Hypomagnesemia

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Hypomagnesemia is a common entity occurring in up to 12% of hospitalized patients (1). The incidence rises to as high as 60 to 65% in patients in intensive care settings in which nutrition, diuretics, hypoalbuminemia, and aminoglycosides may play important roles (2–4).

Signs and Symptoms of Magnesium Depletion

Symptomatic magnesium depletion is often associated with multiple biochemical abnormalities such as hypokalemia, hypocalcemia, and metabolic alkalosis. As a result, it is often difficult to ascribe specific clinical manifestations solely to hypomagnesemia. In 1960, five patients were reported with symptoms considered to be typical of magnesium depletion, including tetany, positive Chvostek and Trousseau signs, and generalized convulsions (5). Somewhat similar findings—generalized weakness, anorexia, hypokalemia, hypocalcemia, and positive Trousseau and Chvostek signs—were noted when magnesium depletion was induced in volunteers (6). Tetany can occur in the absence of hypocalcemia and alkalosis and is presumably due to lowering of the threshold for nerve stimulation (7).

Hypokalemia

Hypokalemia is a common event in hypomagnesemic patients, occurring in 40 to 60% of cases (8). This relationship is in part due to underlying disorders that cause both magnesium and potassium loss, such as diuretic therapy and diarrhea. There is also evidence of renal potassium wasting in hypomagnesemic patients (6) that is likely due to increased potassium secretion in the loop of Henle and perhaps the cortical collecting tubule.

There are several mechanisms that may explain how this might occur. Potassium secretion from the cell into the lumen in the cells of the thick ascending limb and cortical collecting tubule is mediated by ATP-inhibitable luminal potassium channels (9). Hypomagnesemia is associated with a reduction in cell magnesium concentration, which may then lead to a decline in ATP activity, and, due to removal of ATP inhibition, an increase in the number of open potassium channels (9). In addition, decreasing cytosolic magnesium has been shown to directly increase the activity of potassium channels of ascending limb cells (10). Given the very high cell potassium concentration, these changes would promote potassium secretion from the cell into the lumen and enhanced urinary losses. The hypokalemia in this setting is relatively refractory to potassium supplementation and requires correction of the magnesium deficit (11).

Bone and Calcium Metabolism

The most classical sign of severe hypomagnesemia (<1.0 mEq/L, 0.5 mmol/L, or 1.2 mg/dl) is hypocalcemia. Early *in vitro* studies showed that a reduction in extracellular magnesium concentration stimulated the secretion of parathyroid hormone (PTH) in the absence of changes in calcium concentration. However, immunoreactive PTH levels in most hypomagnesemic-hypocalcemic patients have been either normal or low (and in some cases undetectable), indicating inappropriately low PTH secretion (12,13). Further evidence for a suppressive effect of hypomagnesemia on PTH secretion is the observation that, in the majority of these patients, parenteral magnesium supplementation leads to a rapid rise in plasma PTH levels (12,13). Several other factors play a role in the mechanism of the hypocalcemia.

Parathyroid Hormone Resistance. Failure of hormone secretion cannot explain all of the hypocalcemia, as bone resistance to PTH also plays a role (13). Studies in isolated perfused bone have shown that magnesium depletion interferes with the generation of cAMP in response to perfusion with PTH (14). Why this occurs is not clear. It is possible that severe hypomagnesemia may interfere with G protein activation in response to PTH, thereby minimizing the stimulation of adenylate cyclase.

Several findings suggest that PTH resistance may be of greater importance than diminished secretion in most patients. In general, PTH-induced release of calcium from bone is substantially impaired when the plasma magnesium concentration falls below 0.8 mEq/L (1 mg/dl or 0.4 mmol/L); in comparison, diminished PTH secretion appears to require more severe hypomagnesemia. Furthermore, there may be a variable time course for the normalization of the different aspects of calcium and PTH metabolism in hypomagnesemic patients. In some patients, PTH secretion rises significantly earlier than correction of hypocalcemia and restoration of PTH responsiveness (13). This observation is compatible with a primary role for PTH resistance.

As noted above, symptomatic hypocalcemia is almost always associated with plasma magnesium levels below 1.0 mEq/L (0.5 mmol/L or 1.2 mg/dl). Mild hypomagnesemia (plasma magnesium concentration between 1.1 and 1.3 mEq/L)

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can also lower the plasma calcium concentration, but the change is quite small (0.2 mg/dl or 0.05 mmol/L) (15).

Vitamin D Deficiency. Low plasma levels of calcitriol (1,25-dihydroxyvitamin D, the most active metabolite of vitamin D) have been noted in hypocalcemic, hypomagnesemic subjects and can contribute to the fall in the plasma calcium concentration. Why this occurs is not clear since, in one study, several days of magnesium replacement normalized plasma calcium and PTH levels but not the concentration of calcitriol (16).

Normomagnesemic Magnesium Depletion. A small number of patients have been reported with hypocalcemia responsive to magnesium administration in the absence of detectable hypomagnesemia (13,17). In most of these patients, other tests suggested the presence of magnesium depletion (presumed isolated cellular depletion), such as alcoholism or diarrhea. In a prospective study of 82 patients with alcohol-related admission diagnoses, for example, 30 had unexplained hypocalcemia (8.0 mg/dl or 2.0 mmol/L), 14 were hypomagnesemic, and 16 had a normal plasma magnesium concentration (17). However, both of the hypocalcemic groups had low mononuclear cell magnesium levels, a finding also seen in normocalcemic patients, and both groups showed normalization of the plasma calcium concentration after the administration of 32 to 64 mEq of elemental magnesium per day for 3 to 5 d.

These findings, however, do not conclusively demonstrate that intracellular magnesium depletion is the cause of unexplained hypocalcemia in patients with a normal plasma magnesium concentration. Most patients with chronic alcoholism and diarrhea have tissue magnesium depletion that is independent of the presence or absence of hypocalcemia. Sepsis, hypoalbuminemia, stress, and vitamin D deficiency are among the many factors in these patients that can lower the total and ionized calcium. Furthermore, there were no untreated time controls in this study, and it is possible that resolution of the hypocalcemia may have occurred without magnesium repletion as the clinical status of the patients improved after admission. Nevertheless, it seems reasonable to consider a trial of magnesium replacement in patients with normal renal function who have persistent, unexplained hypocalcemia and are at risk for magnesium deficiency.

Heart and Cardiovascular System

Magnesium depletion can induce changes in the electrocardiogram. Widening of the QRS complex and peaking of T waves have been described with modest magnesium loss, while more severe magnesium depletion can lead to prolongation of the PR interval, progressive widening of the QRS complex, and diminution of the T wave (18).

There are conflicting data as to whether hypomagnesemia is associated with arrhythmia in otherwise healthy subjects. A report on more than 3000 patients from the Framingham Heart Study suggests that the manner in which arrhythmia is defined is an important determinant (19). No association with hypomagnesemia was noted for more than 10 ventricular premature complexes (VPC) per hour or for repetitive VPC. There was,

however, an increased risk of complex or frequent (>30/h) PVC with reductions in the plasma magnesium concentration of 0.16 mEq/L (0.2 mg/dl or 0.08 mmol/L) or more.

The clinical disturbance of greatest potential importance, however, is the association of mild hypomagnesemia with ventricular arrhythmias in patients with cardiac disease. A number of uncontrolled studies suggest that hypomagnesemia may be an important risk factor for arrhythmias in the setting of an acute ischemic event, congestive heart failure, torsade de pointes, after cardiopulmonary bypass, or in the acutely ill patient in the intensive care unit.

The mechanism underlying a possible association between hypomagnesemia and arrhythmias is at present unknown. Arrhythmias could be due to concurrent hypokalemia, hypomagnesemia itself, or both. Magnesium regulates several cardiac ion channels, including the calcium channel and outward potassium currents through the delayed rectifier (20). Lowering the cytosolic magnesium concentration in magnesium depletion will markedly increase these outward currents, shortening the action potential and increasing susceptibility to arrhythmias.

Acute Ischemic Heart Disease. Patients with acute myocardial infarction who have mild hypomagnesemia appear to have a two- to threefold increase in the frequency of ventricular arrhythmias in the first 24 h when compared to those with normal plasma magnesium levels (21,22). Uncontrolled studies suggest that the administration of intravenous magnesium at this time can reduce the frequency of potentially fatal ventricular arrhythmias (23,24).

A relationship has also been found between the plasma magnesium concentration and ventricular arrhythmias occurring in the second or third week after myocardial infarction. In one study, for example, the mean plasma magnesium concentration was 1.83 mg/dl (0.76 mmol/L) in patients with no abnormal rhythms, 1.68 mg/dl (0.7 mmol/L) in those with multifocal ventricular premature complexes, and 1.55 mg/dl (0.65 mmol/L) in those with unsustained ventricular tachycardia (25). Thirteen patients with complex arrhythmias and hypomagnesemia received intravenous magnesium over 24 h; a normal rhythm was restored in 10.

Congestive Heart Failure. An increased incidence of hypomagnesemia has been found repeatedly in patients with congestive heart failure and is presumably due in part to diuretic therapy. A role for magnesium depletion in sudden death has been suggested but is not proven. In a prospective study involving more than 1000 patients with class III or IV heart failure, for example, no correlation was found between hypomagnesemia at the beginning of the study and survival at a median follow-up of 6 mo (26). However, measurements were not made later in the study and all patients were receiving digoxin, diuretics, and an angiotensin-converting enzyme inhibitor, any or all of which may have altered magnesium balance during the course of the study.

Torsade De Pointes. The American Heart Association 1992 Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiac Care now include a recommendation that magnesium sulfate be added for the management of torsade de

pointes, severe hypomagnesemia, or refractory ventricular fibrillation (27). Torsade de pointes is a unique ventricular tachycardia most commonly precipitated by drugs that prolong the QT interval (*e.g.*, quinidine), electrolyte imbalance (hypokalemia and hypomagnesemia), or a slow heart rate. Treatment is aimed at accelerating the heart rate and/or shortening the QT interval. Intravenous magnesium is now regarded as the treatment of choice even when hypomagnesemia is not present.

Cardiopulmonary Bypass. Hypomagnesemia may develop during cardiopulmonary bypass and predispose to arrhythmias. The cause of hypomagnesemia in this setting is unclear. Possible contributing factors include chelation by free fatty acids and/or citrate, and enhanced cellular uptake induced by increasing circulating levels of catecholamines.

One prospective study, for example, evaluated 101 patients: 18% had hypomagnesemia before induction compared with 71% following cessation of bypass (28). The hypomagnesemic patients had a significantly higher frequency of atrial dysrhythmias and an increased requirement for prolonged mechanical ventilatory support. A separate study suggested that 2 g of magnesium sulfate given after surgery reduced the level of ventricular ectopy (29).

These findings were corroborated in a prospective study of 100 patents who were randomized to either placebo or 2 g of magnesium chloride intravenously after the termination of cardiopulmonary bypass (30). Normomagnesemic patients had significantly fewer postoperative supraventricular and ventricular dysrhythmias, higher indices of cardiac performance, and a less frequent requirement for prolonged mechanical ventilatory support than patients with low plasma magnesium levels.

Intensive Care Unit. Hypomagnesemia is extremely common in patients in the intensive care unit and is frequently associated with hypokalemia and hypocalcemia (2,3,31). In one study, for example, hypomagnesemia present on admission to the intensive care unit was associated with a mortality rate approximately twice that of comparably ill normomagnesemic patients (31). It has not been shown, however, that magnesium supplementation would improve the outcome.

Coronary Heart Disease. Two large prospective epidemiologic studies have examined the relationship between the serum magnesium concentration and the subsequent development of coronary heart disease (CHD) (32,33). Both suggest that a low serum magnesium is a risk factor for coronary artery disease.

One study, for example, examined and followed a cohort of 15,792 subjects aged 45 to 64 yr old over a 4- to 7-yr period as part of the Atherosclerosis Risk in Communities (ARIC) Study (33). The relative risk of CHD across quartiles of serum magnesium in women was 1.0 (in the lowest quartile), 0.92, 0.48, and 0.44. The data in men showed a similar trend but were less striking and did not achieve statistical significance. Both men and women who developed CHD had a lower mean baseline serum magnesium concentration than the disease-free controls. How a low serum magnesium might predispose to CHD is not known.

Causes of Hypomagnesemia

Approximately one-third of dietary magnesium is absorbed (120 mg) principally in the small bowel. In addition, there is secretion of approximately 40 mg in intestinal secretions and absorption of another 20 mg in the large bowel. Balance is achieved by the urinary excretion of the approximately 100 mg that is absorbed. There is no physiologic hormonal control of plasma magnesium and urinary magnesium excretion. Changes in intake are balanced by changes in urinary magnesium reabsorption, principally in the loop of Henle and the distal tubule in response to changes in plasma magnesium concentration. There are therefore two major mechanisms by which hypomagnesemia can be induced: gastrointestinal or renal losses. Regardless of the cause, hypomagnesemia begins to occur after a relatively small magnesium deficit, because there is little rapid exchange of extracellular magnesium with the much larger bone and cell stores.

Gastrointestinal Losses

Gastrointestinal secretory losses, which contain some magnesium, are continuous and not regulated. Although the obligatory losses are not large, marked dietary deprivation can lead to progressive magnesium depletion. Magnesium loss will also occur when the intestinal secretions are incompletely reabsorbed as with most disorders of the small bowel, including acute or chronic diarrhea, malabsorption and steatorrhea, and small bowel bypass surgery.

A much rarer disorder is an inborn error of metabolism characterized by a selective defect in magnesium absorption (primary intestinal hypomagnesemia). This disease presents in the neonatal period with hypocalcemia responsive to magnesium administration. In some instances, the defect has X-linked recessive inheritance and in others the disorder is autosomally recessive with linkage to chromosome 9q (34).

Hypomagnesemia can also be seen in acute pancreatitis. The mechanism is presumably similar to that responsible for at least part of the associated hypocalcemia: saponification of magnesium and calcium in necrotic fat. The degree of hypocalcemia may be exacerbated by the hypomagnesemia, which can both lower PTH secretion and induce end-organ resistance to its effect.

Renal Losses

Urinary magnesium losses can be inappropriately increased by inhibition of sodium reabsorption in those segments in which magnesium transport passively follows that of sodium or, by a primary defect in renal tubular magnesium reabsorption.

Loop and Thiazide-Type Diuretics. Both loop and thiazide diuretics can inhibit net magnesium reabsorption, while the potassium-sparing diuretics may enhance magnesium transport and lower magnesium excretion. The degree of hypomagnesemia induced by the loop and thiazide diuretics is generally mild, in part because the associated volume contraction will tend to increase proximal sodium, water, and magnesium reabsorption.

Volume Expansion. Expansion of the extracellular fluid volume can decrease passive magnesium transport. If sustained, mild hypomagnesemia may ensue as in primary hyperaldosteronism.

Alcohol. Hypomagnesemia is common in alcoholic patients admitted to the hospital; in one study, for example, the prevalence was 30% (35). Excessive urinary excretion of magnesium occurred in 18 of the 38 patients with hypomagnesemia. The defect in urinary excretion appears to reflect alcohol-induced tubular dysfunction that is reversible within 4 wk of abstinence (36). This effect is modest and other factors contribute to hypomagnesemia in these patients, including dietary deficiency, acute pancreatitis, and diarrhea.

Hypercalcemia. Calcium and magnesium seem to compete for transport in the thick ascending limb of the loop of Henle. The increased filtered calcium load in hypercalcemic states will deliver more calcium to the loop of Henle; the ensuing rise in calcium reabsorption will diminish that of magnesium. As an example, some patients with primary hyperparathyroidism develop mild hypomagnesemia.

Nephrotoxins. Many nephrotoxic drugs can produce urinary magnesium wasting (37). Included in this group are the aminoglycoside antibiotics, amphotericin B, cisplatin, pentamidine, and cyclosporine. The impairment in loop and distal magnesium reabsorption may occur before the onset of and may persist after the resolution of overt tubular necrosis and acute renal failure. Studies in the rat, for example, have shown a dose-related, rapidly reversible decrease in renal tubular reabsorption of magnesium and calcium (but not sodium and potassium) within 60 min of beginning an infusion of gentamicin (38). The magnesuria in this setting can be striking and the resulting hypomagnesemia may be sufficient to produce hypocalcemia. Carboplatin, an analog of cisplatin with less nonhematologic toxicity, produces significantly less hypomagnesemia than the parent compound (39).

Loop of Henle or Distal Tubule Dysfunction. Magnesium wasting can occur as part of the tubular dysfunction seen with recovery from acute tubular necrosis, following renal transplantation, during a postobstructive diuresis, or in patients with Bartter's syndrome.

Primary Renal Magnesium Wasting. Primary renal magnesium wasting is an unusual disorder that may present sporadically or as a familial disease (40–45). In some patients, magnesium wasting is also associated with abnormalities in calcium and potassium transport. Three types have been recognized:

- One is associated with **hypercalciuria**, and affected patients usually present in childhood or adolescence with symptomatic hypocalcemia (40–44). Recurrent nephrolithiasis and nephrocalcinosis are also seen, and progression to renal insufficiency and an acidification defect are common. The problem with acidification has been attributed to defective ammonia transfer to the deep nephrons and impaired medullary hydrogen ion secretion due to nephrocalcinosis (46). Some patients present with hypokalemia presumably due to either secondary hyperaldosteronism and/or direct effects of

hypomagnesemia on potassium transport. However, some cohorts with familial hypomagnesemia and hypercalciuria have normal plasma potassium and bicarbonate concentrations. Using a general linkage approach in 14 kindreds with normal plasma potassium levels, the locus for this disorder has been linked to a 1 cM chromosomal interval (42).

- The second form is associated with **hypocalciuria** and hypokalemia and is known as Gitelman's syndrome. It is associated with a defect in the gene coding for the thiazide-sensitive sodium-chloride cotransporter. The hypokalemia is usually attributed to the decreased sodium chloride transport, but there is also evidence for direct effects of hypomagnesemia (47). The hypomagnesemia has also been attributed to the reduction in sodium chloride transport, which presumably decreases the passive transport of magnesium. The hypomagnesemia in this syndrome, however, is significantly more marked than that seen with thiazides. In addition, in a study of mice lacking the cotransporter after gene targeting, hypomagnesemia and hypocalciuria were present but there were only subtle changes in sodium homeostasis (48).

- The third form presents with isolated magnesium wasting with both an autosomal dominant and recessive mode of inheritance (40–41). The gene responsible for one of these syndromes has been mapped to a region on chromosome 11q23 in two unrelated Dutch families with an autosomal dominant mode of inheritance (45).

Because routine measurement of the plasma magnesium concentration is more prevalent, it is likely that acquired renal magnesium wasting due to aging and mild interstitial renal disease will become a more commonly recognized syndrome.

Miscellaneous. Hypomagnesemia can be seen following surgery, at least in part due to chelation by circulating free fatty acids (49), and after foscarnet therapy of cytomegalovirus chorioretinitis (50). Chelation is again involved and the plasma calcium concentration is also typically reduced. Similarly, ionized hypomagnesemia has been seen during liver transplantation as the result of transfusion of citrate-rich blood products in the absence of adequate hepatic function (51).

Hypomagnesemia can also occur as part of the "hungry bone" syndrome, in which there is increased magnesium uptake by renewing bone after parathyroidectomy (for hyperparathyroidism) or thyroidectomy (for hyperthyroidism) or after correction of chronic systemic acidosis (52).

Several studies have demonstrated a higher than expected frequency of hypomagnesemia in patients with diabetes mellitus that seems to be correlated with the degree of hyperglycemia (53). It has been proposed, although not proven, that hypomagnesemia may impair glucose disposal and may play a role in the pathogenesis of some of the complications of diabetes. As a result, the American Diabetes Association has published a consensus statement suggesting that diabetic patients with hypomagnesemia should receive magnesium supplementation.

Diagnosis

The plasma magnesium concentration is often not measured as part of the routine screening blood tests. The possible presence of hypomagnesemia should be suspected in the following situations: chronic diarrhea, hypocalcemia, refractory hypokalemia, and ventricular arrhythmias, particularly during an ischemic event. If the situation is life-threatening, blood should be drawn for measurement of the plasma magnesium concentration, and intravenous magnesium can be given immediately if renal function is relatively normal.

If hypomagnesemia is confirmed, the diagnosis can usually be obtained from the history. If no cause is apparent, the distinction between gastrointestinal and renal losses can be made by measuring the 24-h urinary magnesium excretion or the fractional excretion of magnesium on a random urine specimen. The latter can be calculated from the following formula:

$$FE_{Mg} = \frac{U_{Mg} \times P_{Cr}}{(0.7 \times P_{Mg}) \times U_{Cr}} \times 100$$

U and P refer to the urine and plasma concentrations of magnesium (Mg) and creatinine (Cr). The plasma magnesium concentration is multiplied by 0.7, since only about 70% of the circulating magnesium is free (not bound to albumin) and therefore able to be filtered across the glomerulus.

The normal renal response to magnesium depletion is to lower magnesium excretion to very low levels. Thus, daily excretion of more than 10 to 30 mg or a fractional excretion of magnesium above 2% in a subject with normal renal function indicates renal magnesium wasting due, for example, to drugs such as diuretics, aminoglycosides, or cisplatin. In one study of 74 hypomagnesemic patients, for example, the mean fractional excretion of magnesium in patients with hypomagnesemia of extrarenal origin was 1.4% (range, 0.5 to 2.7%) (54). The FEMg in patients with renal magnesium loss was 15% (range, 4 to 48%).

Normomagnesemic Magnesium Depletion

The possibility of normomagnesemic magnesium depletion, as discussed above, should be considered as a possible cause of refractory hypokalemia or unexplained hypocalcemia in patients at high risk for magnesium loss. It has been suggested that this syndrome can be detected by demonstrating low urinary magnesium excretion (as defined above). One report, for example, evaluated patients with chronic diarrhea due to small bowel resection or diffuse disease (55). Twenty-four-hour urine magnesium excretion was 19 mg in these patients compared to 127 mg in matched control subjects. The plasma magnesium concentration was only slightly lower in the patients with small bowel disease (1.7 *versus* 2.0 mg/dl [0.7 *versus* 0.8 mmol/L]), 56% of whom had a normal level.

Another method to detect underlying magnesium depletion is to demonstrate reduced excretion (<80% over 24 h) of an infused magnesium load (2.4 mg/kg of lean body weight given over the initial 4 h) (56,57). However, the utility of this test is uncertain. Patients with malnutrition, cirrhosis, diarrhea, or long-term diuretic use typically have a positive test, regardless of whether they have signs or symptoms referable to magnesium depletion (56). It seems prudent, therefore, to simply administer magnesium to these patients if they have unexplained hypocalcemia and/or hypokalemia.

Treatment

The route of magnesium repletion varies with the severity of the clinical manifestations. As an example, the hypocalcemic-hypomagnesemic patient with tetany or the patient suspected of having hypomagnesemic-hypokalemic ventricular arrhythmias should receive 50 mEq of intravenous magnesium given slowly over 8 to 24 h. This dose can be repeated as necessary to maintain the plasma magnesium concentration above 1.0 mg/dl (0.4 mmol/L or 0.8 mEq/L). In the normomagnesemic patient with hypocalcemia, it has been suggested to repeat this dose daily for 3 to 5 d (17).

It must be appreciated that the plasma magnesium concentration is the major regulator of magnesium reabsorption in the loop of Henle, the major site of active magnesium transport. Thus, an abrupt elevation in the plasma magnesium concentration will partially remove the stimulus to magnesium retention, and up to 50% of the infused magnesium will be excreted in the urine. Furthermore, magnesium uptake by the cells is slow and repletion requires sustained correction of the hypomagnesemia.

For these reasons, oral replacement should be given in the asymptomatic patient, preferably with a sustained-release preparation. There are several such preparations currently available, including Slow Mag® containing magnesium chloride and Mag-Tab SR® containing magnesium lactate. These preparations provide 5 to 7 mEq (2.5 to 3.5 mmol or 60 to 84 mg) of magnesium per tablet. Six to eight tablets should be taken daily in divided doses for severe magnesium depletion. Two to four tablets may be sufficient for mild, asymptomatic disease.

The underlying disease should also be corrected, if possible. Patients with hypomagnesemia induced by a thiazide or loop diuretic who cannot discontinue diuretic therapy may benefit from the addition of a potassium-sparing diuretic such as amiloride. These drugs may decrease magnesium excretion by increasing its reabsorption in the cortical collecting tubule. Amiloride also may be helpful in conditions associated with persistent urinary magnesium wasting such as Bartter's or Gitelman's syndrome or cisplatin nephrotoxicity. In these settings, magnesium repletion alone may be relatively ineffective, since raising the plasma magnesium concentration will, as mentioned above, lead to increased magnesium excretion.

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Errata

Due to author error, the units of measure for two variables in Tables 2 and 3 of the article, "QT Dispersion Before and After Hemodialysis" (*J Am Soc Nephrol* 9: 160–163, 1999), were incorrect. The Cornell and Sokolow values should have been listed in mm.

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