The B vitamins are found in the aqueous phase of milk. Milk is often fortified with additional vitamin A and D in many countries. Water content of milk is dependent upon the synthesis of lactose, as it is the major osmole in milk and thus is responsible for drawing water into the milk as it is being formed in the mammary epithelial cells. Cow's milk comprises of around 87% water. Milk also contains a range of other components, including leukocyte cells (macrophages, lymphocytes, neutrophils, and somatic cells) and bioactive factors such as hormones and growth factors, enzymes, cellular proteins.

In summary, it is clear that milk is a tremendously diverse and nutrient dense food, providing carbohydrate, fat and protein, as well as vitamins and minerals in various quantities. Throughout the remainder of this review it will become clear that many of the nutrients abundant in milk have been demonstrated to be important to individuals engaged in physical activity, and feature predominantly in many commerciallyavailable sports nutrition products formulated specifically to enhance exercise performance (**see Table 1**).

Table 1.

Composition and energy content of plain water, a commercially-available sports drink and skimmed milk. Macronutrients content and energy density obtained were from the manufacturers and the Dairy Council, UK. Electrolyte content and osmolality have been measured in our laboratory (mean and SD).

	WATER	SPORTS DRINK	SKIMMED MILK
Carbohydrate (g/L)	0	60	50
Fat (g/L)	0	0	3
Protein (g/L)	0	0	36
Energy density (kJ/L)	0	1020	1480
Sodium (mmol/L)	0.3	23.0 ± 0.7	38.6 ± 1.7
Potassium (mmol/L)	0.5	2.0 ± 0.0	45.2 ± 1.7
Chloride (mmol/L)	0.0	1 ± 0	35 ± 1
Osmolality (mosmol/kg)	0.0	283 ± 2	299 ± 3

CARBOHYDRATE AND EXERCISE PERFORMANCE

The development of fatigue during prolonged submaximal exercise has featured as a predominant area of exercise-related research, yet a number of unanswered questions remain. The depletion of muscle glycogen and the loss of body fluids during exercise are widely accepted as the primary causes of fatigue when exercise is performed in a temperate environment, although it is likely that the central nervous system may also play a role. As endogenous stores of carbohydrate found in the muscle and liver are relatively small, and there is a large reliance on carbohydrate as a fuel during strenuous exercise, carbohydrate depletion is widely cited as a possible mechanism. Early investigations highlighted the importance of carbohydrate (CHO) to exercise performance (Christensen & Hansen, 1939), however it was not until the 1960's that the role of glycogen in the genesis of fatigue during prolonged exercise was elucidated. Scandinavian researchers, employing novel needle-biopsy techniques, were amongst the first to provide direct evidence to associate low muscle glycogen concentrations with the onset of fatigue during prolonged exercise (Bergstrom & Hultman, 1967). By manipulating pre-exercise muscle glycogen content, through the ingestion of high or low carbohydrate diets, exercise time to exhaustion was found to be positively correlated with initial levels of glycogen found in the muscle (Bergstrom et al., 1967). The results of this, and other similar studies, paved the way for the introduction of glycogen loading regimes, and the widespread investigation and use of CHO supplementation before and during

exercise. Despite the clear link between muscle glycogen depletion and the onset of fatigue during prolonged exercise, little is yet known regarding the exact biochemical mechanisms by which fatigue arises in this state. It has been suggested that a reduction in muscle glycogen may limit the rate of adenosine diphosphate (ADP) rephosphorylation, reducing the muscle adenosine triphosphate (ATP) content and consequently limiting the cellular processes involved in muscle contraction.

The ingestion of exogenous CHO before and during exercise has been demonstrated to prolong exercise time to exhaustion (Coyle *et al.*, 1986; Gleeson et al., 1986; Coggan & Coyle, 1987, 1989; McConell *et al.*, 1999) through the sparing of muscle glycogen, maintenance of circulating blood glucose levels and an increase the rate of CHO utilisation. Much of the work in this area has focused on long-duration exercise, but there have also been reports of CHO ingestion enhancing the performance of relatively short-duration, high intensity exercise where CHO availability would not be thought to be limiting (Jeukendrup *et* al., 1997). Maximal rates of exogenous glucose oxidation during exercise are typically reported as 1.0-1.1g/min, while sugars requiring hepatic metabolism prior to muscle utilisation (e.g. fructose and galactose) appear to be limited to around 0.4-0.7g/min (Jeukendrup, 2004). Feeding strategies resulting in CHO intakes of between 30-60g/hour, taken as small boli every 10-30 minutes, should ensure a gradual and sustained delivery of CHO from the gut to the circulation without resulting in gastrointestinal discomfort (Coyle, 2004). The performance effects of CHO and fluid ingestion have been reported to be independent and additive (Below et al., 1995), leading

to the widespread use of sports drinks before and during training and competition.

Most commercially-available sports drinks found on sale today are formulated to include CHO, in concentrations between 2 and 10%, typically in the form of glucose, sucrose, fructose and glucose polymers (maltodextrins). Sports drinks also contain relatively small quantities of electrolytes to replace sweat losses, promote the intestinal absorption of glucose and water, and enhance postexercise rehydration. Milk contains a similar concentration of CHO to many sports drinks, as well as protein that also has potential to serve as a fuel during exercise (**Table 1**). Results of a recent study comparing the efficacy of milk ingestion before and during exercise reported a $10.4 \pm 7.7\%$ increase in time to volitional exhaustion when milk ingestion was compared to a plain water placebo (Lee et al., 2008). Sports drink ingestion appeared to result in a greater improvement in exercise capacity (17.5 \pm 13.6%) over the water treatment, but no statistical differences could be indentified between the milk and sport drink performance (Figure **1**). Taking a closer look at the data from this study, there were no differences in blood glucose concentrations or rates of CHO and fat oxidation, but some evidence that milk ingestion produced greater feelings of stomach fullness. While there are few studies looking at the effect of dairy-based products ingested before and during exercise, these results provide some support for milk ingestion in prolonging exercise capacity, with results comparable to many commercially-available sport drinks specifically formulated and marketed to improve exercise performance.

Figure 1.

Percentage difference in exercise capacity compared with the performance on the water trial. Adapted from Lee *et al.*, (2008).



As mentioned previously, exercise results in a progressive reduction in the body's limited stores of glycogen. When exercise is performed infrequently (e.g. once per day or less) it is relatively easy to ensure stores are replaced, but when undertaking training twice (or more) in one day, effective restoration of carbohydrate may need special attention. The rate of glycogen synthesis in the post-exercise period is closely related to the amount of carbohydrate ingested in the first two hours following exercise, due to the activation of glycogen synthase by glycogen depletion, as well as elevated insulin sensitivity and muscle cell glucose

permeability resulting from exercise. Carbohydrate feeding early in this two hour period has been demonstrated to result in higher glycogen synthesis rates, and a greater total glycogen recovery, compared to the ingestion of the same amount of CHO taken two hours later (Ivy et al., 1988). Ingestion of CHO during recovery has been demonstrated to increase the amount of work that can be completed in a subsequent bout of exercise undertaken 4 to 6 hours later (Fallowfield et al., 1995; Wong & Williams 2000), but the benefit of rapid CHO feeding on glycogen replacement after exercise appears to be minimal if there

are prolonged periods (e.g. 24h+) between training sessions (Parkin *et al.*, 1997).

There is some evidence that glycogen storage may be enhanced by the addition of protein to the ingested carbohydrate solution (van Loon *et al.*, 2000; Zawadzki *et al.*, 1992), and this may improve exercise capacity during a second bout of exercise performed on the same day (Niles *et al.*, 2001). Many dairy products contain quantities of CHO and protein, leading to the suggestion that they confer benefits in the recovery of sports performance following periods of heavy training. In the light of these observations, several studies

have examined the effect of milk ingestion on post-exercise recovery. Watson and colleagues compared the recovery of exercise capacity after exercise/heat-induced hypohydration by 2% of body mass following ingestion of either milk or a typical commerciallyavailable sports drink. As mentioned previously, carbohydrate intakes of up to 2g/kg body mass within two hours of exercise result in high rates of muscle glycogen restoration, with comparable amounts administered in the present study (milk trial 1.5 ± 0.1 g/kg body mass; sports drink trial 1.8 ± 0.1 g/kg body mass). Given that the co-ingestion of 75 \pm 8g protein with CHO in the milk trial resulted in a greater total energy intake (Milk 769 ± 82kcal; sports drink 547 \pm 60kcal), it is possible that muscle glycogen concentrations may have been higher at the end of the recovery period following milk ingestion than

on the CE solution (Zawadzki *et al.*, 1992), although this was not directly determined in this study.

This particular study failed to detect any difference in time to exhaustion in the second bout of exercise, with exercise times of 39.6 ± 7.3 min and 39.7 ± 8.1min observed in the CE and M trials respectively (P = 0.952), but this bout was undertaken in warm $(35.3 \pm 0.5 \degree C)$ and humid $(63 \pm 2 \%)$ conditions, where fatigue is typically characterised by hyperthermia, significant levels of hypohydration and a possible central component, rather than the depletion of muscle CHO (Maughan et al., 2007). In contrast to these findings, Karp and colleagues (2006) showed that a milk-based chocolate drink was more effective than a carbohydrateelectrolyte drink (with similar CHO and protein content) in promoting recovery of exercise capacity following exhaustive exercise. The authors of this study suggested that the CHO and protein content of the milk-based solution resulted in improved recovery, with a greater exercise capacity reported in a second bout of exercise undertaken four hours later. Again, muscle glycogen concentrations were not measured during this study, but this does provide some evidence for enhanced rates of post-exercise glycogen restoration with milk compared to a standard sports drink. Wojcik *et al.*, (2001) did investigate muscle glycogen synthesis in subjects fed a CHO-electrolyte solution or a milk-based protein-CHO drink after endurance exercise. Unfortunately no measurement was made until 24 h after exercise, at which time there was no treatment effect, but this study may have missed any response.

PROTEIN AND STRENGTH TRAINING

While there are many myths regarding the protein requirements of active individuals, particularly those taking part in strength training, there is some compelling evidence that those engaged in regular exercise do require greater amounts of protein over and above sedentary individuals. After an extensive review of the available literature. Tipton and Wolfe (2004) highlighted that the protein needs of athletes are greater than sedentary individuals, but the protein requirements should be adjusted to the functional demands of the particular sport and the position/ role occupied within a team. These authors also advised against ingesting very large quantities of protein (>2g/ kg BM), a common practice amongst some groups of athletes, particularly as this often occurs at the expense of other important nutrients. The reality of the situation is that many athletes fall either side of the amount actually required, either due to the consumption of a generally inadequate diet altogether or a belief that large quantities of protein will assist in muscular development (a belief conveniently perpetuated by the multi-million dollar supplement industry).

The role of any training program is to induce adaptations in the physiological systems supporting exercise, resulting in improved performance over time. Protein synthesis is induced by exercise, and the magnitude of change is similar regardless of the type of exercise undertaken (endurance vs strength training). Differences in training response are brought about by activation of different signalling pathways that respond to patterns of contraction by the skeletal muscles. While most athletes will tend to focus on maximising rates of protein synthesis, it is also important to consider the rate of protein breakdown as muscular development is dependent upon the balance between these two factors: termed net protein synthesis.

Consumption of foods containing protein, produces a marked elevation in circulating amino acids, which in itself will cause an increase in muscle protein synthesis and a suppression of muscle protein breakdown for a short period after ingestion. These metabolic conditions are reversed during the postabsorptive state, resulting in a general net balance of protein synthesis and breakdown. The interaction between exercise- (e.g. resistance training) and feeding-induced elevations in protein synthesis result in small incremental additions of new muscle protein mass over time leading to muscle hypertrophy (Tipton & Wolfe, 2004). Athletes make use of the paradigm of resistance training and eating to maximize the gains in their skeletal muscle mass. This was demonstrated by Burke et al., (2001) with greater increases in lean body mass during a 6-week period of strength training when the volunteers were fed a high protein diet (2.1g/kg BM) compared to an isocaloric diet containing moderate levels of protein (1.2g/kg BM). However not all studies support this notion, and the findings of studies using relatively short term training may not be directly applicable to athletes that may have been engaged in training programs for a number of years

It appears that not all sources of protein are equal, and the amino acid composition may play an important role in the muscle protein balance response following exercise. Several studies suggest that protein synthesis can be simulated by the ingestion of essential amino acids at rest, and essential amino acids appear to result in a greater net uptake of phenylalanine following resistance exercise compared to a mixed amino acid supplement (Tipton & Wolfe, 2004). This response occurs due to the abundance of amino acids available in the circulation, coupled with exercise-induced increases in blood flow and muscle protein synthesis rates. The bioavailiablity of amino acids and the time of ingestion may also influence the magnitude of protein synthesis induced. The primary group of proteins found in milk are the caseins, with whey proteins making up the remaining fraction. Caseins are highly digestible in the intestine, and are an abundant source of essential amino acids in the human diet.

Perhaps the strongest evidence for a benefit of dairy products on the sports performer can be found in the area of training to build muscle strength and power. Several reports provide strong evidence for the use of milk, to stimulate protein synthesis and support muscle development following bouts of strength training. Whole milk ingestion following bouts of resistant exercise has been demonstrated to stimulate net protein synthesis in strength trained volunteers (Elliot et al., 2006), whereas no change in amino acid uptake was apparent following the same bout of exercise when a placebo drink was consumed (Tipton et al., 2004). This response was attributed to the presence of essential amino acids found in the milk ingested. The uptake of phenylalanine and threonine into the muscle was measured in this study as these amino acids are not oxidised by muscle tissue. As there was no measureable change in the concentration of phenylalanine found in the muscle, this suggests that they were utilised for the synthesis of proteins. Indeed there is some evidence that milk ingestion immediately following exercise may result in slightly greater gains in fat-free mass over the course of a 10 week training

program compared to a CHO-electrolyte drink (Rankin *et al.*, 2004). This certainly suggests that milk may benefit those involved in strength training programs.

A recent study examined the use of milk and a milk-based protein drink on recovery from muscle damaging exercise (Cockburn *et al.*, 2008). The volunteers completed a series of eccentric contractions (the muscle is lengthening under tension) of the hamstrings, after which they ingested either a bolus of semi-skimmed milk, a milk-based chocolate drink, a commercially-available sports drink or plain water (control) immediately following and 2 hours after exercise. Exercise of this nature typically results in significant delayed onset muscle soreness (DOMS), accompanied with marked reductions in muscle function and an elevation in serum markers of structural muscle damage (creatine kinase and myoglobin). Ingestion of the milk and milk-based protein drinks attenuated reductions in peak torque and total force generated at 24h and 48h after muscle damage, compared to the CHO solution and a placebo control. There was also evidence that the extent of damage sustained was less following ingestion of milk-based drinks, with lower circulating levels of creatine kinase and myoglobin

observed at these time points, but no differences in the perception of muscle soreness was apparent. Similar muscle damage marker responses have been reported when a variety of CHO+amino acid solutions are ingested following exercise-induced muscle damage (Saunders *et al.*, 2004), but many studies have failed to examine the direct effect on muscle function. While it is only possible to speculate on a mechanism for this response, it was generally attributed to alterations in protein metabolism resulting from the elevated levels of amino acids found in the blood immediately following muscle damaging exercise.

HYDRATION

During exercise, muscle contraction required to produce locomotion results in heat production. In coolmoderate ambient conditions, body temperature is typically maintained at a relatively constant level (within 1°C), by the dissipation of excess heat through a number of routes of heat loss (e.g. radiation, conduction, convection and evaporation). As ambient temperature rises, the effectiveness of these routes becomes compromised, and heat loss becomes increasingly dependent upon the evaporation of sweat from the skin's surface. The water that forms the majority of sweat is derived primarily from the blood plasma, with fluid mobilised from intracellular fluid compartments to maintain the circulating blood volume (Nose et al., 1988a). High rates of sweat loss, typically encountered when exercising in hot and humid conditions, can result in a progressive reduction in blood volume and stroke volume, consequently limiting muscle blood flow. This situation is confounded by the need to supply an increased skin blood flow, required to transport heat away from the deep tissues to the periphery (Rowell, 1974). This reduction in total body water has also been implicated in the development of fatigue during prolonged exercise. Following a review of the related literature, Maughan and Shirreffs (1997), concluded that fluids were equally important as the provision of carbohydrate in offsetting fatigue and optimising sports performance.

The loss of fluids occurring results in a steady-state condition of decreased body water content, termed hypohydration (Greenleaf, 1992). Body water losses during exercise have been demonstrated to result in elevated exercise heart rate and the impairment of thermoregulation (Sawka et al., 1985; Sawka et al., 1992), leading to an elevation in core temperature at the same absolute work rate. Hypohydration during exercise in the heat is also associated with a reduction in stroke volume, cardiac output and blood pressure (Gonzalez-Alonso *et al.*, 1997) as well as a marked decline in blood flow to the working muscles (Gonzalez-Alonso et al., 1998). Hypohydration has also been reported to result in increased muscle glycogen utilisation, possibly as a consequence of reduced muscle blood flow, increased core temperature and elevated circulating adrenaline concentrations. A body water deficit of up to 2% appears to have little effect on exercise performance in temperate conditions (Coyle, 2004), but these responses result in marked reduction in exercise capacity when long duration exercise is performed in a warm environment (Below et al., 1995, Walsh *et al.*, 1994). Additionally, evidence suggest that alertness, concentration and performance of cognitive tasks can be compromised at relatively mild levels of dehydration (Maughan, 2003). This is a particularly important consideration for individuals participating in skill-based sports, including football and tennis.

The ingestion of fluids during exercise enhances exercise capacity through the maintenance of circulating blood volume, which appears to reduce cardiovascular and thermoregulatory strain (Montain & Coyle, 1992; Maughan *et al.*, 1996a). This is particularly important when exercise is performed in warm ambient conditions. The effectiveness of milk ingestion before and during to exercise has been examined in the carbohydrate section, here the focus will be the restoration of lost fluids following exercise. Individuals typically do not consume sufficient volumes of fluid to match their sweat losses during exercise; voluntary drinking often only replaces about two-thirds of the body water lost as sweat (Noakes, 1993). Sweat rates of 1-2 litres/hour have been recorded during exercise in hot and humid environments. and under these conditions it is common for individuals to dehydrate by 2%-6% of their body weight despite the availability of adequate amounts of fluid. To confound this situation, the volume and frequency of fluid consumption may be limited by the rules of competition (e.g. the number of breaks in play) or their availability (e.g. drinks stations on a race course). As hypohydration typically develops throughout exercise, particularly in warm environments, starting exercise in a state of negative fluid balance will serve to further limit performance. While it is relatively easy to ensure sweat losses are replaced when exercise is performed infrequently (e.g. once per day or less), when training twice in one day, effective restoration of fluid balance becomes important to ensure any deficit from the first bout is replaced before commencing a second session. Given the tendency for individuals to fail to match sweat losses during exercise and the relative importance of ensuring the restoration of whole-body fluid balance before the start of a subsequent bout of exercise, postexercise rehydration has be extensively investigated over the past 15 years.

Several factors have been highlighted as key to the effective restoration of exercise/heat-induced fluid losses, including the volume and electrolyte content of fluid ingested. For many years it was recommended that individuals should aim to consume a volume of fluid equal to the amount of sweat of sweat lost (e.g. 1 litre of drink per 1 kg of body mass lost; (Convertino *et al.*, 1996). Obligatory fluid losses, which are necessary to ensure the elimination of metabolic waste products, continue even when an individual is in a state of hypohydration. Additionally the ingestion of large volumes of fluid, in particular solutions

with little or no solute content, results in the stimulation of diuresis due to a fall in serum osmolality and a transient increase in plasma volume (Nose *et al.*, 1988b). Therefore it is clear that the volume of fluid ingested must be significantly greater than the volume of sweat lost, with evidence suggesting that a volume equal to at least 150% of the body mass lost should be consumed to ensure adequate restoration of fluid losses (Shirreffs *et al.*, 1996).

It is clear that the electrolyte content of the drink plays a key factor in the rehydration process, with the fraction of fluid retained directly related to the amount of ingested sodium (Maughan & Leiper, 1995). The presence of electrolytes in an ingested fluid prevent the transient fall in serum osmolality seen when large volumes of water are consumed (haemodilution). Changes in serum osmolality are detected by osmoreceptors in the hypothalamus, which help regulate fluid homeostasis primarily through the release of vasopressin (anti-diuretic hormone, ADH). There is

also some evidence that a quantity of potassium in the ingested solution can aid the restoration of fluid balance following exercise-induced dehydration (Maughan *et al.*, 1994). Additional factors that may be important to the effective restoration of fluid losses are the timing of fluid intake and the co-ingestion of electrolytecontaining foods (Maughan *et al.*, 1996b).

Recently the effectiveness of milk to restore fluid losses has been examined (Shirreffs et al., 2007; Watson et al., 2008). Following exercise/heat-induced dehydration by 2% of initial body mass (e.g. 1.4kg in a 70kg individual), volunteers ingested a volume of fluid equal to 150% of the volume of the body mass lost. The drinks examined in this study were skimmed milk, skimmed milk+additional electrolytes, a commercially-available sports drink and plain water. Changes in net fluid balance (calculated relative to the pre-exercise time point, taking into account the volumes of sweat lost, beverage ingested and urine produced) are shown in Figure 2.

Ingestion of all the drinks resulted in a net positive fluid balance of 0.56±0.06 l at the end of the drinking period. Ongoing urine excretion observed with the sports drink and water resulted in a rapid return to euhydration 1 hour after the end of drinking, with further losses resulting in a net negative fluid balance at the end of the recovery period. As the ingestion of both milk and milk with added NaCl resulted in significantly less diuresis and consequently a greater percentage of drink retention, subjects remained in net positive fluid balance 1h after the end of the drinking period and then remained euhydrated until the end of the 4 hour recovery period. This response was attributed to the naturally high electrolyte content of milk (Na 38mmol/l; K 45mmol/l; Cl 35mmol/l) aiding in the retention of fluid during the 4 hour period after the end of drinking, although a delay in the rate of gastric emptying rates due to the presence of protein and fat in the milk can not be discounted.

Figure 2.

Whole body net fluid balance following exercise/heat-induced hypohydration by 2% of body mass, and subsequent rehydration with either plain water, a sports drink, milk or milk+added sodium. Redrawn from Shirreffs *et al.*, (2007).



A follow up study produced a similar outcome, albeit with a slightly smaller difference in net fluid balance apparent between milk and a sports drink at the end of the recovery period (Watson *et al*, 2008). The results of these studies suggest that milk is an effective solution to promote recovery following exercise/ heat-induced dehydration, compared to the ingestion of the same volume of either plain water or a commercially available sports drink. Given the evidence supporting the use of milk to enhance recovery from resistance training and the suggestion that milk-based solutions may enhance muscle glycogen restoration, it appears that milk is suitable for use after exercise.

EXERCISE IMMUNOLOGY

It is generally accepted that regular participation in physical activity is an important factor in the maintenance of health and well being. However in recent years, exercise physiologists have realised that athletes may be at a greater risk of developing infections, particularly of the upper respiratory tract (a sore throat), during periods of heavy training and/or competition (Nieman, 1994). Although at rest an athlete's immune system is similar to a sedentary individual, a single bout of strenuous exercise or prolonged periods of heavy training has been demonstrated to produce an 'open window' of altered immunity. This may last anywhere between 3–72 hours, during which time an individual's risk of contracting an infection may be increased. Moreover, a serious athlete may undertake several bouts of training throughout this period, which serves to further stress the immune system when already in a weakened state.

A single bout of prolonged exercise has been shown to result in a marked increase in circulating cortisol and growth hormone and an increase in the ratio of neutrophils to lymphocytes. This blood concentration ratio is thought to be a robust marker of exercise stress and subsequent recovery (Nieman, 1998). Immune cell function also appears to be impaired following strenuous exercise, with a significant reduction in the bacteriastimulated elastase release, suggesting a reduction in the killing capacity of neutrophils. Currently the exact nature of this response remains undetermined. Although it appears that a combination of insufficient recovery between training sessions, coupled with a persistent elevation of stress hormones (in particular cortisol), causes a fall in the circulating levels of cells important in fighting

infection (Nieman, 1994). As a result, the body may be less effective at tackling bacteria and viruses, exposing the body to the risk of infection. In addition, regular participation in sport typically expose individuals to conditions that may increase their chances on contracting infection, including travel, changing rooms and an increased respiration rate.

Diet is one of several lifestyle factors that can significantly influence the immune system. There is considerable evidence that chronic manipulation of dietary intake and acute supplementation with specific nutrients can alter immune responses in a number of situations. It is estimated that around 10% of the UK population take some form of vitamin and mineral supplement on a daily basis. While most take these as a form of 'insurance policy', many athletes believe that consuming doses many times greater than recommended will improve their performance and protect against illness and injury. Currently, there is no good evidence in the scientific literature to suggest that taking vitamin and mineral supplements is effective in reducing the risk of illness and infection in athletes, and large doses of some vitamins and minerals may actually be detrimental to health. Eating a well-balanced diet, sufficient to meet the increased energy needs of training, will typically provide ample levels of the vitamins and minerals required.

While it appears that vitamin supplementation may provide little benefit, carbohydrate supplementation does seem to be valuable in the prevention of infection. A diet rich in carbohydrates is widely advocated for individuals taking part in regular training and competition, due to the strong link between the depletion of the body's limited stores of carbohydrate and the development of fatigue during prolonged exercise. A reduction in carbohydrate availability during exercise causes an increase in the release of stress hormones, which negatively influence the production of many immune cells. It is known that feeding carbohydrate during and after exercise can reduce the negative impact of exercise on some components of the immune system (Nehlsen-Cannarella et al., 1997; Henson et al., 1998; Bishop et al., 2002). In addition the ingestion of a highcarbohydrate diet over a 3-day period attenuated exercise-induced increases in stress hormone release and decrements in immune cell function (Gleeson *et al.*, 1998). Milk contains carbohydrate, as well as additional nutrients that may have implications for the health of the immune system (e.g. conjugated linoleic acid, proteins, amino acids and calcium). Thus the mixture of nutrients found in milk has the potential to reduce the negative effects of hard exercise.

While there are an abundance of studies examining the influence of numerous chronic manipulations of dietary intake and acute supplementation with specific nutrients to immune response to exercise, little work has examined the effect of commercially-available dairy products. In fact, at present there does not appear to be any published evidence that cow's milk can influence the immune system in humans, but there are limited reports from the animal literature supporting a benefit of milk ingestion (Kobayashi et al., 1998). There was a trend some time ago for the ingestion of bovine colostrum by athletes engaged in heavy training. Bovine colostrum is the milk produced by cows during the first several days following birth. This "early" milk has a nutrient profile and immunological composition that differs substantially from "mature" milk, including higher amounts of immunoglobulins, growth factors, cytokines, and nucleosides than

are found in milk. There is some evidence that colustrum ingestion may reduce the incidence of upper respiratory tract infection (URTI) (Shing *et al.*, 2007) and potentially improve cycling performance (Coombes *et al.*, 2002), but the widespread use of this early milk amongst athletes appears to have died out in recent years.

A recent study examined the hormonal and immune response to a strenuous bout of cycle exercise before and after a 7 day period of dietary supplementation with either milk or a sports drink (Watson et al., 2008). The results of this study suggest that 2.5 hours of moderateintensity cycle exercise invoked a hormonal and immune response similar to that observed during previous investigations, with a marked increase in numbers of circulating immune cells and consequently an increase in the ratio of neutrophils to lymphocytes. This blood concentration ratio is thought to be a robust marker of exercise stress and subsequent recovery (Nieman, 1998). Immune cell function also appeared to be impaired following each exercise bout, with a significant reduction in the bacteriastimulated elastase release, suggesting a reduction in the killing capacity of neutrophils. The supplementation regimen resulted in subjects ingesting an additional $82 \pm 23g/day$ and $69 \pm 19g/day$ of carbohydrate over the course of the week in the CHO and milk trials respectively, but the data collected failed to show a benefit for either supplementation regimen, with similar hormonal and immune responses observed before and after supplementation.

BONE HEALTH

The link between dairy products, calcium intake and bone health has been expertly reviewed in a recent issue in this review series (Cashman, 2008), and will not be covered in detail here. With an increasingly larger and older population, the incidence of low bone mass and the number of cases of osteoporosis have grown dramatically. Osteoporosis is characterised by structural deterioration of the microarchitecture of the bone tissue, resulting in bone fragility and consequently an increased risk of fracture. Several studies support the link between the ingestion of dairy products and a positive benefit on bone mineral density. This effect can be attributed to the presence of calcium and phosphorus found in many dairy products, but there may also be a significant benefit from the whey protein found in milk (Kumegawa, 2006). Exercise itself has been shown to enhance bone mass in most cases, particularly when the activity is weight baring so physical loads are placed on the bones. However evidence for a positive interaction between exercise and calcium intake on bone health is mixed, with a recent report demonstrating a significant effect of exercise on bone mineral density, but no additional influence of fortified milk (Kukuljan *et al.*, 2008).

OVERVIEW

Many dairy products display a number of characteristics that make them suitable to support the nutritional requirements of sports performers: e.g. quantities of carbohydrate, protein and other nutrients. In recent years several studies have examined the potential benefit of milk in particular to individuals engaged in exercise, with a number of positive outcomes. Milk shows great promise as a post-exercise recovery beverage, with a stimulation muscle protein synthesis, maintenance of muscle function and effective restoration of muscle glycogen and fluid apparent following ingestion.

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