

The Nutritional Relationships of Magnesium

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Magnesium is a key element in cellular metabolism, and its involvement in critical enzymes systems within the body is extensive. As an intracellular element, magnesium is needed for the activation of hexo-kinase, which is required in the conversion of glucose to glucose-6-phosphate. This is the first step in the glycolysis cycle involving carbohydrate metabolism. The requirement for magnesium continues into and through the function of the Krebs cycle and is involved in the conversion of pyruvates to coenzyme A. Magnesium is an important requirement for normal functioning of both anaerobic and aerobic metabolism.

Distribution and Requirements

Magnesium is the fourth most abundant cation found in the human body. Approximately twenty-five grams is present in an adult, half of which is contained in the bone and the remainder in soft tissues. The highest concentrations are found in the striated muscles, liver, heart, and pancreas. The higher the metabolic rate of a cell, the higher the magnesium content.

The Recommended Dietary Allowances for magnesium are; infants, 60 to 70 milligrams; children, 150 to 250 milligrams; adults, 300-400; and pregnant or lactating women, 450 milligrams per day.¹

Magnesium and Tissue Mineral Analysis (TMA)

Tissue mineral analysis of human hair has contributed substantially to the understanding of magnesium and its relationship to other nutrient minerals. Considering the limitations of other tests for accurately measuring magnesium (except through muscle and bone biopsy and loading tests, which are inconvenient),

TMA of hair may be the most useful and economical screening tool. Seelig has pointed out the many errors involved in serum and plasma magnesium determinations, as well as the unreliability of erythrocyte magnesium levels.² It has been reported that serum magnesium does not give a true indication of magnesium stores and that hypomagnesemia can occur when the cellular content of magnesium is normal.^{3 4} Also, cellular depletion can exist without a corresponding reduction in serum levels.^{5 6 7} Serum magnesium levels can be affected by the tourniquet technique when drawing the sample⁸ and by temperature variations.⁹ Serum values are maintained at the expense of intracellular stores; therefore, it is considered unreliable as a means of evaluating magnesium status.¹⁰

The value of TMA is not in determining just the magnesium level alone, but more importantly it provides an easy means of evaluating magnesium in relation to the other elements. When interpreted correctly, TMA can indicate hormonal influence on magnesium and its cofactors. The "ideal" TMA level of magnesium, as determined by Trace Elements, Inc., is 6 milligrams percent. The most important "ideal ratios" of magnesium to other elements include calcium/magnesium (ideal 7.1 to 1), and sodium/magnesium (ideal 4 to 1).

Manifestations of Magnesium Deficiency

Two types of magnesium deficiencies can occur: either an *absolute deficiency* or *relative deficiency*. An absolute deficiency develops as a result of decreased absorption with increased excretion. A relative deficiency develops as a result of compartmental displacement of magnesium without an increase in its excretion. Therefore symptoms of magnesium deficiency and response to magnesium supplementation may vary markedly from one individual to

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another. An example of a relative deficiency is seen in hyperparathyroidism in which magnesium absorption is increased but the TMA level is found low relative to calcium. In this case, magnesium supplementation would decrease hyperparathyroid activity. However, in hypoparathyroidism, which usually occurs in conjunction with hyperthyroidism, an absolute magnesium deficiency is frequently found. Magnesium supplementation in this case would result in a reduction of thyroid activity and an increase in parathyroid function. Since the signs and symptoms of magnesium deficiencies vary from one individual to the next, it would be appropriate to recognize magnesium requirements based upon absolute (A) or relative (R) deficiencies, which include:

| | |
|-----------------------------|---------|
| Anxiety | (A) |
| Arthritis, Osteo | (R) |
| Depression | (R) |
| Calculi | (R) |
| Hyperactivity | (A) |
| Tremors | (A) |
| Eclampsia | (R) |
| Hyperreflexia | (A) |
| P.M.S. | (R) |
| Osteoporosis | (A) (R) |
| Hyperthyroidism | (A) |
| Cardiovascular Disease | (A) (R) |
| Insomnia (Type II) | (R) |
| Excessive Perspiration | (A) |
| Positive Chvostek Sign | (A) |
| Positive Trousseau Sign | (A) |
| Increased Noise Sensitivity | (A) (R) |
| Adrenal Insufficiency | (R) |
| Adrenal Hyperactivity | (A) |
| Arthritis, Rh. | (A) |
| Convulsions | (A) |
| Epilepsy | (A) |
| Body Odour | (A) |
| Hypertension, Diastolic | (R) |
| Hypertension, Systolic | (A) |
| Tetany | (A) |
| Hyperparathyroidism | (R) |
| Hypoparathyroidism | (A) |
| Psychotic Behaviour | (A) |
| Hypothyroidism | (R) |

Other conditions that may be associated with magnesium deficiency are gastrointestinal disorders such as malabsorption syndromes due to sprue, bowel resection, prolonged diarrhea, alcoholic cirrhosis, pancreatitis, and prolonged

diarrhea.

Magnesium deficiency has also been reported with endocrine disorders, renal disease, malignant osteolytic disease, excessive lactation, and diuretic therapy.

Symptoms of magnesium deficiency can be difficult to distinguish from those of a calcium deficiency. Classical signs of magnesium deficiency are type II insomnia, excessive perspiration, and general body odour. (Excessive odour of the feet is peculiar to zinc deficiency.) Type II insomnia, characterized by falling asleep easily but awakening frequently throughout the night, is often the reason individuals find themselves tired even after several hours of sleep. Type I insomnia, however, is associated with a calcium deficiency and causes difficulty in falling asleep.

Another characteristic of magnesium deficiency is muscle cramps upon exertion as well as carpedal spasms. Muscle spasms that occur in the hands and feet during rest are often associated with magnesium deficiency but can also be indicative of a need for increased potassium. This is due to the requirement of sufficient magnesium for cellular potassium retention. Muscle cramps associated with calcium deficiency often occur at night and without exertion. Such cramps usually involve the calves and thighs but not the hands or feet.

Diastolic hypertension with normal or low systolic blood pressure is seen with relative magnesium deficiency states, whereas an elevated systolic pressure without a corresponding elevation in diastolic pressure is indicative of an absolute magnesium deficiency. Absolute deficiencies of calcium and magnesium together are associated with an elevation of both the diastolic and systolic pressure. A relative magnesium deficiency found with hypothyroidism results in a "mounding phenomenon" of the muscle body with direct percussion. This "mounding phenomenon" is of objective diagnostic value in screening for magnesium requirements.¹¹

The toxic shock syndrome has been associated with the absorption of magnesium from the vaginal region with a concomitant increase in the proliferation of staphylococcus aureus. Apparently staph aureus will thrive more readily in the absence of magnesium. It is interesting

to note that other infectious conditions having staph aureus as the pathogen are also associated with magnesium deficiency as seen from TMA studies. These conditions include endocarditis, impetigo, osteomyelitis, septicemia, sinusitis, prostatitis, pneumonia, and otitis media.

Endocrine Influence on Magnesium

The thyroid, parathyroid, and adrenal glands have a marked influence on magnesium. Heightened thyroid activity increases magnesium requirements due to increased oxidative phosphorylation. Hypomagnesemia is found in hypothyroid states.^{12 13 14} This observation has also been consistent in TMA studies.

Parathyroid glandular activity affects magnesium opposite to that of the thyroid. Increased parathyroid activity increases magnesium absorption and renal reabsorption.¹⁵ The parathyroids also increase calcium absorption and therefore can produce a relative deficiency of magnesium. Conversely, hypomagnesemia is often found in hypoparathyroidism. Magnesium can affect parathyroid activity by either increasing or decreasing its effects.^{16 17 18} Apparently in an absolute deficiency state, magnesium will stimulate the parathyroid, and in a relative deficiency condition, magnesium will sedate the parathyroid.

Increased activity of the adrenal gland, both cortical and medullary, will produce an increase in magnesium excretion. Magnesium deficiency has been reported in hyperaldosteronism, during increased corticosteroid secretion, and with high adrenal medullary activity.^{19 20 21} The opposite occurs in adrenal insufficiency, resulting in an increase in magnesium retention.^{22 23 24}

Minerals Antagonistic to Magnesium

Magnesium requirements are affected by stress, diet, medications, as well as twenty-eight other nutritional factors. Figure 1 represents the minerals that are considered antagonistic to magnesium. An antagonistic response of these elements upon magnesium can occur on either an absorptive or metabolic level. Excessive intake or tissue retention of any one or combination of these elements can induce a magnesium

deficiency (absolute or relative), or increase its requirements.

Toxic metals such as lead and cadmium interfere with most of the nutrient minerals including magnesium. Lead absorption through the intestinal tract is lessened in the presence of adequate magnesium.²⁵ Lead accumulates in the mitochondrial membrane and directly interferes with magnesium on a metabolic level. Cadmium also affects magnesium adversely on a metabolic level due to its aldosterone-like effect of increasing tissue retention of sodium.

Calcium is closely related to magnesium in many metabolic processes, and when in a proper balance, will allow normal muscular function, neurotransmission, and hormone release. Calcium in excess will inhibit magnesium on both an absorptive and metabolic level. An excess amount of magnesium relative to calcium will result in decreased calcium mediated insulin secretion^{26 27} (TMA indication = $\text{Ca/Mg} < 4:1$).²⁸ However, an excess of calcium relative to magnesium (TMA indication = $\text{Ca/Mg} > 12:1$)²⁹ results in an increase in insulin secretion.³⁰

The excessive accumulation of potassium within the cell, mediated by increased adrenal secretion,^{31 32} can also result in excessive magnesium losses from the body. Excessive adrenal function using TMA is indicated by an elevated Na/Mg ratio greater than 4:1, with an elevated Ca/Mg ratio greater than 10:1³³

Excessive phosphorus intake leads to a deficiency of magnesium by interfering with its absorption.^{34 35} Foods high in phytic acid, and protein, which are high in phosphorus, will increase magnesium requirements.

Both manganese and iron decrease the absorption of magnesium either directly or indirectly. Manganese, however, can take the place of magnesium in some enzyme systems that require magnesium. These minerals in Figure 1 are mutually antagonistic to magnesium. Therefore we can see that excessive magnesium intake can antagonize toxic heavy metals and produce a deficiency of the nutrient minerals.

Vitamins Antagonistic to Magnesium

Less recognized are the effects of vitamins

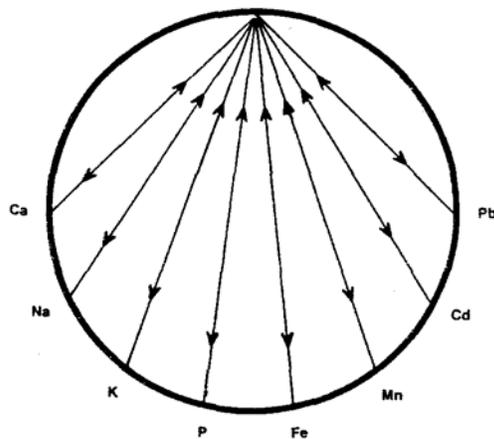


Figure 1.

upon magnesium status. Figure 2 shows the vitamins that are considered antagonistic to magnesium. These antagonisms can occur either directly or indirectly by increasing the metabolic requirements of magnesium.

Vitamin D is known to enhance magnesium deficiency.³⁶ The mechanism may be direct by the action of vitamin D upon calcium. Increased calcium accumulation within the tissues can displace magnesium. Vitamin D contributes indirectly to magnesium deficiency by its effect of increasing intestinal calcium absorption over that of magnesium. Vitamin D also affects parathyroid activity, which as discussed previously also affects magnesium status.

Vitamins B₁,³⁷ C, E and B₆ have a stimulating effect upon metabolic functions thereby increasing magnesium requirements in cellular enzymatic functions. These vitamins are also known to support adrenal activity, the consequence of overactivity having been discussed previously. The occasionally encountered hypertensive effect of high dosages of vitamin E may be related to a low magnesium status of some individuals.

Vitamin B₁₂ contains the mineral element cobalt. Cobalt in high dosages has been implicated in causing cardiac failure,^{38 39} a condition that became apparent in heavy beer drinkers. Beer, once laden with cobalt to enhance foam formation, has now been replaced with chromium. Cardiac disturbances are well known to be associated with magnesium deficiency. Since cobalt has been reported to antagonize thyroid activity,^{40 41} it can be surmised that excessive cobalt intake can produce either a

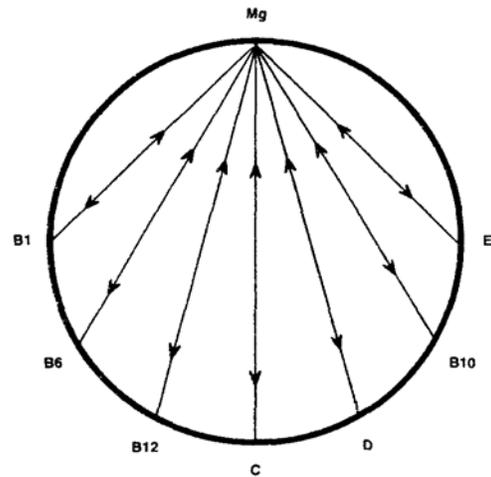


Figure 2.

relative deficiency or exacerbate an existing absolute deficiency of magnesium.

Folic acid (B₁₀) increases the activity of a number of glycolytic enzymes that require magnesium. Folic acid, therefore, can increase the metabolic needs for magnesium.⁴²

Excessive magnesium intake in turn, can contribute to a deficiency of any of these vitamins or increase their requirements.

Vitamin-Mineral Synergists

The following minerals are considered synergistic to magnesium and include calcium (Ca), potassium (K), zinc (Zn), manganese (Mn), phosphorus (P), and chromium (Cr).

Vitamins synergistic to magnesium are Vitamin A, B₁, B₂, B₃, C, and E.

Some minerals and vitamins appear as both synergistic and antagonistic. Within a physiological range, a nutrient can act as a synergist in magnesium dependent metabolic processes and absorption, but in higher (pharmacological) amounts can antagonize magnesium absorption and metabolic functions, or can increase the requirements for magnesium.

Conclusion

The role of magnesium in important biological processes is extensive. Recognition of its synergistic and antagonistic role with other nutrients can greatly enhance its therapeutic effectiveness, thus avoiding nutritionally induced deficiencies. TMA can be one of the most useful laboratory tests for evaluating magnesium status and requirements when assessed according to its physiological range with other nutritional factors.

References

1. Wilson ED, et al: *Principles of Nutrition, 4th Ed.* John Wiley and Sons, N.Y. 1979.
2. Seelig MS: *Magnesium Deficiency in the Pathogenesis of Disease.* Plenum Pub., N.Y. 1980.
3. L'Estrange JL, Axford R: Study of Magnesium and Calcium Metabolism in Lactating Ewes Fed Semi-Purified Diet Low in Magnesium. *J. Agric. Sc.* 62, 1964.
4. Richardson JA, Welt LG: Hypomagnesemia of Vitamin D Administration. *Proc. Soc. Exper. Biol, ir Med.* 118, 1965.
5. Fourman P, Morgan DB: Chronic Magnesium Deficiency. *Proc. Nutr. Soc.* 21, 1962.
6. Montgomery RD: Magnesium Metabolism in Infantile Protein Malnutrition. *Lancet*, 2, 1960.
7. MacIntyre I, et al: Intracellular Magnesium Deficiency in Man. *Clin. Sc.* 20, 1961.
8. Whang R, Wagner R: The Influence of Venous Occlusion and Exercise on Serum Magnesium Concentration. *Clin. Res.* 12, 1964.
9. Daniels F, et al: Plasma Magnesium Changes During Cold Acclimation in Man. *Fed. Proc, Fed. Am. Soc. Biol.* 12, 1953.
10. Theodore H, Siddiqui DA: Magnesium and the Pancreas. *Am. J. Clin. Nutr.* 26, 1973.
11. Ramsay I: *Thyroid Disease and Muscle Function.* Yearbook Pub., Inc., Chicago, II. 1974.
12. Jones JE, et al: Magnesium Metabolism in Hyperthyroidism and Hypothyroidism. *J. Clin. Invest.* 45, 1966.
13. Doe RP, et al: Magnesium Metabolism in Hyperthyroidism. *J. Lab. ir Clin. Med.*, 54, 1959.
14. Prasad AS, et al: Ultrafiltration Studies on Serum Magnesium in Normal and Diseased States. *J. Lab. & Clin. Med.* 54, 1961.
15. Guyton AC: *Textbook of Medical Physiology, 4th Ed.* Saunders Pub., Phil. 1971.
16. Oldham SB, et al: Dynamics of Parathyroid Hormone Secretion. *Am. J. Med.* 50, 1971.
17. Jones KH, Fourman P: Effects of Infusion of Magnesium and of Calcium in Parathyroid Insufficiency. *Clin. Sc.* 30, 1966.
18. Homer L: Hypoparathyroidism Requiring Massive Amounts of Medication, with Apparent Responses to Magnesium Sulfate. *J. Clin. Endocrinol, ir Metab.* 21, 1961.
19. Cohen, et al: Serum Magnesium in Children with Cirrhosis. *J. Fed.* 76, 1970.
20. Mader IJ, Iseri LT: Spontaneous Hypopotassemia, Hypomagnesemia, Alkalosis, and Tetany, Due to Hypersecretion of Corticos-terone-Like Mineralcorticoid. *Am. J. Med.* 19, 1955.
21. Hanna S, MacIntyre I: Influence of Aldosterone on Magnesium Metabolism. *Lancet*, 2, 1960.
22. Douglas WW, Rubin RP: Effects of Alkaline Earths and Other Divalent Cations on Adrenal Medullary Secretion. *J. Physiol.* 175, 1964.
23. Harrop GA, et al: Studies on the Suprarenal Cortex. *J. Exp. Med.* 58, 1933.
24. Wacker WE, Vallee BL: Magnesium Metabolism. *N.E.J.M.* 254, 1958.
25. Fine BP, et al: Influence of Magnesium on the Intestinal Absorption of Lead. *Environ. Res.* 12, 1976.
26. Malaisse WJ, et al: The Stimulus-Secretion Coupling of Glucose-Induced Insulin Release. *J. Lab. Clin. Med.* 76, 1970.
27. Bennett LL, et al: Calcium-Magnesium Antagonism in Insulin Secretion by the Perfused Rat Pancreas. *Endocrinol.* 85, 1969.
28. Watts DL: Determining Osteoporotic Tendencies from Tissue Mineral Analysis of Human Hair, Type I and Type II. *T.L.F.D.* 40-41, 1986.
29. *Ibid.*
30. Leclercqu-Meyer V, et al: Effect of Calcium and Magnesium on Glucagon Secretion. *Endocrinol.* 93, 1973.
31. Rosa RM, et al: Adrenergic Modulation of Extrarenal Potassium Disposal. *N.E.J.M.* 302, 1980.
32. Silva P, et al: Sympathetic System in Potassium Homeostasis. *Am. J. Physiol.* 241, 1981.
33. Watts DL: The Assessment of Hypertensive Tendencies from Hair Trace Element Analysis. *Chiro. Econ.* Mar. 1986.
34. Brisco AM, Ragan C: Effects of Magnesium on Calcium Metabolism in Man. *Am. J. Clin. Nutr.* 19, 1966.
35. Lifshitz F, et al: Intestinal Transport of Calcium and Phosphate in Experimental Magnesium Deficiency. *Proc. Soc. Exp. Biol. Med.* 125, 1967.
36. *Magnesium in Human Nutrition.* Home Econ. Res. Report No. 19. U.S.D.A. 1962.
37. Itokawa Y, et al: Effects of Thiamine on Serotonin in Magnesium Deficient Animals. *Metabol.* 21, 1972.
38. Epidemic Cardiac Failure in Beer Drinkers. *Nutr. Rev.* 26, 1968.
39. Alexander CS: Cobalt-Beer Cardiomyopathy. *Am. J. Med.* 53, 1972.
40. Sederholm T, et al: Cobalt-Induced Hypothyroidism and Polycythemia in Lipid Nephrosis. *Acta. Med. Scand.* 184, 1968.
41. Washburn TC, Kaplan E: Cobalt Therapy and Goiter. *Clin. Ped.* 3, 1964.
42. Hodges RE, Ed: *Human Nutrition: A Comprehensive Treatise.* Plenum Press, N.Y. 1979.