Vitamins & Minerals
ISSN: 2376-1318

Mini Review Open Access

Magnesium: The Mitochondrial Blockbuster in Competitive Sports

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Abstract

Magnesium is an essential cofactor of more than 600 enzymatic reactions in intermediary metabolism and is involved in all ATP-dependent processes. Be it oxygen utilisation, neuromuscular coordination or cardiopulmonary performance, magnesium is a key element in the trouble-free progression of numerous metabolic processes in the athlete. Magnesium is the second most common intracellular divalent cation; it is present in its ionised form Mg^{2+} and combines with adenosine triphosphate (ATP) to form Mg-ATP complexes. For many physical functions, magnesium is essential to regulate the tone and contractility of smooth muscle in vascular structures. It is particularly important in the regulation of blood pressure, vascular resistance, glucose utilisation, metabolomics, lipid profiles and lactate clearance. DNA polymerases and DNA-dependent RNA polymerase also require magnesium as a cofactor, making metabolic steps in DNA replication, RNA transcription, nucleic acid and protein synthesis dependent upon magnesium. Magnesium stabilises, for example, the active conformation of nucleic acids and is required to reduce or compensate the charge of multivalent anions or polyanions.

Keywords: Mitochondrial blockbuster; Radiotherapy

Introduction

The alkaline earth metal is a component of energy-rich phosphate compounds and, in particular, catalyses ATP-dependent enzyme systems. Magnesium is thus involved in the energy metabolism of every single cell. Cellular energy production depends on the magnesium status, as Mg-ATP compounds are used in all physical activities. An inadequate supply of magnesium impairs these metabolic processes. Through its effects on glucose homeostasis and oxidative phosphorylation, magnesium plays a key role in glucose metabolism. For example, ATP is not able to transfer the phosphate group as free ATP, but only in the form of an Mg-ATP complex. Glycolysis, the citric acid cycle and the mitochondrial respiratory chain are responsible for the breakdown and energy utilisation of carbohydrates, fats and proteins (Figure 1).

As a cofactor of adenine nucleotides, magnesium is an important regulator of many enzymes involved in glycolysis. Mg-ATP is required for hexokinase, phosphofructokinase-1, aldolase A, and phosphoglycerate kinase and pyruvate kinase activity. Key enzymes of glucose homeostasis such as pyruvate dehydrogenase and creatine kinase also need magnesium as an essential cofactor. In addition, magnesium supports the parameters of glycaemic regulation in athletes through its effects on the tyrosine kinase activity of insulin receptors and the signalling pathway at the post-receptor level.

Literature Review

Sporting activities lead to a redistribution of energy-supplying substrates (e.g. carbohydrates). For example, moderate physical exercise lowers the glucose concentration and raises the lactate level, which is associated with a reduction in muscle performance. Sports also induce a cellular redistribution of magnesium as part of the metabolic adjustment of the muscles and cardiorespiratory system. In response, magnesium is transported around the body to those areas where cellular energy is being produced. With endurance sports, the magnesium in the athlete is shifted from the blood to the muscle cells to ensure continued muscle performance.

Magnesium supplements (e.g. oral magnesium 10 mg/kg body weight/day for four weeks) have a significant beneficial effect on glucose utilisation ($p<0.05$) and insulin metabolism ($p<0.05$) in competitive athletes, both under resting conditions and on physical exertion.

Through interactions with phospholipids, magnesium has a membrane-stabilising effect and, as a cofactor of Na^+/K^+-ATPase, regulates conduction in nerve and muscle cells. Magnesium deficiency increases the permeability of potassium through K^+ channels, which in turn affects cardiac muscle action potentials. A sodium-magnesium antiport has also been described. The antagonistic effect of magnesium against calcium (→NMDA receptor antagonist) protects the myocardial cells from calcium overload during ischaemic perfusion disturbances. Thanks to this property, magnesium leads to the economisation of muscular and cardiac bioenergy in athletes. Interactions between magnesium, vitamin D and interleukins likewise play an important role. Patients with sarcopenia often have magnesium and vitamin D deficiencies, while their interleukin levels (e.g. IL-6) are clearly elevated.

The magnesium content of skeletal muscle is considerably higher than that of vascular smooth muscle. Cross-striated cardiac muscle has about twice as much magnesium as in the smooth muscle cells. Most of the magnesium is found in magnesium-ATP complexes, with only a small amount bound to various proteins and enzymes. Muscle contraction is the active shortening of muscle. The forces released thereby arise from the conversion of chemical energy into mechanical energy via the actin-myosin complex in the individual muscle cells, which in turn has gained its chemical energy from the hydrolysis of ATP (Figure 2). Magnesium inhibits muscle contractility in both smooth and striated muscle and thus reduces the risk of muscle cramps in athletes [1-6].

Magnesium requirements- an individual value not only for sporting activities

The prevalence of hypomagnesaemia (<0.76 mmol/l) in athletes is given in the literature as between 20% and 65%. In the

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Received November 29, 2018; **Accepted** January 08, 2019; **Published** January 15 2019

Citation: Kisters K, Gröber U, Adamietz I (2019) Magnesium: The Mitochondrial Blockbuster in Competitive Sports. Vitam Miner 8: 181.

Department of Medicine I in Herne, our own investigations on first division professional footballers showed that 35% of the players had a suboptimal magnesium status based on serum Mg levels (<0.8 mmol/l). The higher magnesium requirement seen in athletes is due to the increased metabolic activity resulting from growth and repair processes as the body adapts in response to the increased demands. Competitive athletes have daily magnesium (Mg^{2+}) requirement that is at least 20% higher than non-athletes, as they lose more of the mineral in sweat and urine. This requirement applies especially to elite athletes (→magnesium requirements per day: (a) women: 370 mg; (b) men: 480 mg), who participate in endurance sports (e.g. marathon running). The magnesium requirement during sporting activities also increases due to the accelerated glucose and energy metabolism, as the relevant enzymes need magnesium for activation.

As early as 2006, evidence was presented that a dietary intake of magnesium <260 mg/day in male athletes and<220 mg/day in

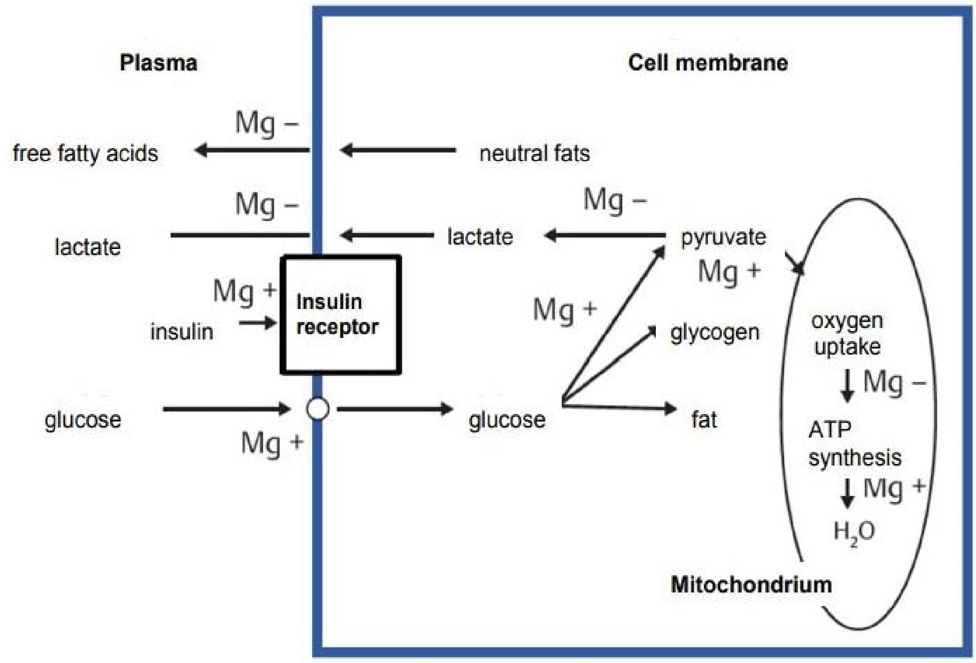

Figure 1: Magnesium and energy metabolism (model).

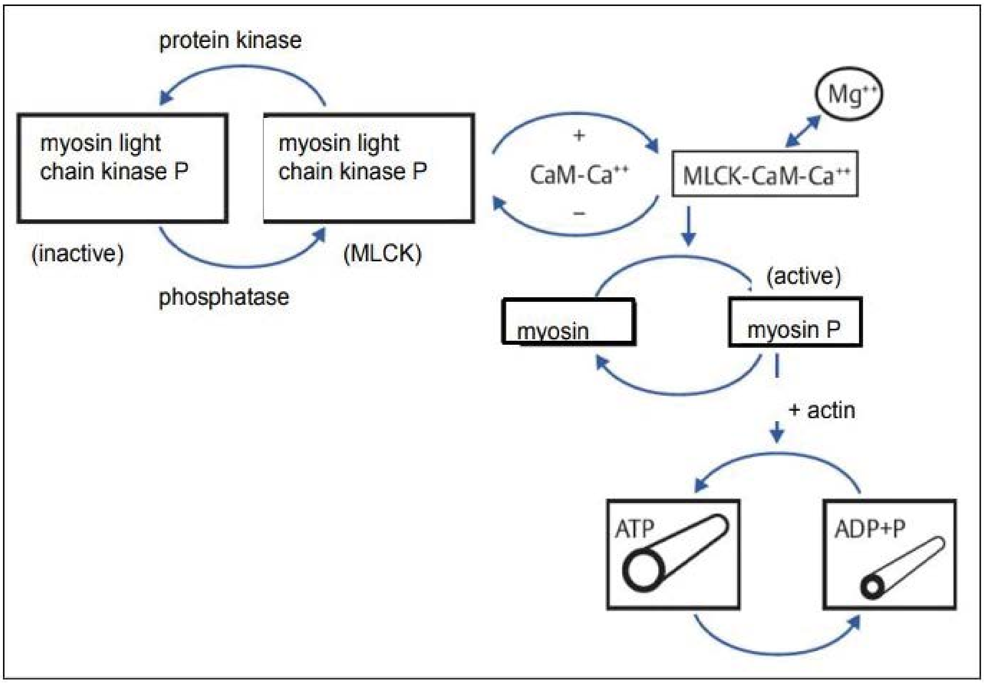

Figure 2: Magnesium and muscle contraction.

Reference	Intervention	Results
Cinar et al. [6]	10 mg Mg/kg body weight/day for 4 weeks or control	Significant improvement of lactate clearance ($p<0.05$) compared with controls
Brilla et al. [8]	8 mg Mg/kg body weight/day for 7 weeks or placebo	Supplementation led to a significant improvement of quadriceps torque ($p<0.05$)
Kass et al. [10]	T1: 300 mg Mg/day for 1 week (acute) T2: 300 mg Mg/day for 4 weeks (chronic)	Significant improvement of physical performance (e.g. bench presses, cardiovascular function)
Veronese et al. [16]	300 mg Mg/day for 12 weeks or placebo	Significant improvement of physical performance: Short Physical Performance Battery ($p=0.03$), wall sit time ($p<0.0001$), 4 m walking speed ($p=0.006$) Mg supplements prevent age-related reduction in physical performance.
Mg: Mg supplements		

Table 1: Magnesium and physical performance, results from selected randomised controlled trials.

female athletes results in a magnesium deficiency that has serious consequences on the performance of these athletes. Depending on the nature of the sport and the physical strain involved (e.g. marathon running), it may be necessary in individual cases to take a considerably higher dose of magnesium supplements than usual. Doses of up to 1000 mg magnesium/day are not uncommon here. Recent investigations also show that the administration of magnesium shortly before a competition or just before extreme mental stress seems to be beneficial to athletes.

Magnesium deficiency and its sequelae

When there is an inadequate oxygen supply, muscles produce more lactate. The athlete's body also needs magnesium to excrete lactate. Studies have shown that magnesium supplements promote muscular endurance in competitive athletes, prevent tissue damage and support natural tissue regeneration. Magnesium acts against over-acidification and high lactate loads: supplements (e.g. ~10 mg magnesium/kg body weight/day) assist anaerobic alactic acid energy metabolism (→cleaving the stored energy-rich phosphate ATP and creatine phosphate). A suboptimal magnesium status in weight training exercises may lead to inefficient energy metabolism and reduce endurance. In anaerobic sporting activities, a higher magnesium supply is associated with a lower oxygen requirement and better cardiorespiratory fitness.

Effects on performance parameters

Various studies on athletes have reported an improvement in physical performance parameters with magnesium supplements. The physiological performance parameters that have been investigated include blood pressure, glucose availability and grip strength of the hands, heart rate, muscle lactate clearance, jump performance and VO_2 max. These effects have also been confirmed by the results of randomised double-blind and placebo-controlled trials (Table 1) [7-10].

Discussion

Marathon runners in particular have an increased magnesium requirement, as sport-induced magnesium loss leads to severe magnesium deficiency, which results in muscle weakness and neuromuscular dysfunction. Also, for brief intense physical activity, magnesium loss and the effects of magnesium loss in sporting activities are well documented. A study by Matias and co-workers looked at the relationship between intra erythrocytic magnesium and the effect of intracellular water loss on hand grip strength in elite judo athletes. The authors found that the magnesium supply correlated with grip strength and intracellular water concentration. Similar investigations have been carried out on basketball, handball and volleyball players. Santos and co-workers found a direct relationship between muscle activity and magnesium deficiency [10-16].

Conclusion

In summary, recent studies have shown that magnesium plays an important role in competitive sports. Magnesium is important for both muscle strength and endurance sports. Likewise, there is a cardio protective effect, with a slight lowering of the blood pressure by magnesium being well documented. Magnesium supplements should not be taken directly before or during sporting activities (→increased risk of gastrointestinal disturbances). The daily dose should be sufficiently high (e.g. ~10 mg magnesium/kg body weight/day) and taken in divided doses over the day during the regeneration phase (e.g. 200 mg four times a day, as citrate, orotate or taurate). Consumption of magnesium-rich mineral water (>100 mg Mg/litre) supports a healthy magnesium balance in athletes.

Renal magnesium excretion or ionized serum magnesium can be used to diagnose magnesium efficiencies in athletes, especially when there are normal serum levels (0.76-1.15) mmol/l despite existing clinical symptoms of magnesium deficiency (reference range: 1). in urine: (2.5-8.5) mmol magnesium per day; 2). ionized serum magnesium: (0.54-0.67) mmol/l).

Conflict of Interest

Author has no conflict of interest.

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