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Bovine Colostrum Supplementation and Exercise Performance

Potential Mechanisms

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Abstract

Bovine colostrum (BC) is rich in immune, growth and antimicrobial factors, which promote tissue growth and the development of the digestive tract and immune function in neonatal calves. Although the value of BC to human adults is not well understood, supplementation with BC is becoming increasingly popular in trained athletes to promote exercise performance. The combined presence of insulin-like growth factors (IGF), transforming growth factors, immunoglobulins, cytokines, lactoferrin and lysozyme, in addition to hormones such as growth hormone, gonadotrophin-releasing hormone, luteinizing hormone-releasing hormone and glucocorticoids, would suggest that BC might improve immune function, gastrointestinal integrity and the neuroendocrine system, parameters that may be compromised as a result of intensive training. A review of studies investigating the influence of BC supplementation on

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exercise performance suggests that BC supplementation is most effective during periods of high-intensity training and recovery from high-intensity training, possibly as a result of increased plasma IGF-1, improved intramuscular buffering capacity, increases in lean body mass and increases in salivary IgA. However, there are contradicting data for most parameters that have been considered to date, suggesting that small improvements across a range of parameters might contribute to improved performance and recovery, although this cannot be concluded with certainty because the various doses and length of supplementation with BC in different studies prevent direct comparison of results. Future research on the influence of BC on sports performance will only be of value if the dose and length of supplementation of a well-defined BC product is standardized across studies, and the bioavailability of the active constituents in BC is determined.

1. Bovine Colostrum

Bovine colostrum (BC) is the milk produced by cows in the first days after parturition. BC is rich in immune, growth and antimicrobial factors that are homologous to those found in human colostrum but expressed in greater concentrations.[1] The concentrations of bioactive components are greatest in the first milkings with concentrations decreasing over the subsequent 3 days.[2-5] For this reason, colostrum produced on the first day of calving is considered superior in quality to that produced in the later days of lactation.

BC provides passive transfer of immunity to the newborn calf whose immune system is not fully developed at birth, and a source of growth factors to contribute to the development of the digestive tract.[6] Immune factors such as immunoglobulins, cytokines, lactoferrin and lysozyme are found in colostrum while the predominant growth factors are insulin-like growth factors (IGFs) and transforming growth factors (TGFs). Immunoglobulins make a significant contribution to the protein content of colostrum and the concentration of IgG is up to 100 times greater than the concentration found in normal milk.[7] IgG is able to bind complement, a complex group of immune proteins, to directly lyse infected cells. It can also enhance cytotoxic activity of natural killer cells and phagocytosis by binding to macrophages and neutrophils.[8] BC also contains a number of cytokines that are important in stimulating the calf immune system and are also important messengers within the human immune system.[9] Of the growth factors contained in BC, the most prevalent is IGF-1 (reported at concentrations of 50–2000 μg/mL),[10] which has an amino acid sequence homologous to human IGF-1.[11] IGF-1 mediates the effects of growth hormone on muscle protein synthesis[12] and plays an important role in the regulation of metabolism.[13] Other growth factors in colostrum include TGF-β, epidermal growth factor and fibroblast growth factor, which all play a role in cell proliferation and repair.[14]

Colostrum also contains a number of hormones that are known to influence the hypothalamus, pituitary and adrenal glands and gonadal function.[15] Specific hormones include growth hormone, gonadotrophin-releasing hormone, luteinizing hormone-releasing hormone, glucocorticoids and possibly testosterone.[15] The function of these hormones in colostrum is not clear; however, it is postulated that they play a role in gastrointestinal development and immune system maturation of the neonate. Oligosaccharides and glycoproteins contained in BC may provide an energy source for the calf[16] while α-1 acid glycoprotein may be an important modulator of inflammation.[17] For an extensive review of the components of BC the reader is referred to van Hooijdonk et al.,[18] Korhonen et al.[2] and Gopal and Gill.[16]

The importance of colostrum for the development of the neonate is well recognized. The homologous composition of BC to human

colostrum, and the fact that growth and immune factors are expressed in much greater concentrations in BC, has led to the use of BC by humans to 'boost' immune function and promote tissue growth. Supplementation in humans has been associated with the successful treatment of enteric pathogens,[19] inhibition of gastrointestinal damage associated with non-steroidal anti-inflammatory drug (NSAID) administration[20-22] and reduction of upper respiratory illness symptoms.[23,24] In more recent years, BC has been used by some athletes as a nutritional supplement to enhance immune function, improve exercise performance and recovery, and increase lean muscle mass.

While all BC contains antibodies specific to a variety of antigens, a distinction should be made between BC and hyperimmune BC that is the result of immunization against specific micro-organisms. Studies investigating the effects of colostrum on exercise performance have used non-hyperimmune, standard BC preparations which are more readily available and cost effective than hyperimmune BC. As the focus of this review is on the effects of BC supplementation on exercise performance and potential mechanisms, we have confined the review of literature to research that has used non-hyperimmune, standard BC preparations.

1.1 Gastrointestinal Health and Integrity

Gastrointestinal differentiation and maturation observed in newborn calves following colostrum ingestion reinforces the importance of BC for their survival,[25,26] particularly as the absence of parenteral nutrition is associated with an increased risk of disease and mortality.[27] Growth factors in colostrum include IGF-1, TGF-β, epidermal growth factor and fibroblast growth factor, which play a role in gastrointestinal growth, cell proliferation and repair.[14] *In vivo* human studies have demonstrated a significant increase in gastrointestinal villus height and depth following epidermal growth factor administration in neonates with congenital microvillus atrophy.[28] *In vivo* animal studies have also provided evidence for the positive effects of epidermal growth factor and IGF-1 on enhanced recovery following bowel resections.[29]

The potential for BC to improve gastrointestinal health and integrity has led to human supplementation trials, one of which has shown BC supplementation to be successful in the treatment of distal colitis. Colostrum, self-administered twice daily via an enema, significantly improved the histology score of muscle biopsies taken from the affected area, as well as symptom severity and duration when compared with a placebo.[30] A mechanism proposed for the improvements associated with colostral enema administration was an increase in cell growth and proliferation of the epithelium, and a possible cytoprotective effect to prevent gastric damage.[30] Reductions in gastric damage and improved epithelial integrity may dampen inflammation.

In healthy humans, colostrum supplementation may prove beneficial to gut health. BC co-administered with NSAIDs reduced the increase in intestinal permeability otherwise observed when NSAIDs were administered with a whey protein placebo.[22] A similar reduction in gastrointestinal damage following BC administration in rats has been observed following TGF-β administration.[21] When administered alone, TGF-β is susceptible to digestion with fasting gastric juices, but in the presence of casein, enzyme inhibitors and other peptides contained in BC, the breakdown of growth factors can be prevented, maintaining their activity following ingestion.[31] Growth factors within colostrum may be responsible for the observed reduction in intestinal damage associated with NSAID administration and increases in cell proliferation in both rats and humans.[21,22] BC containing 2 mg/L of IGF-1 and 25 μg/L of TGF-β was administered to rats and associated with reduced gastric damage in a dose-dependent manner when compared with a standard milk preparation.[21] Recent investigations by Kim and colleagues[32] also support the benefit of co-administration of colostrum with NSAIDs, showing that colostrum supplementation in combination with diclofenac administration prevents mucosal damage of the small intestine and reduces intestinal permeability.[20]

Research suggests that BC has no influence on intestinal absorption in healthy humans.[33] Potential changes in nutrient uptake were investigated by Brinkworth and Buckley[33] following an 8-week period of BC supplementation at 60 g/day. Subjects completed an oral L-alanine tolerance test and an oral glucose tolerance test pre- and post-supplementation. No differences were observed in glucose and insulin levels or alanine uptake in the plasma. Although plasma concentrations of nutrients reflect the balance of their addition to and removal from the circulation, Brinkworth and Buckley[33] concluded that it was unlikely that BC affected intestinal absorption, because in animals, improved intestinal absorption is associated with an increase in plasma nutrient concentrations. Changes in intestinal permeability following colostrum supplementation require further research.

The potential of colostrum in improving gastrointestinal health may also explain improved exercise performance following BC supplementation. BC supplementation in humans may only be beneficial to the gastrointestinal system during inflammation and disruption of the gastric mucosa. Supplementation (12 weeks at 3 g/day) has recently been associated with a significant decrease in recurrent diarrhoea in children,[23] which suggests BC may reduce gastrointestinal disturbance during periods of inflammation and stress. While direct application of BC to the colon is associated with enhanced cell growth and proliferation,[30] the influence of oral BC supplementation on the morphology of the gastrointestinal tract requires further research.

1.2 Immune System

Colostrum provides the newborn with immunoglobulins, maternal lymphocytes and cytokines that contribute to mucosal immunity.[34] Unlike humans, where IgG transfer takes place *in utero*, bovine calves are dependent on the transfer of IgG and other immunoglobulins via colostrum from the mammary glands.[35] Attainment of passive immunity is essential within the first hours of life as the ability of neonatal calves to absorb macromolecules is reduced due to the process of intestinal closure that begins after birth and is complete around 24 hours *post partum*.[36] Insufficient or inadequate colostrum intake, and therefore IgG supply, has been related to increased morbidity and mortality in calves.[25,26] Conversely, high colostrum feedings have been associated with enhanced intestinal development.[37]

BC contains a number of cytokines that are important messengers within the human immune system. These are also important in stimulating the calf immune system (i.e. interleukin [IL]-1β, IL-6, tumour necrosis factor [TNF]-α, interferon [IFN]-γ and IL-1 receptor antagonist).[9] Pro-inflammatory BC cytokines have been found to regulate the blastogenic activity of peripheral blood mononuclear cells from calves, although adult cow cells were less active when treated with the same cytokines.[38] While there has been research to show that the integrity of bovine immunoglobulins and growth factors are maintained following the processing of colostrum to powder,[39] little is known of the cytokine content of commercially processed BC.

While the cytokine content of commercial BC preparations is yet to be determined, other factors in BC may influence the human immune system following supplementation through the stimulation of cytokine production. BC has been shown to increase cytokine messenger RNA in cells of intestinal Peyer's patches in weaned piglets receiving 1–5 g/day of BC for 3 weeks,[40] and recently our group has investigated the ability of a commercially available BC supplement to stimulate cytokine secretion from peripheral blood mononuclear cells under resting and inflammatory conditions.[41] IFN-γ, IL-10 and IL-2 secretion significantly increased with increasing concentrations of BC under resting conditions *in vitro*. The addition of BC to cells co-cultured with lipopolysaccharide significantly reduced the secretion of TNF, IL-6 and IL-4,[41] suggesting that supplementation may reduce pro-inflammatory cytokine production following strenuous exercise, which is associated with elevated lipopolysaccharide concentrations.[42]

A depressed immune system is associated with an increased risk of upper respiratory tract

infection (URTI). The potentially beneficial effects of BC on immune function may be related to the observed reduction in URTI symptoms following a period of supplementation. Children experiencing recurrent URTIs experienced a significant reduction in the incidence of URTIs with 12 weeks of BC supplementation at 3 g/day.[23] Although this study was not placebo-controlled, other studies support a reduction in URTI symptoms in athletes following a period of BC supplementation.[24] It is thought that an increase in salivary IgA affords greater protection against URTI,[43] and the authors speculated that this may have been the primary mechanism responsible for the decreased incidence of URTI associated with BC supplementation.[24] A recent study by our group showed no change in salivary IgA concentration or secretion rate over 8 weeks of supplementation at a dose of 10 g/day, but reported a trend ($p = 0.05$) for a reduction in URTI symptoms.[44] The relationship between BC, salivary IgA concentration and URTI requires further investigation using similar doses and supplementation periods.

1.3 Influence on the Neuroendocrine System

Colostrum has been shown to enhance maturation of the hypothalamic-pituitary-somatotropic axis and influence neuroendocrine function of calves[34] via the direct transport of colostral proteins into cerebral spinal fluid.[45,46] Homeostasis is maintained by the hypothalamic-pituitary-adrenal (HPA) axis and interactions between autonomic and immune tissues are well established. A blunted HPA axis, which may be modulated by cytokines, is associated with increased mood disturbance, fatigue and other sickness behaviour.[47] BC contains hormones that influence the HPA axis and gonadal hormone production.[28] Specific hormones include growth hormone, gonadotrophin-releasing hormone, luteinizing hormone-releasing hormone, glucocorticoids and possibly testosterone.[15] While the specific function of these hormones in colostrum is not clear, it is postulated that they play a role in gastrointestinal development, immune system maturation of the neonate and modulation of the neuroendocrine system. It is yet to be determined whether components of BC cross the blood-brain barrier in humans and hormone concentrations in processed BC are yet to be quantified.

Negative perturbations in mood state, that may be influenced by hypothalamic neuropeptides and releasing factors, are associated with periods of intense training.[48] BC protein concentrate (bovine CPC) supplementation has been associated with a decrease in fatigue and increase in vigour (determined by profile of mood states) in healthy males following 8 weeks of BC supplementation at 20 g/day.[49] BC supplementation appears to positively influence mood state, which may reflect maintenance of homeostasis of neuroendocrine function;[50] however, further research is required to confirm previous findings and determine mechanistic pathways via which BC may influence mood state.

1.4 Additional Pathways of Action

In combination with the influence of BC on immune, gastrointestinal and neuroendocrine properties, colostrum may also act as an antioxidant and promote tissue growth outside the gut.[51] The addition of BC to rat tumour cell lines *in vitro* has been shown to reduce levels of lipid hydroperoxides in culture supernatants.[51] The antioxidant properties of BC may be attributed to lactoferrin, an iron chelator that reduces neutrophil oxidant production associated with inflammation. BC also contains the antioxidants vitamin E, vitamin C and selenium;[52] however, lactoferrin is present in greater concentrations (reported to range from 1.5 to 5 mg/mL).[53] The implications of exercise-associated oxidative damage remains unclear, as does the role of BC in preventing lipid peroxidation in humans.

The ability of a commercial BC powder to promote tissue growth was recently investigated by Torre and colleagues.[54] Canine skin fibroblasts were cultured in the presence of colostrum at concentrations of 0.1–1.0 mg/mL for 24 and 48 hours. Skin cells proliferated in a dose-dependent manner with increasing concentrations of colostrum. While the authors did not investigate a specific mechanism responsible for

cell proliferation, Sporn and colleagues[55] demonstrated that bovine TGF, isolated from salivary gland and kidney tissue, promoted wound healing in rats where increased protein, collagen and DNA at the wound site were reported. The ability of BC to promote human skeletal muscle tissue growth *in vitro* has yet to be investigated.

2. Supplementation for Improved Exercise Performance

BC supplementation has increased among athletes as a means of enhancing immune function, increasing lean body mass and/or improving exercise performance. Mero and colleagues[56] were the first to investigate the effect of BC on serum immunoglobulins, IGF-1 and explosive power performance in an athletic population in 1997. Since then, research has investigated the ability of BC supplementation to improve endurance performance, increase strength and improve anaerobic performance, and determine mechanisms responsible for improvements in exercise performance associated with BC.

There is evidence to suggest that BC supplementation may improve anaerobic and power performance; improvements in repeat sprint performance,[57] peak vertical jump power[58,59] and peak cycle power[58] have been reported. Improvements in cycling time-trial performance following prolonged endurance performance,[60] improved repeat running performance following a short recovery period,[61] and maintenance of ventilatory threshold following a high-intensity training period[44] suggest that colostrum may also enhance recovery, and in turn improve repeat endurance performance. Strength improvements following BC supplementation are less clear, with some investigations reporting an increase in one-repetition maximum (1RM) following 12 weeks of supplementation[62] and others reporting no change in upper or lower body strength following 8 weeks of supplementation.[63,64] One study has reported increases in lean body mass;[63] however, this occurred independent of strength gains. Studies investigating the effects of BC supplementation on exercise performance, body composition and biochemical variables in healthy adult humans are presented in table I.

2.1 Body Composition, Strength and Power

As well as providing calves with a concentrated source of protein, non-nutrient factors in BC contribute greatly to their growth and development. Calves fed BC have increased amounts of protein and improved growth performance compared with calves fed a milk replacer.[76] BC has been shown to increase the hypothalamic-pituitary-somatotropic axis in calves, significantly increasing IGF-1 concentration,[77] which is associated with stimulation of muscle growth.[78] Several studies conducted since the work of Mero and colleagues[56] have considered the influence of colostrum supplementation on possible changes in body composition, strength and power. While colostrum in combination with other components such as creatine may significantly enhance muscle strength,[64,65] the potential for colostrum alone to stimulate these changes remains unclear.

The first investigation to examine whether colostrum supplementation would elicit changes in body composition was conducted by Antonio and colleagues.[63] Resistance-trained males ($n = 14$) and females ($n = 8$) were randomly assigned to either a colostrum (20 g/day) or a placebo group prior to participating in an 8-week resistance and aerobic programme that involved three training sessions per week. Body composition was assessed prior to and on completion of the study using dual energy x-ay absorptiometry. Exercise performance was also assessed pre- and post-supplementation with 1RM strength tests, running time to fatigue and total repetitions to fatigue at 50% and 100% of bodyweight (females and males, respectively). Bodyweight significantly increased for the placebo group (2.44 kg, $p < 0.05$), primarily due to an increase in fat mass, while the colostrum group showed a significant increase in lean body mass (1.49 kg, $p < 0.05$) without recording any significant change in bodyweight (due to a decrease in fat mass). There were no significant differences between groups in time to fatigue, maximum strength or muscular endurance. Unfortunately, as IGF-1 was not measured, it is not clear whether the

Table I. Summary of studies that have examined the influence of bovine colostrum (BC) supplementation on exercise performance, body composition and blood and saliva variables in healthy, adult humans

Study, year	Subjects	Dose (per day) and period of supplementation	Study design	Training protocol	Variables measured	Findings* (compared with placebo)
Mero et al.,[56] 1997	M sprinters and jumpers (n = 9)	Group 1: 25 mL Group 2: 125 mL for 8 days	db, pc, r, co	6 days of training that included speed, strength and aerobic components	IGF-1 IgA IgG Amino acid Hormones Countermovement jump	4.32 nmol/L ↑ IGF-1 for 125 mL BC
Leppäluoto et al.,[59] 2000[a]	M and F athletes (n = 10)	400 mL for 12 days	db, pc, co	Not reported although testing was carried out day 11 of supplementation and repeated on day 12	$\dot{V}O_{2max}$ Countermovement jump Squat jump IGF-1 GH Testosterone	Maintenance of O_2 uptake from day 11 to day 12 (↓ 7% in placebo group) ↑ flight times from day 11 to day 12
Antonio et al.,[63] 2001	M and F active (n = 22)	20 g for 8 weeks	db, pc	Aerobic and heavy resistance training minimum three times per week	1RM bench press Submaximal bench press Running time to fatigue Lean body mass	2.4% ↑ in lean body mass
Kreider et al.,[65] 2001[a]	M and F resistance trained (n = 49)	Group 1: 60 g BC Group 2: 60 g creatine Group 3: 60 g BC + creatine for 12 weeks	db, pc, r	Periodized resistance training programme 4 days per week	Total mass Fat-free mass Fat mass	↑ total mass (groups 1 to 3: 2.0 kg, 1.7 kg, 3.0 kg) ↑ fat-free mass (groups 1 to 3: 1.3 kg, 1.9 kg, 2.6 kg)
Kerksick et al.,[62] 2001[a]	M and F resistance trained (n = 49)	Group 1: 60 g BC Group 2: 60 g creatine Group 3: 60 g BC + creatine for 12 weeks	db, pc, r	Periodized resistance training programme 4 days per week	1RM bench press 1RM leg press 30s Wingate test 80% 1RM	↑ in bench press 1RM (groups 1 to 3: 62 kg, 70 kg, 121 kg)
Buckley et al.,[61] 2002	M untrained (n = 39)	60 g for 8 weeks	db, pc, r	45 min running training at threshold three times per week	2 x treadmill TTF separated by 20 min IGF-1	4.6% ↑ in peak running speed during second treadmill run

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Table I. Contd

Study, year	Subjects	Dose (per day) and period of supplementation	Study design	Training protocol	Variables measured	Findings* (compared with placebo)
Hoffman et al.,[66] 2005	M and F elite hockey players (n = 35)	60 g for 8 weeks	db, pc, r	Normal training	5 × 10 m sprints Vertical jump Shuttle-run test Body composition	4.8% ↑ in 5 × 10 m sprint performance
Brinkworth et al.,[67] 2002	F elite rowers (n = 13)	60 g for 9 weeks	db, pc, r	Rowing training and strength-plyometric training	2 x rowing ergo tests separated by 15 min passive recovery Blood buffer capacity	22% ↑ in blood buffering capacity
Mero et al.,[68] 2002	M and F active adults (n = 35)	20 g for 2 weeks	db, pc, r	2 weeks of specific event training (75%) and strength training (25%)	IGF-1 Serum IgA Serum IgG Salivary IgA	17% ↑ in IGF-1 33% ↑ in salivary IgA
Coombes et al.,[60] 2002	M trained cyclists (n = 42)	Group 1: 20 g Group 2: 60 g for 8 weeks	db, pc, r	Normal training	$\dot{V}O_{2max}$ test Work-based time-trial IGF-1	20 g: 19% improvement in time-trial performance 60g: 16% improvement in time-trial performance
Buckley et al.,[58] 2003	M active (n = 51)	60 g for 8 weeks	db, pc, r	Alternate resistance and plyometric training 6 days per week	Vertical jump power Peak anaerobic cycle power Anaerobic capacity 1RM IGF-1	7.2% ↑ in peak vertical jump 13.8% ↑ in peak cycle power
Fry et al.,[64] 2003	M and F recreationally weight trained (n = 19)	Group 1: 60 g Myovive + BC Group 2: 60 g Myovive + protein Group 3: 60 g BC + protein for 12 weeks	db, pc, r	Heavy resistance training 4 days per week	Body composition 1RM Fibre type distribution Fibre type area Myosin heavy chain content	No significant differences
O'Leary,[69] 2003[a]	M active (n = 16)	20 g for 8 weeks	Not stated	Not stated	30s Wingate test Creatine kinase Lactate	No significant differences

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Table I. Contd

Study, year	Subjects	Dose (per day) and period of supplementation	Study design	Training protocol	Variables measured	Findings* (compared with placebo)
Brinkworth et al.,[70] 2004	M active (n = 34)	20 g for 8 weeks	db, pc, r	Resistance training of non-dominant arm elbow flexors	1RM Maximal voluntary contraction of flexors Upper arm CSA Upper arm circumference	4.2% ↑ in CSA 2.3% ↑ in circumference
Brinkworth and Buckley,[71] 2004	F elite rowers (n = 13)	60 g for 9 weeks	db, pc, r	Rowing training and strength-plyometric training	Haemoglobin Plasma buffer capacity	No significant differences
Sample et al.,[72] 2004[a]	Active healthy elderly aged 59–74 years (n = 16)	20 g for 8 weeks	db, pc, r	Maintained normal physical activity levels	1RM leg press Hand grip strength $\dot{V}O_2$ Capillary density Fibre type	No significant differences
Mero et al.,[73] 2005	M physically active (n = 12)	20 g for 14 days	db, pc, co	Strength training session	Muscle protein (biopsy of vastus lateralis) Serum amino acids (femoral arterial and venous blood sampling) Maximal voluntary contraction	13% ↑ serum concentrations of essential amino acids ↑ muscle protein synthesis and breakdown
Crooks et al.,[74] 2006	M and F marathon runners (n = 35)	26 g for 12 weeks	db, pc, r	Marathon training, culminating in a marathon race	URTI symptoms Salivary IgA	79% ↑ in IgA
Shing et al.,[75] 2006	M trained cyclists (n = 29)	10 g for 8 weeks	db, pc, r	Normal cycle training including 5 days of HIT	40 km time-trial Ventilatory threshold TTF	BC maintained ventilatory threshold following HIT (4.6% drop in placebo group)
Shing et al.,[44] 2007	M trained cyclists (n = 29)	10 g for 8 weeks	db, pc, r	Normal cycle training including 5 days of HIT	Lymphocyte and neutrophil surface markers Serum Igs Serum cytokines URTI symptoms Salivary IgA	89% ↑ pre-exercise serum soluble TNF receptor 1 and suppressed the post-exercise decrease in cytotoxic/ suppressor T cells during HIT period (BC: −1.0%, placebo: −9.2%)

a Abstract only.

co = crossover; **CSA** = cross-sectional area; **db** = double blind; **F** = female; **GH** = growth hormone; **HIT** = high-intensity training; **Igs** = immunoglobulins; **IGF-1** = insulin-like growth factor-1; **M** = male; **min** = minutes; **Myovive** = supplement containing creatine; **pc** = placebo controlled; **r** = randomized; **RM** = repetition maximum; **TNF** = tumour necrosis factor; **TTF** = time to fatigue; **URTI** = upper respiratory tract infection; $\dot{V}O_{2max}$ = maximum oxygen uptake/consumption; ↑ indicates increase; ↓ indicates decrease; * $p < 0.05$.

observed increase in lean body mass following BC supplementation was related to an increase in serum IGF-1 concentration.[63]

In contrast to the findings of Antonio and colleagues, Kerksick et al.[62] reported an increase in maximal strength following 12 weeks of BC supplementation. Forty-nine resistance-trained male and female subjects participated in a 12-week training programme in which participants were assigned to a placebo group, a colostrum group (60 g), a creatine group or a colostrum-creatine combined group. Maximal strength was determined by 1RM bench press and leg press followed by a strength endurance bench and leg press at 80% 1RM. Potential changes in anaerobic performance were examined using a 30-second Wingate test and body composition was monitored during the study using dual energy x-ray absorptiometry. 1RM bench press for the colostrum, creatine and combined creatine and colostrum groups increased significantly when compared with the placebo group ($p < 0.05$). No significant differences were observed for sprint performance between the four groups. There was a significant interaction of group and fat-free mass, with greatest gains experienced by the combined BC and creatine group (placebo = 0.8 kg, colostrum = 1.3 kg, creatine = 1.9 kg, colostrum-creatine combined = 2.6 kg).[65]

While colostrum supplementation in combination with 12 weeks of resistance training has been shown to improve maximal strength,[62] supplementation at the same dose (60 g/day) during 8 weeks of strength and plyometric training was not associated with changes in maximal strength.[58] Fifty-one physically active (but not specifically resistance-trained) males participated in six exercise sessions per week, alternating between resistance and plyometric training. Resistance training was performed at high and low intensities and the plyometric training was performed with maximal effort three times a week. There were significant improvements from baseline in 1RM, training volumes completed and anaerobic work capacity for both groups across the experimental period ($p < 0.01$). BC supplementation significantly improved peak cycle power and vertical jump height, suggesting that colostrum was beneficial to explosive power activities. Adaptations to plyometric training include increased type IIa fibres and increased fibre diameter.[79] Fry and colleagues[64] investigated changes in fibre type and diameter following 12 weeks of BC supplementation and resistance training and reported a non-significant increase in type IIa fibre average cross-sectional area (BC [n = 6]: before = $5428 \pm 802\ \mu m^2$, after = $6588 \pm 529\ \mu m^2$; placebo [n = 5]: before = $7908 \pm 1042\ \mu m^2$, after = $7688 \pm 789\ \mu m^2$). Because of small subject numbers, the power to detect a difference in fibre type area was <0.8. Greater subject numbers would be required to determine if BC influences fibre type area.

Improvements in explosive activities following colostrum supplementation are supported by the work of Leppäluoto and colleagues.[59] In a double-blind, crossover design, ten athletes performed maximal oxygen uptake testing and two jump tests on days 11 and 12 of supplementation.[59] Colostrum significantly improved jump flight times and maintained maximal oxygen uptake from day 11 to day 12 of supplementation when compared with the placebo group ($p < 0.05$). There were no differences between groups for IGF-1, growth hormone, creatine kinase, testosterone or IL-6. While the authors concluded that BC supplementation was beneficial during heavy training periods, limited conclusions can be drawn from the study, as neither the dose administered nor details of training and diet control were reported by the authors and the investigation is yet to be published in a peer-reviewed journal. Previous work by Mero and colleagues[56] showed that 8 days of BC supplementation was not sufficient to influence vertical jump performance.

Brinkworth and colleagues[70] again investigated the influence of colostrum on potential changes in body composition over 8 weeks using the same dose (60 g) that was used in their previous work. Physically active males strength-trained the elbow flexors of their non-dominant arm 4 days a week. One RM bicep curl, magnetic resonance imaging and maximal voluntary isometric contraction of the upper arm were measured at baseline and following 4 and 8 weeks of supplementation. When compared with both

their untrained arm and with the placebo group, upper limb circumference and total cross-sectional area were increased in the trained arm of subjects supplementing with colostrum. There were no significant differences between groups for upper limb muscle cross-sectional area. The authors attributed the increase in cross-sectional area following colostrum supplementation to an increase in skin cross-sectional area, and indeed previous research has shown that canine skin cells proliferate in a dose-dependent manner with increasing concentrations of colostrum.[54] However, the MRI did not allow for differentiation between skin and subcutaneous fat so an increase in subcutaneous fat of the trained arm cannot be excluded.[70] Strength improvements were not significantly different between trained and untrained limbs.

Mero and colleagues have been the only group to date to report increases in serum IGF-1 concentration following BC supplementation for 8[56] and 14 days.[68,80] Typically degraded in the gastrointestinal tract, it has been suggested that factors contained in BC may aid the absorption of IGF-1 by preventing its breakdown and digestion.[31] Previous research involving rats has shown that 9% of IGF-1 ingested alone appears in the bloodstream, while 67% of IGF-1 survives digestion when administered with casein.[81] Absorption of IGF-1 contained in BC may therefore be assisted by proteins that aid its uptake and prevent gastric breakdown. Normal serum IGF-1 values for 20- to 30-year-olds range from 14 to 48 nmol/L. The average increase in IGF-1 reported by Mero and colleagues[80] was 5.32 nmol/L (from 20 to 25.32 nmol/L). The amount of IGF-1 contained in the dose was approximately 74 μg/day. At this dose, if approximately 65% of IGF-1 was absorbed, the concentration of IGF-1 would only be expected to rise by approximately 1.05 nmol/L. This suggests that the increase in serum IGF-1 reported by Mero and colleagues[80] was probably due to an increase in endogenous production.

To confirm that the source of additional IGF-1 was endogenous, Mero et al.[56,80] investigated the origin of increased serum IGF-1 following colostrum supplementation. Twelve recreationally active males and females ingested labelled human recombinant IGF.[80] Total, free and bound IGF-1 were subsequently measured in serum; the ingested labelled IGF-1 appeared fragmented in circulation. Only 4% of ingested ^{123}I-rhIGF-1 eluted at 40-90 kDa, whereas previous research has shown ^{123}I-rhIGF-1 to elute at 150 and 43 kDa. IGF-1 has also been shown to have a rapid *in vivo* breakdown. The authors did not give the total yield of ^{123}I-rhIGF-1, and it is not therefore clear whether there was significant digestion of the ^{123}I tracer. Their findings led the authors to conclude that IGF-1 is unlikely to be absorbed from BC and that the increase in IGF-1 observed in their earlier work was due to an increase in endogenous production.[80] This conclusion cannot be supported as labelled IGF-1 was administered alone and it is unlikely that these results would directly reflect the absorption of IGF-1 in a BC preparation where components of BC would prevent the breakdown and digestion of IGF-1 in the gastrointestinal tract.[31]

While Mero and colleagues reported significant increases in serum IGF-1 concentrations following BC supplementation for 8 and 14 days,[56,68] other researchers using similar doses but longer supplementation periods have reported no change.[58,60] Kuipers et al.,[82] Buckley et al.[58] and Coombes et al.[60] analysed IGF-1 following 4–8 weeks of BC supplementation and showed no significant changes. Buckley et al.[58] suggested that an increase in IGF-1 may be transient as negative feedback mechanisms may act to return circulating IGF-1 concentrations to baseline during longer supplementation periods. An increase in IGF-1 concentration even following a short supplementation period remains equivocal, however, as IGF-1 levels following 12 days of BC supplementation remained unchanged, as reported by Leppäluoto et al.[59] Circulating IGF concentrations are sensitive to energy intake and levels of physical activity,[83] and it is therefore necessary to ensure that energy balance is monitored in future when investigating changes in IGF-1 following BC supplementation.

BC supplementation has been associated with an increase in lean body mass,[63,65] increases in strength,[62] increases in vertical jump height and flight times[58,59] and improved peak power

output.[58] However, these findings remain inconsistent across studies, possibly due to differences in training protocols, the training status of subjects, supplementation duration and measures used to assess performance. While there is a significant stimulatory effect of colostrum on bovine epithelial cell lines cultured *in vitro,* smooth muscle cells do not grow when cultured with colostrum.[84] Increases in lean body mass following BC supplementation that have not been associated with increases in strength may be attributable to an increase in the non-contractile portion of muscle. Fibroblast growth is stimulated by BC[54] and it is possible that increases in lean body mass are the result of increases in collagen; however, this remains speculative. The influence of colostrum supplementation on skeletal muscle growth requires further investigation.

2.2 Endurance Performance

BC supplementation has been shown to improve recovery from repeat bouts of exercise,[61] improve time-trial performance following prolonged submaximal exercise,[60] and maintain exercise performance following a period of high-intensity training.[75] The reported increase in circulating IGF-1 following BC supplementation by Mero and colleagues[56] led Buckley and co-workers[61] to investigate the potential benefit of BC on endurance performance.

If colostrum supplementation leads to an increase in serum IGF-1 concentration, it is possible that exercise capacity may be enhanced as a result of alterations in substrate utilization and/or cardiac output. IGF-1 has been shown to increase stroke volume and cardiac output in healthy males[85] and elicit a decrease in insulin concentration and an increase in the concentration of free fatty acids, increasing lipolysis.[85,86] To examine this possibility, Buckley and colleagues[61] supplemented 39 male subjects with either colostrum (60 g/day) or a placebo for 8 weeks. Training over the experimental period included three 45-minute running sessions per week. Participants performed two incremental treadmill tests, separated by 20 minutes' passive recovery, at baseline and following 4 and 8 weeks of supplementation. No significant changes in running performance were observed following 4 weeks of supplementation. However, at 8 weeks, subjects in the colostrum group covered a significantly greater distance and completed more work in the second treadmill test than the placebo group (4.6% increase; $p < 0.04$). The mechanism for the significant improvement in running performance could not be explained by alterations in respiratory exchange ratio, lactate threshold or IGF-1 concentration and, to date, there has been no reported increase in maximum oxygen uptake/consumption ($\dot{V}O_{2max}$) following BC supplementation despite increases in endurance performance.[60,61]

The first study to investigate a dose response of BC on endurance performance was conducted by Coombes and colleagues.[60] Cyclists ($n = 42$) completed a work-based cycle time-trial (2.8 kJ/kg), following a 2-hour endurance ride, both before and after 8 weeks of supplementation. The study was a double-blind, placebo-controlled trial in which cyclists were assigned to ingest 20 or 60 g/day of BC or a placebo (whey protein powder). Time-trial performance significantly improved in cyclists who were supplemented with colostrum when compared with the placebo group (20 g = decrease of 158 seconds, 60 g = decrease of 134 seconds; both $p < 0.05$). The similar improvements in performance observed for the two colostrum groups suggest that there may be a limit beyond which a higher BC dose does not provide any added performance benefit.[60] As with the findings of Buckley et al.,[87] performance improvements could not be explained by an increase in IGF-1 concentration. The authors speculated that improved endurance performance may have been the result of enhanced nutrient uptake from the small intestine, mediated by other growth factors found in colostrum. Increases in nutrient uptake and improved gastrointestinal absorption have been associated with colostrum administration in calf studies.[6] BC supplementation in humans has not been associated with increased plasma nutrient concentrations;[33] however, to date the influence of BC on gastrointestinal changes in humans has not been directly measured, possibly because of the invasive nature of the techniques required (i.e. an endoscopy).

While increases in endurance performance following a period of BC supplementation cannot be explained by an increase in circulating IGF-1, a study has shown maintenance of ventilatory threshold and improved economy during periods of high-intensity training.[75] A 10 g/day dose of BC improved 40 km time-trial performance at the end of a 5-day high-intensity training period but not during normal training when compared with a whey protein placebo.[75] Research has previously found that colostrum feeding in newborn calves increases plasma glucose concentrations and is associated with enhanced activity of the gluconeogenesis rate-limiting enzymes pyruvate carboxylase and phosphoenolpyruvate carboxykinase.[88] While increased muscle glycogen levels during normal training do not improve 1-hour cycling performance[89] or 45-minute cycling performance (at an average intensity of 82% $\dot{V}O_{2max}$),[90] during repeated days of high-intensity exercise enhanced muscle glycogen content may prevent and/or delay fatigue.[91,92] Whether BC improves muscle glycogen resynthesis during periods of intense training warrants investigation.

The disparate findings of improved endurance cycling performance by Coombes et al.[60] and an unclear influence of BC supplementation on 40 km time-trial performance during normal training in our recent investigation[75] may be explained by differences in the time-trial protocol used (2.8 kJ/kg [approximately 13 minutes] following a 2-hour submaximal ride and a 40 km time-trial) and fasting state. It is also possible that the smaller dose (10 g) of bovine CPC used in the study by Shing et al.[75] may not have been sufficient to elicit the same improvements in performance during normal training periods.[60] It remains to be determined if a 10 g dose of colostrum improves short duration (approximately 13 minutes) cycle time-trial performance following 2 hours of submaximal endurance performance.

BC appears to be beneficial to endurance performance, particularly during periods of intense training or overload that may be associated with fatigue and a reduction in ventilatory threshold. Although Mero and colleagues have reported an increase in serum IGF-1 concentration following BC supplementation,[56,68,80] changes in endurance performance and repeat exercise performance appear to be independent of increases in IGF-1, although to date only two studies have investigated IGF-1 and endurance performance.[60,61] While IGF-1 may increase in response to strength training with BC supplementation,[56,80] increases in serum IGF-1 are yet to be reported in combination with improvements in endurance performance.

2.3 Anaerobic Performance

BC ingestion increases circulating proteins and stimulates skeletal muscle growth in the neonatal calf.[76,93] If colostrum is able to increase muscle fibre size and systemic protein concentrations it may prove beneficial for anaerobic performance.

Limited evidence suggesting that colostrum may elicit increases in muscle protein content in humans[63,65] led Brinkworth and colleagues[67] to examine whether colostrum supplementation could enhance the buffering of H^+. The main buffers of H^+ come from skeletal muscle and include protein, inorganic phosphate and phosphocreatine, while components of blood including haemoglobin, bicarbonate and plasma proteins also buffer H^+. Brinkworth and colleagues[67] suggested that the rate of intramuscular acidosis during intense work could potentially be reduced following colostrum supplementation. They examined the influence of BC supplementation on blood buffering capacity in response to a 9-week training programme with 13 elite female rowers; subjects consumed either 60 g of colostrum per day or 60 g of whey protein powder.[67] Two incremental rowing tests (consisting of 4×3-minute stages) each separated by 15 minutes were used to assess performance prior to and on completion of the supplementation period; buffering capacity was estimated from differences in blood lactate and blood pH measures taken at the end of each workload during the tests. Analysis found that blood buffering capacity was significantly increased following 9 weeks of BC supplementation (BC = 40.8 ± 5.9 slykes [unit of buffer capacity] vs placebo = 33.4 ± 5.3 slykes; $p < 0.05$). Whilst the

buffer capacity of blood was increased, there were no significant differences in exercise performance between the two groups.

Brinkworth and Buckley[71] conducted a further investigation using data collected from the previous study of Brinkworth and colleagues[67] to determine the component of blood buffering capacity that was enhanced following BC supplementation. Results from this study revealed no significant differences in resting haemoglobin concentrations, plasma bicarbonate levels or plasma buffering capacity (all systemic buffers) between colostrum-supplemented and placebo groups. Interestingly, the authors concluded that the observed increase in buffering capacity from their previous work[67] was the result of enhanced muscle buffering capacity. Muscle buffering capacity was unable to be determined as no biopsy samples were collected. As blood buffering capacity was improved in the original investigation, some component of systemic circulation must have changed as a result of BC supplementation as systemic markers were used to calculate blood buffering capacity. It is possible that the increase in blood buffer capacity observed by Brinkworth and colleagues[67] was due to an increase in the ability of haemoglobin to buffer H^+ (deoxyhaemoglobin is superior to oxygenated haemoglobin) or an increase in intracellular phosphate. An increase in muscle buffer capacity following BC supplementation is yet to be determined and will require direct measurement of muscle pH and muscle lactate concentrations.

In light of the data reported by Brinkworth and colleagues,[67] it is possible that improved buffering capacity may have been responsible for the changes in sprint performance reported by Hofman and colleagues[57] following colostrum supplementation. Elite male ($n = 18$) and female ($n = 17$) hockey players were supplemented with either colostrum (at 60 g/day) or placebo for 8 weeks. Repeated sprint running performance (5×10 m) significantly improved in the colostrum supplemented group ($p < 0.05$) compared with the placebo group. Unfortunately, only performance measures were reported in this study so the mechanism behind the improvement in sprint performance remains unclear.

In contrast, other authors have shown no improvements in the anaerobic measures of a 30-second Wingate test[69] or a time-to-fatigue test at 110% of ventilatory threshold.[75] At present, data are too limited to support the use of BC supplementation for improvements in anaerobic performance; however, BC may influence recovery suggesting the potential for supplementation to benefit repeat anaerobic performance.

2.4 Immune Function

The importance of BC for the development of the calf immune system has led to the use of BC as a supplement in humans that is purported to enhance immunity. Intense exercise is known to suppress immunity for up to several hours post-exercise[94] and due to the large volumes of high-intensity training that endurance athletes undertake, they are often at a relatively high risk of symptoms of overreaching[95-97] and URTIs.[98] Brinkworth and Buckley[24] recently investigated the relationship between BC supplementation and URTI incidence. Retrospective self-reported data from daily illness log books were collected from studies involving resistance training or endurance training interventions in which subjects ingested BC 60 g/day ($n = 93$) or a placebo ($n = 81$) over an 8-week period. Although data from individual studies were not presented, the combined results suggest that the percentage of subjects experiencing URTIs was greater in the placebo group than in the BC-supplemented group (48% and 32%, respectively; $p = 0.03$), although the duration was not significantly different between groups. While the benefits of BC on reduced URTI symptoms are recognized, to date only four investigations have examined the influence of BC supplementation on immune markers in trained populations.[44,56,74,80]

Early work by Mero and colleagues[56] reported that 8 days of supplementation with a BC liquid (25 mL and 125 mL) during normal training did not increase salivary IgA concentration. Subsequent work by the same authors showed that athletes ingesting BC powder for 2 weeks at a dose of 20 g/day experienced a 33% increase in resting salivary IgA concentrations ($p < 0.01$).[80] While the duration of supplementation was

longer in the later study, the disparate results could also be explained by the lower concentrations of active growth and immune factors in the BC liquid used in the initial investigation. The liquid BC (125 mL) contained 8.45 μg of IGF-1, 0.048 g of IgG and an undetectable amount of IgA,[56] while the BC powder contained 74 μg of IGF-1, 4.5 g of IgG and 0.3 g of IgA per dose. A significant increase in resting salivary IgA concentration has been shown following 12 weeks of BC supplementation (at 26 g/day) in marathon runners (colostrum group = 101.5 mg/L and placebo group = 58.2 mg/L, $p < 0.05$).[74] Interestingly, this increase in salivary IgA was not associated with a significant difference in the reported incidence of URTIs between groups. A recent investigation by our group showed no change in salivary IgA concentrations following 8 weeks of supplementation.[44] Differences in colostrum dosage and supplementation duration may be responsible for the disparate findings. Crooks and colleagues[74] supplemented runners with BC at 26 g/day for 12 weeks while Mero and colleagues[80] reported an increase in salivary IgA following only 2 weeks of colostrum supplementation with a 20 g/day dose. Eight weeks of BC supplementation at 10 g/day had no effect on salivary IgA concentration.[44]

The potential of colostrum to allow athletes to tolerate higher volumes of (or more intense) training, without the same degree of post-exercise immune suppression was recently investigated by our group. As there is no ideal single marker to measure immune modulation following a nutrition intervention,[99] a number of immune variables and activation markers were chosen to provide an overview of immune function. A 10 g/day dose of BC had no effect on natural killer cell cytotoxicity, lymphocyte or neutrophil surface markers; however, BC supplementation did increase circulating concentrations of the anti-inflammatory cytokine serum soluble TNF receptor 1. While other circulating cytokines did not significantly change, it is possible that local cytokine production was influenced by BC supplementation. The potential for BC to influence cytokine profile is supported by an increase in cytokine production (IFN-γ and IL-2) from peripheral blood mononuclear cells *in vitro* following co-culture with colostrum.[41] BC supplementation also prevented a decrease in post-exercise IgG_2 and cytotoxic/suppressor T cells following high-intensity training. Reductions in IgG_2 and cytotoxic/suppressor T cells have been associated with strenuous exercise.[100-102] While the clinical significance of maintained concentrations remains to be determined, they may offer protection during the 'open window' period and contribute to the trend for reduced upper respiratory illness.[41] Cytotoxic/suppressor T cells have been reported to secrete a T helper-1 cytokine profile,[103] which has been associated with the down-regulation of the binding site for rhinovirus.[104] Symptoms that present as URTIs may also actually be associated with an elevation of pro-inflammatory cytokines,[105] so it is possible that a reduction in URTI symptoms may be independent of increases in salivary IgA concentration.

Direct *in vitro* stimulation of peripheral blood mononuclear cells is associated with the secretion of cytokines associated with cell-mediated immunity. Alterations in cytokine production, in particular the proinflammatory cytokine IL-1β, which is associated with exercise-related fatigue,[106] could potentially influence exercise performance. Lakier Smith[107] proposed a cytokine hypothesis of overtraining in which repeated training without adequate recovery leads to fatigue, decreased mood state, activation of sympathetic nervous system and suppression of HPA-gonadal axis. Changes in cytokine concentrations that may result from BC supplementation have the potential to influence exercise performance and aspects of recovery.

2.5 Gastrointestinal Health and Integrity

Evidence indicates that BC positively influences gastrointestinal integrity,[55] permeability[37,38,60] and inflammation,[55] particularly when taken with NSAIDs. An increase in intestinal permeability may impair exercise performance as a result of translocation of bacterial endotoxin, nausea and diarrhoea.[108] BC may be beneficial during intense exercise that could increase intestinal permeability, particularly in the heat.[42] Gastrointestinal hyperpermeability and endotoxin concentration in

rats following heat stress is reduced with colostrum supplementation.[109] Mechanisms contributing to heat stress include increases in plasma lipopolysaccharide and inflammatory cytokines.[110] To date, only one investigation has reported on the influence of BC on intestinal permeability during exercise. Buckley and colleagues[111] investigated the potential of BC supplementation to reduce exercise-associated increases in intestinal permeability. Subjects ingested colostrum, whey protein (placebo) or nil (control) over an 8-week period of running training; intestinal permeability determined by urinary excretion of lactulose and rhamnose was measured pre-supplementation and on completion of the training period. In contrast to the findings of previous rat studies,[22] the BC and whey protein groups showed a significant increase in intestinal permeability when compared with the control group. Buckley and colleagues[111] speculated that the increase in intestinal permeability resulting from colostrum and whey protein supplementation may stimulate macromolecular transport and uptake of colostrum components. Increased intestinal permeability has been associated with adverse gastrointestinal symptoms and enhanced endotoxin translocation across the gut into circulation.[112] If BC and whey protein do increase intestinal permeability, supplementation may not be advisable for athletes prone to 'leaky gut' syndrome. Whether the reported increase in intestinal permeability was associated with increased endotoxin translocation across the gut remains to be determined. It is important to note that this research is only published as an abstract and no performance measures were reported by the authors,[111] limiting the conclusions that may be drawn for this investigation. Nevertheless, BC may be beneficial during exercise in the heat and endotoxaemia-related heat stroke, and to date there is no published research investigating the effect of colostrum on gastrointestinal permeability in humans exercising in the heat. This would be an interesting area of future research.

3. Kinetics and Safety

BC ingestion in newborn calves increases plasma IgG, lactoferrin and total protein.[46] While an increase in serum essential amino acids following BC supplementation has been reported in humans,[73] the pharmacokinetics of BC following ingestion in humans is yet to be determined. The tight junctions in the adult human gut reduce passive absorption and, for many years, it was unclear if and how ingested immunoglobulins could be absorbed in humans or if BC would be degraded in the stomach. Recently, however, the major histocompatability complex class I-related Fc-receptor has been shown to mediate *in vitro* IgG epithelial transport by trancytosis.[113] This may be a possible mechanism for transport of colostral IgG to mucosal surfaces in humans and there is recent evidence to suggest absorption in humans and animals despite gut closure.[40]

Following BC ingestion, immunoglobulins have been shown to withstand digestion in the gut and to be able to exert their effects on the small and large intestine.[114] The integrity of BC after digestion in humans is yet to be extensively researched. It has been suggested that factors contained in BC may aid the absorption of active components by preventing their breakdown and digestion in the gastrointestinal tract.[31] Research is required to determine the absorption of active components into the circulation and to further explore the influence of BC on the gastrointestinal environment, where BC has previously been shown to stimulate gastrointestinal-associated lymphoid tissue.[40]

The ingestion of BC is well tolerated and to date there is only one peer-reviewed investigation that has reported slight stomach discomfort associated with BC supplementation.[74] While reports of adverse effects of BC supplementation in humans are limited, those intolerant to cow's milk proteins, such as casein and whey or lactose (which are present in small concentrations), should avoid BC. No reported toxicological or histopathological abnormalities have been found in rats supplemented with BC at 3% and 10% of total food intake for a period of 3 months,[115] and similarly no adverse reactions have been reported in humans ingesting 26 g/day for 3 months.[74] The long-term (>12 weeks) safety of supplementation in humans is yet to be determined so caution should be taken when ingesting colostrum for prolonged, continuous

periods. Colostrum sold in Australia and New Zealand must be from local herds or herds from countries considered bovine spongiform encephalopathy-free and must conform to the Therapeutic Goods Administration guidelines.

BC is not considered a banned substance despite containing IGF-1, which is banned by the International Olympic Committee under the category of peptide hormones, mimetics and analogues. As BC may have the potential to increase serum IGF-1 following supplementation,[56] athletes taking colostrum run the risk of testing positive for banned substances. To date, only one published investigation has examined the likelihood of this occurring. Kuipers and colleagues[82] supplemented athletes with 60 g/day of colostrum and collected blood prior to and following 4 weeks of supplementation for the analysis of IGF-1 and associated binding protein, IGF binding protein-3. Urine was also collected for routine analysis of banned substances (e.g. peptide hormones, anabolic agents, stimulants) by an accredited International Olympic Committee Laboratory; urine was collected both after an overnight fast and 2 hours following BC ingestion. Analysis of blood samples revealed no significant increase in IGF-1 or its associated binding protein and there were no positive doping tests returned for the athletes (i.e. no banned substances detected) from the International Olympic Committee Laboratory. Whether this finding reflects the lack of bioavailability of IGF-1 or whether BC ingestion over an extended period (>4 weeks) would result in a positive doping test is yet to be determined, particularly as improvements in performance are often reported after 8 weeks of supplementation but not after 4 weeks.[58,61]

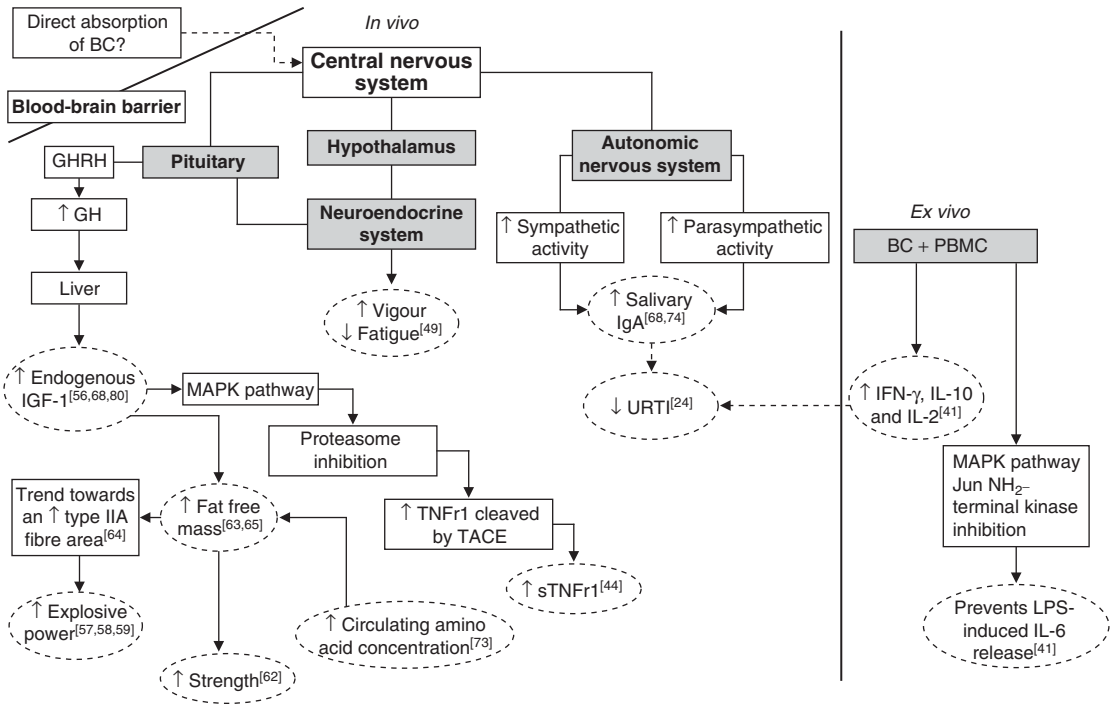

Fig. 1. Potential pathways of action for reported changes associated with bovine colostrum (BC) supplementation. Dashed circles denote significant changes observed in previous literature. Dashed arrows represent possible interactions. **GH** = growth hormone; **GHRH** = gonadotrophin hormone-releasing hormone; **IFN** = interferon; **IGF** = insulin-like growth factor; **IL** = interleukin; **LPS** = lipopolysaccharide; **MAPK** = mitogen-activated protein kinase; **PBMC** = peripheral blood mononuclear cells; **sTNFr1** = soluble tumour necrosis factor receptor 1; **TACE** = tumour necrosis α-converting enzyme; **URTI** = upper respiratory tract infection; ↑ indicates increase; ↓ indicates decrease.

4. Combined Effects

It is more than likely that BC supplementation influences numerous pathways within the human body given the varied components of colostrum. Figure 1 presents significant findings reported in humans following a period of BC supplementation and potential pathways that may be influenced by BC. It is important to note that the influence of BC on these pathways remains speculative; however, the intention is to present potential mechanisms for observed changes following BC supplementation and possible pathways of action to investigate in future work.

5. Conclusions

BC contains a range of proteins, immune factors and hormones, which are homologous to the contents of human colostrum. The influence of BC on the growth and development of calves is well understood, but the influence of BC on adult human health is not. Whilst supplementation with BC may be increasing among athletes, in many instances conclusions from studies showing the effect of BC on exercise performance and recovery are equivocal. Data that show improvements in exercise performance and recovery, and changes in immune function during and following supplementation are limited. BC supplementation does not appear to influence body composition during a period of endurance training; however, the data suggest that supplementation is beneficial to exercise performance following consecutive days of high-intensity training (HIT) and to recovery in the days following HIT. Potential mechanisms that researchers have speculated may be responsible for observed improvements in exercise performance and immune surveillance following colostrum supplementation include increases in plasma concentrations of IGF-1,[56] improved intramuscular buffering capacity,[67] increases in lean body mass[63] and increases in salivary IgA concentrations.[74,80] Given that there are contradictory reports regarding the influence of BC on each of these parameters, the changes may be considered modest, but the cumulative effect on a range of parameters may result in improved performance and recovery. Repeated trials, using a well-defined BC product at a standard dosage and length of supplementation, and measuring a wide range of performance and immune parameters, are required to confirm this hypothesis. However, the interpretation of data from such trials will only be relevant once the metabolism and uptake of BC constituents from the gut has been elucidated and researchers are confident of the possible bioactive constituents that may contribute to improved exercise performance.

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