Cow's milk as a post-exercise recovery drink: Implications for performance and health

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Abstract

Post-exercise recovery is a multi-facetted process that will vary depending on the nature of the exercise, the time between exercise sessions and the goals of the exerciser. From a nutritional perspective, the main considerations are: 1) optimisation of muscle protein turnover; 2) glycogen resynthesis; 3) rehydration; 4) management of muscle soreness; 5) appropriate management of energy balance. Milk is approximately isotonic (osmolality of 280-290 mosmol/kg), and the mixture of high quality protein, carbohydrate, water and micronutrients (particularly sodium) make it uniquely suitable as a post-exercise recovery drink in many exercise scenarios. Research has shown that ingestion of milk post-exercise has the potential to beneficially impact both acute recovery and chronic training adaptation. Milk augments post-exercise muscle protein synthesis and rehydration, can contribute to post-exercise glycogen resynthesis, and attenuates post-exercise muscle soreness/function losses. For these aspects of recovery, milk is at least comparable and often out performs most commercially available recovery drinks, but is available at a fraction of the cost, making it a cheap and easy option to facilitate post-exercise recovery. Milk ingestion post-exercise has also been shown to attenuate subsequent energy intake and may lead to more favourable body composition changes with exercise training. This means that those exercising for weight management purposes might be able to beneficially influence post-exercise recovery, whilst maintaining the energy deficit created by exercise.

Key words: muscle protein synthesis; glycogen resynthesis; rehydration; muscle damage; appetite; energy balance

Introduction

Milk and milk-based products (i.e. dairy products) are an important food group in many omnivorous and vegetarian populations, representing important sources of a number of essential nutrients, particularly protein and calcium. As such, milk and dairy products help meet nutrient recommendations and assist with the maintenance of human health, as well as potentially protecting against a number of chronic diseases (Thorning et al., 2016). In this regard, milk will likely play an important role in the day-to-day diet of many non-vegan exercisers. Cow's milk is widely available with different relative fat contents, ranging from skimmed (~0.3 g/100 mL) to whole (~3.7 g/100 mL) milk. Milk also contains carbohydrate (4.7-5.0 g/100 mL) and protein (3.6-3.7 g/100 mL), with the slight variation dependent on the fat content of the milk (see Table 1).

Milk is approximately isotonic (osmolality of 280-290 mosmol/kg), and the mixture of high quality protein, carbohydrate, water and micronutrients (particularly sodium) makes milk uniquely suitable for use as a post-exercise recovery drink in many situations. Consequently, most of the research examining supplemental milk ingestion around exercise has focussed on ingestion post-exercise. Therefore, this brief review article will focus on the utilisation of milk as a post-exercise recovery drink, rather than its ingestion during exercise.

From a nutritional perspective, the main considerations for post-exercise recovery are: 1) optimisation of muscle protein turnover and particularly muscle protein synthesis, to promote remodelling of skeletal muscle; 2) glycogen resynthesis to replace used carbohydrate stores in muscle and liver; 3) rehydration to replace water stores lost though sweating; 4) management of any exercise-associated muscle soreness; and 5) appropriate management of energy balance. Clearly, which of these are (most) relevant will depend on the nature of the exercise undertaken, the time available for recovery and the specific goals of the individual. Because of its nutritional properties, milk has the potential to influence each of these components of post-exercise recovery and therefore might provide a simple strategy for the athlete/recreational exerciser to optimise the recovery process (Figure 1). This article will evaluate the impact of post-exercise milk ingestion on these components of the recovery process and, where relevant highlight areas where exercise and post-exercise milk ingestion might interact to influence health outcomes.

Muscle protein balance

Skeletal muscle is important for athletes and recreational exercisers alike, due to its important role in locomotion, strength and metabolic regulation. Thus, optimising skeletal muscle mass and function has significant implications for human health, as well as performance in both sporting activities and activities associated with daily living (Devries & Phillips, 2015).

Muscle protein synthesis (MPS) and muscle protein breakdown (MPB) fluctuate over the day, with the difference between the two determining net protein balance. In sedentary individuals, protein intake in meals provides the main anabolic stimulus, with transient periods of positive protein balance after meals offset by periods of negative protein balance between meals (Morton, McGlory, & Phillips, 2015). The balancing of these two processes means that skeletal muscle mass remains relatively constant, at least in young healthy populations achieving energy balance. Exercise acts as an additional stimulus to increase the turnover of muscle protein, producing increases in both MPS and MPB (Phillips, Tipton, Aarsland, Wolfe, & Wolfe, 1997). The biological relevance of this response is presumably to enable remodelling of skeletal muscle through the removal of old/damaged proteins and the production of new, exercise phenotype-specific proteins (Wilkinson et al., 2008).

Whilst exercise provides an anabolic stimulus that increases net protein balance, without protein intake muscle protein balance remains negative, albeit less negative than at rest (Phillips et al., 1997). Thus, appropriate protein intake around exercise is likely to be fundamental for optimising training induced adaptation of skeletal muscle. MPS appears to play a more important role in feeding-induced changes in muscle protein balance (Biolo, Tipton, Klein, & Wolfe, 1997), and consequently most studies have focused on the measurement of MPS, rather than MPB. However, it is also worth mentioning that another reason for the focus towards measuring MPS is that the measurement of MPB is far more technically challenging; requiring either arterial-venous catheterisation for 2/3-pool modelling of amino acid kinetics across the limb of interest, or by observing the decay in arterial and intracellular enrichment after ceasing the infusion of a second, isotopically-labelled amino acid tracer in order to infer fractional breakdown rates.

Research on resistance exercise has shown that the source (Tang, Moore, Kujbida, Tarnopolsky, & Phillips, 2009; van Vliet, Burd, & van Loon, 2015; Wilkinson et al., 2007), amount (Moore et al., 2009; Witard et al., 2014; MacNaughton et al., 2017) and pattern (Areta et al., 2013) of protein intake after exercise may all influence the resultant MPS. To maximise MPS after resistance exercise, 20 g of high quality protein appears to be sufficient for lower body exercise (Moore et al., 2009; Witard et al., 2014), with higher amounts possibly necessary following whole-body exercise (MacNaughton et al., 2017), at least in young adults. A litre of milk contains ~36 g protein, meaning ~600 mL (i.e. 1 pint) should be sufficient to maximise MPS, at least for lower-body exercise. The source of protein after resistance exercise is an important consideration for maximising post-exercise MPS. Animal protein sources, as found in milk, are generally superior to plant protein sources on a gram-for-gram basis. This has generally been attributed to differences in the amino acid, and particularly leucine, content of the protein, as well as the protein's post-prandial digestion and absorption kinetics (van Vliet et al., 2015).

In this regard, milk protein is high in essential amino acids and leucine, and when ingested after resistance exercise, skimmed milk has been shown to increase MPS compared to a macronutrient matched soy drink (i.e. plant protein; Wilkinson et al., 2007). In a subsequent study, the same group observed enhanced MPS following whey protein compared to soy protein, whilst the MPS following casein protein was lower than either whey or soy (Tang et al., 2009). When considered together, these results are intriguing as the protein in milk is principally casein (~80% casein and ~20% whey). Given these two studies demonstrated similar increases in MPS for milk (Wilkinson et al., 2007) and whey (Tang et al., 2009) compared to soy, it is possible the combination of proteins in milk is sufficient to maximise MPS post-exercise. Although this is a question that has not been tested after exercise, at rest, isolated milk and whey proteins induce a similar post-prandial MPS (Mitchell et al., 2015).

These acute studies suggest that milk has the potential to increase hypertrophy if ingested chronically after resistance training, and the results of two training studies (Hartman et al. 2007; Josse, Tang, Tarnopolsky, & Phillips, 2010) support this notion. Both studies had young subjects perform 12 weeks of whole-body resistance exercise, with 5 sessions/week. Post-exercise recovery drinks (500 mL) were provided immediately and 1 h post-exercise for all sessions. In these studies, providing skimmed milk as the post-exercise drink augmented the increase in lean body mass compared to a macronutrient matched soy drink in males (Hartman et al., 2007) or an energy-matched carbohydrate drink in males and females (Hartman et al., 2007; Josse et al., 2010), at least in young healthy subjects. In contrast, Rankin et al., (2004) reported that the increase in lean mass after 10 weeks resistance training (3 sessions/week) was not different between groups who ingested low-fat chocolate milk (0.21 g protein/kg body mass) or an energy-matched carbohydrate drink immediately after exercise. Whilst there was no significant difference for change in lean mass between groups, there was a trend (P = 0.13) for a greater lean mass gain in the chocolate milk group (+1.6 kg) compared to the carbohydrate group (+0.8 kg). It is possible that the lower post-exercise protein intake (~16 g vs ~35 g) and/or lower number of training sessions (30 vs 60) account for the discrepant findings between these studies.

Endurance exercise stimulates MPS (Wilkinson et al., 2008), with subsequent protein ingestion accentuating this response (Breen et al., 2011; Hulston, Wolsk, Grøndahl, Yfanti, & van Hall, 2011; Lunn et al., 2012). Interestingly, this protein-induced increase in MPS appears to be driven by changes in myofibrillar MPS, as mitochondrial MPS is not influenced by post-exercise protein intake (Breen et al., 2011). In contrast to resistance exercise, there is a paucity of data examining factors related to protein feeding after endurance exercise. Intuitively, increases in MPS and muscle protein turnover produced by endurance exercise and subsequent protein intake will facilitate the opportunity to optimise remodelling of skeletal muscle protein and consequently the adaptive response to endurance training. Therefore, it is likely that protein intake strategies to maximise adaptation to endurance exercise will be similar to those following resistance exercise, which is reflected in a recent review of the topic (Moore, Camera, Areta, & Hawley, 2014). Therefore, ingestion of ~600 mL of milk should provide adequate protein to maximise MPS, with the other nutrients contained in milk facilitating other aspects of post-exercise recovery (discussed later).

Whilst the effect of chronic post-exercise milk ingestion on endurance training adaptation has not specifically been studied, two studies (Ferguson-Stegall, McCleave, Ding, Doerner, Liu, et al., 2011; Robinson, Turner, Hellerstein, Hamilton, & Miller, 2011) have examined the effect of milk protein-containing drinks in this context. These studies both observed greater increases in $\dot{V}O_2$ max when milk-based drinks were ingested post-exercise compared to energy-matched carbohydrate drinks in previously untrained young (~22 y; Ferguson-Stegall, McCleave, Ding, Doerner, Liu, et al., 2011) and older (~50 y; Robinson et al., 2011) adults. Although the mechanisms have not been elucidated, combining endurance exercise training with the ingestion of milk or milk-based drinks after exercise seems to be a simple, practical strategy to increase, at least some, aerobic training adaptations.

Milk ingestion post-exercise appears to beneficially effect muscle protein turnover and enhance some phenotypic adaptations to exercise, with clear implications for performance (i.e. increased strength or aerobic fitness). These beneficial adaptive responses to exercise might also have significant ramifications for health in situations where exercise is performed with this goal in mind. Maintenance of muscle mass and function has implications for a number of chronic health conditions, including metabolic health (Wolfe, 2006), as well as in the prevention of trips and falls (Devries & Phillips, 2015). Therefore, ingesting milk after exercise (resistance or endurance) might help to optimise the adaptive response to exercise in a manner conducive to facilitating beneficial performance and health outcomes regarding protein balance and muscle mass/function.

Glycogen resynthesis

Performance at high intensities increases the utilisation of endogenous carbohydrate (glycogen) stores, and if prolonged in nature (>60 min) can lead to substantial depletion of this finite store (Betts & Williams, 2010). Commencing exercise with reduced muscle glycogen levels impairs exercise capabilities (Bergstrom & Hultman, 1967), meaning restoration of muscle glycogen between exercise sessions is vital if optimal performance is desired. Dietary carbohydrate intake is the most important factor dictating muscle glycogen resynthesis (Burke, Hawley, Wong, & Hawley, 2011), and if time between exercise bouts is sufficient, muscle glycogen stores will recover with adequate dietary carbohydrate intake. However, if rapid recovery of muscle glycogen is required, 1-1.2 g carbohydrate/kg body mass/h for up to 4 h post-exercise is recommended to maximise muscle glycogen resynthesis (Burke et al., 2011). Protein intake also enhances post-exercise muscle glycogen resynthesis, likely via insulin mediated mechanisms, but only if carbohydrate intake is suboptimal (Betts & Williams, 2010).

The carbohydrate in milk provides substrate for muscle glycogen resynthesis, although the volume of milk required to reach target ingestion rates for maximal muscle glycogen resynthesis is large. Therefore, if maximal rates of muscle glycogen resynthesis are required, milk alone is unlikely to suffice. Whilst the protein in milk will further increase muscle glycogen resynthesis, ingesting milk alongside other carbohydrate containing foods or ingesting carbohydrate-supplemented milk (i.e. flavoured milk) are practical approaches to optimise post-exercise muscle glycogen replenishment. Whilst there is no specific research that has examined the effect of milk on muscle glycogen resynthesis, ingestion of flavoured milk, which contains additional carbohydrate, results in similar muscle glycogen resynthesis to an energy-matched carbohydrate drink (Ferguson-Stegall, McCleave, Ding, Doerner, Wang, et al., 2011), at least when carbohydrate ingestion rates are sub-optimal. Moreover, when recovery between exercise bouts is short, ingestion of a milk protein-containing drink after the first bout of exercise results in similar (Pritchett, Bishop, Pritchett, Green, & Katica, 2009) or enhanced (Ferguson-Stegallet al., 2011; Lunn et al., 2012) performance in the second bout of exercise compared to a carbohydrate-only drink.

Alongside muscle glycogenolysis, exercise, at least in the absence of substantial carbohydrate ingestion, induces liver glycogenolysis, meaning resynthesis might be necessary post-exercise (Gonzalez, Fuchs, Betts & van Loon, 2016). Although research in this area is limited, it appears that the type of carbohydrate ingested might influence the liver glycogen resynthesis response (Decombaz, Jentjens, Ith, Scheurer, Buehler et al., 2011). Galactose, one of the monosachariseds that makes up the milk sugar lactose is preferentially metabolised by the liver (Gonzalez et al., 2016). Indeed, post-exercise liver glycogen resynthesis following galactose ingestion is increased compared to glucose ingestion and similar compared to fructose ingestion (Decombaz et al., 2011). Therefore, as well as providing substrate for muscle glycogen resynthesis, ingestion of milk post-exercise might also provide a preferential substrate to enhance/accelerate liver glycogen resynthesis, particularly if it replaces glucose in the recovery diet.

Post-exercise rehydration

Exercise increases metabolic rate and metabolic heat production, leading to an increased sweat production to assist with heat loss via evaporative cooling. Ad-libitum fluid intake during exercise is commonly less than fluid loss and exercisers therefore generally finish exercise in a dehydrated state (Sawka et al., 2007). Starting exercise dehydrated impairs endurance (James, Moss, Henry, Papadopoulou, & Mears, 2017), strength (Minshull & James, 2013), and skilled performance (Baker, Dougherty, Chow, & Kenney, 2007), meaning appropriate rehydration between exercise sessions is paramount to optimise sports performance. When dehydration is significant or the time between training sessions is short, athletes might benefit from a structured rehydration plan. Skimmed milk has been shown to enhance post-exercise rehydration compared to either a commercially available carbohydrate-electrolyte drink or water (Shirreffs, Watson, & Maughan, 2007; Seery & Jakeman, 2016). Milk contains sodium, carbohydrate and protein, which all have been shown to independently enhance rehydration (Evans, James, Shirreffs, & Maughan, 2017). Sodium, which is the main electrolyte in the extra-cellular fluid and sweat is well known to enhance post-exercise rehydration (Shirreffs & Maughan, 1998; Evans et al., 2017). However, the sodium content in milk (~20 mmol/L) is insufficient to independently increase rehydration (Shirreffs & Maughan, 1998). Therefore, the increased energy density (Clayton, Evans, & James, 2014) and/or the milk protein content (James, Clayton, & Evans, 2011; James et al., 2013) provide the most plausible mechanisms by which rehydration is enhanced. Although it is possible these ingredients act in synergy with the electrolytes, and possibly the lactose in milk, to enhance rehydration. Interestingly, regarding the impact of protein on rehydration, it appears to be specific to milk protein, as whey protein addition to rehydration drinks does not appear to enhance rehydration (James, Mattin, Aldiss, Adebishi, & Hobson, 2014; Hobson & James, 2015).

The acute rehydration benefit observed with milk/milk protein following a single exercise bout is relatively small (~0.5-1% body mass) and is therefore unlikely to influence subsequent performance (Sawka et al., 2007). The chronic effects of manipulating the specific post-exercise rehydration strategy are unknown, but these small differences in fluid balance following individual sessions might accumulate to a meaningful loss of body water over time. Indeed, many athletes start training sessions with elevated urine osmolality (Volpe, Poule, & Bland, 2009), which is indicative of dehydration and suggests fluid intake between training sessions might often be inadequate to fully restore fluid balance. Therefore, ingesting milk post-exercise might assist with the restoration of fluid balance between exercise sessions and potentially reduce the prevalence of dehydration at subsequent exercise sessions.

Whilst there are clear effects of dehydration on exercise performance, the effects on health are less well documented, although evidence is beginning to emerge (Perrier, 2017). However, given that dehydration is associated with a number of chronic diseases (Perrier, 2017) and may alter glycaemic control, at least in type 2 diabetics (Johnson et al., 2017), maintaining adequate day-to-day hydration status may be of importance for those exercising for health purposes. Consequently, post-exercise milk ingestion might help to restore body water losses and help maintain hydration status in these populations, possibly mitigating any associated negative health consequences.

Exercise-induced muscle damage

Muscle soreness is a common side effect of some forms of exercise, particularly those that involve a large eccentric component. Ingestion of milk after muscle damaging exercise attenuates decrements in physical performance (Cockburn, Hayes, French, Stevenson, & St Clair Gibson, 2008; Cockburn, Robson-Ansley, Hayes, & Stevenson, 2012; Cockburn, Bell, & Stevenson, 2013) and increases in muscle soreness (Rankin et al. 2015). Cockburn et al. (2008) reported that performance in concentric knee flexion exercise was better maintained after a muscle damaging knee flexion protocol in groups that ingested milk or flavoured milk compared to groups that ingested a carbohydrate-electrolyte drink or water. The drinks were ingested in a volume of 500 mL immediately and 2 h after the damaging exercise. Subsequent work using similar protocols reported that 500 mL of milk was sufficient to attenuate performance decrements during unilateral knee flexion (Cockburn et al., 2012) and one-off/repeated sprinting (Cockburn et al., 2013).

Whilst the mechanisms explaining these effects are not currently clear, there are some important potential implications of these findings. Firstly, enhanced physical performance might improve training quality and/or assist with injury prevention in athletes following rigid training programmes. In recreational exercisers, reducing the severity or duration of any post-exercise muscle soreness might increase training frequency and/or adherence, with important implications for fitness or weight management goals.

Exercise and weight management

For many, weight management (i.e. reducing or maintaining body mass and/or body fat) is one of the primary aims of exercise training. For example, many recreational exercisers strive for weight loss or to prevent weight gain for health and/or aesthetic reasons. Similarly, appropriate body mass and composition is vital for optimal sports performance. Many athletes will aim to manipulate body mass to enhance performance or, in the case of weight categorised athletes, achieve a specific body weight for competition. Additionally, in many settings body recomposition might be desirable, meaning athletes or recreational exercisers might strive for both fat mass loss and fat-free mass gain.

Given the continued rise in the prevalence of overweight and obesity (NCD Risk Factor Collaboration, 2017), there is a clear and growing need for strategies that can attenuate or prevent weight gain. Weight gain occurs due to a chronic positive energy balance (i.e. energy intake greater than energy expenditure), and strategies that combine both exercise and nutrition interventions appear to be most successful for sustained weight loss and maintenance (Franz et al., 2007). Exercise increases energy expenditure without a concomitant increase in voluntary energy intake, creating an energy deficit that should help facilitate weight loss (Shubert, Desbrow, Sabapathy, & Leveritt, 2013). In the absence of a later compensation in eating behaviour, nutritional intake in the post-exercise period will weaken the energy deficit created by exercise. Therefore, the nutritional choices made in the post-exercise period could have important implications for energy balance and consequently weight loss/maintenance in the long term.

In this regard, there is evidence that milk or milk-based drinks might offer some benefit to those exercising for weight management. At rest, milk ingestion decreases subsequent energy intake compared to energy-matched carbohydrate drinks (Dove et al., 2009). Recently, this effect has also been reported following aerobic exercise, with ingestion of 600 mL skimmed milk post-exercise reducing energy intake at an ad-libitum meal 1 h later compared to a volume and energy-matched carbohydrate drink in recreationally active females (Rumbold, Shaw, James, & Stevenson, 2015). The complex mixture of nutrients in milk makes it difficult to attribute this effect to a specific nutrient or property.

There is some evidence that post-exercise ingestion of milk-derived proteins (i.e. whey) can attenuate subsequent energy intake (Clayton, Stensel, Watson, & James, 2014; Monteyne et al., 2018). Additionally, both lactose (Bowen, Noakes, Trenerry, &

Clifton, 2006) and calcium (Gonzalez et al., 2015) have been shown to suppress appetite and reduce ad-libitum energy intake at rest, although their effects in a post-exercise context are unknown. Finally, irrespective of nutrient content, drinks that are more thick and creamy in texture, such as milk, have been shown to suppress subsequent energy intake independent of their nutrient composition (Bertenshaw, Lluch, & Yeomans, 2013). These various factors in milk might act independently or in combination to explain the impact of milk on acute energy intake.

The proposition that ingesting milk post-exercise attenuates energy intake at subsequent eating occasions is extremely attractive, as it means an exerciser can receive the positive recovery benefits associated with post-exercise milk ingestion without increasing energy balance or having to consciously restrict subsequent energy intake.

Chronic exercise training studies that have compared milk-based drinks with other recovery drinks provide some evidence to support the notion that milk might favourably alter energy balance. Josse et al. (2010) reported that following 12 weeks resistance training, women who ingested skimmed milk post-exercise (2 x 500 mL) lost more body fat than women who ingested energy and volume matched carbohydrate drinks (-1.6 kg vs -0.3 kg). Whilst there was also a greater increase in muscle mass (discussed earlier), these changes in body composition represent a reduction in body energy stores, suggesting post-exercise milk ingestion helped facilitate a negative energy balance in this group. Some studies in males demonstrate trends for a similar effect when milk or milk-based drinks are ingested post-exercise (Hartman et al., 2007; Ferguson-Stegall, McCleave, Ding, Doerner, Liu, et al., 2011), whilst others show no effect (Rankin et al., 2004; Robinson et al., 2011). The duration of these studies or the frequency of training/milk ingestion might not have been sufficient to allow small differences in daily energy balance to manifest in changes in body composition. Clearly further work is required to better evaluate the chronic effects of post-exercise milk ingestion on energy balance. Finally, one must consider the contribution of the energy consumed in milk to daily energy balance. Consumption of 1000 mL skimmed milk provides ~350 kcal, which is not an insignificant amount of energy. Future studies should also consider the effect of energy provision on energy/fat balance in response to exercise training.

Summary

In summary, milk is readily available and has a unique nutritional composition that makes it ideal as a post-exercise recovery drink for many exercisers. Ingestion of milk post-exercise has the potential to beneficially impact both acute recovery and chronic training adaptation. Milk augments post-exercise muscle protein synthesis and rehydration, can contribute to post-exercise glycogen resynthesis, and attenuates post-exercise muscle soreness/function losses. In these regards, milk is at least comparable and often out performs most commercially available recovery drinks. However, milk is available at a fraction of the cost of most commercially available drinks and therefore offers a cheap and easy option to facilitate post-exercise recovery for those exercising on a budget (see Table 1). Additionally, milk ingestion post-exercise appears to attenuate subsequent energy intake and may lead to more favourable body composition changes with exercise training. This means that those exercising for weight management purposes might be able to facilitate post-exercise recovery without negatively effecting energy balance.

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Table 1. Nutritional composition (per 100 mL) and prices of different milks, dairy milk alternatives and sports specific beverages.

	Skimmed Milk	Semi-skimmed milk	Full-fat milk	Soya milk [b]	Almond milk [b]	Rice milk	Carbohydrate Sports drinks [c]	Recovery products [d]
Energy (kcal)	37	50	66	33-42	19-32	47	10-28	16-70
Protein (g)	3.6	3.6	3.5	3.4	<0.5	0.1	0.0	3.7-10.0
Carbohydrate (g)	5.0	4.8	4.7	<0.5-2.6	1.3-3	9.5	2-6.5	0.0-10.9
Fat (g)	<0.5	1.8	3.7	1.9	1.3-1.9	1.0	0.0	0.0-2.2
Sodium (mg)	47	43	43	35-51	55-86	35	35-51	31-110
Calcium (mg)	130	124	124	120	120	120	0-37	Unknown-239
Price (£/L)	0.44-0.88 [a]	0.44-0.88 [a]	0.44-0.88 [a]	0.90	1.00	1.40	0.55-2.00	4.13-8.00
Price (£/20 g protein)	0.24-0.49	0.24-0.49 [a]	0.24-0.49 [a]	0.53	4.00	28.00	N/A	1.31-2.50

Data obtained from 2 of the largest online UK supermarkets: www.Tesco.com; www.Sainsbury's.co.uk. For all milk/ milk alternatives, the cheapest products where used. [a] Variation in price of milk due to price of different quantities (i.e. 1-6 pint bottles). [b] Soya and almond milk represent sweetened and unsweetened varieties. [c] Sports drinks represents three different beverages. [d] Recovery products represents nine different beverages.

Figure 1. Diagrammatic representation of the recovery benefits of milk.