The Potential Nutrition-, Physical- and Health-Related Benefits of Cow's Milk for Primary-School Aged Children

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Abstract

Cow's milk is a naturally nutrient-dense foodstuff. A significant source of many essential nutrients, its inclusion as a component of a healthy balanced diet has been long recommended. Beyond milk's nutritional value, an increasing body of evidence illustrates cow's milk may confer numerous benefits related to health. Evidence from adult populations suggests that cow's milk may have a role in overall dietary quality, appetite control, hydration and cognitive function. Although evidence is limited compared to the adult literature, these benefits may be echoed in recent paediatric studies. This article, therefore, reviews the scientific literature to provide an evidence-based evaluation of the associated health benefits of cow's milk consumption in primary-school aged children (4-11 years). We focus on seven key areas related to nutrition and health comprising nutritional status, hydration, dental and bone health, physical stature, cognitive function, and appetite control. The evidence consistently demonstrates cow's milk (plain and flavoured) improves nutritional status in primary-school aged children. With some confidence, cow's milk also appears beneficial for hydration, dental and bone health and beneficial to neutral concerning physical stature and appetite. Due to conflicting studies, reaching a conclusion has proven difficult concerning cow's milk and cognitive function therefore a level of caution should be exercised when interpreting these results. All areas, however, would benefit from further robust investigation, especially in free-living school settings, to verify conclusions. Nonetheless, when the nutritional-, physical- and health-related impact of cow's milk avoidance is considered, the evidence highlights the importance of increasing cow's milk consumption.

Introduction

Commonly cited as nature's perfect food[1], milk is the foundation of life for all mammalian neonates[2, 3]. Representing a complex and unique liquid, milk (which is produced by the mammary glands[4]) is the only foodstuff designed by nature to serve as a complete food, at least during the pre-weaning period. In this sense, milk contains numerous biological constituents and an assortment of nutrients necessary for immunological protection and initial growth[2, 5]. Shortly after weaning, most mammals stop consuming milk[6]. With domestication and milking of various animals, however, some humans continue to drink milk throughout life[7], mostly cow's milk. The value of cow's milk in the human diet has been heavily debated for many years[8] and has been portrayed by some as 'white poison', a health hazard and promoter of Western chronic diseases[9]. This position is based on numerous hypotheses including that cow's milk contains blood, pus, hormones and antibiotics, causes acne and cancer and has a high cholesterol and fat/saturated fat content collectively contributing to cardiovascular disease risk, weight gain and obesity. Nevertheless, such perceptions of cow's milk being harmful to health are not supported by evidence. Conversely, cow's milk has often been signified as the white elixir[6].

Childhood is a key stage for the development of healthy eating patterns[10], and the school environment provides a valuable setting to develop such behaviours. This is particularly true considering children spend much of their time at school. Indeed, dietary habits shaped throughout the childhood years might carry forth and track into adulthood. Between the ages of 4-11 years (primary-school age), children grow and mature at a rapid rate preceding the onset of puberty[11]. Childhood is therefore a critical transition period preceding adolescence, characterised by growing independence and marked physical development. Good nutrition for the childhood period is therefore particularly important[12]. Not only may good nutrition support proper growth and maturation, but it may therefore act as a base for immediate and lasting health, well-being and disease prevention. This is best achieved by consuming a balanced and varied diet that provides all the nutrients needed. The inclusion of cow's milk as a staple component of a healthy balanced diet has been long recognised and is central in most public dietary recommendations[13]. Milk is naturally nutrient-dense and is a significant source of many essential macro and micronutrients. Indeed, cow's milk may confer nutrition-, physical- and health-related benefits beyond that of helping children to simply meet nutrient targets. Based on the available literature, it appears that many of these effects are a product of milk's nutritional composition. It therefore seems relevant to provide readers with a brief description of the nutritional composition of cow's milk.

Nutritional Composition of Cow's Milk and Patterns of Consumption

The nutritional composition of cow's milk is influenced by factors including genes (species and breed), physical state (age and stage of lactation) and environment (available nutrition and climatic conditions)[14]. The composition of whole cow's milk is approximately 87 % water and 13 % solids[1]. The percentage split of water and solids of cow's milk, as well as energy, is primarily determined by the amount of fat[15] but is also influenced by added sugars and sweeteners. Cow's milk is approximately 4.9 % carbohydrate. The primary carbohydrate portion of milk is lactose, a disaccharide comprising glucose and galactose. The lipid component of cow's milk and other milk-based dairy foods contribute numerous properties including the provision of fat-soluble micro-nutrients and essential fatty acids, as well as influencing flavour, texture and appearance[15]. Of the lipid content within cow's milk, roughly 64 % are saturated fatty acids, with a considerable amount (~26 %) from monounsaturated fatty acids and a small contribution from trans and polyunsaturated fatty acids (both ~3 %)[16]. Additionally, cow's milk provides high-quality proteins, namely casein and whey. Casein and whey constitute approximately 82 % and 18 % of the total protein found in cow's milk and provide an abundance of essential amino acids[17]. Aside from the macronutrient content, cow's milk contains essential micronutrients that contribute to dietary quality and overall nutritional status. As shown in Table 1, with the exception of vitamin C (which is broken down during pasteurisation) and vitamin D (unless fortified), cow's milk is a good source of all vitamins[18]. Calcium and phosphorus, crucial to healthy growth and maturation, as well as other biological processes, are the most prominent minerals present in cow's milk. Cow's milk also makes significant contributions to intakes of other major minerals[19]. In this sense, cow's milk makes a substantial contribution to, and is the main dietary source of, calcium (26 %), iodine (37 %), riboflavin (25 %), magnesium (10 %) and potassium (14 %) in the diets of primary-school aged children[20]. While volume specific data are limited, in the UK, the National Diet and Nutrition Survey (NDNS) provides a nationally representative assessment concerning dietary habits of individuals, aged 1.5 y and older, living in private households and remains the only surveillance programme to do so. Temporal and age-related trends of cow's milk to average daily total energy, macro and micronutrient intake from 2009/10 through to 2015-16 are presented in Table 2 for children (4-10 years) and adolescents (11-18 years). Despite the clear value of cow's milk in the everyday diet it is clear intakes steadily decline as children age. This trend is not only restricted to the UK, it is also true in the US[21, 22], Australia[23] other European countries[24]. This is of great concern among children, especially as dietary habits may track into adulthood, as milk avoidance may have detrimental implications over time, leaving populations vulnerable to micronutrient deficiencies (e.g. calcium, iodine and riboflavin deficiencies to name a few[25]) and lasting nutrition-and health-related complications (e.g. cardiovascular disease[26], metabolic syndrome[27], hypertension[27, 28], poor weight management and bone health[25, 29]).

Scope and Methodology of the Narrative Review

Evidence from adult populations suggests that adequate cow's milk consumption is associated with a reduced risk of cardiovascular disease[30], metabolic syndrome[28, 31] and obesity[32-34]. Emerging data also suggests that cow's milk may have a role in overall dietary quality, appetite control, hydration and cognitive function. Although the evidence to date is limited compared to the adult literature, these benefits appear echoed in recent paediatric studies. There is a need to review the literature to assess whether there is sufficient evidence of a beneficial or detrimental effect of cow's milk in the diet and health of children. The aim of this narrative review is therefore to summarise and appraise the scientific literature to form an accurate, evidence-based evaluation of the associated nutrition-, physical- and health-related benefits of cow's milk consumption in primary-school aged children (4-11 years). Based on recent publications, it is not the intention of this narrative review to focus on body weight and body composition as with some confidence it is known cow's milk consumption is inversely (or not) associated with body weight and body composition in children and adolescents[35]. Where possible, this review focuses solely on literature in children aged 4-11 years, however, where there is no applicable literature, data from general child studies will be reviewed (and possibly some adult studies). This is particularly true for mechanistic considerations as much of this evidence comes from adult studies, therefore any adult-specific data should be interpreted with some caution as the observations cited may not always be replicated in children. The narrative review will also highlight current knowledge gaps in this field and suggest directions for future research.

To identify research articles to facilitate this narrative review, PubMed (US National Library of Medicine National Institutes of Health) and Web of Science (Thomson Reuters, UK), were searched using various combinations of keywords relevant to the scope of the review up to August 2020. Search terms included: humans, child, milk, flavoured milk, animal milk, cow milk, infant, adolescent, preschool, primary-school, paediatric, diet, energy intake, nutritional status, diet quality, obesity, school-age children, food habits, dairy products, milk beverages, height, stature, anthropometry, calcium, health association, health benefits, dental health, caries, decay, bone health, appetite, cognition, memory, mental performance, school milk, insulin, glucose, hydration, snack. Studies were considered eligible for inclusion in the review if (i) they were conducted in children 4-11 years; (ii) participants received cow's milk, and not supplemental forms of dairy minerals (unless a milk group was included); (iii) the study had been peer-reviewed. Results from studies that grouped data over a wider age-range were also considered where this was deemed appropriate. This was especially true for prospective and intervention studies, yet the mean age of participants had to fall between the stipulated age range. Studies were excluded if (i) human participants were not used; (ii) participants lay directly outside of the stipulated age-range; (iii) studies used supplements only (iv) studies used different dairy foods (i.e. yogurt, cheese, dairy desserts) (v) the milk consumed included different sources of animal milk; (vi) data reporting was poor and/or not published in English.

In this narrative review we have summarised the evidence base, which we identified by related benefits; nutrition-, physical- and health-related and provide a summary for the studies identified. As this is not a systematic review, we did not perform a quality assessment of each study (based on design and implementation) or conduct a meta-analysis by study design but summarise the findings for each study and sub-section in Tables 3 (nutrition-related benefits), 4 (physical-related benefits) and 5 (health-related benefits). Symbols ↑ and ↓ indicate a statistically significant positive and negative effect/relationship, respectively, between cow's milk and related subsections, with ↔ indicating no statistically significant effect/relationship or a neutral effect. This approach has successfully been used in a recent narrative review in this journal[35], and therefore direct readers to this paper for justifications and interpretations for this approach. In brief, however, a tabulated summary allowed us to draw overall conclusions for this narrative review, although we did not undertake a detailed assessment of quality of individual studies.

Nutrition-Related Benefits of Cow's Milk

Nutritional Status

The importance of regular cow's milk consumption in children has been recognized for over 40 years[36]. As described, cow's milk is a naturally nutrient-dense foodstuff, providing a rich source of many essential nutrients. While the potential of cow's milk to improve nutritional status may be unsurprising, the effect of this in primary-school aged children has only been investigated by numerous observational studies[37-42] and three intervention-based study[43-45] (see Table 3). All reported improved nutritional status with increased cow's milk consumption, yet, due to the study designs utilised, findings must be interpreted with caution. In the few intervention-based studies[43-45], which ranged from 16 weeks to 6 months, primary school children were provided with flavoured milk or no drink (control)[44], 200 mL[43] and 250 mL[45] of multi-micronutrient fortified milk or unfortified milk to establish whether unfortified and fortified cow's milk influences micronutrient status in primary-school aged children. In those consuming fortified versus unfortified cow's milk significant increases in blood riboflavin and vitamin B_{12} were observed, with all other analytes (selenium, ferritin, and vitamin D) comparable between drinks[43]. Additionally, significant increases in serum ferritin and zinc increased have been observed after 6 months with both fortified versus unfortified cow's milk compared to a control drink[45]. With respect to nutritional status, dietary patterns characterised by high cow's milk consumption (both plain and flavoured milk) resulted in greater intakes of energy, protein, phosphorus, magnesium, calcium, potassium, vitamin A, zinc, riboflavin (vitamin B_2), and niacin compared to children who seldom consumed cow's milk. Notably, diets high in cow's milk may also limit intakes of foods and beverages high in fat and sugar. In studies of Dutch[37] and American primary-school aged children[46], for example, cow's milk intake was inversely related with the intake of sugar-sweetened beverages. In these studies, children with low cow's milk intakes had lower protein, fibre, calcium, magnesium, potassium and phosphorus intakes. Low cow's milk consumption has significant implications for intakes of several key nutrients that are of importance in childhood. Based on the nutritional contribution to dietary intakes, it is important to note that children who drink cow's milk regularly are more likely to meet dietary recommendations for many nutrients, and thus have a better nutritional status[13]. It could therefore be argued that milk intake might be a marker for healthier eating habits[37].

With the above in mind, in the UK, it should be noted that dietary intakes of vitamin D in primary-school aged children are low. Considering UK cows' milk is generally not a good source of vitamin D because it is not fortified, as it is in other countries, this narrative review may provide justification for UK policy makers to reconsider widespread fortification. There is evidence (albeit from a theoretical modelling perspective) from Northern Ireland that cows' milk can be used as a successful vehicle for vitamin D fortification[47]. Fortification of cows' milks with 1 µg, 1.5 µg and 2.0 µg/100g, theoretically increased median vitamin D intakes from 2.0 µg/day to 4.2 µg, 5.1 µg and 5.9 µg/day, respectively and may therefore provide strong evidence for the efficacy of widespread fortification. This modelling appears to translate to human studies. In support of this, a recent review comprising of 20 studies showed positive associations between the consumption of vitamin D fortified milk and 25(OH)D status in different population groups[48]. Furthermore, in Finland, Canada, United States who exercise a national vitamin D fortification policy (covering various fluid milk products), milk products contributed 28–63 % to vitamin D intake, while in countries without a fortification policy, or when the fortification covered only some dairy products (Sweden, Norway), the contribution was much lower or negligible[48]. Based on the above, widespread fortification of milk seems helpful to help bolster vitamin D intakes and could be adopted by the UK to increase vitamin D intakes in primary-school children.

Concerns about added sugars in foods and beverages has increased recently. Accordingly, many schools have limited access to foods and beverages high in added sugars, included flavoured cow's milk. In some studies, removal of flavoured cow's milk from the school environment reduces energy and sugar intake, but negatively impacts essential nutrient intake and even reduced the overall intake of non-flavoured cow's milk[49, 50]. In this sense, total milk consumption (both plain and flavoured) decreased by 12.3 %[50]. Contrariwise, children who drink more flavoured cow's milk generally have higher non-flavoured milk intakes and display nutritional intakes similar to children who only consume non-flavoured milk[51]. While greater cow's milk consumption (both plain and flavoured) is generally associated with higher daily energy intake with some confidence we know this does not impact body mass or composition[35]. If daily energy intake is of concern for children predisposed to overweight and obesity, results of a recent study suggest that replacement of whole cow's milk or semi-skimmed cow's milk with skimmed cow's milk may help reduce total energy intake, without impacting on nutrient provision[52].

When taken together, these results suggest that cow's milk consumption (both plain and flavoured) might serve as a useful strategy to boost nutritional status in primary-school age children and may act as a surrogate marker of diet quality. There may be a need for widespread vitamin D fortification of cow's milk, however, and based on the above seems justified and should be reviewed by UK policy makers. Cow's milk is a readily available, accessible, and affordable means of providing valuable essential nutrients to the diets of primary-school children. The nutritional implications of cow's milk provision and/or removal in the school environment must be considered and is especially relevant in children suffering with nutritional inadequacies. The data are, however, primarily limited to observational investigations and require verification in more controlled intervention-based studies covering differing populations.

Hydration

Whole cow's milk is approximately 87 % water[1] and may therefore be a beneficial choice for hydration. For children, maintenance of euhydration is important for good health[53] but may also increase concentration and mental performance (cognitive function)[54] while helping reduce instances of headaches, constipation and other disorders[53]. This is important as children are at a greater risk of dehydration compared to adults, having relatively greater fluid losses at rest and during exercise and being less able to recognise thirst[54]. Given that water is continually being lost from the body water pool, it is important to constantly replenish fluid losses to prevent dehydration. Establishing beverages that encourage longer-term fluid retention and maintenance of euhydration has real clinical and practical implications[55]. This is particularly true in situations where free access to fluids is limited or when frequent breaks for urination are not desirable[55], such as in in the school setting where many children arrive at school in an already hypo-hydrated state[56]. There is little research concerning the impact of cow's milk on hydration in primary-school aged children (see

Table 3). To date, three studies have been conducted[57-59]. Two of these were exercise-based intervention studies conducted by the same research group in Canada[58, 59], and the remaining study was cross-sectional[57]. Nonetheless, all reported improved hydration status with cow's milk in comparison to water or alternative beverages. While these findings show promise, additional controlled-intervention studies should be performed in different settings to examine repeatability of these effects.

In the two exercise-based intervention studies, researchers examined the influence of post-exercise cow's milk consumption on rehydration in 7-11-year-old[59] and 10-12-year-old children[58]. The rehydration potential of cow's milk (or milk-protein) was compared to water or a carbohydrate-electrolyte drink, zero or a low cow's milk protein beverage and were given at 100 % and 150 % of the children's body mass losses following exercise, respectively. In both studies, children exercised in the heat (~34.5 °C) and consumed the test beverages immediately following exercise. The children were subsequently observed for a period of 2 hours[59] and 4 hours[58], respectively, during which measures of hydration status were collected (urine output and fluid balance). Findings over 2 hours showed cow's milk was more effective than both water and the carbohydrate-electrolyte drink at replacing fluid loss during exercise[59]. This was similar over 4 hours. The authors suggested that the protein in cow's milk may be a factor responsible for the rehydrating properties[58].

Montenegro-Bethancourt and colleagues[57] conducted a cross-sectional study designed initially to establish the contribution of fruit and vegetable intake on hydration status. Children (4-10-year-old) recorded all food and beverages consumed over 3 days using a weighed food diary alongside 24 hour urine samples. Regular intake of fruit and vegetables made a substantial contribution to hydration status, but notably, cow's milk consumption was also a strong dietary predictor of hydration status. In particular, cow's milk increased free water reserve by 25 mL in boys and 33 mL in girls per 100 g of intake. These findings corroborate studies in adult populations[60-62].

Based solely from adult studies, there are a number of potential mechanisms explaining the greater fluid retention (and thus hydration potential) with cow's milk[63]. Firstly, milk contains modest amounts of sodium (~20 mmol/L, similar to most commercial sports drinks) and large amounts of potassium (~40 mmol/L). Sodium, as the main cation in the extracellular fluid plays a major role in fluid retention[64], whilst potassium may exert some beneficial effects[65], although this is not a consistent finding. Secondly, the protein content of cow's milk may help facilitate greater fluid retention[66, 67]. While water and alternative beverages meet the basic intentions of rehydration, they do not offer the abundance of nutrients present in cow's milk that will also aid in normal growth and maturation. Nevertheless, it should be considered that while these findings suggest that cow's milk helps improve the hydration status of children, there remains room for further studies to clarify the role of cow's milk in hydration, especially in a free-living school setting. While the intervention-based studies show promise, many primary-school children do not exercise in such conditions.

Physical-Related Benefits of Cow's Milk

Dental Health

Milk contains multiple nutrients that may offer anticariogenic properties, protecting against the development of dental caries, and thus supporting dental health in children[68, 69]. The nutrients principally believed to play a role in dental health include calcium, phosphorus and protein[68-70]. As reported earlier, cow's milk intake has been shown to be inversely related with the intake of sugar-sweetened beverages[37, 46]. Although speculative, one could argue increased cow's milk intake might indirectly improve dental health. Calcium is required for bone and teeth formation, whereas phosphorus ions works alongside calcium to maintain tooth strength[70]. Cow's milk proteins (particularly α_{s1}-, α_{s2}- and ß-casein) may act to prevent tooth enamel erosion and demineralisation of the tooth surface by producing casein phosphopeptides[71]. Based on the available evidence, inverse associations between cow's milk intake and the incidence of tooth decay have frequently been reported[72-75] (see Table 4). The evidence, however, has been derived from cross-sectional research, so causal conclusions cannot to be justified and caution must be exercised.

The findings of the cited studies were generated from recall methods which have obvious shortcomings. Nevertheless, all studies (following visual examinations accompanied with food frequency questionnaires) reported inverse associations with cow's milk and the development of dental caries. Interestingly, though sugar is suggested to possess acidogenic and cariogenic potential[76], one study[74] reported the association between cow's milk consumption and protection against of dental caries was stronger for children with diets high in sucrose. This might suggest that cow's milk offers protection against the harmful effects of sugar, though this is speculative. To this end, cow's milk intake during primary-school years has been reported as a predictor of incidences of caries later in childhood[72]. In this sense, greater cow's milk intake is inversely associated with indices of dental caries. Collectively, these studies support the suggestion that dietary habits established and maintained during primary-school years could have longer-term effects on health outcomes.

Although no controlled trials have been conducted in primary-school children, the available literature appears to suggest that cow's milk could help reduce the incidence of dental caries and contribute to dental health in children. To reduce the occurrence of tooth decay, it is recommended primary-school children limit their consumption of sugary beverages (especially when not consumed with a meal) and increase consumption of cow's milk. The exact mechanism by which cow's milk reduces the incidence of dental caries remains uncertain, though calcium, phosphate and casein phosphopeptides may all play a role[68-70]. Casein phosphopeptides are phosphorylated casein-derived peptides produced by tryptic digestion of casein in the duodenum[71]. The anticariogenic activity of casein phosphopeptides is due to their ability to stabilise high levels of amorphous calcium phosphate on tooth surface, preventing demineralisation and enhancing remineralisation of enamel caries[77]. In addition, milk fat could be adsorbed onto the enamel surface and may have a protective role; and thirdly, milk enzymes may have a role in reducing the growth of acidogenic plaque bacteria[78]. Where prior observational research provides a solid foundation, any future work should seek to implement robust randomised clinical trials (RCT) to confirm any causal relationships between cow's milk consumption and dental health in primary-school aged children.

Bone Health and Physical Stature

Childhood is a critical time for bone growth and lasting bone health[79, 80] and the nutritional composition of cow's milk has evolved to stimulate and support this[2, 5]. The scientific opinion that regular cow's milk consumption is associated with greater physical stature has a long history, dating back to the 1920s[81, 82]. Cow's milk contains multiple nutrients that may support childhood growth[80] and lasting bone health[79]. The beneficial effects of cow's milk consumption on bone health in children may include increased bone mineral content (BMC) and bone mineral density (BMD), characteristics necessary for the prevention of bone-related diseases later in life (osteoporosis). Evidence of these benefits, however, is equivocal showing a beneficial to neutral effect of cow's milk on these constructs[25, 29, 83-88]. In this sense, of the cited studies, two reported greater total body BMC[85, 88], while one reported no effect. One study reported no effect on total body BMD[87], yet three studies reported increased regional BMC[29, 83, 86] and another two studies reported increased regional BMD[25, 84] (see Table 4). The mixed findings reported throughout these studies may be due to a lack of consistency in methodological approaches, length of study, location and measures of bone health, all of which confound comparisons and prevent a clear conclusion. Furthermore, age and sex differences must be considered, especially as puberty and bone mineralisation typically occurs earlier in girls compared to boys[89].

In two recent studies[85, 88], school milk interventions increased total body and regional (forearm) BMC and BMD compared to children who seldom drank cow's milk. In these studies, the beneficial effects of cow's milk on bone health were observed in n = 435-757 children (mean age 11 years) following daily school milk intake for 1-2 years.

On a comparative basis with other animal sources, whole cow's milk is the richest source of calcium and represents the biggest contributor of dietary calcium during childhood[90]. In addition, considering beef meat and eggs for example, cow's milk is the cheapest source of protein, calcium, phosphorus, and vitamin D[91]. During childhood, the beneficial effects of cow's milk on bone health in children are commonly attributed to calcium[92]. However, many other nutrients including phosphorus and protein are needed for normal growth and lasting bone health[93]. In 5-11-year-old children (n = 99), for example, calcium supplementation for 10 months did not influence total body or regional BMC[87]. In contrast, in an earlier study where cow's milk (and dairy) was supplemented daily for 1 year (distributed to deliver 1200 mg calcium daily), lumbar (lower back) BMD increased compared to children who maintained their usual eating habits[84]. This may illustrate that calcium and other nutrients work together for bone growth, and thus lasting bone health[93]. It is important to note, however, that children in the calcium supplementation study were already consuming near daily recommended amounts, which may illustrate intakes exceeding calcium recommendations (from either supplemental calcium or cow's milk) offers no further benefit to bone health in children.

In several studies, it has been observed that children who avoid consuming cow's milk characteristically exhibit low calcium intakes, short statures, increased fatness and lower BMC (and thus exhibit reduced bone health) compared to their cow's milk-drinking counterparts[25, 86]. In children (mean age = 8 years) who previously avoided cow's milk, the introduction of cow's milk to the diet increased not only habitual cow's milk consumption but also increased total body BMC[29]. This may suggest it is never too late for children to introduce cow's milk into their diet for bone health benefits.

From a stature perspective, available data appear to suggest that cow's milk consumption almost certainly has a positive effect on growth in children. To date, fourteen studies in primary-school aged children have evaluated this aspect of cow's milk consumption[25, 29, 36, 44, 81-83, 85, 94-99]. Seven were intervention-based, four were observational, and the remaining three were prospective designs. Based on these studies, the evidence suggests that cow's milk intake positively influences physical stature in primary-school aged children. All six intervention studies showed increased stature with increased cow's milk (one study included milk calcium). In addition, all prospective studies reported increased stature with increased cow's milk. With regards to the cross-sectional studies, two illustrated cow's milk avoiders displayed stunted growth compared to cow's milk drinkers while the remaining study showed increased adult stature with increased cow's milk consumption in childhood. Although trends are consistent across studies, there remains a need for evidence from robust controlled-intervention trials in primary-school aged children to verify causality.

Beneficial effects on physical stature were observed with both whole and reduced fat cow's milk, distributed at a range of 190 mL – 568 mL daily. In several of these studies, it was reported that childhood cow's milk intake was associated with higher skeletal development (BMD of the hip and the forearm), bone growth and periosteal bone expansion. These were likely established earlier during growth periods and maintained into late adolescence and young adulthood[96-99], supporting the notion that dietary habits established and maintained during the primary- and secondary-school years may not only induce short-term effects but offer lasting benefits. Indeed, in children with prolonged cow's milk avoidance, stunted growth and physical stature is observed compared to children who habitually consume cow's milk, and this is maintained into adulthood[25, 29, 86]. During a pubertal growth spurt, about 37 % of the entire skeletal mass is accumulated[100]. Therefore, inadequate calcium intake during this period may compromise volumetric bone density and overall stature attained. Notably, in a study that explored both cow's milk and supplemental calcium, those children in the cow's milk (and dairy) group were 3 cm taller (166 cm) compared to the supplemental calcium (163 cm) and placebo (163 cm) group[96]. This may indicate that cow's milk has more of a beneficial effect on physical stature and growth than single cow's milk constituents (i.e. calcium).

The precise mechanisms or nutrients in cow's milk responsible for stimulating growth and lasting bone health are not yet clear. Evidence suggests that maintaining adequate calcium intake during childhood might be advantageous for the attainment of peak bone mass, which may be crucial in reducing the risk of bone-related diseases later in life[101]. Interestingly, it appears that whole foods may offer greater benefits than the equivalent amount of calcium in supplemental form. It has also been suggested that the growth-stimulating effect of cow's milk is likely attributed to hormonal effects that can be influenced by ingested cow's milk proteins (predominantly whey protein and the release of amino acids during digestion but also casein), micronutrients and also energy[102-104]. Observations from child studies show these nutrients stimulate the secretion of insulin-like growth factor-1 and insulin, both of which are anabolic hormones that play an essential role in the regulation of growth and accrual of bone mass during childhood[102-104] though there is some controversy that cow's milk intake upregulates insulin and insulin-like growth factor-1 signalling and thus promotes chronic diseases such cancer (prostate, breast and colorectal) and cardiovascular disease[9], though these perceptions are hypothetical at present and not supported by evidence.

Nonetheless, when taken together, it appears that cow's milk consumption promotes both health and may increase physical stature in primary-school aged children. This suggests that cow's milk consumption during childhood might be important to ensure full growth potential is achieved. While there is some suggestion about the improved bone health with increased cow's milk consumption and the mechanisms responsible for the growth-stimulating properties of cow's milk, more intervention studies are needed to elucidate the components responsible for these effects and to prove and/or disprove the chronic diseases hypotheses. This is especially prudent when considering bone health as the methodological approaches previously employed have been diverse in nature.

Health-Related Benefits of Cow's Milk

Appetite Regulation

Appetite comprises numerous regulatory processes associated with the initiation and termination of eating and the selection and amount of food consumed. The regulation of appetite and eating behaviour depend on the detection and integration of signals relaying nutritional status, and their interaction with signals associated with food palatability and gastrointestinal handling, in addition to circadian, social, emotional, habitual and other situational influences[(105)]. Consequently, appetite and the regulation of eating behaviour are complex processes, regulated by homeostatic and non-homeostatic influences[(106)]. Cow's milk contains a host of nutrients that might exert a favourable effect on appetite and eating behaviour[(107)], yet in primary-school children there is limited evidence concerning the short-term effect of cow's milk on these measures. There are also no data on the moderate- and longer-term effects of daily cow's milk consumption on these outcomes in primary-school children.

From the available studies[(108-112)], cow's milk has principally been given as a mid-morning snack or alongside breakfast, with the volume of cow's milk offered to children ranging from 160–250 mL. Based on these studies, the evidence concerning cow's milk and appetite regulation is inconclusive. Three of these studies found a decrease in energy intake after cow's milk consumption yet three reported no effect. Two studies reported cow's milk consumption reduced subjective appetite, one reported increased subjective appetite compared to a fruit-based snack, while two studies did not measure subjective appetite. Only one study measured hormonal indicators of appetite and reported cow's milk consumption stimulated the secretion of glucagon-like peptide-1.

In two studies of 34 overweight and obese boys (mean age = 11 years)[(109, 110)], when compared with volume and energy matched servings of water or fruit-juice, 240 mL of low-fat cow's milk with breakfast reduced energy intake at an *ad-libitum* lunchtime meal. In another study comprising of 48 obese children (mean age = 11 years), girls reported higher satiety scores 4 hours after drinking whole cow's milk compared to skimmed milk, and low-fat cow's milk significantly reduced appetite compared to apple juice 2 hours after consumption. These differences, however, did not transpire to changes in energy intake at an *ad-libitum* lunchtime meal across all conditions in girls, boys and the group as a whole[(108)]. As mentioned, only one investigation (comprising two experiments) has sought to establish the effect of cow's milk (and other dairy products) on appetite and feeding behaviour in normal weight and overweight/obese children (mean age = 11.5), where subjective appetite and appetite-related analytes were measured[112]. In both experiments, preloads (experiment 1: 1 % fat (1 g/100g) chocolate cow's milk, 2 % (2 g/100g) fat cow's milk, 1.5 % (1.5 g/100g) fat yogurt drink, fruit punch or a water drink; experiment 2: 2 % (2 g/100g) fat cow's milk or a fruit punch) were provided 60 min preceding and during an *ad libitum* pizza meal. All preloads were matched for volume (250 mL) and energy content (130 kcal, 543.9 kJ; except water in experiment 1). The first experiment comprised measures of subjective appetite, whereas the second experiment included measures of subjective appetite together with appetite-related analytes (serum glucose, insulin and plasma GLP-1 and peptide YY). Reduced energy intake was observed following chocolate cow's milk and yogurt consumption compared to a water drink in the first experiment. Consistent with a reduction in energy intake, subjective appetite (combined appetite score) was significantly lower following 2 % (2 g/100g) fat cow's milk compared with the yogurt drink only. No additional effects were observed concerning energy intake following the consumption of 2 % (2 g/100g) fat cow's milk and fruit punch or on subjective measures of appetite after 1 % fat chocolate cow's milk, 1.5 % (1.5 g/100g) fat yogurt drink, fruit punch or water. Compared with the fruit punch preload, cow's milk consumption resulted in a significantly greater GLP-1 area under the curve. Nonetheless, *ad libitum* energy intake, insulin and glucose AUC were comparable between trials. Considering all aforementioned studies, it is important to consider that in these studies, energy intake was principally assessed via *ad libitum* assessments which may not be reflective of free-living eating behaviour.

The mechanism(s) by which cow's milk consumption might influence eating behaviour are not fully understood, but there are several plausible suggestions from the adult literature and constituents of cow's milk that may act synergistically to explain possible actions. In the studies where cow's milk reduced appetite and subsequent eating behaviour, it is probably unsurprising that cow's milk consumption suppressed energy intake at *ad-libitum* assessment meals, considering the macronutrient composition of cow's milk compared to fruit-juice drinks and water. Cow's milk contains considerably more protein than fruit-juice drinks and water. Although it is not a universal finding, it is widely recognised that dietary proteins are more satiating than energetic equivalents of carbohydrate and fat under most conditions, commonly suppressing eating behaviour at the next meal[113-115]. Consequently, cow's milk proteins (whey and casein, and their products of digestion) may act to potentiate peptides of gastrointestinal, pancreatic and adipose tissue origin, increasing perceptions of satiety and acutely reducing energy intake (anorexigenic behaviours)[113]. Moreover, medium-chain triglycerides, conjugated linoleic acid (CLA) and lactose may also be implicated in the reduction of energy intake after cow's milk intake[107]. Medium-chain triglycerides are absorbed directly into the portal circulation and transported to the liver for rapid oxidation. A combined action of increased energy expenditure, decreased fat deposition and increased satiety may reduce of energy intake via pre-absorptive signals, post-absorptive changes in metabolites and appetite-related analytes[107] and similar appetite-related analyte responses have been observed with lactose[116]. When considering CLA intake and its potential implications in appetite regulation, cow's milk (and dairy) and cattle meat (cows and lamb) represents the almost exclusive dietary sources[117] where the predominant isomer of CLA (accounting for more than 90 % of the total CLA intake) is the *cis*-9, trans-11-CLA. It is, however, strongly proposed that other isomers, such as trans-10, *cis*-12-CLA may influence body-weight and fat changes[118]. In agreeance with an earlier narrative review[34], it remains unknown whether cow's milk (and dairy), when providing physiological doses of CLA, can elicit any meaningful impact on appetite and body weight regulation in humans. This is especially prudent when considering experimental design, age, sex, energy intake and CLA metabolism of the participants, and the dose and chemical form of the CLA isomer administered as differences may arise solely from these methodological differences[119]. From a child perspective, potential underlying mechanisms of CLA on appetite regulation are poorly understood though evidence from adult studies suggested that CLA can inhibit fatty acid synthase and stearoyl-CoA desaturase-1[118], enhance fat oxidation and thermogenesis and reduce lipogenesis and preadipocyte differentiation and proliferation[120].

In summary, evidence suggests that cow's milk may have a unique potential to influence elements of energy balance. Macro and micronutrients and other bioactive constituents might act individually, though probably synergistically, to impart beneficial effects on energy balance and body mass regulation through actions related to appetite, eating behaviour and metabolism. However, there is little mechanistic exploration of cow's milk consumption and appetite regulation from a paediatric perspective. Understanding the relationship between cow's milk consumption and appetite regulation could provide novel nutritional interventions to contribute toward the fight against childhood overweight and obesity[121], whilst bolstering nutritional status and improving elements of cognitive function and hydration. Controlled intervention studies are necessary to determine the best possible timings to administer cow's milk and establish whether consumption delivers these benefits when administered during the school day.

Collectively, the effects of cow's milk intake on appetite regulation in primary-school aged children are unclear and could be dependent on BMI. The studies summarised suggest that mid-morning milk consumption influences eating behaviour at the next meal in overweight and obese children, showing that cow's milk could be beneficial for reducing body mass. In lean children, the evidence suggests there is no effect of cow's milk consumption on appetite and eating behaviour, but cow's milk may boost the nutritional quality of the diet. There is much scope for further studies to clarify the role of cow's milk on appetite and eating behaviour, especially in a free-living school environment where methodological approaches are more reflective of habitual eating behaviours. In addition, it will be important to fully distinguish the effects of cow's milk on appetite- and on metabolism-related peptides and subsequent eating behaviour.

Cognitive Function

Compared to children with better dietary quality, those with nutritional inadequacies demonstrate decreased attention and academic performance[122]. Aside from improving nutritional status and dietary quality, emerging evidence illustrates that cow's milk may positively influence cognitive function in primary-school children[43, 123, 124]. Varying in duration from 2 hours to 9 months, studies of an intervention-based nature generally report that cow's milk consumption increases elements of cognitive function, though some of the specific outcome measures demonstrate no effect or in some cases a negative effect of cow's milk. These studies highlight that consideration should be given to potential moderators such as sex and to the use of cow's milk as a non-stigmatised method for providing nutrients through fortification[125]. One non-interventional study considered the adherence of n = 1595 children to Canadian nutrition recommendations in Grade 5 (10-11 years) and in relation to academic achievement in the provincial achievement tests taken approximately one year later[126]. A positive association was identified for boys, with those who met the nutrition recommendations for milk and alternatives (at the time of the study: 3-4 servings per day) scoring 3.45 % better on an average measure of Math and Language Arts tests than those who did not meet the recommendations[126]. An account of the intervention studies follows, but overall, the varying methodological approaches used suggests caution is needed in making firm conclusions about potential links between cow's milk consumption and improved cognitive function.

In a study[124] involving n = 469 boys and girls (mean age = 8 years), evaluating the effects of daily mid-morning cow's milk consumption on physical, mental and school performance, researchers found that a school feeding scheme focusing on daily cow's milk intake had beneficial effects on school performance for girls. In this study, children received a serving of cow's milk (250 mL) daily for 12 weeks. Assessments of physical, mental and school performance were conducted prior to and at the end of the 12-week supplementation period. Similarly, in a smaller study[123] involving 40 children (mean age 11 years), the effects of a carbohydrate drink, a cow's milk drink or a combination of both on subsequent cognitive function (processing speed, memory, attention and perceptual speed) was assessed over a 3 hour period[123]. Findings showed cow's milk consumption improved short-term memory. Children were able to recall 0·7–0·8 more words compared with 0·5 fewer words after the carbohydrate drink. However, this effect was only observed in girls and not boys[123, 124]. There were slightly more mixed findings from a crossover study in which 84 children (mean age 10 years) were given 237 mL of cow's milk or apple juice[127]. While the beverages were not standardised for temperature, participants were asked to complete computerised tasks of inhibitory control, speeded working memory and sustained attention at baseline and 30-, 90- and 120-min following beverage consumption. Although the significant results following cow's milk compared to juice consumption were, again, only apparent in girls, there was a negative effect (decreased working memory accuracy) alongside the positive one (improved reaction time on the sustained attention task). There were non-significant trends in the opposite direction for boys. No significant effects of the beverages were observed for on-task behaviour during the testing.

The mechanisms responsible for the beneficial effects of cow's milk on improved cognitive function are unclear. One suggestion is a sustained blood glucose response following consumption[128, 129]. Findings from Anderson et al.[127], an adult-based study, suggest that glucoregulation may play a role as participants with higher fasting glucose levels demonstrated faster reaction times on an inhibition task following cow's milk compared to juice. There were however no sex differences in initial glucose elevation or change in glucose levels over time to explain the apparent sex differences in cognition. Such findings suggest a likelihood that factors other than glucoregulation will explain why cow's milk differentially affects the cognition and behaviour of boys and girls. The micronutrient content of cow's milk is another potential mechanism for the observed effects[43]. Low intakes of vitamin B_1, folate and vitamin B_{12} affect short-term memory and impair learning, causing low cognitive scores and development in primary-school age children[130]. In addition, low iron and riboflavin intake may adversely affect motor skill development and psychomotor performance[131]. All of these micronutrient are heavily present in cow's milk. In one of the longer intervention-based studies available (5 months), Kuriyan and colleagues[43] attempted to establish if fortification of cow's milk with multiple micronutrients influenced the mental and physical performance of children (7-10 years) compared to an unfortified cow's milk drink. The children were randomised into groups and were provided with cow's milk (2 x 200 mL) 6 days a week for 5 months, with assessments of attention and executive function conducted at baseline and 5 months. The findings showed improved cognitive and physical performance in both groups, illustrating that further fortification of cow's milk provided no additional benefits to cognitive and physical performance but did improve some elements of nutritional status[39]. Finally, in a double-blind RCT (9 months), the learning potential of 7-9-year-olds (31.9 % with a moderate or severe iodine deficiency at baseline) improved to a greater degree following 200 mL daily of fortified cow's milk (fortified with 45 µg iodine (given as potassium iodide) and other micronutrients) than following nonfortified milk (20.8 µg iodine)[132].

Some of the components of cow's milk may be detrimental for the cognitive performance of lactase deficient children. In a study involving children of 5-6 years (85 % lactase deficient), information processing efficiency was assessed after 5 days' consumption of 150mL twice daily of conventional cow's milk (containing A1 and A2 β-casein) or cow's milk containing A2 β-casein only[133]. While post-intervention response times were significantly improved from baseline for both cow's milk products, error rates reduced in the A2 β-casein only condition. Furthermore, consuming conventional cow's milk in the second phase of the crossover study appeared to undo the positive effects on error rate obtained from the A2 β-casein only milk in the first phase, which were maintained through the 9 day washout period.

It is prudent to highlight that none of the studies of cognition in primary-school children have compared cow's milk to a control beverage. It is therefore difficult to ascertain whether these studies simply show less detrimental effects of cow's milk than comparator beverages. Furthermore, where no comparators have been employed this could reflect practice effects. Nonetheless, based on the published studies, and bearing in mind the varying methodological approaches employed, it is difficult to ascertain the role of cow's milk in cognitive function for primary-school aged children but it may at the very least be a useful conduit for nutrient fortification. This could be particularly meaningful within the school environment. The intervention studies did not measure academic achievement directly, but their findings have relevant scholastic implications that warrant further investigation using RCTs to establish if increased milk consumption influences academic achievement in primary-school aged children. This is especially so given the identification of a positive association for boys between academic achievement and meeting the recommendations for consumption of milk and alternatives[126].

Future Directions and Conclusions

The aim of this narrative review was to evaluate evidence for the potential nutritional-, physical- and health-related benefits of cow's milk consumption for primary-school aged children (4-11 years). Cow's milk consumption (both plain and flavoured) improves nutritional status without adversely impacting on body mass and body composition[35]. With some confidence, cow's milk also appears beneficial for hydration, dental and bone health and to have a beneficial to neutral effect concerning physical stature and appetite. Due to conflicting studies, reaching a conclusion has proven difficult concerning cow's milk and cognitive function therefore a level of caution should be exercised when interpreting these results. All areas, however, would benefit from further robust investigation, especially in free-living school settings, to verify conclusions. Improving elements of cognitive function, hydration and appetite regulation could have important long-term health and scholastic implications that should certainly be explored further. Indeed, recent research involving adolescent populations illustrates that high intakes of cow's milk are positively associated with academic performance[134], increased motivation for learning[134] and impact favourably on eating behaviour following acute and chronic consumption[135].

Despite a growing body of scientific literature exploring the potential benefits of cow's milk consumption, there are several pertinent knowledge gaps that would benefit from further investigation. This is particularly true for cognitive function, hydration status and appetite regulation, where there is little research available, especially in free-living school settings. Further research, especially of a robust and methodologically sound nature (such as double-blind randomised controlled trials), should seek to explore the mechanisms responsible for any effects observed. At present, few studies on this population have attempted to establish mechanisms. Most purported mechanisms given throughout this narrative review come from adult-specific data and should therefore be interpreted with some caution as the observations cited may not always be replicated in children. When working with child populations there are various considerations that must be accounted for. The methodological approaches deemed most appropriate for the study of cognitive function, hydration status and appetite regulation in children will differ according to the objective of the study, type of data required, and resources available[136]. In children, it is of great importance to adopt approaches that are non-invasive with a low level of participant stress. Current techniques available to assess cognitive function, hydration status and appetite are arguably invasive, elicit a moderate level of participant stress and increased ethical risk. This might explain the current lack of studies and mechanistic insight from a child perspective. In recent years, however, research groups have been pursuing non-invasive techniques that offer an opportunity to conduct comprehensive mechanistic work in vulnerable populations. For example, developments in appetite and metabolism research have identified fingertip-capillary blood sampling as an efficacious, comparable and reproducible alternative to antecubital-venous blood sampling for the quantification of appetite-related peptides[137, 138]. These developments will certainly help provide a better understanding of mechanisms that influence appetite and eating behaviour in younger populations, where traditional methods of venous blood sampling might be contraindicated. Furthermore, fingertip-capillary blood sampling offers many advantages including simplistic application, cost/time effectiveness and reduced volume of blood required for analysis[139].

Considering the nutritional-, physical- and health-related impact of cow's milk avoidance, the evidence begins to highlight the importance of increasing cow's milk consumption. Cow's milk is a naturally nutrient-dense foodstuff, providing a significant contribution of several essential nutrients and bioactive constituents that potentially impact human health favourably. Establishing and shaping healthy eating behaviours during the primary-school years is vital. Dietary behaviours shaped throughout the childhood years progress through to adolescence and adulthood[(140)], making healthy eating environments crucial. For primary-school aged children, the school setting may be an ideal environment to promote cow's milk consumption, and school milk schemes are a great place to start developing healthy eating behaviours given 35 % to 40 % of children's daily nutritional needs are met at school[(141)]. Cow's milk is a readily available, accessible and affordable means of providing valuable essential nutrients to the diets of primary-school children. Based on the evidence presented in this manuscript, there appears no reason for primary-school children to limit cow's milk consumption and there may, in fact, be many potential benefits to milk consumption.

Author Contributions

Benjamin Green and Penny Rumbold conceived and planned this narrative review. Penny Rumbold, Nicola McCullogh, Ruth Boldon and Benjamin Green sourced the relevant literature. All authors contributed to the writing and critically reviewed and approved the final manuscript.

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Conflicts of Interest

Penny Rumbold has previously received funding from The Dairy Council (UK), Nourishmenow and Cool Milk Ltd. Benjamin Green has previously been supported by The Dairy Council (UK) in the award of a PhD studentship and has received funding from Cool Milk Ltd and is presently an employee of Danone Specialised Nutrition. Lewis James has previously received funding from Volac International Ltd. Emma Stevenson has previously received funding from The Dairy Council (UK) and Arla Food Ingredients. Collectively, the above (with the exception of Cool Milk Ltd) was not related in any way to the work presented in this article. Nicola McCullogh, Ruth Boldon and Crystal Haskell-Ramsay declare no conflicts of interest.

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Table 1.0 Nutritional composition of cow's milk

Per 100 g	Whole milk	Semi-Skimmed milk	Skimmed milk	Flavoured milk*
Energy (kJ)	274	195	144	270
Protein (g)	3.3	3.5	3.5	3.6
Carbohydrate (g)	4.6	4.7	4.8	9.6
of which sugars (g)	4.6	4.7	4.8	8.9
Fat (g)	3.9	1.7	0.3	1.5
of which saturates	2.5	1.1	0.1	1
monounsaturates	1	0.4	0.1	0.3
polyunsaturates	0.1	Trace	Trace	0.1
trans fatty acids	0.1	0.1	Trace	Trace
Thiamin (mg)	0.03	0.03	0.03	0.03
Niacin (mg)	0.2	0.1	0.1	0.1
Niacin from Tryptophan (mg)	0.6	0.6	0.7	0.8
Calcium (mg)	118	120	125	120
Riboflavin (mg)	0.23	0.24	0.22	0.17
Vitamin B6 (mg)	0.06	0.06	0.06	0.03
Vitamin B12 (µg)	0.6	0.9	0.8	0.1
Folate (µg)	8	9	9	2
Vitamin D (µg)	Trace	Trace	Trace	Trace
Biotin (µg)	2.5	3.0	2.5	2.2
Pantothenate (mg)	0.6	0.7	0.5	0.3
Vitamin C (mg)	2	2	1	Trace
Retinol (µg)	30	19	1	20
Carotene (µg)	19	9	Trace	8
Sodium (mg)	43	43	44	52
Potassium (mg)	155	156	162	168
Magnesium (mg)	11	11	11	12
Phosphorus (mg)	93	94	96	102
Zinc (mg)	0.4	0.4	0.5	0.4
Copper (mg)	Trace	Trace	Trace	Trace
Selenium (µg)	1	1	1	N/A
Manganese (mg)	Trace	Trace	Trace	Trace
Iodine (µg)	31	30	30	N/A

Note: N/A = values not available for this food; Trace = nutrient is present in less than 0.1g per 100g. *Data taken from a sample of strawberry and banana flavoured sugar sweetened milk.
Adapted from the Dairy UK. Available at: http://www.milk.co.uk/publications/default.aspx

Table 2. Percentage contribution of cow's milk to average daily total energy, macro- and micro-nutrient intake overtime by sex and age

	NDNS Rolling Programme Years 1-2; 2009/10				NDNS Rolling Programme Years 3-4; 2011/12				NDNS Rolling Programme Years 5-6; 2013/14				NDNS Rolling Programme Years 7-8; 2015/16	
	4-10 years		11-18 years		4-10 years		11-18 years		4-10 years		11-18 years		4-10 years	11-18 years
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Combined	Combined
Energy	8	8	4	4	7	7	5	4	8	7	4	4	7	4
Protein	14	12	8	7	13	12	9	8	13	13	10	7	11	8
Carbohydrate	5	5	4	3	5	5	4	3	5	5	4	3	5	4
Fat	9	10	6	5	9	10	6	4	10	11	6	4	9	6
Saturated fat	17	16	8	9	15	14	9	7	16	17	9	8	14	9
trans fatty acids	14	12	8	8	19	19	14	11	20	21	14	12	17	13
Vitamin A	11	10	7	7	10	10	9	4	12	12	9	7	11	9
Calcium	31	29	21	22	29	27	22	19	29	29	23	20	26	22
Riboflavin	32	29	22	21	28	29	23	20	29	31	23	18	25	19
Vitamin D	0	0	0	0	1	0	0	0	0	1	0	0	1	1
Sodium	5	4	3	4	6	5	3	2	6	6	3	4	6	4
Potassium	16	15	9	9	14	13	11	10	15	16	11	8	14	9
Magnesium	12	10	8	8	11	10	8	7	11	12	8	7	10	7
Zinc	14	13	8	9	13	13	9	8	13	13	10	8	12	8
Iron	1	1	0	1	1	0	1	0	1	1	1	1	1	1
Selenium	6	5	3	3	5	5	3	3	5	5	3	3	4	3
Folate	9	8	4	5	8	7	5	5	8	9	6	4	7	5
Iodine	40	38	30	30	37	37	32	28	39	28	34	27	37	30

Note: Percentage contribution information taken from National Diet and Nutrition Survey (NDNS) rolling programme. Percentage contributions for Vitamin B_6, Vitamin B_{12}, Vitamin C and Phosphorus are not reported in the NDNS. * The NDNS rolling programme for 2015/16 (https://www.gov.uk/government/statistics/ndns-results-from-years-7-and-8-combined) stopped providing sex specific intake data so the data are presented as boys and girls combined.

Table 3 Studies in primary-school aged children that measured nutritional status and hydration with cow's milk consumption

Reference	Details	Design	Methodological approach	Results and conclusion	Effect
Nutritional Status					
Cook et al. (1975)[38]	n 312 (159 boys) Age: 8-11 years United Kingdom	Observational	7 day diet record	Nutrient intake was higher in children drinking school milk every day than non-consumers. Boys: energy ($P < 0.05$), protein ($P < 0.01$), fat ($P < 0.05$), calcium ($P < 0.001$), thiamin ($P < 0.01$) and riboflavin ($P < 0.001$) intakes higher than non-consumers Girls: energy ($P < 0.001$), protein ($P < 0.001$), fat ($P < 0.01$), calcium ($P < 0.001$), thiamin ($P < 0.001$) and riboflavin ($P < 0.001$) intakes higher than non-consumers	↑ ↑ ↑
LaRowe et al. (2007)[39]	n 793 (410 boys) Age: 6-11 years United States	Observational	24 hour dietary recalls collected during NHANES 2001-2002.	General linear models showed children clustered as high-fat milk consumers had higher ($P < 0.05$ for all) intakes of energy, protein, riboflavin, folate, vitamin A, vitamin C and calcium compared to clusters of water, SSB, soda and mix/light drinks	↑
Albala et al. (2008)[44]	n 98 (56 boys) Age: 8-10 years Chile	Randomised, control trial	16 week intervention. Children drank 3 servings/d of flavoured milk or control (no drink)	Protein and calcium intakes increased ($P = 0.0001$) and energy intake decreased ($P = 0.009$) with milk compared to controls	↑
Murphy et al. (2008)[40]	n 2097 (1061 boys) Age: 6-11 years United States	Observational	24 hour dietary recalls collected during NHANES 1999-2002. Participants grouped by age (2-5 years; 6-11 years; 12-18 years).	Calcium, phosphorus, magnesium, potassium, and vitamin A intakes comparable between plain and flavoured milk consumers Calcium, phosphorus, magnesium, potassium, and vitamin A intakes significantly higher ($P < 0.05$ for all) with milk consumption (plain and flavoured) compared to non-consumers	↔ ↑

Lien et al. (2009)[45]	n 454 (217 boys) Age: 7-8 years Vietnam	Double-blind, intervention	Volume matched drink (250 mL) served twice daily (morning), 6 days per week for 6 months: (a) multi-micronutrient fortified milk (b) unfortified milk (c) control (no drink)	Intakes of energy, protein, fat, sugar and vitamin A increased (P < 0.05 for all) after 6 months in conditions (a) and (b) and compared with condition (c) Serum ferritin and zinc increased (P < 0.05 for all) after 6 months in conditions (a) and (b) and compared with condition (c) Zinc levels however also increased in condition (c) (P < 0.05)	↑ ↑
Wang et al. (2012)[42]	n 632 Age: 8-10 years Canada	Observational	3 24 hour diet recalls	FM drinkers had a higher mean intake for calcium (930 vs. 837 mg; P = 0.010), Vitamin D (6.9 vs. 5.9 µg; P = 0.021) and total sugar (99 g vs. 90 g, P = 0.015) than non-consumers	↑
Rangan et al. (2013)[41]	n 222 (121 boys) Age: 8-10 years Australia	Observational	3 non-consecutive 24 hour diet recalls	Milk (and dairy) intake significantly associated with increased intake of energy (P < 0.001), protein (P = 0.02), calcium (P < 0.001), phosphorus (P < 0.001), magnesium (P < 0.001), potassium (P = 0.009), zinc (P = 0.019), vitamin A(P < 0.001), riboflavin (P < 0.001), and niacin (P = 0.03)	↑
Campmans-Kuijpers et al. (2016)[37]	n 1007 (504 boys) Age: 7-13 years Netherlands	Observational	Two non-consecutive 24 hour dietary recalls with an interval of 2 to 6 weeks	Higher milk consumption was associated with significantly higher intakes of energy (P = 0.003), protein (P < 0.0001), fat (P = 0.03), fibre (P = 0.02), calcium (P < 0.0001), folate (P < 0.0001), iodine (P < 0.0001), potassium (P < 0.0001), magnesium (P < 0.0001), phosphorus (P < 0.0001), selenium (P = 0.002), zinc (P < 0.0001) and vitamins B_1 (P < 0.0001), B_2 (P < 0.0001) and B_{12} (P < 0.0001)	↑
Kuriyan et al. (2016)[43]	n 225 (52 boys) Age: 7-10 years India	Double-blind, randomised placebo-controlled	Volume matched drink (200 mL) served twice daily (morning and afternoon), 6 days per week for 5 months: (a) multi-micronutrient fortified milk	At the end of the intervention, levels of blood Vitamin B_{12}, and riboflavin were significantly different (P < 0.001) between the study groups, in favour of the fortified milk group	↑ ↔

			(b) unfortified milk	Vitamin D, selenium and body iron showed no difference with either group	
Hydration					
Montenegro-Bethancourt et al. (2013)[57]	n 442 (309 boys) Age: 4-10 years, Germany	Observational	DONALD Study 3 day weighed dietary records	Milk consumption significantly increased FWR ($P < 0.05$) by 25 mL in boys and 33 mL in girls per 100 g of intake	↑
Volterman et al. (2014)[59]	n 38 (19 boys) Age: 7-11 years and 14-17 years, Canada	Randomised, repeated-measures cross-over	3 exercise sessions in 34.5 °C (2 × 20-min cycling bouts at 60% peak oxygen uptake) followed by consumption of: (a) plain water (W) (b) a carbohydrate/electrolyte solution (CES) (c) skimmed milk (SM)	Fraction of ingested beverage retained at 2 hour of recovery was greater with SM (74% ± 18%) than W (47% ± 26%) and CES (59% ± 20%, $p < 0.001$ for both), and greater in CES than water ($p < 0.001$)	↑
Volterman et al (2016)[58]	n 15 (7 boys) Age: 10-12 Canada	Randomised, counterbalanced crossover design	45 min of alternating running and cycling exercise in 34.5 °C followed by consumption (150% of body mass loss) of isocaloric and electrolyte-matched beverages containing: (a) 0 g (control), (b) 0.76 g (Lo-PRO) (c) 1.5 g (Hi-PRO) of milk protein/100 mL	Less negative fluid balance at 2 hour of recovery after consumption of Hi-PRO vs. CONT ($P = 0.01$) Compared with CONT, beverage retention was enhanced by Hi-PRO at 2 h ($P < 0.05$)	↑ ↑

Abbreviations in order of appearance: FM = flavoured milk; NHANES = National Health and Nutrition Examination Survey; SSB = sugar sweetened beverage; FWR = free water reserve; W = water; CES = carbohydrate/electrolyte solution; SM = skimmed milk; Lo-PRO = low protein; Hi-PRO = high protein.

Table 4 Studies in primary-school aged children that measured dental health, bone health and physical stature with cow's milk consumption

Reference	Details	Design	Methodological approach	Results and conclusion	Effect
Dental Health					
Petti et al. (1997)[74]	n 439 (217 boys) Age: 6-11 years Italy	Descriptive cross-sectional	24 hour diet diary, oral examination using Plaque Index and number of decayed, extracted or filled teeth	Milk consumption significantly reduced the probability of carries ($P < 0.05$); greater significance in high-sucrose (<4/day) consuming children ($P < 0.01$)	↑
Levine et al. (2007)[72]	n 315 Age: 7-11 years England	Prospective cohort/cross-sectional	Three-day dietary diary, tooth brushing habits, dental examination using BASCD survey	Significantly ($P < 0.05$) less caries associated with moderate consumption (1-2/day) of milk (and dairy) products by children aged 11-15 years	↑
Llena & Forner (2008)[73]	n 369 (220 boys) Age: 6-10 years Spain	Descriptive cross-sectional	Food frequency questionnaire, one dental examination for caries and fillings	No significant impact of milk on the incidence of carries	↔
Curtis et al. (2018)[75]	n 392 (183 boys) Age: 0-19 years United States	Longitudinal, observational	Dietary questionnaires at six-month intervals, cavities assessed age 5, 9, 13 and 17 years	Higher milk intake associated with lower expected adjusted decayed and filled surface increments, however, was not significant	↑
Bone Health and Physical Stature					
Cook et al. (1979)[36]	n 1210 (581 boys) Age 6-7 years United Kingdom	Prospective cohort	Free school milk consumed (190 mL/d at school) vs control; height gain	Significantly greater height gain in the milk group in Scottish females ($P < 0.05$) No difference in males or any groups in England	↑ ↔
Rona & Chinn (1989)[98]	n 670 Age 5-11 years United Kingdom	Prospective cohort	Free school availability (190 mL/d at school) vs unavailable; change in standardised height score	Significantly greater increments in standardised height scores in 'milk available' group after 2 years in Scotland ($P < 0.05$) No difference in England	↑ ↔
Baker et al. (1980)[94]	n 581 (267 boys) Age 7-8 years United Kingdom	Randomised, control trial	12 month intervention; 190 mL/d of milk at school vs control; height gain	Significantly greater height gain in milk group than control ($p < 0.05$)	↑
Chan et al. (1995)[84]	n 48 females Age: 9-13 years USA	Randomised control trial	12 month intervention; ≥ 1200 mg/d calcium from dairy vs control; DXA of total body bone mineral content	Greater gain in total body bone mineral content in dairy calcium group ($P < 0.001$)	↑

Bonjour et al. (1997)[83]	n 149 females Age: 6-10 years Switzerland	Randomised control trial	12 month intervention; 850 mg/d milk-extracted calcium vs placebo; DXA of regional bone mineral content, height gain and change in lumbar spine length	Greater increment in six-site mean bone mineral content in supplementation group ($P < 0.05$). At 1 year follow-up greater increment in femoral shaft bone mineral content ($P < 0.02$) No difference in height though significance approached ($P \leq 0.08$) favouring supplement group Significant difference in lumbar spine length following intervention and 1 year follow up ($P \leq 0.05$)	↑ ↔ ↑
Black et al. (2002)[25]	n 250 (120 boys) Age 3-10 years New Zealand	Cross-sectional	Food frequency questionnaire, and DXA of total body and regional bone mineral content and height	Milk avoiders had significantly lower total body bone mineral content than age, sex-matched controls ($P < 0.01$) Milk avoiders significantly shorter than control children of the same age and sex ($P < 0.01$)	↑ ↑
Du et al. (2004)[85]	n 757 (girls) Age 10-12 years China	Randomised control trial	24 month intervention; 330 mL fortified milk (560 mg calcium) / school day vs 300mL fortified milk (560 mg calcium) and 5 or 8 µg cholecalciferol / school day vs control group. DXA of regional and total body bone mineral content with stature assessed pre, mid and post-trial	Greater increase in total-body bone mineral content (> 1.2%) and bone mineral density (> 3.2%) in milk groups compared to control Significantly greater % change in height in milk supplement groups compared to control group ($P < 0.005$)	↑ ↑
Goulding et al. (2004)[86]	n 50 (20 boys) Age: 3-10 years New Zealand	Observational longitudinal	Milk avoiders vs birth cohort population, DXA of total body and regional bone mineral content, history of bone injuries, estimation of calcium intake	Greater number of children reporting fractures and increased total fractures in milk-avoidance compared to control ($P < 0.001$)	↑
Rockell et al. (2005)[29]	n 46 (18 boys) Age 5-12 years New Zealand	Cross-sectional, longitudinal	Food frequency questionnaire, four-day food diary and DXA of total body bone mineral content and stature	Increase in total body bone mineral content in prior milk avoiders when milk consumption had increased ($P < 0.05$) but remained lower than none milk avoiders	↑

Wiley (2005)[99]	n 2592 Age 5-11 year United States	Cross-sectional	24 hour recall, milk frequency in past 30 day; height and adult height	Milk intake not associated with height at age 5-11 years (P = 0.385)	↔
Iuliano-Burns et al. (2006)[87]	n 99 (58 boys) Age 5-11 yearrs Austria	Randomised control trial	10 month intervention; 800 mg/d of calcium from $CaCO_3$ vs 800 mg/d of calcium from milk vs placebo, DXA or total and regional bone mineral content	Greater gain in pelvic bone mineral content in pre-pubertal children vs. controls at 10 months in the milk mineral group (P < 0.02) but not biologically meaningful	↔
Albala et al. (2008)[44]	n 98 (56 boys) Age: 8-10 years Chile	Randomised, control trial	16 week intervention; Children drank 3 servings/d of flavoured milk or control (no drink)	Significantly greater increase (P = 0.01) Smaller increase in height in females in intervention group vs control (P = 0.10)	↑ ↔
Zhou et al. (2011)[88]	n 435 (188 boys) Age 10-12 years China	Retrospective cohort	School milk group (1 year, 4/wk or 3 year, 1-3/wk) vs. 'seldom milk' group, ulna bone mineral content	Greater ulna bone mineral content in school milk group (P < 0.001)	↑
Guo et al. (2020)[95]	n 41,439 (19,618 boys) Age 6-17 years China	Cross-sectional	Validated questionnaire assessing milk intake classified as low, medium and high; stature	Milk intake not associated with stature (P > 0.05)	↔

Abbreviations in order of appearance: DXA = dual energy X-ray absorptiometry; $CaCO_3$ = calcium carbonate.

Table 5 Studies in primary-school aged children that measured appetite and cognitive function with cow's milk consumption

Reference	**Details**	**Design**	**Methodological approach**	**Results and conclusion**	**Effect**
Appetite Regulation					
Rumbold et al. (2013)[111]	n 25 (11 boys) Age: 9-10 years United Kingdom	Randomised controlled cross-over	Energy matched (0.3 MJ) preloads during school mid-morning break: (a) 160 mL of semi-skimmed milk (b) 153 g of apple	Boys and girls felt less hunger and expressed a lower desire to eat when apple was consumed compared to semi-skimmed milk (P = 0.02) Energy intake comparable at lunch between semi-skimmed milk and apple (P > 0.05)	↓ ↔
Mehrabani et al. (2014)[110]	n 34 (obese boys) Age: 10-12 years Iran	Three-way repeated measure randomised controlled cross-over	Volume matched preloads with breakfast (all 240 mL): (a) low fat milk (1.5 %) (b) apple juice (isoenergetic control) (c) water (control)	Energy intake lower at lunch following low fat milk consumption compared to water (*P*<0.005) and apple juice (*P*<0.05)	↑
Vien et al. (2014)[112]	Normal and overweight children Mean age: 11.5 years Av age: 11.5 years Canada	Not stated	Volume (250 mL) and energy matched (130 kcal) with the exception of water given pre- and within meals: (a) 1 % fat (1 g/100 g) flavoured milk (b) 2 % fat (2 g/100 g) milk (c) 1.5 % fat (1.5 g/100 g) yogurt drink (d) fruit punch (e) water	*Experiment 1* Energy intake lower after chocolate milk and yogurt (P < 0.01) compared to water Post-meal SA was lower after milk than yogurt (P < 0.01) Post-meal SA was lower after milk than fruit punch (P < 0.01) *Experiment 2* GLP-1 AUC was higher after milk than fruit punch and in OWOB compared to NW children (P < 0.03). Post-prandial drop in ghrelin was greater after milk than fruit punch in OWOB children (-24 vs. -14%) but was not significant (P = 0.06)	↑ ↑ ↑ ↑ ↔ ↔

				Energy intake, insulin and glucose AUC were comparable between all preloads (P > 0.05)	
Mehrabani et al. (2016)[109]	n 34 obese boys Age: 10-12 years Iran	Three-way repeated measure randomised controlled cross-over	Volume matched preloads with breakfast (all 240 mL): (a) low fat milk (1.5 %) (b) apple juice (isoenergetic control) (c) water (control)	Higher satiety scores after drinking low fat milk with breakfast compared with water and apple juice (P < 0.05) Energy intake lower at lunch following low fat milk compared to water (P < 0.001) and apple juice (P = 0.03)	↑ ↑
Cognitive Function					
Rahmani et al. (2011)[124]	n 469 (230 boys) Av age: 8 years Iran	Case-control population-based intervention	Drink at morning school break: (a) tetra-pack sterilised and homogenised milk (250 mL) (b) control (no milk supplementation)	Grade-point average increased from pre- to post-test in girls with milk (P < 0.05) No change for the control group, nor for either of the groups of boys. Mean IQ after milk was better in boys compared to boys at post-test in the control (P < 0.05)	↑ ↔ ↑
Brindal et al. (2013)[123]	n 40 (19 boys) Age: 10-12 years, Australia	Double-blind, randomised three-way repeated measures crossover	Volume matched (455 mL) morning drink following ≥ 8 hours fasting: (a) glucose beverage (b) full milk beverage (c) half milk/glucose beverage	No effect of beverage type in speed of processing, working memory, short-term memory, attention switching, perceptual speed and inspection time No interactions between beverage type and timing of the cognitive testing (60, 120 and 180 minutes post-drink) In the conditions with milk, girls recalled 0·7–0·8 more words but in the glucose condition they recalled 0·5 fewer words (P = 0.014). For boys, no difference between beverages was found (*P*>0.09). Sex differences identified for change in word recall after full milk (P < 0.001) and half	↔ ↔ ↑ ↔ ↔

				milk/glucose (P < 0.001) conditions: girls showed an increase and boys showed a decrease	
Kuriyan et al. (2016)[43]	n 225 (52 boys) Age: 7-10 years India	Double-blind, randomised placebo-controlled design	Volume matched drink (200 mL) served twice daily (morning and afternoon), 6 days per week for 5 months: (a) multi-micronutrient fortified milk (b) unfortified milk	No group × time interaction for short-term memory and executive functions from baseline	↔
Zahrou et al. (2016)[132]	n 200 Age: 7-9 years Morocco	Double-blind, controlled design	Volume matched (200 mL) drink served daily at school for 9 months, including weekends: (a) fortified milk; added potassium iodide and other micronutrients (b) non-fortified milk	Fortified milk group performed significantly better than the non-fortified milk group (*P*=0.02) on a dynamic testing procedure designed to assess children's learning potential	↔
Faught et al. (2017)[126]	*n* 1595 (732 boys) Age: 10-11 years Canada	Observational	Analysis of secondary data (food frequency questionnaire) from a 2012 population-based survey using a stratified random sampling design	Boys meeting the nutrition recommendations for milk and alternatives (3-4 servings per day) scored 3.45 % better on an average measure of Math and Language Arts standardised provincial achievement tests than those not meeting the recommendations (*P*=0.02)	↑
Petrova et al. (2019)[125]	n 103 (52 boys) Age: 8-14 years Spain	Double-blind, randomised controlled design	Volume matched (200 mL) drink served three times per day for 5 months: (a) fortified milk beverage; added micronutrients and essential fatty acids (b) regular full milk	Greater baseline to post-intervention increases in working memory capacity in the fortified milk group (32 % increase) compared to the regular milk group (13 % increase) (P = 0.027)	↔
Sheng et al. (2019)[133]	n 75 (42 boys) Age: 5-6 years China	Double-blind, multicentre randomised controlled parallel crossover	Volume matched (150 mL) drinks consumed twice daily following meals for 5 days: (a) conventional milk, containing A1 and A2 β -casein (b) milk containing only A2 β-casein	Subtle Cognitive Impairment Test improved following both conventional milk (P < 0.014) and milk containing only A2 β-casein (P < 0.002) No difference in Subtle Cognitive Impairment Test between drinks	↔ ↔ ↔

				Consumers of conventional milk in phase 1 and milk containing only A2 β-casein in phase 2, no effect on error rates in phase 1 (P = 0.101) but a decrease in error rates in phase 2 (P < 0.001) Consumers of milk containing only A2 β-casein in phase 1 and conventional milk in phase 2, there was a decrease in the error rate in phase 1 which continued through the washout period (P < 0.001), but error rates then increased in phase 2 (P < 0.001)	↓
Anderson et al. (2020)[127]	n 84 (39 boys) Age: 8-12 years, United States	Randomised counterbalanced crossover	Volume matched (237 mL) morning drink following ≥ 8 hours' fasting: (a) 1% fat milk (b) apple juice	*Inhibitory control* Reaction time significantly faster after milk compared to apple juice ($P<0.05$) No effect of beverage on accuracy *Speeded working memory* No difference between the beverages on reaction time (P = 0.45) Sex × beverage interaction for accuracy (P = 0.003); compared to apple juice, milk decreased performance accuracy for females whereas non-significant increase in accuracy for males *Sustained attention* Sex × beverage interaction (P = 0.02); compared to apple juice, milk significantly improved reaction time for females whereas reaction time decreased in males (though not significantly)	↑ ↔ ↔ ↑↔ ↑↔

Abbreviations in order of appearance: SA = subjective appetite; GLP-1 = glucagon like peptide-1; OWOB = overweight and obese; NW = normal weight; AUC = area under the curve; IQ = intelligence quotient