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HUMAN NEEDS FOR MAGNESIUM ARE NOT MET BY MOST PEOPLE

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The American diet is rich in proteins, carbohydrates and fats but it is commonly poor in magnesium (Mg). Additionally, most supplements of vitamins and minerals, that are taken by many to assure adequate nutrition, provide Mg in only minimal amounts, if at all. Mg is a mineral that is essential for health in optimal quantities, if we are to obtain full benefit from the foods we eat and from the supplements we take. Mg is needed by our bodies to activate numerous enzymes that control metabolism of carbohydrates, fats and electrolytes; to assist in the utilization of other essential minerals, including calcium (Ca) and to build the nucleic acids and our body's proteins from the amino acids provided by the proteins found in food. Without adequate Mg, energy production falters and proteins cannot be produced in sufficient quantity for normal growth and development of infants, children, adolescents and pregnant women. Mg also is important in repair of wear and tear of everyday living, in maintaining resistance to infection, in protecting against cardiovascular, kidney and bone disease and in meeting the excess needs caused by emotional or physical stress.

MAGNESIUM REQUIREMENTS

On a milligram per kilogram (mg/kg) of lean body weight basis, women have been shown to need 4.5-5 mg/kg/day and men to need least 6 mg/kg/day to remain in Mg balance as determined by analysis of metabolic balance studies done worldwide^{1,2}. These studies disclosed that, on marginal intakes, there was better retention of Mg by young women than by young men. The Food and Nutrition Board of the National Research Council, National Academies of Science, have long estimated that the Recommended Dietary Allowances (RDAs) for Mg intakes (an amount estimated as enough to prevent diseases associated with Mg deficiency) are 300 mg/day for women and 350/day for men.³ The RDA for Mg was increased to 310-320 mg/day for women and 400-420 mg/day for men in the 1997 edition, entitled Dietary Reference Intakes (DRI),⁴ in which new dietary categories were developed, including Tolerable Upper Limits (UL). The UL designates supplemental amounts estimated to result in adverse effects if habitually exceeded. The Mg UL was limited to avoid diarrhea in unduly vulnerable subjects. The ULs for Ca, phosphate and vitamin D, high intakes of which interfere with Mg utilization (see below), were increased substantially

more than was the UL for Mg.

ARE THE RDAs FOR MAGNESIUM OPTIMAL?

Optimal Mg intakes are amounts that maintain normal functioning of the body and prevent disorders treatable with Mg supplements. Research, done throughout the world, shows that the original RDA for Mg is not even sufficient to assure compensation for the amount lost in excreta and sweat, in the presence of even minor physical or mental exertion or competition, aggravation or other stresses, all of which increase Mg requirements⁵⁻⁸ (see below). Even for adults living non-stressful, not particularly active lives, it is not enough merely to maintain Mg balance, which is the term used to describe the equilibrium between Mg intake and output.

The amount actually consumed from self-selected diets, as shown in the United States⁹⁻¹⁴, Europe¹⁵⁻¹⁸ and Asia¹⁹⁻²¹ is less than the RDA, and is far less than the amount shown to be required to maintain equilibrium in metabolic balance studies^{1,2,10,32}.

No one can afford to lose more Mg than is provided by the diet. When that happens, the person is in negative Mg balance. This means that, in order to maintain normal vital functions, the Mg that is already in the body that is serving to activate enzymes, to maintain energy and normal electrolyte levels in the cells, as well as to form healthy structures, is drawn upon, with the result that some tissues are broken down to meet the demands of organs needed to sustain life.

The higher figures for the RDA established in 1997 might be closer to optimal amounts of Mg, being estimated as the amounts needed to prevent damage to the body and to maintain health. All tissues are at risk of malfunction and/or physical injury when Mg levels are low; they include the heart, arteries, kidneys, bones, hormones, muscles, nerves, brain, skin and the gastrointestinal organs. Chronic or long-term Mg deficiency is contributory to development of many disorders and diseases.⁸ Treatment of these illnesses can intensify the problem because many medications increase Mg loss. When the deficiency is acute and severe, it can cause seizures or rapid irregular heart beats (arrhythmias) that can prove fatal. Which disorders develop will depend upon one's hereditary predisposition.²²⁻²⁴ Some families are prone to high blood pressure and other types of cardiovascular disease, some to kidney stones, some to bone thinning, chronic fatigue, muscle cramping, nervousness and some types of severe recurrent



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headaches – in all of which subnormal Mg levels have been encountered and increased Mg intakes have proven helpful.

Positive Mg balance is achieved when the body retains some of the Mg that is consumed, rather than eliminating an amount equal to the amount ingested and absorbed. The retained Mg participates in building healthy new tissue, a state that is called anabolism. This is the condition found in pregnant and nursing mothers, in those who have not reached full growth and maturation and in athletes who are developing their musculature. It is also the state of people recovering from illness, surgery or accidental trauma. A positive Mg balance indicates that this vital mineral is being used in the formation of the proteins of muscles, whether of our limbs, heart, arteries, kidneys and hormones. Mg is also necessary to form normal bones – to convert vitamin D to one of the hormones needed for utilization of Ca,²⁵⁻²⁷ which is the major structural component of bone. Less widely considered is the role of Mg in forming the organic portion of bone (bone matrix) that prevents brittleness and protects against fractures.²⁸

To attain positive Mg balance, its daily intake must be optimal – adequate to meet special requirements. The amount needed by those undergoing growth and development, repair or participating in strenuous exercise is greater than the amount needed by adults living sedentary lives. Even the recently increased RDAs are unlikely to be optimal for individuals with such special needs. Adolescent boys and girls, especially those engaged in athletics, can require as much as 7-10 mg/kg/day. Pregnant women, particularly those with more than one fetus, those who have undergone frequent pregnancies, or who themselves have not attained full growth, have high Mg requirements – at least 450 mg/day or possibly up to 15 mg/kg/day.²⁹ Growing and developing infants and children are also in need of high daily intakes of Mg.

DIETARY COMPONENTS THAT INCREASE MAGNESIUM REQUIREMENTS

Calcium, Phosphate and Vitamin D

Mg intakes have fallen slightly over the twentieth century in the United States, but the Ca/Mg dietary ratio, which was about 2/1 in the first quarter of the century,³⁰ has risen, and the RDAs for Ca and vitamin D (the vitamin that increases Ca absorption) have been increased. These are nutrients that have been shown to interfere with Mg retention yet require Mg for their normal utilization. Phosphate intake has also risen as a result of its addition to processed foods and soft drinks and this also interferes with Mg absorption.³¹ The RDAs for Ca and phosphate are given as 1000 mg/day each in the 1997 book that raised the RDA for Mg to a lesser degree.⁴ The tolerable upper level (UL) for Ca is given as 2500 mg, for phosphate as 3500 mg and for vitamin D as 2000 units. However, the UL for Mg supplements is limited to 350 Mg, which, added to that in food and water, might increase the daily Mg intake to about 650 Mg. For those accepting the upper limit as desirable, unphysiologic Ca/Mg ratios can result. The high tolerable

upper limit for Ca, phosphate and vitamin D can intensify Mg deficiency.

Carefully done human metabolic studies have verified that high Ca/Mg and phosphate/Mg dietary intakes (within the limits of usual diets and below the ULs cited by the Food and Nutrition Board) have been shown to cause negative Mg balance. Compilation and analysis of early extensive Mg balance studies of normal young adults showed that at Mg intakes below 5 mg/kg/day, negative balances of both Mg and Ca develop when Ca intakes are not particularly high.^{1, 32} On Mg intakes below 300 mg/day, Mg balances were consistently either negative or barely in balance at Ca intakes of 1 g/day. At 5-6 mg/kg/day of Mg, Ca intakes below 1 g/day allowed for positive Mg balances, that Ca intakes above 1 g/day diminished. Very high Ca intakes can result in negative Mg balance if Mg intake is low. The Ca balance is positive with high Ca/Mg dietary ratios, but in such a circumstance, the Ca deposition can be in the soft tissues such as the arteries and kidneys, as well as in bone. High Mg intakes do not interfere with Ca retention and improve Ca retention unless Ca intake is very low. This is implemented by the favorable effect Mg has on the hormones that control Ca absorption and its metabolism.

A Ca/Mg ratio of 2/1, provided by the daily Mg intake of 600 mg and a Ca intake of 1200 mg/day was considered suitable for maintenance of health in 1935³⁰, on the basis of study of the literature then available. The current RDA allowances provide a Ca/Mg ratio of 3/1; the UL allows for 4/1 or higher ratios. Since phosphate excess intensifies Mg loss,³¹ the high UL for phosphate can aggravate the problem. Until there are definitive data as to optimal intakes under different physiologic and pathologic conditions, Mg intakes should be increased to not less than 6 mg/kg/d for young adults^{1,2,16}.

In a study of elderly men, whose dietary Mg intake was maintained at their customary 250 mg/day and their Ca intake was raised to 1400 mg/day, negative Mg balance developed.³³ When their Mg intake was increased to 500 mg, Mg equilibrium was restored. Similarly, a negative Mg balance was produced by increasing their phosphate intake from the close to the RDA level of 975 mg/day to 1500 mg daily – an amount that is common in the American diet and is less than half of the tolerable UL.

An important study of 15 young women, who underwent three consecutive 20 day balance periods, while on a diet that provided RDA levels of Mg (265 to 305 mg), Ca (1008 to 1085 mg), RDA levels of phosphate and which provided a Ca/Mg ratio of 3.7/1, showed that on controlled RDA intakes, they lost about 50 mg of Mg a day.³⁴ The authors considered this to be an indication that not less than 6 mg/kg/day of Mg is needed by young women. They also observed a gradual rise in serum cholesterol, despite low dietary fat intake during the three observation periods. That vitamin D is required for the absorption of Ca is widely recognized, an effect that has been relied upon to prevent rickets in children. High doses are now recommended, along with a high dosage of Ca, to protect against osteoporosis. Excess Vitamin D also raises blood levels of cholesterol.^{35,36}



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Fat, Sugar and Alcohol

High levels of fat within the intestine, whether it is derived from fatty foods or intestinal dysfunction, such as steatorrhea, or short bowel, directly interfere with the absorption of both Mg and Ca by formation of indigestible complexes of Mg and/or the Ca with the fat.³⁷ Excess absorbed fat can lead to high blood cholesterol. Most important are resultant high levels of low density lipoprotein-cholesterol (LDL-C), which is called a “bad” fat, because it, and the triglycerides, cause atherosclerosis. In contrast, the high density cholesterol (HDL-C) fraction is the “good” lipid because it reduces fat deposition in arteries. HDL-C is low in patients with cardiovascular disease, while the level of LDL-C is high.

Very important is what Mg does to the ratio of HDL-C to LDL-C. The observation that Mg supplements increase the HDL-C/LDL-C ratio in the blood of normal subjects and in patients with high blood pressure or with coronary heart disease³⁸⁻⁴¹ is an explanation of one of the benefits of increasing Mg uptake.

High sugar intake, high blood sugar levels common in diabetic patients and moderate alcohol consumption cause renal loss of Mg.^{42,43} Heavy alcohol drinking causes severe Mg deficiency, not only from the renal loss, but also as a result of poor diet and hormonal disturbances that develop in patients with cirrhosis of the liver, a consequence of chronic alcoholism.

Protein

Adequate protein intake is necessary for optimal Mg retention. This was shown in adolescent girls and boys and women on diets that had marginal supplies of Mg and protein. Their Mg balance was improved by increasing their protein intake from low to normal. Diets containing sufficient Mg for growth and development (10-16 mg/kg/day) in adolescent boys resulted in positive balances regardless of the protein intake.⁴⁴ However, very high protein intakes have been shown to increase the risk of Mg deficiency, when the diets were low or marginal in Mg. This was first shown in infants with protein calorie malnutrition, whose protein deficiency had been repaired without correcting their Mg deficit. They developed cardiac arrhythmias that could terminate fatally in those not provided Mg supplementation.⁴⁵ Arrhythmias, attributable to loss of Mg, have also been reported as a result of consuming a liquid protein diet for weight reduction,⁴⁶ an approach to obesity that resulted in what was called “liquid protein mayhem” because it resulted in deaths caused by ventricular arrhythmias.⁴⁷

MAGNESIUM DEFICIENCY INCREASES
VULNERABILITY TO DISEASE; DECREASES
RESISTANCE TO STRESS

Cardiovascular, Renal, Bone Diseases

The diseases receiving most attention as being associated with Mg deficiency are those of the arteries and the heart.^{8,22} Many experimental studies in laboratory animals

have demonstrated that Mg deficiency alone, especially in combination with nutrients that interfere with Mg utilization, causes cardiovascular damage resembling that seen in diseases that afflict mankind. Studies of disease frequency in different parts of the United States, and throughout the world, have disclosed that poor Mg intake from food and/or water is more prevalent in regions where cardiovascular diseases are a greater problem than where Mg intake is high.⁴⁸ Hard water (containing predominantly Mg) has been found to be protective. The southeast of the United States, where the water is soft and poor in Mg, is known as the “heart disease–kidney stone belt.” In contrast, the north Midwestern states, which have water supplies rich in Mg, have fewer cases of heart disease. Since some hard waters are rich in Ca, its possibly protective effect has also been proposed. However, studies from Finland implicate a Ca/Mg ratio of 4/1 in the very high death rate of middle-aged men from coronary heart disease in that country.⁴⁹ Because high Ca intake is currently recommended to decrease the risk of osteoporosis, it is noteworthy that the incidence of osteoporosis is very high in Finland, despite lifelong high Ca/Mg intake ratios.^{48,49} Another clue that high Ca/Mg dietary ratios and nutrients such as vitamin D that increase Ca absorption but intensify cardiovascular damage of Mg deficiency is the increase in cardiovascular disease in Japan, since their diet has become more like the low Mg, high Ca American diet.²⁰ Their earlier low incidence of coronary heart disease was correlated with their low Ca/Mg dietary ratio.⁴⁹

Physicians have used Mg to treat patients since the first third of the twentieth century, regarding it as a medication, rather than a nutrient, that might protect against manifestations of diseases that respond favorably to its administration. Its use to manage the seizures and high blood pressure of women with toxemia of pregnancy was begun by 1925,⁵⁰ a use predicated on the early demonstration that experimental Mg deficiency induced convulsions, hypertension and arterial lesions in animals. Mg treatment has been used to control the arrhythmias caused by digitalis treatment of congestive heart failure, an effect that was first reported in Germany in 1935⁵¹ and in the United States in 1943.⁵² It is accepted treatment in conditions in which arrhythmias are a risk (in congestive heart failure⁵³⁻⁵⁵ and after cardiac surgery^{56,57}) and even in forms of arrhythmia resistant to drug therapy.⁵⁸ Loss of Mg caused by diuretic drugs used to control edema or hypertension also causes side effects which are manageable by Mg repletion. Poorly controlled diabetic patients are another group long known to have Mg loss⁵⁹ for whom Mg administration has been helpful.

Syndromes: X, Insulin Resistance, Cardiovascular
Metabolic Disease

Determination of intracellular Mg and Ca levels has provided important insights into the interrelationships of several diseases usually considered quite separate. It has been discovered that resistance to the effects of insulin, previously thought to be a problem only in diabetes, is also found in



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patients with other metabolic disturbances involving abnormal Mg and Ca levels in their tissues.⁶⁰⁻⁶⁶ Among these disorders are hypertension (with and without heart disease or diabetes), obesity (with and without diabetes), pregnancy complicated by high blood pressure and abnormal processes associated with aging. The existence of insulin resistance in these different conditions has led to the use of encompassing terms such as: syndrome X, insulin resistance syndrome and generalized cardiovascular-metabolic disease. Common to them all are subnormal intracellular Mg/Ca ratios. It is thus provocative that Mg deficiency has been directly correlated with development of insulin resistance⁶⁷ and that Mg supplements have restored responsiveness to insulin. The observation that healthy people, who reach and surpass 100 years of age, have higher total body Mg and lower Ca levels than the usual elderly person,⁶⁶ suggests an intriguing possibility: might increased Mg allay some of the deleterious processes of aging?

Stress and Neuromuscular Disorders

Stress increases the secretion of adrenalin and corticosteroid hormones. These stress hormones mobilize Mg from the cells and increase its renal excretion. It is paradoxical that Mg inadequacy increases secretion of stress hormones⁵⁻⁷ – a vicious cycle. Might this be why Type A individuals are more prone to heart attacks than are those of a more tranquil disposition? The types of stresses that can increase Mg requirements can be physical (exhausting or competitive exercise, exposure to extremes of temperature, accidental or surgical trauma) or psychological (anger, fear, anxiety, depression, grief, tension). In continental Europe, individuals who complain of such psychological manifestations are often diagnosed as having latent tetany, associated with marginal Mg deficiency.⁶⁸⁻⁷⁰ These patients frequently suffer from pronounced fatigue, leg cramps and recurrent headaches, including migraine, as well as psychological problems. In the United States, where Mg levels are not often determined in seeking an explanation of the complaints that often lead to psychiatric consultation, a comparable disorder is usually diagnosed as chronic fatigue syndrome.⁷⁰

WHY IS MAGNESIUM DEFICIENCY OFTEN MISSED?

Difficulties in Diagnosis

Most of the body's Mg is within the cells, rather than in the blood plasma or serum, and it is from analysis of serum or plasma levels of minerals that a diagnosis of Mg deficiency is usually made.⁷¹

The kidneys can limit the loss of Mg to very small amounts if plasma levels drop. However, there can be Mg deficiency in the tissues even when plasma levels are normal.

When plasma Mg is below what is accepted as the low limit of normal, that is a clear indication of deficiency. Adequacy, however, is not assured by plasma levels that remain within a normal range of values. On request, more information can be provided on the methods of determining Mg levels.

The signs of Mg deficiency universally recognized are

convulsions and cardiac arrhythmias, but these are signs of severe deficiency. The early arterial lesions (of the linings of the arteries and their muscles) are free of signs, as are early lesions of the heart and kidneys. The neuromuscular signs of nervousness, irritability, anxiety, gastrointestinal symptoms are more often considered manifestations justifying psychiatric care or investigation of intestinal status rather than closer attention paid to the diet. Osteoporosis, accepted as a largely nutritional problem, is treated by increasing mineralization (Ca and vitamin D intakes) without attention to the fact that in Finland, where Ca intake is high and Mg intake is low, both osteoporosis and cardiovascular disease are serious problems.⁴⁸

Adaptation to Long-Term Low Magnesium Intakes

The difficulty in diagnosing Mg deficiency stems from the unreliability of plasma values and the fact that there are few overt signs of early Mg deficiency – which affect internal tissues that have symptom-free damage. Furthermore, the body has the ability to maintain equilibrium, even when levels of essential nutrients (like Mg) in the body are subnormal.^{32,72} The available evidence indicates that it takes varying but usually prolonged periods of time for the body to adjust to changed Mg intakes by retaining amounts needed for optimal functioning.

CONCLUSIONS

When the first analysis of Mg intakes and balances in normal young adults³² was published in 1964¹, Mg deficiency was suggested as a neglected factor in vulnerability to heart disease. It was then suggested that an explanation of the lesser risk of young women might be their maintenance of Mg equilibrium on lower intakes. The lower rates of cardiovascular diseases in men in the East than the West was deemed attributable in part to higher mg/kg/day Mg intakes in the Orient (from diets comprised largely of soy products, vegetables and fish) than in occidental countries. More cardiovascular disease, however, has become a problem in countries such as Japan and in some areas in China, where the diet has changed.^{20,76-80} A high sodium intake is unquestionably a factor in high blood pressure, but low Mg intake is contributory. In Japan, emphasis is placed on the need, not only to lower salt, but to increase the Mg content of the diet in order to protect against cardiovascular disease.^{20,76-78,80} Large-scale American surveys and reviews of data implicate low dietary intake and serum levels of Mg in cardiovascular disease in the United States.^{48,73-75} Fewer studies have correlated low Mg intake with osteoporosis but the coexistence of both heart and bone disease in conditions associated with Mg loss, including diabetes⁸¹ and alcoholism,⁸² is provocative.⁴⁸ This recalls the prevalence of both heart disease and osteoporosis in Finland where Mg intake is low.⁴⁸ Also, the elderly who eat diets rich in vegetables, which are diets high in Mg, have greater bone density and thus are less prone to osteoporosis, than are those with less Mg-rich diets,⁸³ just as they are less prone to cardiovascular disease.



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