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# The Role of Magnesium in Neonatal Calcium Homeostasis: Effects of Magnesium Infusion on Calciotropic Hormones and Calcium

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**ABSTRACT. Magnesium (Mg) deficiency is a possible etiologic factor contributing to neonatal hypocalcemia. In adults, parathyroid hormone (PTH) secretion is negatively feedback regulated by acute changes in serum Mg concentration, but paradoxically Mg deficiency may lead to functional hypoparathyroidism and hypocalcemia. We hypothesized that in neonates, Mg administration will cause changes in PTH secretion and serum Ca concentration that will be inversely related to serum Mg status. We also hypothesized that Mg administration will result in increased calcitonin (CT) secretion. Thirty-nine newborn infants with birth weights >1500 g were studied on day 3 of life. Ten received placebo, and 29 intravenous magnesium sulfate ($MgSO_4$), 6 mg elemental Mg/kg body weight, over 1 h. Serum Mg, Ca, PTH, and CT were measured at time 0 (baseline, preinfusion) and 1, 2, 6, 12, 24, and 48 h postinfusion. In both groups combined, baseline PTH correlated with baseline Mg ($r = 0.72$, $p < 0.005$), and with baseline Ca ($r = 0.68$, $p < 0.005$). In the control group there was no change in serum Mg, Ca, PTH, and CT during the study period. In magnesium sulfate-infused infants: 1) serum Mg concentration rose from 1.80 ± 0.06 to 2.82 ± 0.07 mg/dl (mean ± SEM, $p < 0.001$); 2) the change from baseline in serum PTH at 1, 6, and 12 h postinfusion correlated inversely with baseline Mg ($p < 0.05$); 3) the change from baseline in serum Ca at 1, 2, and 24 h postinfusion correlated inversely with baseline Mg ($p < 0.005$); 4) serum CT remained unchanged. We conclude that Mg plays an important role in neonatal calcium metabolism. PTH and Ca responses to magnesium sulfate infusion were inversely related to neonatal serum Mg concentrations, consistent with the hypothesis tested. Mg infusion, however, did not affect neonatal serum CT concentrations. (*Pediatr Res* 22: 319–323, 1987)**

### Abbreviations

**PTH, parathyroid hormone**
**Mg, magnesium**
**Ca, calcium**
**$MgSO_4$, magnesium sulfate**
**CT, calcitonin**

Hypocalcemia is a frequently encountered problem in the neonatal period (1–7). Magnesium deficiency and transient hypoparathyroidism are two etiologic factors that have been implicated in this disorder. These two etiologic factors may be interrelated. In Mg-replete adults, PTH secretion is negatively feedback regulated by acute changes in serum Mg concentration (8, 9). Acute decreases in serum Mg concentration stimulate PTH secretion, and acute increases in serum Mg reduce PTH secretion. However, paradoxically Mg deficiency in adults suppresses PTH secretion by affecting the Ca-sensitive, Mg-dependent adenylate cyclase system or other Ca-mediated mechanisms of PTH secretion. In this instance the infusion of Mg has been associated with increases in serum PTH concentration (10).

A third etiologic factor that may contribute to the pathogenesis of neonatal hypocalcemia involves neonatal CT production. Serum CT concentrations have been found to be relatively elevated at birth, with further increases in the immediate postnatal period (11, 12). It has been suggested that an elevated serum CT concentration in the neonate may be physiologic, protecting the skeleton from excessive bone resorption, and protecting the newborn from acute hypercalcemia during milk feedings. However, elevated CT theoretically may also contribute to the neonatal tendency for hypocalcemia (13). It has been found that neonatal CT secretion increases when Ca is administered (12, 14). The effect of Mg administration on CT secretion in the neonate has not been previously investigated.

The present study was conducted to further our understanding of the role of Mg in neonatal Ca homeostasis by examining the effects of Mg infusion on PTH and CT secretion, and serum Ca concentration. We hypothesized that in neonates, Mg administration will cause changes in PTH secretion and serum Ca concentration that will be inversely related to serum Mg status. Infants with lower initial serum Mg concentrations will respond with increased PTH secretion and increased serum Ca concentrations, while those with higher initial serum Mg concentrations will respond with decreased PTH secretion and decreased serum Ca concentrations. We also hypothesized that the effect of Mg on CT secretion is similar to the effect of Ca, such that Mg administration results in an increase in CT secretion.

## METHODS

Thirty-nine newborn infants in the Neonatal Intensive Care Unit at the University of Cincinnati Medical Center or at the Children's Hospital Medical Center between 1982 and 1984 were enrolled in the study by the second day of life. Infants chosen for study had birth weights of more than 1500 g, and had intravenous access for clinical indications. By study design there were infants enrolled who were at low risk for hypomagnesemia, as well as infants in high risk categories, such as infants of diabetic mothers (17), small for gestational age infants (17), and birth-asphyxiated infants (18).

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To avoid the risks of hypermagnesemia during the study we excluded infants born to mothers who received $MgSO_4$ prior to delivery for the treatment of preeclampsia or for tocolysis (19, 20). We also excluded infants with possible impairment in renal function on the day of study since Mg is primarily excreted by the kidney. Impaired renal function was determined by any of the following criteria: blood urea nitrogen concentration greater than 15 mg/dl, serum creatinine concentration greater than 1.2 mg/dl, or urine output less than 1.0 ml/kg body weight/h. Infants with serum Mg concentration of more than 2.5 mg/dl on day 1 or 2 of life were also excluded. By study design it was decided that hypocalcemia (serum total Ca concentration <7 mg/dl) would not be treated with Ca salts unless the infant was symptomatic, or the serum total Ca concentration was <6 mg/dl. None of the enrolled infants fulfilled those criteria and none received calcium supplementation prior to or during the study period.

The study was approved by the University of Cincinnati Human Research Committee and written informed parental consent was obtained at the time of enrollment.

The first 20 infants studied all received a $MgSO_4$ infusion. It was then decided that examination of Mg-induced changes in Ca metabolism by comparison to baseline measurements was insufficient, and a control group receiving a placebo infusion was formed. The subsequent patients enrolled were randomized to either $MgSO_4$ or placebo infusion in a double-blinded manner. The final study and control groups consisted of 29 and 10 infants, respectively. Since there were no differences between the earlier and later $MgSO_4$-infused infant groups, these are presented as a single $MgSO_4$ infusion group.

The study was performed at 72 ± 12 h of age. Infants who were on oral feedings were given nothing by mouth for 4 h prior to the infusion. Intravenous fluids were administered from 2 h preinfusion to 2 h postinfusion with the rate and composition determined by the physicians caring for the infant. The fluid rate was based on the patient's weight and postnatal age and it ranged from 80 to 110 ml/kg/day. Electrolytes added to the fluids included NaCl, 2 to 3 mEq/kg/day, and KCl, 1 to 2 mEq/kg/day. Feedings were resumed 2 h postinfusion. Infants who were exclusively on intravenous fluids prior to the onset of the study remained on those fluids during the study period.

The infants who received the $MgSO_4$ infusion were given 6.0 mg elemental Mg/kg body weight as 5% $MgSO_4$ 7 $H_2O$, 1.2 ml/kg, added to the intravenous fluids for 1 h. This Mg dose is equal to an infant's approximate daily requirement of Mg and to the recommended dose of Mg for the acute treatment of hypomagnesemia (15). It is also a dose that we expected to keep the serum Mg concentration within normal range. The control infants received a placebo infusion of an equal volume of $D_5W$ added to the intravenous fluids for 1 h. The 5% $MgSO_4$ 7 $H_2O$ and $D_5W$ vials were prepared, coded, and randomized by the Children's Hospital pharmacy. Serum Mg, Ca, PTH, and CT concentrations were measured preinfusion at time 0 (baseline) and at 1, 2, 6, 12, 24, and 48 h postinfusion. The volumes of blood sampled were in accordance with University of Cincinnati Human Research Committee guidelines, which stipulate that the total amount of blood drawn must be less than 5% of blood volume. When the size of an infant limited blood sampling, the priority specimens obtained were usually at 0, 1, and 6 h postinfusion.

During the infusion period the heart rate and respiratory rate were determined continuously and blood pressure was measured every 15 min. These precautions were taken to detect the development of respiratory depression or hypotension, which are theoretically possible complications of a Mg infusion (21–24). Side effects were not observed in any infant.

Serum Ca and Mg concentrations were measured by atomic absorption spectrophotometry (25). Serum PTH concentration was determined as outlined by Arnaud *et al.* (26), with modifications that have been previously described (6). Antiserum was produced in guinea pigs in response to injection with partially purified bovine PTH. The antibody produced detects 1-84 PTH (27). Plasma obtained from chronic hemodialysis patients was employed as the standard. $^{125}$I-labeled highly-purified bovine PTH was used in the radioimmunoassay. The normal adult range is 33–117 μl Eq/ml, with intraassay and interassay coefficients of variation of 8 and 15%, respectively. Serum CT concentration was measured by a modification of the radioimmunoassay procedure described by Heath and Sizemore (14, 28). Normal adult values are less than 107 pg/ml, with intraassay and interassay coefficients of variation of 6 and 15%, respectively.

Statistical analysis was performed using repeated measures analysis, analysis of variance, and linear regression methods for continuous data. Discrete data were analyzed by the $\chi^2$ test. When the number of patients in any of the cells was less than 5, the Fisher-exact test was employed. The BMDP statistical package was utilized for repeated measurement analyses (29), and the SAS package for analysis of variance and linear regression (30). Results are expressed as mean ± SEM. A $p$ value of <0.05 is considered significant.

## RESULTS

The clinical characteristics of the infants studied are depicted in Table 1. Gestational age, as determined by history from the mother's last menstrual period, and birth weight were similar for the two groups. The number of infants who were small for gestational age (birth weight less than the 10th percentile for gestational age), large for gestational age (birth weight greater than the 90th percentile for gestational age), and appropriate for gestational age (birth weight between the 10th and 90th percentile for gestational age) (31) were also similar for the two groups. The rate of birth asphyxia, defined by a 1-min Apgar score less than 7, and the number of infants born to mothers with insulin-dependent diabetes also did not differ between the groups.

Serum Mg concentrations for both groups are shown in Table 2. Baseline serum Mg was similar for the two groups. In the study group the serum Mg increased from 1.80 ± 0.06 to 2.82 ± 0.07 mg/dl ($p < 0.001$) by the end of the $MgSO_4$ infusion, and it then slowly declined back to baseline by 48 h postinfusion. In the control group there was no change in serum Mg concentration throughout the study period.

Baseline serum PTH concentrations were similar for the control and $MgSO_4$ infusion groups (Table 3). The two groups were therefore pooled together to examine the relationships between baseline serum PTH concentrations and serum Mg and Ca concentrations. Baseline PTH correlated with baseline Mg ($r = 0.72$, $p < 0.005$) and with baseline Ca ($r = 0.68$, $p < 0.005$). Examination of Table 3 reveals that there was no change in mean serum PTH concentration during the study period in either the control or $MgSO_4$ infusion groups. However, in the $MgSO_4$ infusion group the absolute change from baseline in serum PTH

Table 1. *Clinical characteristics of infants studied**

| | Control ($n = 10$) | $MgSO_4$ infusion ($n = 29$) |
|---|---|---|
| Gestational age (wk) | | |
| Mean ± SEM | 35.2 ± 0.8 | 35.6 ± 0.6 |
| Birth weight (kg) | | |
| Mean ± SEM | 2.43 ± 0.22 | 2.57 ± 0.24 |
| SGA *n* (%) | 2 (20) | 5 (17) |
| AGA *n* (%) | 7 (70) | 21 (72) |
| LGA *n* (%) | 1 (10) | 3 (10) |
| Birth asphyxia | | |
| *n* (%) | 5 (50) | 15 (52) |
| IDMs *n* (%) | 1 (10) | 2 (7) |

* SGA, small for gestational age; AGA, appropriate for gestational age; LGA, large for gestational age; IDMs, infants of diabetic mothers.

Table 2. *Serum Mg and Ca concentrations in control and $MgSO_4$ infusion groups**

| Time postinfusion (h) | Mg (mg/dl) | | Ca (mg/dl) | |
|---|---|---|---|---|
| | Control | $MgSO_4$ | Control | $MgSO_4$ |
| Baseline | 1.89 ± 0.06 (10) | 1.80 ± 0.06 (29) | 8.01 ± 0.15 (10) | 7.89 ± 0.19 (29) |
| 1 | 1.84 ± 0.04 (10) | 2.82 ± 0.07† (29) | 8.06 ± 0.15 (9) | 7.91 ± 0.19 (29) |
| 2 | 1.82 ± 0.07 (5) | 2.62 ± 0.06† (16) | 8.23 ± 0.30 (5) | 7.89 ± 0.23 (16) |
| 6 | 1.88 ± 0.07 (10) | 2.45 ± 0.06† (27) | 8.23 ± 0.30 (10) | 7.93 ± 0.16 (27) |
| 12 | 1.88 ± 0.09 (4) | 2.55 ± 0.14† (12) | 7.86 ± 0.12 (3) | 8.01 ± 0.28 (11) |
| 24 | 1.90 ± 0.07 (9) | 2.18 ± 0.07† (26) | 8.64 ± 0.24 (9) | 8.30 ± 0.16 (26) |
| 48 | 1.95 ± 0.07 (9) | 2.08 ± 0.07 (23) | 8.96 ± 0.18 (9) | 8.55 ± 0.16 (23) |

* Values represent means ± SEM; values in parentheses represent the number of subjects.

† $p < 0.05$ compared to baseline and to control group.

Table 3. *Serum PTH and calcitonin concentrations in control and $MgSO_4$ infusion groups**

| Time postinfusion (h) | PTH (μl Eq/ml) | | CT (ng/ml) | |
|---|---|---|---|---|
| | Control | $MgSO_4$ | Control | $MgSO_4$ |
| Baseline | 30.4 ± 5.5 (7) | 34.5 ± 3.8 (24) | 123 ± 20 (9) | 224 ± 67 (25) |
| 1 | 27.4 ± 5.8 (7) | 32.0 ± 2.6 (27) | 100 ± 14 (7) | 254 ± 105 (22) |
| 2 | 25.0 ± 2.3 (3) | 27.9 ± 3.1 (14) | 93 ± 22 (4) | 298 ± 197 (13) |
| 6 | 31.5 ± 5.7 (8) | 29.4 ± 2.8 (23) | 90 ± 13 (9) | 192 ± 62 (20) |
| 12 | 29.0 ± 6.1 (3) | 30.7 ± 5.7 (10) | 40 ± 9 (3) | 140 ± 5 (7) |
| 24 | 30.5 ± 6.9 (6) | 30.5 ± 3.2 (25) | 78 ± 16 (7) | 99 ± 16 (22) |
| 48 | 35.0 ± 5.6 (7) | 34.5 ± 4.7 (16) | 79 ± 22 (8) | 70 ± 8 (17) |

* Values represent mean ± SEM; values in parentheses represent the number of subjects.

concentration in individual subjects correlated inversely with baseline serum Mg concentration when PTH was measured at 1 h ($r = 0.64$, $p < 0.001$), at 6 h ($r = -0.49$, $p < 0.05$), and at 12 h postinfusion ($r = -0.62$, $p = < 0.05$). Figure 1 depicts this relationship at 1-h postinfusion.

Serum Ca concentrations for both groups are shown in Table 2. Baseline serum Ca was similar for the two groups, and there was no change in mean serum Ca during the study period in either the control or $MgSO_4$ infusion groups. However, examination of the responses of individual subjects reveals that there was a relationship between the baseline serum Mg concentration and the absolute change in serum Ca concentration in response to $MgSO_4$ infusion. The absolute change from baseline in serum Ca concentration correlated inversely with baseline serum Mg concentration when Ca was measured at 1 h ($r = -0.56$, $p < 0.002$), at 2 h ($r = -0.85$, $p < 0.001$), and at 24 h postinfusion ($r = -0.54$, $p < 0.005$). Figure 2 depicts this relationship at 2 h postinfusion.

In both groups there was great variability in serum CT concentrations (Table 3). Baseline serum CT concentrations were similar. Pooling of baseline data from the two groups revealed no relationship between baseline serum Mg or Ca concentration and baseline serum CT concentration. In both the control and $MgSO_4$ infusion groups there was a trend of declining mean serum CT concentrations over the study period which did not reach statistical significance. No relationship was found between changes in serum CT concentration following Mg infusion and baseline serum Mg concentration.

## DISCUSSION

The population studied included infants who were preterm as well as term, small for gestational age and large for gestational age as well as appropriate for gestational age infants, and infants who were at high risk for hypomagnesemia or hypocalcemia as well as those who were at low risk for those conditions (7, 17, 18). Such a varied population was chosen to theoretically provide a group of infants who would have Mg status ranging from "depleted" to "normal." Many more infants would be required to examine the specific effects of variables such as gestational age, intrauterine growth retardation, maternal diabetes, or perinatal asphyxia on the PTH or CT response to $MgSO_4$ administration.

The serum Mg concentration following the $MgSO_4$ infusion remained within or close to the normal range for neonates, which is 1.5 to 2.8 mg/dl (15–17). This permitted the evaluation of the

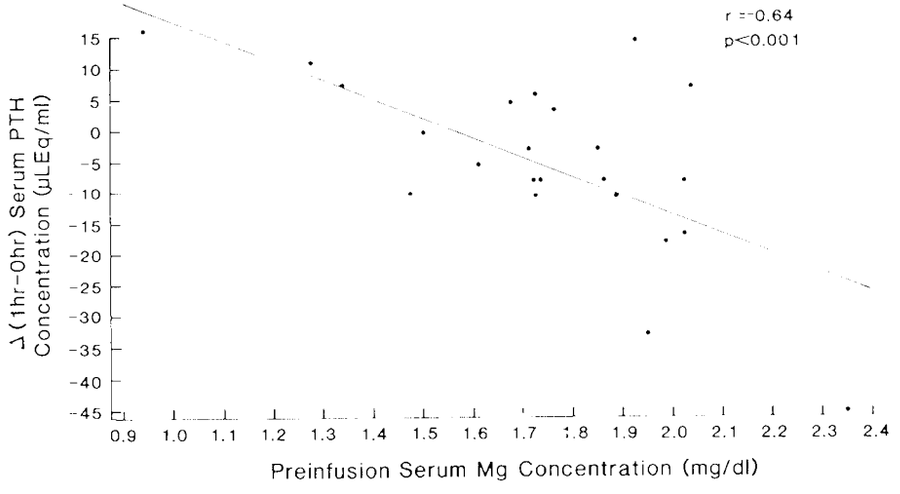


Fig. 1. Relationship between preinfusion serum Mg concentration and the change in serum PTH concentration from baseline to 1 h post-$MgSO_4$ infusion [Δ PTH (1-0 h)].

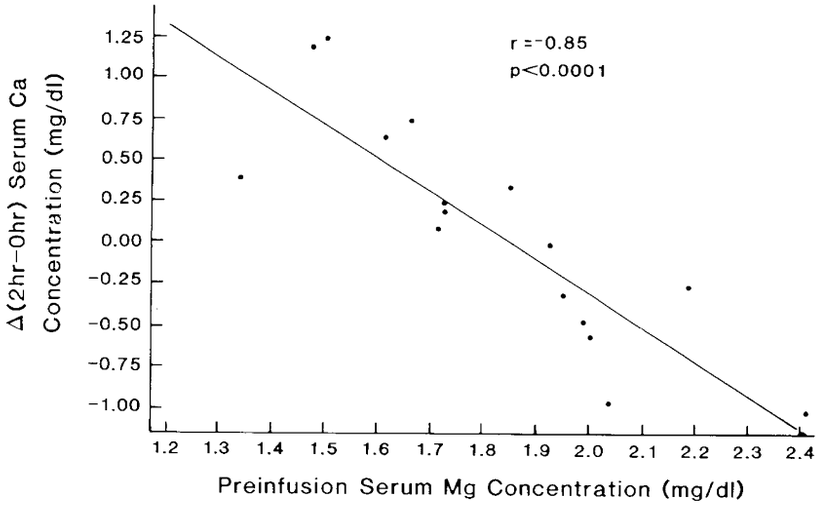


Fig. 2. Relationship between preinfusion serum Mg concentration and the change in serum calcium concentration from baseline to 2 h post-$MgSO_4$ infusion [Δ Ca (2-0 h)].

effects of Mg on PTH and CT secretion in ranges of serum Mg concentration that were close to probable "physiologic" concentrations as opposed to "pharmacologic" ones. In the present study the serum Mg concentration has been treated as a continuous variable. The infants were not placed into hypomagnesemia *versus* normomagnesemia groups because serum Mg concentration generally has been considered to be a "poor" index of tissue Mg status; Mg is mainly an intracellular ion (33). When serum Mg concentrations are reduced, tissue Mg stores indeed may have been depleted; but in the normal ranges of serum Mg concentrations it has been difficult to assess tissue Mg status. Apparently, reduced tissue Mg stores can be associated with normal serum Mg concentrations (34, 35). The relationship between tissue Mg status and serum Mg concentration in the newborn human or animal remains unclear.

The present findings support the hypothesis that the PTH response to Mg administration is inversely related to initial serum Mg status. The linear regression analyses of the baseline Mg, Ca, and PTH data demonstrate the close relationships that exist among serum Mg, serum Ca, and serum PTH concentrations in the neonatal period. The role of Mg in neonatal parathyroid gland function is not evident, however, until one examines the influence of baseline Mg status on the parathyroid response to Mg infusion. The change in serum PTH concentration following $MgSO_4$ administration was inversely related to the baseline serum Mg concentration. Infants with a comparatively low initial serum Mg concentration responded to Mg infusion with an increase in serum PTH concentration, while infants with a comparatively high initial serum Mg concentration had a decrease in serum PTH concentration postinfusion.

Two previous studies have indirectly examined the neonatal parathyroid response to Mg administration. Donovan *et al.* (19) studied the effect of maternally administered $MgSO_4$ on neonatal serum PTH concentrations during the first 3 days of life. The mean serum Mg concentration was 4.8 mg/dl in cord blood samples and it remained above 3.0 mg/dl for the following 3 days. Throughout the study period the serum PTH concentration was decreased compared to control infants (18). In a similar study Cruikshank *et al.* (20) also found that infants born to $MgSO_4$-treated mothers had decreased serum PTH concentrations in cord blood compared to controls. In contrast to the present study, the neonates in both these reports were overtly hypermagnesemic and their baseline Mg status prior to maternal $MgSO_4$ infusion was unknown.

Rude *et al.* (32) compared the PTH response to Mg administration in Mg-deficient and normal adult subjects. The Mg-deficient adult patients responded with an increase in serum PTH concentration while normal adults had a decrease or little change in the serum PTH concentration. Thus, the response we found in infants with low serum Mg concentrations resembles that of Mg-deficient adults, and the response in neonates with higher serum Mg concentrations resembles that of normal adults.

The serum Ca response to $MgSO_4$ infusion was similar to the PTH response in that it also was inversely related to the baseline serum Mg concentration. Infants with a comparatively low initial serum Mg concentration responded to the infusion with an increase in serum Ca concentration, while infants with a comparatively high initial serum Mg concentration had a decrease in serum Ca concentration postinfusion. The observed changes in serum Ca concentration could be in part due to the effects of $MgSO_4$ administration on PTH secretion, since changes in serum PTH affect directly and positively the serum Ca concentration. There were infants, however, who responded to the $MgSO_4$ infusion with increases in serum Ca concentration who did not have measurable increases in serum PTH concentration. For example, at 2 h postinfusion seven of 10 infants who had increased serum Ca compared to baseline did not have an associated increase in serum PTH concentration. A possible explanation is that Mg administration in these infants resulted in increased exchange of Mg for Ca at the bone surface, shifting Ca from bone to the extracellular space, with a subsequent increase in serum Ca concentration (36). Such a mechanism may account for the observed increase in serum Ca concentration despite decreased serum PTH concentration in the previous cited study of neonatal hypermagnesemia by Donovan *et al.* (19).

There was no change in serum CT concentration in response to $MgSO_4$ administration. In a previous study of the effects of maternal $MgSO_4$ treatment on perinatal Ca metabolism, cord blood CT concentrations in Mg-treated neonates did not differ from controls (19). In the present study, the trend of declining serum CT concentrations over the study period is consistent with the results obtained in investigations of the CT status of infants during the first 2 wk of life (14, 37).

In summary, Mg infusion in the neonatal period resulted in changes in serum PTH and Ca concentrations that were inversely related to the baseline serum Mg concentration, consistent with the hypothesis tested. Elevation of serum Ca concentration following Mg administration may be due to increased PTH secretion and/or increased exchange of Mg for Ca at bone surfaces. CT secretion was not affected by Mg administration. Mg status appears to exert important effects on neonatal Ca homeostasis.

## REFERENCES

1. Tsang RC, Oh W 1970 Neonatal hypocalcemia in low birth weight infants. Pediatrics 45:773–781
2. Tsang RC, Light IJ, Sutherland JM, Kleinman LI 1973 Possible pathogenetic

factors in neonatal hypocalcemia of prematurity. J Pediatr 82:423–429
3. Tsang RC, Kleinman LI, Sutherland JM, Light IJ 1972 Hypocalcemia in infants of diabetic mothers. J Pediatr 80:384–395
4. Tsang RC, Gigger M, Oh W, Brown DR 1975 Studies on calcium metabolism in infants with intrauterine growth retardation. J Pediatr 86:936–941
5. Tsang RC, Chen I, Hayes W, Atkinson W, Atherton H, Edwards N 1974 Neonatal hypocalcemia in infants with birth asphyxia. J Pediatr 84:428–433
6. Tsang RC, Chen IW, Friedman MS, Chen IW 1973 Neonatal parathyroid function: role of gestational age and postnatal age. J Pediatr 83:728–738
7. Tsang RC, Strub R, Brown DR, Steichen JJ, Hartman C, Chen IW 1976 Hypomagnesemia in infants of diabetic mothers: perinatal studies. J Pediatr 89:115–119
8. Buckle RM, Care AD, Cooper CW 1968 The influence of plasma magnesium concentration on parathyroid hormone secretion. J Endocrinol 42:529–534
9. Massry SG, Coburn JW, Kleeman CR 1970 Evidence for suppression of parathyroid gland activity by hypermagnesemia. J Clin invest 49:1619–1629
10. Levine BS, Coburn JW 1984 Magnesium, the mimic/antagonist of calcium. N Engl J Med 310:1253–1255
11. Bergman L, Kjellmer I, Selstam U 1974 Calcitonin and parathyroid hormone relation to early neonatal hypocalcemia in infants of diabetic mothers. Biol Neonate 24:151–157
12. David L, Salle B, Putet G, Grafmeyer DC 1981 Serum immunoreactive calcitonin in low birth weight infants: description of early changes; effect of intravenous calcium infusion; relationships with early changes in serum calcium, phosphorus, magnesium, parathyroid hormone and gastrin levels. Pediatr Res 15:803–808
13. Tsang RC, Steichen JJ, Brown DR 1977 Perinatal calcium homeostasis: neonatal hypocalcemia and bone demineralization. Clin Perinatol 4:385–409
14. Dinesoy MY, Tsang RC, Laskarzewski P, Ho M, Chen IW, Davis N 1982 Serum calcitonin response to administration of calcium in newborn infants during exchange blood transfusion. J Pediatr 100:782–786
15. Mimouni F, Tsang RC 1986 Disorders of calcium and magnesium metabolism. In: Fanaroff AA, Martin RJ (eds) Behrman's Neonatal-Perinatal Medicine: Diseases of the Fetus and Infant, 4th ed. CV Mosby Company, St Louis (in press)
16. Anast CS 1964 Serum magnesium levels in the newborn. Pediatrics 33:969–974
17. Tsang RC, Oh W 1970 Serum magnesium levels in low birth weight infants. Am J Dis Child 120:44–47
18. Tsang RC 1972 Neonatal magnesium disturbances. Am J Dis Child 124:282–293
19. Donovan EF, Tsang RC, Steichen JJ, Strub RJ, Chen IW 1980 Neonatal hypermagnesemia: effect on parathyroid hormone and calcium homeostasis. J Pediatr 96:305–310
20. Cruikshank DP, Pitkin RM, Reynolds WA, Williams GA, Hargis GK 1979 Effects of magnesium sulfate treatment on perinatal calcium metabolism. Am J Obstet Gynecol 134:243–249
21. Stone SR, Pritchard JA 1970 Effect of maternally administered magnesium sulfate on the neonate. Obstet Gynecol 35:574–577
22. Lipsitz PJ, English IC 1967 Hypermagnesemia in the newborn infant. Pediatrics 40:856–859
23. Lipsitz PJ 1971 The clinical and biochemical effects of excess magnesium in the newborn. Pediatrics 47:501–509
24. Randall RE, Cohen MD, Spray CC, Rossmeisl EC 1964 Hypermagnesemia in renal failure, etiology and toxic manifestations. Ann Intern Med 61:73–77
25. Sunderman FW, Carroll JE 1965 Measurements of serum calcium and magnesium by atomic absorption spectrometry. Am J Clin Pathol 43:302–309
26. Arnaud CD, Tsao HS, Littledike T 1971 Radioimmunoassay of human parathyroid hormone in serum. J Clin Invest 50:21–27
27. Dinesoy MY, Tsang RC, Laskarzewski P, Chen WH, Lo D, Donovan EF 1982 The role of postnatal age and magnesium on parathyroid hormone responses during "exchange" blood transfusion in the newborn period. J Pediatr 100:277–283
28. Heath H, Sizemore GW 1977 Plasma calcitonin in normal men: differences between men and women. J Clin Invest 60:1135–1140
29. 1981 BMDP statistical software user's guide. UCLA, Los Angeles, CA
30. Statistical Analysis System (SAS) user's guide. SAS Institute, Cary, NC 1979
31. Lubchenco LO, Hansman C, Dressler M, Boyd E 1963 Intrauterine growth as estimated from live-born birth weight data at 24 to 42 weeks gestation. Pediatrics 32:793–800
32. Rude RK, Oldham SB, Sharp CF, Singer FR 1978 Parathyroid hormone secretion in magnesium deficiency. J Clin Endocrinol Metab 47:800–806
33. Schedewie HK, Fisher DA 1980 Perinatal mineral homeostasis. In: Tulchinsky D, Ryan KJ (eds) Maternal-Fetal Endocrinology. WB Saunders, Philadelphia, pp 355–386
34. Caddell JL, Suskind R, Sillup H, Olson RE 1973 Parenteral magnesium load: evaluation of malnourished Thai children. J Pediatr 83:129–135
35. Harris I, Wilkinson AI 1971 Magnesium depletion in children. Lancet 2:735–736
36. MacManus J, Heaton FW 1970 The influence of magnesium on calcium release from bone in vitro. Biochem Biophys Acta 215:360–367
37. Hillman LS, Rojanasathit S, Slatopolsky E, Haddad JG 1977 Serial measurements of serum calcium, magnesium, parathyroid hormone, calcitonin, and 25-hydroxyvitamin D in premature and term infants during the first week of life. Pediatr Res 11:739–744